UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
NORTHEAST REGION
55 Great Republic Drive
Gloucester, MA 01930-2276

AUG 3 1 2012

Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
888 First Street, N.E.
Washington, DC 20426

RE: Endangered Species Act Section 7 Formal Consultation for the Stillwater, Orono, Milford, West Enfield, and Medway Hydroelectric Projects (FERC Project Nos. 2712, 2710, 2534, 2600, and 2666)

Dear Secretary Bose:

Enclosed is NOAA's National Marine Fisheries Service (NMFS) Biological Opinion (Opinion), issued under section 7(a)(2) of the Endangered Species Act (ESA), for the Federal Energy Regulatory Commission's (FERC) authorization of Black Bear Hydro Partners' (Black Bear) proposal to construct and operate new powerhouses at the Orono and Stillwater Projects; install new fishways at the Milford, Orono and Stillwater Projects; incorporate the provisions of a Species Protection Plan at the Milford, Orono, Stillwater and West Enfield Projects; and, to add a license article to protect Atlantic salmon at the Medway Project.

This Opinion is based on your March 8, 2012 Biological Assessment (BA) and other sources of information. In the Opinion, we conclude that the proposed actions may adversely affect but are not likely to jeopardize the continued existence of the Gulf of Maine Distinct Population Segment (GOM DPS) of Atlantic salmon, shortnose sturgeon, or the GOM and New York Bight DPSs of Atlantic sturgeon. Four of these projects (all except Medway) are within the designated critical habitat for the GOM DPS of Atlantic salmon. Although ongoing operations of these hydroelectric facilities will continue to adversely affect essential features of this habitat, the proposed action is anticipated to improve the functioning of critical habitat in the Penobscot River. We concur with you that the action will not adversely modify or destroy critical habitat designated for the GOM DPS of Atlantic salmon.

Our Opinion includes an Incidental Take Statement (ITS). Incidental take is defined as take that is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity. "Otherwise lawful activities" are those actions that meet all State and Federal legal requirements, including any state endangered species laws or regulations, except for the prohibition against taking in ESA Section 9. Under the terms of section 7(b)(4) and section 7(o)(2), taking that is incidental to and not intended as part of the agency action is not considered to be prohibited under the ESA provided that such taking is in compliance with the terms and conditions of this ITS.

The ITS exempts the incidental taking of Atlantic salmon adults, smolts, and kelts from activities associated with the construction of the new powerhouses, ongoing operations of the hydroelectric facilities, and upstream and downstream passage and survival studies. It also exempts the trapping of one shortnose and Atlantic sturgeon per year at the proposed fish traps at the Orono and Milford Projects; as well as the stranding of one Atlantic sturgeon a year in the bypass reach of the Orono Project when water levels are dropped to allow for flashboard maintenance and replacement. These Atlantic sturgeon could originate from the GOM or NYB DPS.

The ITS also specifies Reasonable and Prudent Measures (RPMs) and implementing Terms and Conditions necessary to minimize and monitor the impact of these activities on Atlantic salmon, shortnose sturgeon, and Atlantic sturgeon. The ITS specifies five RPMs necessary to minimize and monitor take of listed species. The RPMs and implementing Terms and Conditions outlined in the ITS are non-discretionary, and must be undertaken so that they become binding conditions for the exemption in section 7(o)(2) to apply. Failure to implement the terms and conditions through enforceable measures may result in a lapse of the protective coverage of section 7(o)(2). Annual reporting that is required by the ITS will continue to supply information on the level of take resulting from the proposed action. The RPMs and the Terms and Conditions have been reviewed by your staff and no objections have been raised.

Section 7(a)(1) of the ESA directs Federal agencies to utilize their authorities to further the purposes of the ESA by carrying out conservation programs for the benefit of endangered and threatened species. Conservation recommendations are discretionary agency activities to minimize or avoid adverse effects of a proposed action on listed species or critical habitat, to help implement recovery plans, or to develop information. To further reduce adverse effects of the proposed project, NMFS provides five conservation recommendations for endangered Atlantic salmon, shortnose sturgeon and Atlantic sturgeon. While these recommendations are discretionary, NMFS strongly urges FERC to carry out this program.

This Opinion concludes consultation for the FERC's proposed authorization to amend the licenses of five hydroelectric projects on the Penobscot River. Reinitiation of consultation is required and shall be requested by FERC or by NMFS, where discretionary Federal involvement or control over the action has been retained or is authorized by law and: (1) the amount or extent of taking specified in the incidental take statement is exceeded; (2) new information reveals effects of the action that may not have been previously considered; (3) the identified action is subsequently modified in a manner that causes an effect to listed species; or (4) a new species is listed or critical habitat designated that may be affected by the identified action.

We look forward to continuing to work with you and your staff on future consultations. Please contact Dan Tierney of my staff at (207) 866-3755 or Dan.Tierney@noaa.gov for any questions involving this consultation.

Sincerely,

for
John K. Bullard
Regional Administrator

EC: Dan Tierney, F/NER3
Sean McDermott, F/NER4
Steve Shepard, USFWS
Norm Dube, MDMR

File Code: Sec 7 FERC Maine Black Bear Hydro (Penobscot)
PCTS: F/NER/2012/01568

NATIONAL MARINE FISHERIES SERVICE
ENDANGERED SPECIES ACT
BIOLOGICAL OPINION

Agency: Federal Energy Regulatory Commission (FERC)
US Army Corps of Engineers, New England District

Activity Considered: **Construction of new powerhouses at the Orono (2710) and Stillwater (2712) Projects;**
Fish passage improvements at the Orono, Stillwater and Milford (2534) Projects;
Species Protection Plan for the Orono, Stillwater, Milford, West Enfield (2600) and Medway (2666) Projects.

F/NER/2012/01568

Conducted by: National Marine Fisheries Service
Northeast Region

Date Issued: 8/31/12

Approved by: [signature] for John Bullard

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1. INTRODUCTION AND BACKGROUND

This constitutes the biological opinion (Opinion) of NOAA's National Marine Fisheries Service (NMFS) under the Endangered Species Act (ESA) of 1973, as amended (16 U.S.C. 1531-1543) concerning the effects of the Federal Energy Regulatory Commission's (FERC) approval of applications to amend the licenses for the construction of new powerhouses at the Stillwater (2712) and Orono (2710) Projects, as well as the incorporation of protection measures for Atlantic salmon and other listed species at the Orono, Stillwater, Milford (2534), West Enfield (2600) and Medway (2666) Projects.

By applications filed with FERC on May 18, 2011, Black Bear Hydro Partners, LLC (Black Bear) requested that its licenses for the Orono and Stillwater Projects be amended to authorize Black Bear to construct a second powerhouse at each project. In letters dated July 19, 2011 and September 14, 2011, the FERC designated Black Bear as their non-federal representative to conduct informal ESA consultation with us. These consultations would consider effects of actions proposed in the two amendment applications, as well as effects of applications to amend the licenses for its other licensed projects in the Penobscot River Basin (Milford, West Enfield and Medway) to incorporate protection measures to minimize effects to ESA-listed species as proposed in a Species Protection Plan (SPP).

This Opinion is based on information provided in the FERC's April 27, 2012 Biological Assessment and SPP, the updated SPP and study plan issued by FERC on June 27, 2012, as well as additional information provided in Black Bear's amendment applications for the Stillwater and Orono Projects. A complete administrative record of this consultation will be maintained at our Maine Field Office in Orono, Maine. Formal consultation was initiated on May 3, 2012.

In addition to FERC, another federal agency, the U.S. Army Corps of Engineers (ACOE), is taking action to authorize the construction of the new powerhouses at the Orono and Stillwater Projects. The ACOE proposes to authorize the proposed actions pursuant to section 404 of the Clean Water Act and section 10 of the Rivers and Harbors Act for wetlands impacts and fill associated with the projects. Pursuant to the section 7 regulations (50 CFR §402.07), when a particular action involves more than one Federal agency, the consultation responsibilities may be fulfilled through a lead agency. FERC is the lead Federal agency for the proposed actions under consideration in this consultation.

1.1. Consultation History

- **July 2009 -** Black Bear submitted a letter to the USFWS and NMFS acknowledging the expanded listing for Atlantic salmon and confirming its commitment to work with the USFWS and NMFS to maintain compliance with the ESA with respect to the additional powerhouses at the Projects.

- **August/September/October 2009 -** Black Bear participated in various meetings with state resource agencies, NMFS and the USFWS regarding ESA compliance options including section 7 and section 10 of the ESA.

- **September 2009 to December 2011** - Various consultation efforts on fishway designs at Stillwater and Milford Projects (see September 30, 2001 and November 30, 2011 filings, respectively, for additional documentation and details).

- **October 2009 -** NMFS responded to Black Bear's 17 July letter suggesting an early November meeting to discuss ESA compliance.

- **November 2009 -** Black Bear, NMFS, and the USFWS met at NMFS' Gloucester, MA office to discuss options for ESA compliance.

- **December 2009 -** Black Bear met with NMFS and the USFWS staff to discuss the outline and contents of a SPP and associated documents.

- **January/February 2010 -** Informal conversations between Black Bear, the USFWS, and NMFS took place regarding ESA requirements and the scope of supporting documents.

- **April 2010 -** Black Bear convened a meeting with the USFWS and NMFS to discuss ESA process, schedule, and development of a SPP. Black Bear provided an outline for a proposed SPP for discussion purposes.

- **April/May 2010 -** The USFWS and NMFS emailed various ESA documents to Black Bear in support of the Black Bear efforts to develop the content and format of an SPP.

- **June 2010 -** Black Bear convened a second meeting with the USFWS and NMFS to discuss the SPP. NMFS provided a revised SPP outline at the meeting.

- **June 2010 -** Black Bear emailed a revised SPP outline to the USFWS and NMFS.

- **October 2010** - Black Bear submitted a draft SPP to the USFWS and NMFS for review.

- **October 2010 -** NMFS provided certain documents to Black Bear to assist with completing the remaining section of the SPP.

- **December 2010 -** The USFWS and NMFS provided detailed comments on the draft SPP, including a request to include information on Penobscot River Atlantic sturgeon, a species under review as a candidate for ESA listing at that time.

- **February/March/April 2011 -** Informal conversations occurred between Black Bear, the USFWS and NMFS regarding the outline for the SPP, contents and consistency amongst projects within Maine, and schedule. Parties confirmed that the structure of the document would remain the same, but the SPP components would become Attachment A to the Biological Evaluation.

- **May 2011 -** Black Bear requested on May 18 that it be designated as the Commission's non-federal representative for the purpose of conducting informal consultation with USFWS and NOAA (the Services) pursuant to section 7 of the ESA with respect to:

- the effects of the applications to amend the licenses for Orono and Stillwater on Atlantic salmon and other ESA-listed species; and
- the effects of Black Bear's future applications to amend the licenses for Milford, West Enfield, and Medway to incorporate agreed-upon protective measures to aid Atlantic salmon and other ESA-listed species.

- **June 2011** - Black Bear provided draft Biological Evaluation with accompanying protective measures/SPP to the USFWS and NMFS.

- **July 2011** - FERC designated Black Bear as the Commission's non-federal representative for the purpose of conducting informal consultation with the Services pursuant to section 7 of the ESA for the Orono and Stillwater Projects on July 19. Subsequently, Black Bear called the Biological Evaluation a draft BA.

- **July 2011** - Black Bear met with the USFWS and NMFS to discuss the previously distributed draft BA with accompanying protective measures/SPP.

- **July/August 2011** - Black Bear continued consultation with the USFWS and NMFS on the draft BA and developed additional sections/information based on agency comments.

- **August 2011** - The USFWS and NMFS provided additional comments to Black Bear that resulted in revisions to the draft BA by Black Bear.

- **September 2011** - FERC designated Black Bear as the Commission's non-federal representative for the purpose of conducting informal consultation with the Services pursuant to section 7 of the ESA for the Milford, West Enfield, and Medway Projects on September 14.

- **October 2011** - Black Bear provided revised version of the preliminary draft BA to the USFWS and NMFS on October 11; met with USFWS and NMFS to discuss revised documents and performance standards on October 18 and 28.

- **November 2011** - Black Bear met with USFWS and NMFS to discuss SPP and performance standards on November 3. Black Bear provided USFWS and NMFS a revised SPP on November 17. Black Bear met with USFWS and NMFS to discuss SPP and performance standards on November 21. NMFS provided comments on the revised SPP on November 30.

- **December 2011** - Black Bear met with USFWS and NMFS to discuss SPP and performance standards on December 2, and 6, and 19. Black Bear provided revised version of the draft SPP to USFWS and NMFS on December 21.

- **January 2012** - NMFS provided comments on the revised SPP on January 4. Black Bear provided a revised version of the draft BA to USFWS and NMFS on January 4. Black Bear met with the PIN, USFWS, and NMFS to discuss SPP and performance standards on January 5. Black Bear, USFWS, and NMFS met with the Penobscot River

Restoration Trust and state agencies to provide an overview of the SPP efforts on January 18.

- **March 2012** – Black Bear submitted draft license articles to FERC on March 8 to implement the provisions of the SPP and Sturgeon Handling Plan for the final license amendment applications for the Stillwater and Orono Projects. Included in Black Bear's submittal was the revised draft BA and SPP.

- **April 2012** – FERC adopted the BA and SPP and submitted a letter to NMFS on April 27th requesting the initiation of formal consultation.

- **May 2012** – NMFS submitted a letter to FERC on May 17th indicating that all of the information required to initiate a formal consultation for the project had been received. In this letter NMFS noted that the date that the initiation request was received (May 3, 2012) would serve as the commencement of the formal consultation process.

- **June 2012** – Black Bear submitted final Species Protection Plan and Study Plan to FERC on June 7th. FERC issued the updated SPP and study plan on June 27th 2012.

- **July 2012** – Black Bear convened a meeting with NMFS, USFWS and MDMR to review hydraulic modeling at the Orono Project.

1.2. Relevant Documents

The analysis in this Opinion is based on a review of the best available scientific and commercial information. Specific sources are listed in Section 13 and are cited directly throughout the body of the document. Primary sources of information include: 1) information provided in FERC's April 27, 2012 initiation letter and attached BA and SPP in support of formal consultation under the ESA; 2) the final SPP and study plan issued by FERC on June 27, 2012; 3)Black Bear's License Amendment Applications for the Orono and Stillwater Projects (May 2011); 4) Determination of Endangered Status for the Gulf of Maine Distinct Population Segment of Atlantic salmon; Final Rule (74 FR 29345; June 19, 2009); 5) Status Review for Anadromous Atlantic Salmon (*Salmo salar*) in the United States (Fay *et al.* 2006); 6) Designation of Critical Habitat for Atlantic salmon Gulf of Maine Distinct Population Segment (74 FR 29300; June 19, 2009); 7) Final Recovery Plan for Shortnose Sturgeon (December, 1998); and 8) Final listing determinations for the five distinct population segments of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). On February 6, 2012, we published notice in the *Federal Register* listing the Atlantic sturgeon as "endangered" in the New York Bight, Chesapeake Bay, Carolina, and South Atlantic DPSs, and as "threatened" in the Gulf of Maine DPS (77 FR 5880 and 77 FR 5914).

1.3. Application of ESA Section 7(a)(2) Standards – Analytical Approach

This section reviews the approach used in this Opinion in order to apply the standards for determining jeopardy and destruction or adverse modification of critical habitat as set forth in section 7(a)(2) of the ESA and as defined by 50 CFR §402.02 (the consultation regulations).

Additional guidance for this analysis is provided by the Endangered Species Consultation Handbook, March 1998, issued jointly by NMFS and the USFWS. In conducting analyses of actions under section 7 of the ESA, NMFS takes the following steps, as directed by the consultation regulations:

- Identifies the action area based on the action agency's description of the proposed action (Section 2);
- Evaluates the current status of the species with respect to biological requirements indicative of survival and recovery and the essential features of any designated critical habitat (Section 3);
- Evaluates the relevance of the environmental baseline in the action area to biological requirements and the species' current status, as well as the status of any designated critical habitat (Section 4);
- Evaluates the relevance of climate change on environmental baseline and status of the species (Section 5);
- Determines whether the proposed action affects the abundance, reproduction, or distribution of the species, or alters any physical or biological features of designated critical habitat (Section 6);
- Determines and evaluates any cumulative effects within the action area (Section 7); and,
- Evaluates whether the effects of the proposed action, taken together with any cumulative effects and the environmental baseline, can be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of the affected species, or is likely to destroy or adversely modify their designated critical habitat (Section 8).

In completing the last step, we determine whether the action under consultation is likely to jeopardize the ESA-listed species or result in the destruction or adverse modification of designated critical habitat. If so, we must identify a reasonable and prudent alternative(s) (RPA) to the action as proposed that avoids jeopardy or adverse modification of critical habitat and meets the other regulatory requirements for an RPA (see 50 CFR §402.02). In making these determinations, we must rely on the best available scientific and commercial data.

The critical habitat analysis determines whether the proposed action will destroy or adversely modify designated or proposed critical habitat for ESA-listed species by examining any change in the conservation value of the primary constituent elements of that critical habitat. This analysis focuses on statutory provisions of the ESA, including those in section 3 that define "critical habitat" and "conservation", in section 4 that describe the designation process, and in section 7 that set forth the substantive protections and procedural aspects of consultation. Although some "properly functioning" habitat parameters are generally well known in the fisheries literature (e.g., thermal tolerances), for others, the effects of any adverse impacts are considered in more qualitative terms. The analysis presented in this Opinion does not rely on the regulatory definition of "adverse modification or destruction" of critical habitat at issue in the 9th Circuit Court of Appeals (Gifford Pinchot Task Force *et al.* v. U.S. Fish and Wildlife Service, No. 03-35279, August 6, 2004).

2. PROJECT DESCRIPTION AND PROPOSED ACTION

FERC is proposing to amend the licenses held by Black Bear for their Orono and Stillwater projects. The modifications to the licenses will authorize the construction of a second powerhouse at each project, as well as increase the length of the license term for each project to 2048. In addition, FERC is proposing to authorize the installation of new fishways at the Milford, Orono and Stillwater Projects and to modify the licenses for the Milford, Orono, Stillwater and West Enfield Projects to incorporate the provisions of a Species Protection Plan. Although no new measures or structures are being proposed for the Medway Project, FERC is proposing to amend the license for the Medway project to require Black Bear to meet with NMFS every five years to ensure that operation of the project is consistent with the recovery objectives for Atlantic salmon and other listed fish species. This Opinion considers effects of the operation of Orono, Stillwater, Milford and West Enfield by Black Bear under the terms of the revised operating licenses as proposed by FERC, through the expiration of their licenses (see Table 1).

Table 1. License expiration dates for the projects considered in this Opinion. Dates in parentheses indicate the proposed extension of the license term.

Project	Expiration Date
Orono	2045 (2048)
Stillwater	2038 (2048)
Milford	2038
West Enfield	2024
Medway	2029

2.1. Orono Project - FERC No. 2710

2.1.1. Existing Hydroelectric Facilities and Operations

The Orono Project is located in the town of Orono, Penobscot County, Maine, on the Stillwater Branch of the Penobscot River. The Stillwater Branch is 10.5 miles long. It is not a true tributary of the Penobscot River, but is actually a channel of the Penobscot River that flows around the west side of Orson and Marsh Islands. The Orono Project is located at the downstream confluence of the Stillwater Branch where it rejoins the main stem of the Penobscot River (Figure 1).

The existing Orono Project consists of a concrete dam totaling 1,174 feet in length; an overflow spillway section with four foot high hinged flashboards; a non-overflow spillway section on the north end of the dam; a forebay intake supplying water to a single concrete penstock; a surge tank; a downstream fishway bypass; an upstream fishway for American eel; a powerhouse containing four turbine-generator units with a total installed capacity of 2.3 megawatts (MW) and a hydraulic capacity of 1,740 cubic feet per second (cfs); a 175-acre reservoir; and appurtenant facilities.

The Orono Project is operated as a run-of-river hydroelectric development with the discharge from the project turbines and spillway equivalent to inflow. The Orono Project includes a downstream fishway that discharges to a plunge pool located in the bypass reach. It also includes an upstream fishway located adjacent to the spillway abutment, which is designed to pass juvenile American eel into the headpond, although it is temporarily configured to trap migrant eels. There are currently no upstream passage facilities for other diadromous species. The Project provides a minimum flow to the bypass reach of 200 cfs through a combination of leakage through the flashboards and the discharge of the downstream bypass.

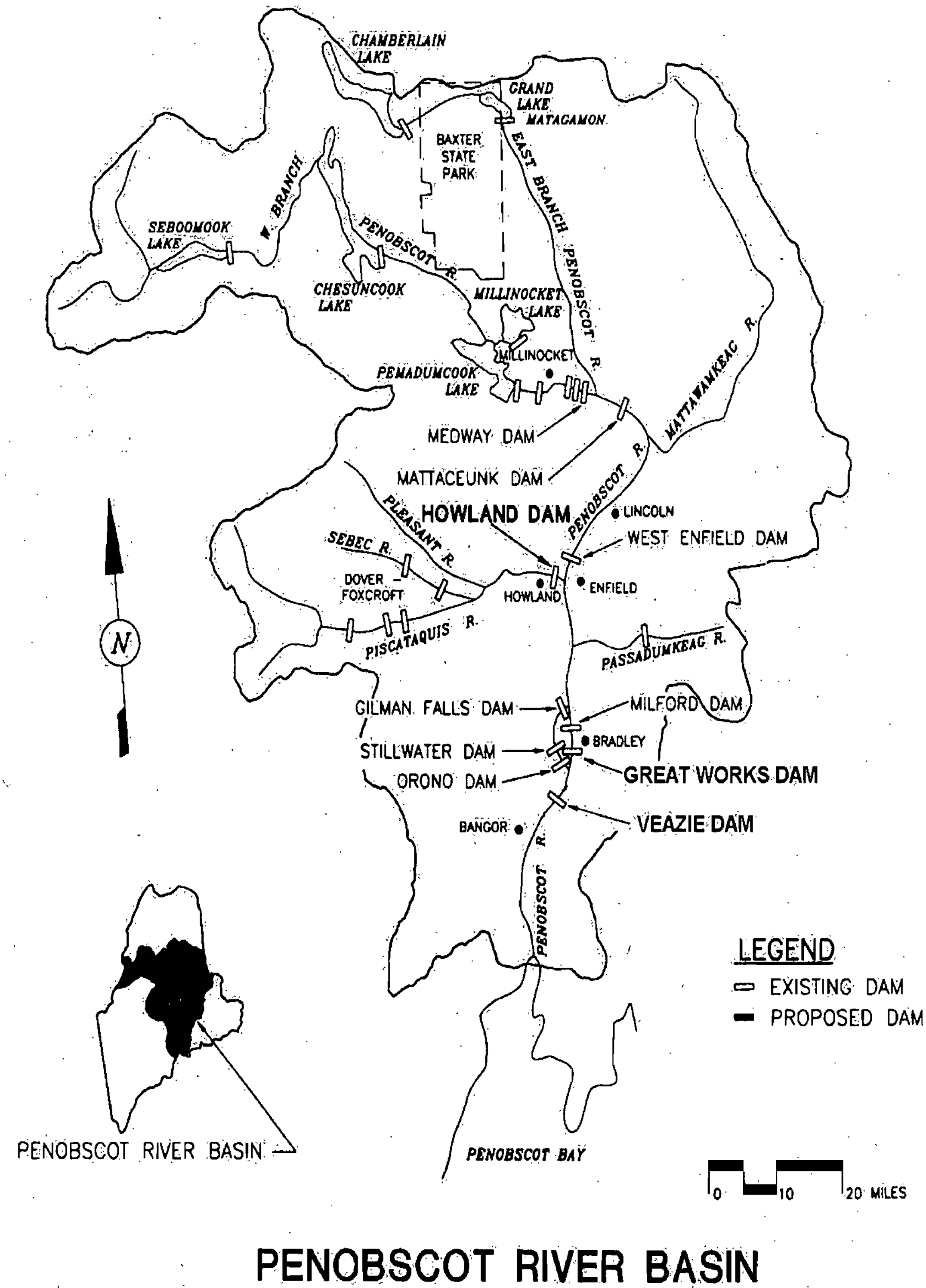

Figure 1. Penobscot River Watershed (Penobscot River Restoration Trust 2008)

2.1.2. Proposed Action

Black Bear filed an application with FERC on May 18, 2011 to amend the license for the Orono Project to include a second powerhouse, an additional downstream fish bypass and a new upstream fish trap. The license modification would also require Black Bear to adhere to the downstream fish passage measures proposed in the SPP, and would extend the term of the current license from 2045 to 2048.

2.1.2.1.New Powerhouse Construction

The proposed modifications at the Orono Project will consist of a new powerhouse and an expanded intake structure in line with the current trashracks and supplying water to a second penstock. This penstock will be located on the south shore of the bypass reach and generally adjacent to the existing penstock. The powerhouse will be situated in the bypass reach upon ledges. It will be located approximately 420 feet downstream of the existing dam in the existing bypass area, approximately 90 feet to the left of the existing penstock looking downstream. A tailrace will be constructed by removing some ledge from the existing channel to the main stem of the Penobscot River.

Active construction will occur below the mean high water (MHW) line of the Penobscot River for the construction of a new powerhouse at the Orono Project. Protection, mitigation and enhancement measures that address anticipated project effects to environmental resources at the Project have been proposed by Black Bear. Short-term effects to aquatic species and habitats anticipated from construction activities below the normal high water elevation in the project facility footprints are addressed by the following:

- Develop a soil erosion and sediment control plan prior to the start of any construction activity to prevent any short-term erosion or sedimentation effects in the river;
- Coordinate with fisheries management agencies to implement a fish passage plan for upstream migrating adult Atlantic salmon during the construction period including trap and truck from Veazie Dam to above the Milford Project;
- Maintain minimum bypass reach flows during construction activities to minimize effects to aquatic habitat;
- Conduct excavation and blasting activities in the dry to the extent possible; and
- Limit charge weights and delay individual blasts to keep detonation related sound pressures at a safe level for aquatic resources (less than an SPL of 206 dB re 1 uPa (3.6 psi), and below an SEL of 187 dB re 1 uPa sq.-sec) and implement blasting monitoring/reporting provisions.

New construction and alteration of the Orono Project will include the construction of a second powerhouse containing three Canadian Hydro Components (CHC) 1700 mm (5.6 feet) diameter vertical axial flow turbine-generating units having a nameplate capacity of 1,355 kW per unit. The new powerhouse will have a total rated capacity of approximately 3,738 kW and a total hydraulic capacity of 2,082 cfs. A new intake and 292 feet long by 25 feet wide by 12 feet high concrete box penstock will supply the powerhouse. A surge chamber measuring 60 feet long by

25 feet wide, flaring to 44 feet wide at the powerhouse by 32 feet high on three walls and 27 feet high on the spillway wall will be installed. Aerial transmission lines will be installed from the new powerhouse's generating step-up transformer unit (GSU) to the existing 12.5 kV, local substation near the existing powerhouse.

The new powerhouse will be a combination reinforced concrete structure with some corrugated tin walls and a beam and girder roof system measuring approximately 56 feet wide by 40 feet long by 60 feet high and housing the three, 1,246 kW generating units. The new units will have a combined maximum hydraulic capacity of 2,082 cfs and a minimum operating capacity of approximately 175 cfs, with a net head of 26.51 feet (under full station operation).

Once the second powerhouse is constructed, the Orono Project will have a total combined maximum hydraulic capacity of 3,822 cfs (1,740 cfs existing capacity at the existing powerhouse plus 2,082 cfs capacity at the new powerhouse) and a minimum operating capacity of approximately 100 cfs (minimum operating capacity of one unit at the existing powerhouse). In accordance with the existing Operation and Flow Monitoring Plan, the required minimum flow in the project bypass reach of 200 cfs will be handled by 153 cfs being routed through the proposed upstream/downstream fish passage facility and 47 cfs being leakage through the installed flashboards or an appropriate point source discharge.

The new powerhouse intake will be 84 feet wide by 20 feet high. It will be integral to the existing powerhouse intake via a singular trashrack. The trashrack will measure 156 feet wide by 20 feet high, and bars will be spaced at 1-3/8 inches on center (1 inch clear spacing), and situated at a 14.0 degree slope from vertical (1H:4V+/- slope). The new penstock transitions to an open surge chamber at the powerhouse, as discussed above. An overhead transmission line will extend from the GSU transformer at the new powerhouse to the existing substation that is within the existing project boundary. The transmission line is approximately 600 feet in length, will transmit at 12.5 kV, and will be interconnected with Bangor Hydro Electric Company's local, 12.5 kV distribution system. It is assumed that no interconnections are necessary with the use of the GSU. In addition to proposed structures for power generation, Black Bear is proposing to enhance generation output by increasing the normal impoundment level at the Orono Project by 0.6 feet, from 72.4 feet NGVD to 73.0 feet NGVD. The impoundment elevation will be accomplished by increasing the existing flashboard system height by 0.6 feet. The existing non-overflow section of the dam is at elevation 73.0 feet NGVD; the modified flashboards will be installed at the same elevation as the existing non-overflow section of the dam. This will allow for the normal headpond elevation increase while maintaining flood flow discharge capacity by not changing the existing spillway crest elevation. There will be no changes to minimum flows in the bypass channel reach.

Temporary Cofferdams

Three areas will be isolated for approximately a year at the Orono Project using solid fill cofferdams, in addition to a water diversion.

- Intake Cofferdam: A 300-foot long solid fill dam will be installed in the impoundment, upstream of the existing dam, to facilitate construction of the new intake structure. It will be constructed of clean, bank-run gravel, fill material. The top of the cofferdam will be approximately ten feet wide and it will have 2:1 side slopes. The footprint of the cofferdam will be approximately 20,000 square feet (0.5-acres) and the total volume of fill will be approximately 6,700 cubic yards (cy), of which 5,600 cy will be below the normal pond elevation of 72.4 feet NGVD.

- Powerhouse Isolation Cofferdam: A combination sheathing and solid fill cofferdam will be used to create a dewatered work environment to drill and blast bedrock in the new powerhouse area. The sheathing will be pinned to bedrock and will consist of typically 4 feet high flashboards. The footprint of the isolation cofferdam will be 3,870 square feet (0.09 acres) and the total volume of fill will be 653 cy, of which 437 cy will be below 42.0 feet NGVD, the normal tailwater elevation when the project is not operational.

- Tailrace Cofferdam: A 300-foot long earthen cofferdam will be placed across the naturally occurring alluvial deposits at the junction of the Stillwater Branch and the main stem of the Penobscot River to create a dewatered work environment to drill and blast bedrock. The downstream side of the dam will be selectively armored with rip-rap to minimize erosion. The footprint of the cofferdam will be approximately 18,000 square feet (0.41 acres) and the total volume of fill will be approximately 5,200 cy, of which 1,900 cy will be below 42.0 feet NGVD (the normal tailwater elevation when the Project is not operational).

- Water diversion: A pinned flashboard river flow control cofferdam structure will be erected to minimize, or eliminate, normal river flows from encroaching on the penstock and powerhouse construction work areas. The pinned flashboards will be attached to an existing concrete dam, as well as a new concrete sill that will be constructed on dry bedrock. Once complete the new sill will allow for a continuous pinned wooden flashboard system, approximately five feet tall, to be mounted from beneath the railroad trestle near the center pier to a high ledge outcropping near the right-hand end of the non-overflow dam forebay wall. The total length of the pinned flashboard system will be approximately 210 feet. Black Bear will retain the diversion wall (water diversion structure) from the dam to the existing low diversion wall just upstream of the railroad trestle. The diversion wall will have a stop log slot in it that will be removed at the end of construction to allow the approximate 153 cfs discharge from the new downstream fishway/upstream trapping facility (concentrating flow in the easternmost reach of the channel) to flow on into the mainstream of the Penobscot River.

Powerhouse Construction

Once the powerhouse isolation cofferdam is in place, construction of the powerhouse will occur. The overall footprint of the powerhouse is about 59.5 feet by 55.5 feet (3,300 square feet). However, as the entire footprint does not need to be excavated down to the same elevation, it will be excavated in steps to reduce the amount of excavation. The lowest area to be excavated is for the draft tube elbows and extensions and it is approximately 18 feet by 55 feet (990 square feet). This area will be excavated down to about 23.75 feet NGVD and then a concrete foundation slab placed. The total amount of ledge anticipated to be removed from the powerhouse area is approximately 1,900 cy. Ledge will be removed by drilling and blasting. Holes will be drilled into the bedrock down to a specified depth and then blast charges will be installed in the resulting cavities. Upon blasting the fractured bedrock will be removed by mechanical means such as an excavator or a crane.

After the site has been prepared, the powerhouse substructure can be constructed. The substructure is made of reinforced concrete with walls a minimum of two feet thick. The turbine floor is at 36.25 feet NGVD and the generator floor is at 63.9 feet NGVD. It is anticipated that the substructure would be constructed to about 63.9 feet NGVD and this includes setting the three steel square-to-round transition pieces, steel 90 degree elbows, and runners. Also placed would be the draft tube gate piers made of reinforced concrete to 53.0 feet NGVD. The draft tube gates could then be installed. The draft tube gates are approximately 15.4 feet wide by 19 feet high each and made of steel members. The head gate slots, head gates, and deck will also be installed immediately upstream of the square-to-round transitions. The three headgates will be 9.5 feet wide by 9 feet tall each and made of steel members. There will be a steel monorail hoist system installed on the deck to raise and lower the gates. The tailrace cofferdam can be removed at this point. With the turbidity curtain in place, removal of the earthen cofferdam will be done in sections by mechanical means, such as an excavator. Cofferdam removal will be timed with low inflows or will be conducted with flashboard removal.

The remaining powerhouse construction, which includes the setting of the units and the superstructure construction, will take place next. The powerhouse superstructure will be made of corrugated metal siding with four roof hatches for ease of generator and runner maintenance in the future.

Penstock and Surge Chamber Construction

A concrete box type penstock will be constructed from the new intake, passing under the railroad trestle down to an open surge chamber immediately upstream of the powerhouse. The reinforced concrete penstock is made from both cast-in-place concrete and pre-cast concrete roof panels. The base slab and walls will be cast-in-place concrete while the roof will be ten feet by 25 feet precast roof panels with concrete placed between the precast panels. The penstock has a clear width of 25 feet and inside height of 12 feet. The total length of the penstock is about 393 feet from the intake to the surge chamber. There is no excavation anticipated for the construction of the penstock.

The open surge chamber will be constructed at the downstream end of the penstock immediately upstream of the powerhouse. The footprint of the surge chamber is approximately 60 feet long with the width increasing from 25 feet at the penstock end to 44 feet at the powerhouse end. The surge chamber is made of reinforced concrete with an open top. The base slab is at EL 50.56 feet and the walls extend to EL 75.0 feet on the east side and EL 80.0 on the north and west sides. There is no excavation anticipated for the construction of the surge chamber.

Tailrace Excavation

The bedrock excavation will take place by drilling and blasting. The total amount of ledge removed for the project structures and tailrace is approximately 3,550 cy. This includes 1,900 cy for the powerhouse foundation, 50 cy for the intake structure, 1,100 cy for the tailrace, and 500 cy of additional bedrock removal to extend the permanent tailrace channel to re-enter the Penobscot River. Prior to excavation activities, site preparation will include mechanical removal of debris and overburden. Drilling will occur down to the specified elevation depending on the area being excavated. Blast charges will be installed into the drilled cavities. Upon blasting, the fractured bedrock will be removed by mechanical means such as an excavator or crane. The excavated rock will be repurposed as fill and/or shoreline stabilization where feasible and will otherwise be disposed of onsite to the extent possible. Blasting activities will be conducted in accordance with a blasting plan, which Black Bear will develop in consultation with the agencies.

Trashrack Installation and Intake Structure Completion

After the intake and gate structure is complete, the upstream cofferdam will be installed and the concrete portion of the existing dam upstream of the new powerhouse intake will then be demolished. This section is an existing non-overflow structure and it is essentially between the existing spillway abutment and the existing head works abutment. Once this is removed, the intake structure wall extensions can be finalized and the trashrack structure can be constructed. The intake walls are 3-feet-thick reinforced concrete with a large footing. The top of wall elevation is 78.3 feet and the walls extend west to meet the new trashrack structure. The new trashrack structure will be in the same alignment as the existing intake rack and rake structure. The sill of the trashracks will be EL 57.9 feet and the top of the deck will match the top of the intake walls at EL 78.3 feet. The trashracks will have one inch clear bar spacing from top to bottom and they will be supported by structural steel frames. The top of the structure will have an11.3 feet wide deck with rails installed, splicing the existing rails so the existing trash rake will be able to travel on the new deck and be utilized.

The new upstream fish trapping facility will be constructed adjacent to and below the new downstream fish passage facility. The upstream trapping facility will consist of a fixed brail system, a blocking screen, and an elevating hopper to retrieve the trapped fish. Black Bear will provide short distance trucking of trapped fish to a location upstream of the dam.

Cofferdam Removal

Once construction activities are complete, the powerhouse isolation and tailrace cofferdams will be removed by flooding the area by pumping or natural fill, to make the cofferdam water levels equal with the tailrace elevation. An excavator will travel on top of the cofferdams and remove the material in sections. The turbidity curtains will be in place and maintained during the removal of the cofferdams. Cofferdam removal will be timed with inflows to allow the maintenance of the normal pond elevation or lower to prevent spill in the tailrace during cofferdam removal activities.

The upstream cofferdam will be flooded and then removed by mechanical methods, such as an excavator. The upstream turbidity curtain will be in place and maintained during the removal of the cofferdam. Cofferdam removal will be timed with inflows to allow the maintenance of the normal pond elevation or lower to minimize erosion of the cofferdam as it is being removed. This will place the existing powerhouse back in service and initiate operation of the new powerhouse.

Minimum Flows

Minimum flows into the bypass reach will be maintained throughout the construction activities. The commensurate number of flashboards in the spillway section of the dam will be removed to provide the full 200 cfs minimum flow to the eastern channel of the bypass reach during construction activities to maintain aquatic habitat. In addition, during the period of time that the upstream cofferdam is in place, all flows will be passed over the spillway.

2.1.2.2.Upstream Fish Passage

There are currently no upstream fish passage facilities for Atlantic salmon or other anadromous species at the Orono Project. As part of the proposed action, Black Bear will install a fish trap and handling facility at the Orono Project spillway. The purpose of the fish trap is not to serve as a traditional fishway, but rather as an evacuation device that will remove fish that are attracted to the spillage in the Orono bypass reach. The new upstream fish trapping facility will be constructed adjacent to and below the downstream fish passage facility. A portion of the downstream fish passage flow (120 to 130 cfs) will be used for attraction flow for the upstream trapping facility. The upstream trapping facility will consist of a fixed brail system, a blocking screen and an elevating hopper to retrieve the trapped fish. In addition, the existing upstream fishway for American eels will be relocated immediately adjacent to its existing location.

Black Bear will be responsible for operating and maintaining the trap, and for short-distance transfer of trapped fish to mainstem locations approved by the MDMR. Trapped fish will not be released into the Orono headpond as there are no upstream passage facilities at the Stillwater Project, located 2.4-miles upriver. Black Bear will monitor the trap and notify the agencies of the species and numbers of fish trapped each year.

Management authorities, including state resource agencies and the Penobscot Indian Nation (PIN), will conduct long-distance transfer of trapped fish to upstream spawning habitat or to a hatchery. However, Black Bear will provide assistance to the agencies and PIN and will work cooperatively to achieve efficient handling procedures, which could include the sharing of trap and transport equipment.

In conformance with the respective project license requirements, Black Bear has also developed operating and maintenance procedures for various facilities that will accommodate the most effective fish passage operations in conjunction with project operations. In addition to maintaining fishway operations, the procedures, developed in consultation with the state and federal resource agencies and PIN, will include recommended unit sequencing to maximize fishway attraction (e.g., first on and last off operations for the powerhouse intake located closest to the upstream fishway entrance).

2.1.2.3.Downstream Fish Passage

As part of the refurbishment of the Orono Project in 2009, a downstream bypass facility was designed and installed to accommodate diadromous fish species. It includes reduced spacing of the trashracks (1-inch), and downstream fish passage that discharges up to 70 cfs into a plunge pool in the bypass reach immediately below the dam. The proposed project will incorporate the installation of full depth 1-inch-clear spacing trashracks along the entire new common intake. Black Bear will maintain and operate the downstream fish passage throughout fish migration periods defined as: April 1 to June 30 and November 1 to December 15 for Atlantic salmon; July 1 to December 31 for American shad and alewife; August to December 31 for blueback herring; and August 15 to November 15 (or other time periods determined when adequate information is available, and during any spring run that may occur) for American eel. Black Bear will perform all maintenance activities before each migratory period, such that the fishways can be tested, inspected, and operate effectively prior to and during the migratory periods.

The present downstream passage facility will need to be modified as a result of the construction of the new penstock and powerhouse. In addition, a new downstream fish passage facility will be constructed on the left side of the trashrack (looking downstream) at the intake of the powerhouse to allow for the downstream passage of fish. Based on preliminary designs, the downstream fish passage facility will consist of a four foot wide entrance into a 20 foot long by 8 foot wide sluice with a screened floor that narrows to three feet at the exit. Stoplogs will be used to control the level and flow of water at the entrance and exit. The new downstream fish passage facility will allow for a continuous flow of water of approximately 153 cfs, which is more than twice the flow through the current downstream passage facility and is equal to four percent of the combined intake capacity.

The fish will be passed into a plunge pool which will discharge into the bypass reach below the dam. The fish passage facility will also provide for downstream eel passage, which will consist of a two foot diameter downstream eel passage facility installed at the base of the trashrack with an invert at 60.0 feet NGVD extending to a weir controlled box structure which outlets to the downstream side of the new intake structure. The downstream fish passage facility will be designed to pass a combined flow of 153 cfs.

2.1.2.4. Species Protection Plan

Black Bear proposes to implement the protection measures and performance standards associated with their proposed SPP at the Orono Project. The SPP incorporates several components, including fishway enhancements, performance measures, efficiency and survival studies and a decision making process, to minimize the effects that the Project will have on listed species in the Penobscot River.

The performance standard for downstream migrating smolts and kelts at the Orono Project is a minimum of 96% survival, based on a 75% confidence interval. That is, no fewer than 96% of downstream migrating smolts and kelts approaching the dam structure must survive passing the dam structure, which would include from 200 meters upstream of the trashracks and continuing downstream to a point where delayed effects of passage can be quantified. Fish that stop moving prior to reaching the most downstream telemetry array or take longer than 24 hours to pass the Project will be considered to have failed in their passage attempt. The decision process on how to achieve this standard through project operation is described in Figure 2.

Atlantic salmon that are trapped at the new Orono trap and handling facility will be transported to habitat upstream of the Milford Project by Black Bear. There is no upstream performance standard for the Orono Project; however, monitoring will be conducted to determine if Atlantic salmon are being significantly delayed (greater than 48 hours) in either of the Orono tailraces or in the bypass reach.

Decision Making Process and Study Design

Following implementation of the fishway enhancements described above, Black Bear will evaluate smolt survival at the Orono Project for three years to determine whether the downstream survival performance standard is being met. In the event that the performance standard is not met, the first enhancement measure will be implemented (Figure 2). After the implementation of the new measure, another three year study period will be initiated. If this study determines that the standard has still not been met, the next measure will be implemented. This process will continue sequentially through three different enhancement measures, or until the performance standard is met. The enhancement measures are as follows:

1. Increase bypass flow up to the limit of the facility;
2. Increase spill to between 20% and 50% of river flow at station at night during the two-week smolt out migration period; and
3. Two weeks of 100% spill of river flow at night (except for one unit, which will be operated at its lowest possible setting as required for powerhouse startup), followed by two weeks of spill of 25% of river flow during day and night.

After the final measure, a one year study will be conducted to ensure that the standard continues to be met. If, after the final enhancement has been studied, the Orono Project is still not achieving the 96% performance standard, FERC will reinitiate formal consultation with NMFS. Once the 96% standard has been met, Black Bear will conduct a one year study every ten years to verify that the standard continues to be met.

The downstream passage monitoring will be conducted using radio tags. It is anticipated that 102 smolts, plus 45 to 60 paired release fish, will be evaluated at the Orono Project for each year of the study. The evaluation will use three release groups of 34 smolts each, along with 15 to 20 paired release fish, when river flows are within the 10-90th percentile for average May flows.

Ten years after completion of the final enhancements for smolt outmigration at the Orono Project, Black Bear proposes to conduct a downstream kelt study. The intent of this study is to verify that the 96% downstream performance standard is being met. The study will be a three year study that coincides with smolt monitoring and will use no more than 40 male kelts per project per year.

During the evaluation of the effectiveness of the upstream fish lift installed at the Milford Project, Black Bear will deploy telemetry receivers to monitor Atlantic salmon in the tailraces of the new and existing powerhouses at the Orono Project, as well as in the bypass reach, to evaluate if they are delayed significantly (greater than 48 hours) under study conditions by the presence and operation of the project. If significant numbers of salmon are being delayed at the

Project, Black Bear will coordinate with the Services to determine reasonable solutions.

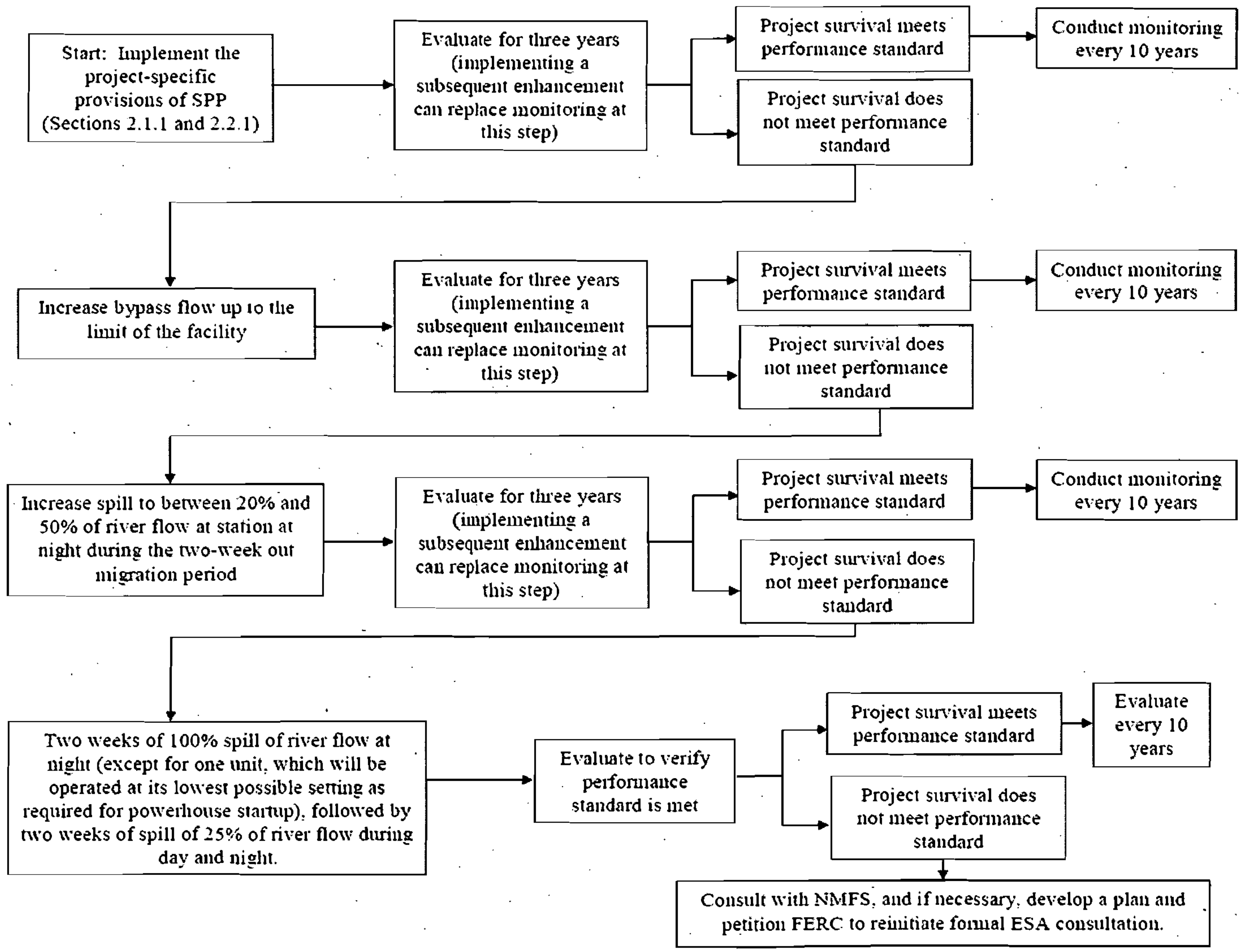

Figure 2. The proposed decision process for implementing the downstream performance standard described in the SPP.

2.1.2.5. Sturgeon Handling Plan

Following removal of the Veazie and Great Works dams, there will be no impediments to sturgeon reaching the Orono Project. Black Bear has committed to implementing a sturgeon handling plan to provide for safe handling of any sturgeon that are encountered during fish lift operations and in the event of stranding during flashboard replacement. FERC is proposing to require adherence to the handling plan as a condition of the amended operating license.

It is possible that sturgeon could be captured at the Orono fish trap and handled during the sorting process. The Sturgeon Handling Plan, which is incorporated into the license amendment proposed for approval by FERC, would require the release of any captured sturgeon back to the river below the project.

Annually, the impoundment of the Orono Project is lowered to a point where the flashboards can safely be replaced, resulting in a short period (a few hours) of receded flows downstream. During this time, fish could become stranded in isolated pools in the bypass reach. The handling plan includes measures to ensure safe handling of any sturgeon stranded during this period. If shortnose or Atlantic sturgeon become stranded, Black Bear will return them to the river downstream.

Fish Lift Operations

Atlantic and shortnose sturgeon will not be passed upstream of the Orono Project as the dam location is thought to be the historical limit of upstream migration for sturgeon on the Stillwater Branch (Houston *et al.* 2007), and because of concerns regarding the safety of downstream passage for shortnose and Atlantic sturgeon. The handling plan requires that if sturgeon are found in the fish lift, the following procedures will be implemented:

- For each sturgeon detected, Black Bear shall record the weight, length, and condition of the fish. Fish will also be scanned for PIT tags. River flow, bypass reach minimum flow, and water temperature will be recorded.
- If alive and uninjured, the sturgeon will be immediately returned downstream. A long handled net outfitted with non-abrasive knotless mesh will be used to place the sturgeon back into the river downstream of the dam. The fish should be properly supported during transport in the net to ensure that it is not injured.
- If any injured sturgeon are found, Black Bear shall report immediately to NMFS. Injured fish must be photographed and measured, if possible, and the reporting sheet must be submitted to NMFS within 24 hours. If the fish is injured, it should be retained by Black Bear, if possible, until transfer to a NMFS recommended facility for potential rehabilitation can be arranged.
- If any dead sturgeon are found, Black Bear will report immediately (within 24 hours) to NMFS. Any dead specimens or body parts should be photographed, measured, scanned for tags and all relevant information should be recorded. Specimens should be stored in a refrigerator by the licensee until they can be obtained by NMFS for analysis.

Sturgeon Stranding

Following removal of the Veazie Dam sturgeon will have access to the Orono Project tailrace and bypass reach. When the flashboards are replaced at the Orono dam, or other operations cause no-spill or no-leakage conditions, there is a possibility that sturgeon may become stranded in pools below the dam. If this situation occurs, the license requires that Black Bear check these pools as soon as possible for the presence of sturgeon. The handling plan requires that Black Bear follow this protocol:

- Designated Black Bear employees and fish lift operation staff must monitor the pools below the dams while the flashboards at the project are replaced.
- For each fish removed from the pool, Black Bear will record the weight, length, and condition. Fish should also be scanned for PIT tags. River flow, bypass reach minimum flow and water temperature will be recorded.
- If stranded but alive and uninjured, the sturgeon will be moved to the river below the dam at a point that will provide for movement of the fish out of the area.
- If any injured sturgeon are found, Black Bear will report it immediately to NMFS. Injured fish must be photographed and measured, if possible, and the reporting sheet will be submitted to NMFS within 24 hours. If the fish is badly injured, the fish should be retained by Black Bear, if possible, until transfer to a NMFS recommended facility for potential rehabilitation can be arranged.
- Black Bear shall report any dead fish immediately (within 24 hours) to NMFS. Any dead specimens or body parts should be photographed, measured, scanned for tags and all relevant information should be recorded. Specimens should be stored in a refrigerator by Black Bear until they can be obtained by NMFS for analysis.

2.2. Stillwater Project - FERC No. 2712

2.2.1. Existing Hydroelectric Facilities and Operations

The Stillwater Project is located in the City of Old Town, Penobscot County, Maine on the Stillwater Branch of the Penobscot River. The Stillwater Dam spans the Stillwater Branch 2.4 miles upstream of its confluence with the main stem of the Penobscot River in Orono (Figure 1).

The existing Stillwater Project works consist of a main concrete gravity dam, totaling about 1,720 feet long, with a maximum height of 22 feet at crest elevation 91.65 feet; a concrete and wooden powerhouse, about 83.5 feet long by 32 feet wide by 45 feet high; a downstream fishway bypass; four horizontal hydroelectric generating units, all totaling a rated capacity of 1,950 kilowatts (kW) and a hydraulic capacity of 1,700 cfs; an impoundment, about 3.1 miles long, having a surface area of about 300 acres; and appurtenant facilities. The Stillwater Project is operated as a run-of-river development with discharge from the project turbines and spillway equivalent to inflow. The Stillwater Project includes a downstream bypass that discharges to the tailrace. The Stillwater Project also includes two upstream fishways for juvenile American eel that are located at the east and west abutments of the spillway. The Project provides a minimum flow to the bypass reach of 195 cfs through weirs located near the west abutment (70 cfs) and near the center of the spillway (125 cfs).

2.2.2. Proposed Action

Black Bear filed an application with FERC on May 18, 2011 to amend the license for the Stillwater Project to include a second powerhouse and a new downstream fish bypass. Black Bear is also proposing that FERC extend the license term for this project by ten years to 2048. FERC is proposing to amend the license as requested by Black Bear and to authorize an additional ten years of project operations. FERC will require that Black Bear implement the protection measures and performance standards associated with their proposed SPP at the Stillwater Project. As there are no upstream anadromous fish passage facilities at the Stillwater Project, only the downstream performance standard will apply at this project. The project will include the construction of a new downstream fish bypass facility at the new powerhouse.

2.2.2.1.New Powerhouse Construction

The modifications proposed at the Stillwater Project consist of a new intake structure replacing the east abutment of the spillway and supplying water to a second powerhouse located integral to the dam. This powerhouse will be situated upon ledges located immediately downstream of the existing spillway abutment. The tailrace will discharge to the existing pool in the bypass reach.

Active construction will occur below the MHW line of the Penobscot River for the construction of a new powerhouse at the Stillwater Project. Protection, mitigation and enhancement measures that address anticipated project effects to environmental resources at the Project have been proposed by Black Bear. Short-term effects to aquatic species and habitats anticipated from construction activities below the normal high water elevation in the project facility footprints are addressed by the following:

- Develop a soil erosion and sediment control plan prior to the start of any construction activity to prevent any short-term erosion or sedimentation effects in the river;
- Maintain minimum bypass reach flows during construction activities to minimize effects to aquatic habitat;
- Conduct excavation and blasting activities in the dry to the extent possible; and
- Limit charge weights and delay individual blasts to keep detonation related sound pressures at a safe level for aquatic resources (less than an SPL of 206 dB re 1 uPa (3.6 psi), and below an SEL of 187 dB re 1 uPa sq.-sec) and implement blasting monitoring/reporting provisions.

New construction and alteration of the Stillwater Project will include the construction of a second powerhouse containing three 1700 mm (5.6 feet) diameter vertical axial flow CHC turbine-generating units having a nameplate capacity of 803 kW per unit. The new powerhouse will have a total rated capacity of approximately 2,229 kW and a total hydraulic capacity of approximately 1,758 cfs. The powerhouse will be located adjacent to the existing left buttress of the dam. A new 60-feet-wide forebay intake will supply the powerhouse. Aerial transmission lines will be installed from the new powerhouse's GSU to the existing adjacent 12.5 kV distribution system.

The proposed second powerhouse will be a reinforced concrete foundation with a steel-framed, metal-sided building and roof measuring approximately 55-feet-long by 40-feet-wide by 56-feet-high and housing the three generating units rated at 743 kW. The new units will have a minimum hydraulic capacity of 160 cfs and a maximum operating capacity of approximately 586 cfs, with a net head of 18.75 feet (under full station operation). Once the second powerhouse is constructed, the Stillwater Project will have a total combined maximum hydraulic capacity of 3,458 cfs (1,700 cfs existing capacity at the existing powerhouse plus 1,758 cfs capacity at the new powerhouse) and a minimum operating capacity of approximately 100 cfs (minimum operating capacity of one unit at the existing powerhouse).

The new powerhouse will include six generator leads, a 60 Hertz, 4.16 kV/12.5kV three phase transformer and appurtenant facilities including; (2) HPU's, (1) sump pump, air compressor, ventilation fans, switch gear and control cabinets, draft tube gate hoist, headgate gate hoist, overhead door and roof hatches. This new powerhouse will operate in conjunction with the existing powerhouse to enhance power production. The new powerhouse intake will be 22 feet high by 60 feet wide and will be integral to the powerhouse. The intake will feature a 60-feet-wide by 22-feet-high trashrack, spaced 1-3/8 inches on center, (1-in clear spacing), situated at a 14.0 degree slope from vertical (1H:4V± slope). A transmission line will extend from the GSU transformer at the new powerhouse to a local 12.5 kV distribution system that is located adjacent to the existing project boundary and along the south side of Stillwater Avenue. The transmission line is approximately 300 feet in length and will transmit at 12.5 kV. It is assumed that no interconnections are necessary with the use of the GSU.

Temporary Cofferdams

As part of the construction activities associated with the Stillwater Project, there will be two areas of limited cofferdamming and one dead-end causeway.

- Intake Cofferdam: A 215-foot long earthen cofferdam will be installed in the forebay of the Stillwater Project, running from the easterly bank to the spillway. The cofferdam will be constructed of washed gravel and will be 10-feet wide on the top. The footprint of the cofferdam will be 16,000 square feet (0.37 acres).

- Powerhouse Isolation Cofferdam: A similarly built 560-foot earthen cofferdam will be constructed downstream of the dam and will affect approximately 33,800 square feet (0.78-acres) of habitat. A turbidity curtain will be placed downstream of the cofferdam and the downstream slope will be selectively riprapped to prevent erosion of material into the river.

- Tailrace Causeway: To remove the downstream extent of ledge, a temporary causeway, of clean, bank-run gravel fill material will be placed upstream of the bedrock berm at the outlet to the eastern side channel. The lower end of the tailrace channel that requires bedrock removal begins approximately 160 feet downstream of the proposed powerhouse and covers a length of approximately 340 feet. The footprint of the causeway will be approximately 23,800 sq feet (0.55 acres).

Cofferdam Removal

Once construction activities are complete, the powerhouse/tailrace cofferdam will be removed by flooding the area by pumping or natural fill, to make the cofferdam water level equal with the tailrace elevation. An excavator will travel over the top of the cofferdam and remove the material in sections. The turbidity curtain will be in place and maintained during the removal of the cofferdam. Cofferdam removal will be timed with inflows to allow the maintenance of the normal pond elevation or lower to prevent spill in the tailrace during cofferdam removal activities. Minimum bypass reach flows will be temporarily suspended during cofferdam removal activities.

Once construction of the intake and powerhouse is complete and the dam is breached, the forebay will be flooded by pumping or by allowing natural refill through seepage. With the turbidity curtain in place, removal of the earthen cofferdam will be done in sections by excavator. Cofferdam removal will be timed with low inflows or will be conducted with flashboards removed to allow the passing of inflows above the capacity of the Project downstream.

The dead-end temporary causeway will be removed by mechanical means with an excavator. The berm at the entrance to the eastern side channel around the island in the tailrace will be lowered during egress by approximately 2.0 feet in elevation at a width of approximately 10ft to allow continued hydrologic input into this reach under the post-construction condition. This removal will occur behind a turbidity curtain and will occur under suspended minimum flows.

Minimum Flows

During construction activities in the powerhouse footprint and tailrace, the minimum flow of 70 cfs into the existing bypass reach will be maintained during installation of the upstream and downstream cofferdams, both of which will be installed behind a turbidity curtain to allow for maintenance of minimum flows. The minimum bypass reach flow may need to be temporarily suspended during some portions of the six to eight weeks of the downstream work. Some of the existing flashboards on the spillway outside of the cofferdam will be lowered in order to pass required minimum flows during construction, otherwise. The 35 cfs fish passage flow at the existing powerhouse downstream fish passage facility will continue throughout the construction process. Once the new powerhouse and tailrace channel excavation work is completed and the material removed, the required minimum bypass reach flow will resume.

The required minimum flows in the project bypass reach of 50 cfs in the east channel will be satisfied with the 70 cfs that will be routed through the proposed downstream fish passage facility at the new powerhouse, both during fish passage season and when it is off-line. Outside of fish passage season, operation of at least one unit of the new powerhouse will satisfy the 50 cfs requirement. The 20 cfs minimum flow will continue to be discharged to the west channel through the flashboard notch in the dam.

2.2.2.2. Upstream Fish Passage

There are currently no upstream fish passage facilities for Atlantic salmon or other anadromous species at the Stillwater Project; and none are proposed. Black Bear will provide short-distance trucking of fish that are captured at the downstream Orono Project, including transfers around the Stillwater dam.

A new upstream eel passage facility will be installed at the top of the forebay, adjacent to the new forebay retaining wall. This structure will consist of a textured climbing surface within a metal trough, similar to the existing upstream eel passage facilities currently installed at the Orono Project.

2.2.2.3. Downstream Fish Passage

The Stillwater Project currently includes a downstream bypass that includes one inch clear spacing of the trashracks and a bypass flume that discharges into the tailrace. As part of the redevelopment of the Stillwater Project, Black Bear will install a new downstream bypass. This will include a downstream fishway at the new powerhouse and refurbishing the existing downstream fishway and adding 1-inch trashracks for the full depth of the new and existing powerhouse intakes. Black Bear will maintain and operate the downstream fish passage throughout fish migration periods defined as: April 1 to June 30 and November 1 to December 15 for Atlantic salmon; July 1 to December 31 for American shad and alewife; August to December 31 for blueback herring; and August 15 to November 15 (or other time periods determined when adequate information is available, and during any spring run that may occur) for American eel. Black Bear will perform all maintenance activities before each migratory period, such that the fishways can be tested, inspected, and operate effectively prior to and during the migratory periods.

Based on preliminary designs, the downstream fish passage facility will be a combination of an opening in the flashboards in the forebay at the trashracks under normal pond conditions and a three foot wide and four foot deep opening in the forebay wall at invert elevation 87.65 feet NGVD (four feet below the permanent crest elevation of the dam) controlled by stoplogs, when the headpond elevation is generally at or below the permanent crest elevation of the dam. A two foot diameter downstream eel passage facility will be installed at the base of the trashrack with an invert at 79.0 feet NGVD extending to a weir controlled box structure which outlets to the tailrace of the powerhouse. The downstream fish passage facility will be designed to pass a combined flow of 70 cfs.

The fish will be passed into a plunge pool that discharges to the tailrace of the new powerhouse. Initial field investigations have shown the existing perched bedrock depression in the vicinity of the proposed downstream fish passage facility to be at least six feet in depth under minimum tailwater elevation conditions. If, during construction of the fish passage facility, the natural depth of the pool is discovered not to consistently be a minimum of six feet in depth, the naturally occurring perched plunge pool will be extended up with concrete walls to provide a minimum of six feet depth, concurrent with construction of the passage facility. The double-regulated unit nearest the downstream fish passage facility at the new powerhouse will be first on and last off to provide attraction to the downstream fish passage facility.

2.2.2.4. Species Protection Plan

Black Bear proposes to implement the protection measures and performance standards associated with their proposed SPP at the Stillwater Project. The SPP incorporates several components, including fishway enhancements, performance measures, efficiency and survival studies and a decision making process, to minimize the effects that the Project will have on listed species in the Penobscot River.

Performance Standards

The performance standard for downstream migrating smolts and kelts at the Stillwater Project is a minimum of 96% survival, based on a 75% confidence interval. That is, no fewer than 96% of downstream migrating smolts and kelts approaching the dam structure will survive passing the dam structure, which would include from 200 meters upstream of the trashracks and continuing downstream to a point where delayed effects of passage can be quantified. Fish that stop moving prior to reaching the most downstream telemetry array or take longer than 24 hours to pass the project will be considered to have failed in their passage attempt. The decision process on how to achieve this standard through project operation is described in Figure 2.

There are no upstream fish passage facilities at the Stillwater Project and, therefore, no upstream performance standard is being proposed.

Decision Making Process and Study Design

Following implementation of the fishway enhancements described above, Black Bear will evaluate smolt survival at the Stillwater Project for three years to determine whether the downstream survival performance standard is being met. In the event that the performance standard is not met, the first enhancement measure will be implemented (Figure 2). After the implementation of the new measure, another three year study period will be initiated. If this study determines that the standard has not been met, the next measure will be implemented. This process will continue sequentially through three different enhancement measures, or until the performance standard is met. The enhancement measures are as follows:

1. Increase bypass flow up to the limit of the facility;
2. Increase spill to between 20% and 50% of river flow at station at night during the two-week smolt out migration period; and
3. Two weeks of 100% spill of river flow at night (except for one unit, which will be operated at its lowest possible setting as required for powerhouse startup), followed by two weeks of spill of 25% of river flow during day and night.

After the final measure, a one year study will be conducted to ensure that the standard is being met. If, after the final enhancement has been studied, the Stillwater Project is still not achieving the 96% performance standard, FERC will reinitiate formal consultation with NMFS. Once the 96% standard has been met, Black Bear will conduct a one year study every ten years to verify that the standard continues to be met.

The downstream passage monitoring is expected to be conducted using radio tags. It is anticipated that 102 smolts will be evaluated at the Stillwater Project for each year of the study. Given the proximity of the two projects, the upstream release for the Orono Project study will be used as the downstream release for Stillwater Project study. The evaluation will use five release groups of 34 smolts each per year, when river flows are within the 10-90th percentile for average May flows.

Ten years after completion of the final enhancements for smolt outmigration at the Stillwater Project, Black Bear proposes to conduct a downstream kelt study. The intent of this study is to verify that the 96% downstream performance standard is being met. The study will be a three year study that coincides with smolt monitoring and will use no more than 40 male kelts per project per year.

2.3. Milford Project - FERC No. 2534

2.3.1. Existing Hydroelectric Facilities and Operations

The Milford Project consists of the 1,159-foot-long, 20-foot-high, concrete gravity Milford dam, topped with 4.5-foot-high flashboards, the 450-foot-long Gilman Falls dam, a 226-foot-long, 85-foot-wide, 78-foot high powerhouse containing four 1,600 kW turbine/generator units with an installed capacity of 6.4 MW, and a 235 acre reservoir with a gross storage of 2,250 acre-feet.

The project license includes approval for the installation of up to an additional 1,600 kW in empty turbine pits in the powerhouse. This additional unit will increase the installed capacity of the project to 8.0 MW.

2.3.2. Proposed Action

The Milford Project includes a four-foot Denil fishway located at the outboard side of the powerhouse tailrace and two American eel fishways located at the center of the spillway. Black Bear proposes to install a new fish lift and handling facility on the shore side of the powerhouse tailrace. The project is operated in a run-of-the-river mode.

2.3.2.1. Upstream Fish Passage

Black Bear proposes to install a fish lift and handling facility at the Milford Project. The fish lift is scheduled to be installed in 2012-2013. This facility will consist of:

- A shore-based fish lift with a single entrance immediately downstream from the powerhouse, an exit channel to include a fish counting station and facilities for sorting and trapping-and-trucking. The exit channel will pass through the basement of powerhouse. This fish lift will require an attraction flow of 210 cfs, an operation control center computer module, and a separate underground viewing facility for public use.
- A rubber dam at the spillway crest, installed on the 390-foot section of spillway between the mid-river ledge outcrop and the east abutment. This rubber dam will reduce flows that might attract upstream migrants, including Atlantic salmon, and will enhance passage at the fish lift.

Construction activities associated with installation of the new upstream and downstream fishways will take place on the easterly shore within the areas of the Milford forebay, powerhouse, tailrace, and parking lot. No work will be done on the spillway.

In order to create a dry work area in which to install the new fish lift, two cofferdams (bulkheads) will be concurrently installed in the tailrace and in the forebay. In the tailrace, this will be done by installing temporary anchors to the bedrock to support a sheetpile cofferdam that will be sealed prior to dewatering. This cofferdam will allow for the dewatering of 509 square feet of river bottom. The cofferdam in the forebay, however, will be constructed by placing prefabricated steel bulkhead panels over the area where the exit flume penetrates the forebay wall. The cofferdam will then be sealed and dewatered. There will not be any excavation or blasting associated with the construction at the Milford Project.

The Gilman Falls dam is a water control structure in the Stillwater Branch that has a breach section, approximately 75 feet wide, that provides passage to adult Atlantic salmon. No changes are proposed for this dam.

2.3.2.2.Downstream Fish Passage

The Milford Project currently operates a downstream bypass facility with interim measures to protect downstream migrating salmon. Black Bear will maintain and operate the downstream fish passage throughout fish migration periods defined as: April 1 to June 30 and November 1 to December 15 for Atlantic salmon; July 1 to December 31 for American shad and alewife; August to December 31 for blueback herring; and August 15 to November 15 (or other time periods determined when adequate information is available, and during any spring run that may occur) for American eel. Black Bear will perform all maintenance activities before each migratory period, such that the fishways can be tested, inspected, and operate effectively prior to and during the migratory periods.

As part of the proposed project, Black Bear will construct a new downstream fish bypass. The new fishway will incorporate the following changes:

- Reduce the clear bar spacing at the inner trashrack to one inch clear spacing over the full depth of rack;
- Install twin four foot wide (eight feet total) openings at the inner trashrack capable of passing up to 280 cfs; and
- Include a four foot by four foot gated bottom intake to the downstream migrant facilities to provide for the downstream passage of American eels. If so indicated by the results of initial effectiveness studies at Milford, evaluate restricted generation at night over a two-week period to enhance downstream passage of adult American eels.

Until the new downstream fish passage facilities are installed, Black Bear will continue to operate the existing surface weir bypass facilities at Milford.

2.3.2.3.Species Protection Plan

Black Bear proposes to implement a SPP to avoid and minimize impacts to Atlantic salmon related to the operation of the Milford Project on the Penobscot River. The SPP incorporates several components, including fishway enhancements, performance measures, efficiency and survival studies and a decision making process, to minimize the effects that Black Bear's hydroelectric projects will have on listed species in the Penobscot River.

Performance Standards

The performance standard for downstream migrating smolts and kelts at the Milford Project is a minimum of 96% survival, based on a 75% confidence interval. That is, no fewer than 96% of downstream migrating smolts and kelts approaching the dam structure will survive passing the dam structure, which would include from 200 meters upstream of the trashracks and continuing downstream to a point where delayed effects of passage can be quantified. Fish that stop moving prior to reaching the most downstream telemetry array or take longer than 24 hours to pass the project will be considered to have failed in their passage attempt. The decision process on how to achieve this standard through project operation is described in Figure 2.

The performance standard for upstream fish passage requires that 95% of upstream migrating Atlantic salmon pass the dam within 48 hours of approaching within 200 meters of the Project when the river temperature is at or below 23 degrees Celsius. The upstream migrants must not exhibit any trauma, loss of equilibrium, or descaling greater than 20% of the body surface. Trauma is defined as injuries including, but not limited to, hemorrhaging, open wounds without fungus growth, gill damage, bruising greater than 0.5 cm in diameter, etc. Fish displaying these injuries or signs of trauma will be categorized as not having passed safely and will be considered failures.

Decision Making Process and Study Design

Following implementation of the fishway enhancements described above, Black Bear will evaluate smolt survival at the projects for three years to determine whether the survival performance standard is being met. In the event that the performance standard is not met, the first enhancement measure will be implemented (Figure 2). After the implementation of the new measure, another three year study period will be initiated. If this study determines that the standard has not been met, the next measure will be implemented. This process will continue sequentially through three different enhancement measures, or until the performance standard is met. The enhancement measures are as follows:

1. Increase bypass flow up to the limit of the facility;
2. Increase spill to between 20% and 50% of river flow at station at night during the two-week smolt out migration period;
3. Two weeks of 100% spill of river flow at night (except for one unit, which will be operated at its lowest possible setting as required for powerhouse startup), followed by two weeks of spill of 25% of river flow during day and night.

After the final measure, a one year study will be conducted to ensure that the standard is being met. If, after the final enhancement has been studied, the Milford Project is still not achieving the 96% performance standard, FERC will reinitiate formal consultation with NMFS. Once the 96% standard has been met, Black Bear will conduct a one year study every ten years to verify that the standard continues to be met.

The downstream passage monitoring will be conducted using radio tags. It is anticipated that 102 smolts, plus 45 to 60 paired release fish, will be evaluated at the Milford Project for each year of the study. The evaluation will use three release groups of 34 smolts each, along with 15 to 20 paired release fish, when river flows are within the 10-90th percentile for average May flows.

Ten years after completion of the final enhancements for smolt outmigration at the Milford Project, Black Bear proposes to conduct a downstream kelt study. The intent of this study is to verify that the 96% downstream performance standard is being met. The study will be a three year study that coincides with smolt monitoring and will use no more than 40 male kelts per project per year.

At Milford, the 95% upstream passage performance standard will be evaluated before and after Veazie Dam is removed. Therefore, it is anticipated that efficiency will be evaluated in one season during which the new fish lift at Milford is in place and the Veazie Dam has not yet been removed. Passage effectiveness will be evaluated using radio tags or similarly accepted methods. Twenty to forty adult Atlantic salmon that are confirmed to have been released as juveniles upstream of the Milford Project, will be trapped at Veazie, radio tagged and released upstream of the Veazie Dam. Tagged fish that swim to within 200 meters downstream of the Milford Dam will be tracked to determine their success in using the upstream passage facility. Another one-year study will be conducted following the removal of Veazie Dam. At that point, if the project does not achieve the 95% performance standard, the facility will be modified to increase efficiency, and evaluated again and repeated as necessary to achieve the performance standard. Once the standard has been met, Black Bear will reevaluate upstream passage with a one-year efficiency study every ten years thereafter.

2.3.2.4.Sturgeon Handling Plan

Following removal of the Veazie and Great Works dams, there will be no impediments to sturgeon reaching the Milford Project. Black Bear has committed to implementing a sturgeon handling plan to provide for safe handling of any sturgeon that are encountered during fish lift operations and in the event of stranding during flashboard replacement. FERC is proposing to require adherence to the handling plan as a condition of the amended operating license.

It is possible that sturgeon could be captured at the Milford fish trap and handled during the sorting process. The Sturgeon Handling Plan, which is incorporated into the license amendment proposed for approval by FERC, would require the release of any captured sturgeon back to the river below the project.

Annually, the impoundment of the Milford Project is lowered to a point where the flashboards can safely be replaced, resulting in a short period (a few hours) of receded flows downstream. As the Milford Project lacks a true bypass reach that would be at risk of dewatering, it is not likely that any fish would become stranded. However, as a precautionary measure, Black Bear has proposed to follow the provisions of the Sturgeon Handling Plan at the Milford Project. The handling plan includes measures to ensure safe handling should any sturgeon become stranded during this period. If shortnose or Atlantic sturgeon become stranded, Black Bear will return them to the river downstream.

Fish Lift Operations

Atlantic and shortnose sturgeon will not be passed upstream of the Milford Project as the dam location is thought to be the historical limit of upstream migration for sturgeon on the Stillwater Branch (Houston *et al.* 2007), and because of concerns regarding the safety of downstream passage for shortnose and Atlantic sturgeon. The handling plan requires that if sturgeon are found in the fish lift, the following procedures will be implemented:

- For each sturgeon detected, Black Bear shall record the weight, length, and condition of the fish. Fish will also be scanned for PIT tags. River flow, bypass reach minimum flow, and water temperature will be recorded.
- If alive and uninjured, the sturgeon will be immediately returned downstream. A long handled net outfitted with non-abrasive knotless mesh will be used to place the sturgeon back into the river downstream of the dam. The fish should be properly supported during transport in the net to ensure that it is not injured.
- If any injured sturgeon are found, Black Bear shall report immediately to NMFS. Injured fish must be photographed and measured, if possible, and the reporting sheet must be submitted to NMFS within 24 hours. If the fish is injured, it should be retained by Black Bear, if possible, until transfer to a NMFS recommended facility for potential rehabilitation can be arranged.
- If any dead sturgeon are found, Black Bear will report immediately(within 24 hours) to NMFS. Any dead specimens or body parts should be photographed, measured, scanned for tags and all relevant information should be recorded. Specimens should be stored in a refrigerator by the licensee until they can be obtained by NMFS for analysis.

Sturgeon Stranding

Following removal of the Veazie Dam sturgeon will have access to the area downstream of the Milford Project. When the flashboards are replaced at the Milford dam, or other operations cause no-spill or no-leakage conditions, there is a possibility that sturgeon may become stranded in pools below the dam. If this situation occurs, the license requires that Black Bear check these pools as soon as possible for the presence of sturgeon. The handling plan requires that Black Bear follow this protocol:

- Designated Black Bear employees and fish lift operation staff must monitor the pools below the dams while the flashboards at the project are replaced.
- For each fish removed from the pool, Black Bear will record the weight, length, and condition. Fish should also be scanned for PIT tags. River flow, bypass reach minimum flow and water temperature will be recorded.
- If stranded but alive and uninjured, the sturgeon will be moved to the river below the dam at a point that will provide for movement of the fish out of the area.
- If any injured sturgeon are found, Black Bear will report it immediately to NMFS. Injured fish must be photographed and measured, if possible, and the reporting sheet will be submitted to NMFS within 24 hours. If the fish is badly injured, the fish should be retained by Black Bear, if possible, until transfer to a NMFS recommended facility for potential rehabilitation can be arranged.

- Black Bear shall report any dead fish immediately (within 24 hours) to NMFS. Any dead specimens or body parts should be photographed, measured, scanned for tags and all relevant information should be recorded. Specimens should be stored in a refrigerator by Black Bear until they can be obtained by NMFS for analysis.

2.4. West Enfield Project - FERC No. 2600

2.4.1. Existing Hydroelectric Facilities and Operations

The West Enfield Project is located on the main stem of the Penobscot River in the towns of Enfield and Howland, Penobscot County, Maine. The West Enfield Project is operated as a run-of-river facility with inflows equaling outflows either through the powerhouse/gates or via spillage over the dams/flashboards.

The West Enfield Project works consist of: a 39-foot high concrete dam with 7-foot high flashboards that are installed on a 363-foot long overflow spillway; a 194-foot long non-overflow spillway; a 107-foot long gated spillway with three radial gates; and a 200-foot-long, 15-foot-high earth dam located on the west bank of Merrill Brook. The earthen dam on Merrill Brook controls flow from the project reservoir to the Piscataquis River using three steel gates. The 1,125-acre project reservoir has a normal maximum water surface elevation of 156.1 feet mean sea level (msl). The powerhouse contains two pit turbine-generator units with a total rated capacity of 13,000 kW, and appurtenant facilities. No changes are proposed to the physical components of the Project as part of this action.

The upstream fishway at West Enfield is a vertical slot fishway with three entrances. The first entrance is located on the west side of the powerhouse near the dam and is eight feet wide and capable of passing up to 130 cfs. The second entrance is located on the west side of the powerhouse on the downstream side and is five feet wide and capable of passing up to 110 cfs. The third entrance is located on the east side of the powerhouse on the downstream side and is seven feet wide and capable of passing up to 160 cfs. The entrances combine into a single gallery that runs along the downstream width of the powerhouse to the diffusion chamber. The diffusion chamber has six pumps that are capable of passing up to 40 cfs each with a total capacity of 280cfs. Historically, not all the pumps or entrances have been continually used. The fishway conveyance flow is approximately 30cfs. The fishway is constructed with 32 vertical slots with approximately a 0.75 foot drop per slot. A crowder and counting window are constructed about midway up the fishway. The counting window is no longer used. Just downstream of the counting window is a "pike jump". The pike jump is constructed to prevent pike from continuing up the fishway. The exit channel has one foot center to center spaced trashracks and conveys fish to the headpond some distance upstream of the powerhouse. No changes to the upstream fishway are proposed as part of this project.

New downstream fish passage facilities integral to the intake structure were installed at West Enfield in 1988 when the hydropower project was redeveloped. The downstream passage facilities were designed in accordance with DOI/USFWS criteria and specifications. The Project has five surface fish bypass weirs along the top of the turbine intake. Two of these four foot wide fish bypass weirs are used to pass the fish bypass flow. Fish are collected in a collection gallery that runs across the length of the intake to a three foot diameter pipe that is capable of passing up to 100 cfs. The project includes bar racks across the intake that have two inch spacing for the first two feet followed by three inch spacing for the remaining depth. No changes to the downstream bypass are proposed as part of this action. Black Bear maintains and operates the downstream fishway at West Enfield between November 1 and June 15.

2.4.2. Proposed Action

2.4.2.1. Species Protection Plan

Black Bear has proposed to implement an SPP to identify enhancements to avoid and minimize impacts to Atlantic salmon related to the operation of the West Enfield Project on the Penobscot River. The SPP incorporates several components, including fishway enhancements, performance measures, efficiency and survival studies and a decision making process, to minimize the effects that Black Bear's hydroelectric projects will have on listed species in the Penobscot River.

Performance Standards

The performance standard for downstream migrating smolts and kelts at the West Enfield Project is a minimum of 96% survival, based on a 75% confidence interval. That is, no fewer than 96% of downstream migrating smolts and kelts approaching the dam structure will survive passing the dam structure, which would include from 200 meters upstream of the trashracks and continuing downstream to a point where delayed effects of passage can be quantified. Fish that stop moving prior to reaching the most downstream telemetry array or take longer than 24 hours to pass the project will be considered to have failed in their passage attempt. The decision process on how to achieve this standard through project operation is described in Figure 2.

The performance standard for upstream fish passage requires that 95% of upstream migrating Atlantic salmon pass the dam within 48 hours of approaching (within 200 meters) the Project. The upstream migrants must not exhibit any trauma, loss of equilibrium, or descaling greater than 20% of the body surface. Trauma is defined as injuries including, but not limited to, hemorrhaging, open wounds without fungus growth, gill damage, bruising greater than 0.5 cm in diameter, etc. Fish displaying these injuries or signs of trauma will be categorized as not having passed safely and will be considered failures.

Decision Making Process and Study Design

Following implementation of the fishway enhancements described above, Black Bear will evaluate smolt survival at the West Enfield Project for three years to determine whether the survival performance standard is being met. In the event that the performance standard is not met, the first enhancement measure will be implemented (Figure 2). After the implementation of the new measure, another three year study period will be initiated. If this study determines that the standard has not been met, the next measure will be implemented. This process will continue sequentially through three different enhancement measures, or until the performance standard is met. The enhancement measures are as follows:

1. Increase bypass flow up to the limit of the facility;
2. Increase spill to between 20% and 50% of river flow at station at night during the two-

week smolt out migration period; and
3. Two weeks of 100% spill of river flow at night (except for one unit, which will be operated at its lowest possible setting as required for powerhouse startup), followed by two weeks of spill of 25% of river flow during day and night.

After the final measure, a one year study will be conducted to ensure that the standard is being met. If, after the final enhancement has been studied, the West Enfield Project is still not achieving the 96% performance standard, FERC will reinitiate formal consultation with NMFS. Once the 96% standard has been met, Black Bear will conduct a one year study every ten years to verify that the standard continues to be met.

The downstream passage monitoring will be conducted using radio tags. It is anticipated that 102 smolts, plus 45 to 60 paired release fish, will be evaluated at the West Enfield Project for each year of the study. The evaluation will use three release groups of 34 smolts each, along with 15 to 20 paired release fish, when river flows are within the 10-90th percentile for average May flows.

Ten years after completion of the final enhancements for smolt outmigration at the West Enfield Project, Black Bear proposes to conduct a downstream kelt study. The intent of this study is to verify that the 96% downstream performance standard is being met. The study will be a three year study that coincides with smolt monitoring and will use no more than 40 male kelts per project per year.

Black Bear has not proposed an initial upstream passage study at West Enfield. The upstream fishway at West Enfield was modified in 2006 to prevent passage of northern pike in response to state invasive species management. At that time, a "jump" was installed in the fishway that would preclude northern pike passage but would continue to allow Atlantic salmon to pass upstream at the project. The University of Maine is currently evaluating upstream passage effectiveness at the West Enfield Project. Preliminary results of the studies indicate the jump may be having some affects to salmon passage. The jump was modified in the spring of 2012 to improve Atlantic salmon passage. It is anticipated that the issues involving northern pike and Atlantic salmon passage will be resolved at the West Enfield Project within ten years, therefore, Black Bear will not be conducting upstream fish passage monitoring at the Project until 2023.

A one-year efficiency study will be conducted every ten years at the West Enfield Project after the license is amended, to verify that the 95% standard is being met. Passage effectiveness will be evaluated using radio tags or similarly accepted methods. Twenty to forty adult Atlantic salmon that are confirmed to have been released as juveniles upstream of the Milford Project, will be trapped at Milford, radio tagged and released upstream of the Milford Dam. Tagged fish that swim to within 200 meters downstream of the West Enfield Dam will be tracked to determine their success in using the upstream passage facility. At that point, if the project does not achieve the 95% performance standard, the facility will be modified to increase efficiency, and evaluated again and repeated as necessary to achieve the performance standard. Once the standard has been met, Black Bear will reevaluate upstream passage with a one-year efficiency study every ten years thereafter.

2.5. Medway Project - FERC No. 2666

2.5.1. Existing Hydroelectric Facilities and Operations

The Medway Project is located on the West Branch of the Penobscot River, just upstream of the confluence with the East Branch of the Penobscot River. The Project consists of a 343-foot-long concrete gravity dam with wooden flashboards, a 64-foot-long concrete gravity forebay wall, a 120-acre impoundment, a powerhouse containing five generating units with a total installed capacity of 3.44 MW, an approximate 144-foot-long underground transmission line, and appurtenant facilities. The Medway Project includes upstream and downstream American eel fishways that are located at the north abutment of the spillway. There are no other upstream or downstream fish passage facilities at this project. The project is operated in a run-of-the-river mode.

2.5.2. Proposed Action

Black Bear is not proposing any changes to the physical components of the Project as part of the proposed action. As there are no fish passage facilities at the project, Black Bear is not proposing that upstream and downstream performance standards be met at the Medway Project. Rather, in a submittal to FERC on May 15, 2012, Black Bear proposed that FERC amend the license for the Medway Project to incorporate the following language as a license article:

"The Licensee shall consult with the National Marine Fisheries Service once every five years regarding the status of Atlantic salmon and other Endangered Species Act-listed fishery species in the Penobscot River to ensure that operation of the Medway Project is consistent with the listing determinations for such species and with the then-current recovery objectives for such species".

2.6. Action Area

The action area is defined as "all areas to be affected directly or indirectly by the Federal action and not merely the immediate area (project area) involved in the proposed action" (50 CFR 402.02). The action area must encompass all areas where both the direct and indirect effects of the proposed action would affect listed species and critical habitat.

Operation of the Milford, West Enfield, Medway, Stillwater and Orono Projects pursuant to the revised licenses proposed to be approved by FERC, will affect much of the Penobscot River watershed, its estuary, and associated waters. In addition, short-term, construction related effects associated with powerhouse and fishway construction will occur in the lower Penobscot River in the vicinity of the Milford, Orono and Stillwater Projects. Therefore, the Penobscot River watershed represents the action area for this consultation (Figure 1).

3. STATUS OF AFFECTED SPECIES AND CRITICAL HABITAT

NMFS has determined that the following endangered or threatened species may be affected by the proposed action:

Fish

Gulf of Maine DPS of Atlantic salmon	Endangered

Shortnose sturgeon	Endangered
New York Bight DPS of Atlantic sturgeon	Endangered
Gulf of Maine DPS of Atlantic sturgeon	Threatened
Chesapeake Bay DPS of Atlantic sturgeon	Endangered
South Atlantic DPS of Atlantic sturgeon	Endangered
Carolina DPS of Atlantic sturgeon	Endangered

Critical Habitat
Designated for the Gulf of Maine DPS of Atlantic salmon

This section will focus on the status of the various species within the action area, summarizing information necessary to establish the environmental baseline and to assess the effects of the proposed action.

3.1. Gulf of Maine DPS of Atlantic Salmon

3.1.1. Species Description

The Atlantic salmon is an anadromous fish species that spends most of its adult life in the ocean but returns to freshwater to reproduce. The Atlantic salmon is native to the North Atlantic Ocean, from the Arctic Circle to Portugal in the eastern Atlantic, from Iceland and southern Greenland, and from the Ungava region of northern Quebec south to the Housatonic River (Bigelow and Schroeder 1953). In the United States, Atlantic salmon historically ranged from Maine south to Long Island Sound. However, the Central New England DPS and Long Island Sound DPS have both been extirpated (65 FR 69459; November 17, 2000).

The GOM DPS of anadromous Atlantic salmon was initially listed jointly by the USFWS and NMFS (collectively, the Services) as an endangered species on November 17, 2000 (65 FR 69459). In 2009 the Services finalized an expanded listing of Atlantic salmon as an endangered species (74 FR 29344; June 19, 2009). The decision to expand the range of the GOM DPS was largely based on the results of a Status Review (Fay *et al.* 2006) completed by a Biological Review Team consisting of Federal and State agencies and Tribal interests. Fay *et al.* (2006) conclude that the DPS delineation in the 2000 listing designation was largely appropriate, except in the case of large rivers that were partially or wholly excluded in the 2000 listing determination. Fay *et al.* (2006) conclude that the salmon currently inhabiting the larger rivers (Androscoggin, Kennebec, and Penobscot) are genetically similar to the rivers included in the GOM DPS as listed in 2000, have similar life history characteristics, and occur in the same zoogeographic region. Further, the salmon populations inhabiting the large and small rivers from the Androscoggin River northward to the Dennys River differ genetically and in important life history characteristics from Atlantic salmon in adjacent portions of Canada (Spidle *et al.* 2003; Fay *et al.* 2006). Thus, Fay *et al.* (2006) conclude that this group of populations (a "distinct population segment") met both the discreteness and significance criteria of the Services' DPS Policy (61 FR 4722; February 7, 1996) and, therefore, recommend the geographic range included in the new expanded GOM DPS.

The current GOM DPS includes all anadromous Atlantic salmon whose freshwater range occurs in the watersheds from the Androscoggin River northward along the Maine coast to the Dennys River, and wherever these fish occur in the estuarine and marine environment. The following impassable falls delimit the upstream extent of the freshwater range: Rumford Falls in the town of Rumford on the Androscoggin River; Snow Falls in the town of West Paris on the Little Androscoggin River; Grand Falls in Township 3 Range 4 BKP WKR on the Dead River in the Kennebec Basin; the un-named falls (impounded by Indian Pond Dam) immediately above the Kennebec River Gorge in the town of Indian Stream Township on the Kennebec River; Big Niagara Falls on Nesowadnehunk Stream in Township 3 Range 10 WELS in the Penobscot Basin; Grand Pitch on Webster Brook in Trout Brook Township in the Penobscot Basin; and Grand Falls on the Passadumkeag River in Grand Falls Township in the Penobscot Basin. The marine range of the GOM DPS extends from the Gulf of Maine, throughout the Northwest Atlantic Ocean, to the coast of Greenland.

Included in the GOM DPS are all associated conservation hatchery populations used to supplement these natural populations; currently, such conservation hatchery populations are maintained at Green Lake National Fish Hatchery (GLNFH) and Craig Brook National Fish Hatchery (CBNFH), both operated by the USFWS. Excluded from the GOM DPS are landlocked Atlantic salmon and those salmon raised in commercial hatcheries for the aquaculture industry (74 FR 29344; June 19, 2009).

Atlantic salmon have a complex life history that includes territorial rearing in rivers to extensive feeding migrations on the high seas. During their life cycle, Atlantic salmon go through several distinct phases that are identified by specific changes in behavior, physiology, morphology, and habitat requirements.

Adult Atlantic salmon return to rivers from the sea and migrate to their natal stream to spawn; a small percentage (1-2%) of returning adults in Maine will stray to a new river. Adults ascend the rivers within the GOM DPS beginning in the spring. The ascent of adult salmon continues into the fall. Although spawning does not occur until late fall, the majority of Atlantic salmon in Maine enter freshwater between May and mid-July (Meister 1958; Baum 1997). Early migration is an adaptive trait that ensures adults have sufficient time to effectively reach spawning areas despite the occurrence of temporarily unfavorable conditions that naturally occur within rivers (Bjornn and Reiser 1991). Salmon that return in early spring spend nearly five months in the river before spawning, often seeking cool water refuge (e.g., deep pools, springs, and mouths of smaller tributaries) during the summer months.

In the fall, female Atlantic salmon select sites for spawning in rivers. Spawning sites are positioned within flowing water, particularly where upwelling of groundwater occurs, allowing for percolation of water through the gravel (Danie *et al.* 1984). These sites are most often positioned at the head of a riffle (Beland *et al.* 1982); the tail of a pool; or the upstream edge of a gravel bar where water depth is decreasing, water velocity is increasing (McLaughlin and Knight 1987, White 1942), and hydraulic head allows for permeation of water through the redd (a gravel depression where eggs are deposited). Female salmon use their caudal fin to scour or dig redds. The digging behavior also serves to clean the substrate of fine sediments that can embed the cobble and gravel substrates needed for spawning and consequently reduce egg survival (Gibson 1993). One or more males fertilize the eggs that the female deposits in the redd (Jordan and

Beland 1981). The female then continues digging upstream of the last deposition site, burying the fertilized eggs with clean gravel.

A single female may create several redds before depositing all of her eggs. Female anadromous Atlantic salmon produce a total of 1,500 to 1,800 eggs per kilogram of body weight, yielding an average of 7,500 eggs per two sea-winter (2SW) female (an adult female that has spent two winters at sea before returning to spawn) (Baum and Meister 1971). After spawning, Atlantic salmon may either return to sea immediately or remain in fresh water until the following spring before returning to the sea (Fay *et al.* 2006). From 1996 to 2011, approximately 1.3 percent of the "naturally-reared" adults (fish originating from natural spawning or hatchery fry) in the Penobscot River were repeat spawners (USASAC 2012).

Embryos develop in redds for a period of 175 to 195 days, hatching in late March or April (Danie *et al.* 1984). Newly hatched salmon, referred to as larval fry, alevin, or sac fry, remain in the redd for approximately six weeks after hatching and are nourished by their yolk sac (Gustafson-Greenwood and Moring 1991). Survival from the egg to fry stage in Maine is estimated to range from 15 to 35 percent (Jordan and Beland 1981). Survival rates of eggs and larvae are a function of stream gradient, overwinter temperatures, interstitial flow, predation, disease, and competition (Bley and Moring 1988). Once larval fry emerge from the gravel and begin active feeding, they are referred to as fry. The majority of fry (>95 percent) emerge from redds at night (Gustafson-Marjanen and Dowse 1983).

When fry reach approximately four centimeters in length, the young salmon are termed parr (Danie *et al.* 1984). Parr have eight to eleven pigmented vertical bands on their sides that are believed to serve as camouflage (Baum 1997). A territorial behavior, first apparent during the fry stage, grows more pronounced during the parr stage, as the parr actively defend territories (Allen 1940; Kalleberg 1958; Danie *et al.* 1984). Most parr remain in the river for two to three years before undergoing smoltification, the process in which parr go through physiological changes in order to transition from a freshwater environment to a saltwater marine environment. Some male parr may not go through smoltification and will become sexually mature and participate in spawning with sea-run adult females. These males are referred to as "precocious parr." First year parr are often characterized as being small parr or 0+ parr (four to seven centimeters long), whereas second and third year parr are characterized as large parr (greater than seven cm long) (Haines 1992). Parr growth is a function of water temperature (Elliott 1991); parr density (Randall 1982); photoperiod (Lundqvist 1980); interaction with other fish, birds, and mammals (Bjornn and Reiser 1991); and food supply (Swansburg *et al.* 2002). Parr movement may be quite limited in the winter (Cunjak 1988; Heggenes 1990); however, movement in the winter does occur (Hiscock *et al.* 2002) and is often necessary, as ice formation reduces total habitat availability (Whalen *et al.*1999). Parr have been documented using riverine, lake, and estuarine habitats; incorporating opportunistic and active feeding strategies; defending territories from competitors including other parr; and working together in small schools to actively pursue prey (Gibson 1993, Marschall *et al.*1998, Pepper 1976, Pepper *et al.* 1984, Hutchings 1986, Erkinaro *et al.* 1998a, O'Connell and Ash 1993, Erkinaro *et al.* 1995, Dempson *et al.* 1996, Halvorsen and Svenning 2000, Klemetsen *et al.* 2003).

In a parr's second or third spring (age 1 or age 2, respectively), when it has grown to 12.5 to 15 cm in length, a series of physiological, morphological, and behavioral changes occur (Schaffer and Elson 1975). This process, called "smoltification," prepares the parr for migration to the ocean and life in salt water. In Maine, the vast majority of naturally reared parr remain in fresh water for two years (90 percent or more) with the balance remaining for either one or three years (USASAC 2005). In order for parr to undergo smoltification, they must reach a critical size of ten centimeters total length at the end of the previous growing season (Hoar 1988). During the smoltification process, parr markings fade and the body becomes streamlined and silvery with a pronounced fork in the tail. Naturally reared smolts in Maine range in size from 13 to 17 cm, and most smolts enter the sea during May to begin their first ocean migration (USASAC 2004). During this migration, smolts must contend with changes in salinity, water temperature, pH, dissolved oxygen, pollution levels, and various predator assemblages. The physiological changes that occur during smoltification prepare the fish for the dramatic change in osmoregulatory needs that come with the transition from a fresh to a salt water habitat (Ruggles 1980, Bley 1987, McCormick and Saunders 1987, McCormick *et al.* 1998). The transition of smolts into seawater is usually gradual as they pass through a zone of fresh and saltwater mixing that typically occurs in a river's estuary. Given that smolts undergo smoltification while they are still in the river, they are pre-adapted to make a direct entry into seawater with minimal acclimation (McCormick *et al.* 1998). This pre-adaptation to seawater is necessary under some circumstances where there is very little transition zone between freshwater and the marine environment.

The spring migration of post-smolts out of the coastal environment is generally rapid, within several tidal cycles, and follows a direct route (Hyvarinen *et al.* 2006, Lacroix and McCurdy 1996, Lacroix *et al.* 2004). Post-smolts generally travel out of coastal systems on the ebb tide and may be delayed by flood tides (Hyvarinen *et al.* 2006, Lacroix and McCurdy 1996, Lacroix *et al.* 2004, Lacroix and Knox 2005). Lacroix and McCurdy (1996), however, found that post-smolts exhibit active, directed swimming in areas with strong tidal currents. Studies in the Bay of Fundy and Passamaquoddy Bay suggest that post-smolts aggregate together and move near the coast in "common corridors" and that post-smolt movement is closely related to surface currents in the bay (Hyvarinen *et al.* 2006; Lacroix and McCurdy 1996; Lacroix *et al.* 2004). European post-smolts tend to use the open ocean for a nursery zone, while North American post-smolts appear to have a more near-shore distribution (Friedland *et al.* 2003). Post-smolt distribution may reflect water temperatures (Reddin and Shearer 1987) or the major surface-current vectors (Lacroix and Knox 2005). Post-smolts live mainly on the surface of the water column and form shoals, possibly of fish from the same river (Shelton *et al.* 1997).
During the late summer and autumn of the first year, North American post-smolts are concentrated in the Labrador Sea and off of the west coast of Greenland, with the highest concentrations between 56°N. and 58°N. (Reddin 1985, Reddin and Short 1991, Reddin and Friedland 1993). The salmon located off Greenland are composed of both 1SW fish and fish that have spent multiple years at sea (multi-sea winter fish or MSW) and also includes immature salmon from both North American and European stocks (Reddin 1988, Reddin *et al.* 1988). The first winter at sea regulates annual recruitment, and the distribution of winter habitat in the Labrador Sea and Denmark Strait may be critical for North American populations (Friedland *et al.* 1993). In the spring, North American post-smolts are generally located in the Gulf of St. Lawrence, off the coast of Newfoundland, and on the east coast of the Grand Banks (Reddin 1985, Dutil and Coutu 1988, Ritter 1989, Reddin and Friedland 1993, and Friedland *et al.* 1999).

Some salmon may remain at sea for another year or more before maturing. After their second winter at sea, the salmon over-winter in the area of the Grand Banks before returning to their natal rivers to spawn (Reddin and Shearer 1987). Reddin and Friedland (1993) found immature adults located along the coasts of Newfoundland, Labrador, and Greenland, and in the Labrador and Irminger Sea in the later summer and autumn.

3.1.2 Status and Trends of Atlantic Salmon in the GOM DPS

The abundance of Atlantic salmon within the range of the GOM DPS has been generally declining since the 1800s (Fay *et al.* 2006). Data sets tracking adult abundance are not available throughout this entire time period; however, a comprehensive time series of adult returns to the GOM DPS dating back to 1967 exists (Fay *et al.* 2006, USASAC 2001-2012) (Figure 3). It is important to note that contemporary abundance levels of Atlantic salmon within the GOM DPS are several orders of magnitude lower than historical abundance estimates. For example, Foster and Atkins (1869) estimated that roughly 100,000 adult salmon returned to the Penobscot River alone before the river was dammed, whereas contemporary estimates of abundance for the entire GOM DPS have rarely exceeded 5,000 individuals in any given year since 1967 (Fay *et al.* 2006, USASAC 2010).

Contemporary abundance estimates are informative in considering the conservation status of the GOM DPS today. After a period of population growth in the 1970s, adult returns of salmon in the GOM DPS declined steadily between the early 1980s and the early 2000s but have been increasing again over the last few years. The population growth observed in the 1970s is likely attributable to favorable marine survival and increases in hatchery capacity, particularly from GLNFH that was constructed in 1974. Marine survival remained relatively high throughout the 1980s, and salmon populations in the GOM DPS remained relatively stable until the early 1990s. In the early 1990s marine survival rates decreased, leading to the declining trend in adult abundance observed throughout 1990s and early 2000s. The increase in the abundance of returning adult salmon observed between 2008 and 2011 may be an indication of improving marine survival.

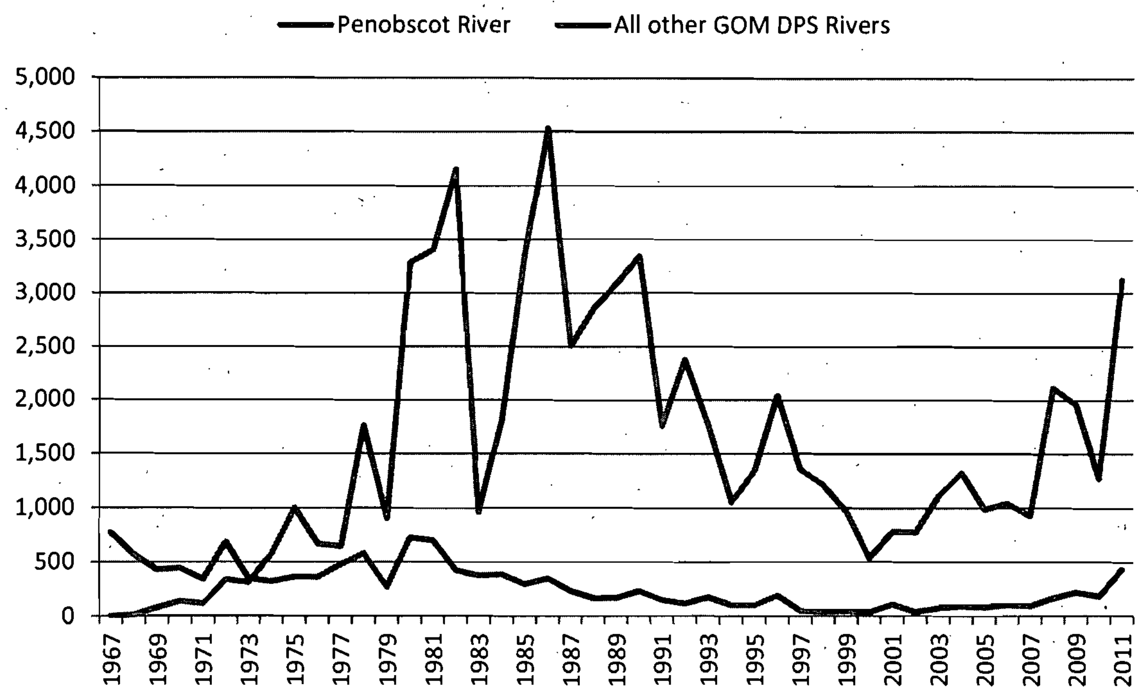

Figure 3. Adult returns to the GOM DPS Rivers between 1967 and 2011(Fay *et al.* 2006, USASAC 2001-2012).

Adult returns to the GOM DPS have been very low for many years and remain extremely low in terms of adult abundance in the wild. Further, the majority of all adults in the GOM DPS return to a single river, the Penobscot, which accounted for 91 percent of all adult returns to the GOM DPS between 2000 and 2011. Of the 3,125 adult returns to the Penobscot in 2011, the vast majority are the result of smolt stocking; and only a small portion were naturally-reared. The term naturally-reared includes fish originating from both natural spawning and from stocked hatchery fry (USASAC 2012). Hatchery fry are included as naturally-reared because hatchery fry are not marked and, therefore, cannot be distinguished from fish produced through natural spawning. Because of the extensive amount of fry stocking that takes place in an effort to recover the GOM DPS, it is possible that a substantial number of fish counted as naturally-reared were actually hatchery fry.

Low abundances of both hatchery-origin and naturally-reared adult salmon returns to Maine demonstrate continued poor marine survival. Declines in hatchery-origin adult returns are less sharp because of the ongoing effects of consistent hatchery supplementation of smolts. In the GOM DPS, nearly all of the hatchery-reared smolts are released into the Penobscot River -- 560,000 smolts in 2009 (USASAC 2010). In contrast, the number of returning naturally-reared adults continues at low levels due to poor marine survival.

In conclusion, the abundance of Atlantic salmon in the GOM DPS has been low and either stable or declining over the past several decades. The proportion of fish that are of natural origin is very small (approximately 6% over the last ten years) but appears stable. The conservation hatchery program has assisted in slowing the decline and helping to stabilize populations at low levels. However, stocking of hatchery products has not contributed to an increase in the overall abundance of salmon and as yet has not been able to increase the naturally reared component of the GOM DPS. Continued reliance on the conservation hatchery program could prevent extinction in the short term, but recovery of the GOM DPS must be accomplished through increases in naturally reared salmon.

3.1.3. Status of Atlantic Salmon in the Action Area

A summary of the status of the species rangewide and designated critical habitat in its entirety was provided above. This section will focus on the status of Atlantic salmon and designated critical habitat in the action area. The Penobscot River watershed supports the largest runs of Atlantic salmon in the GOM DPS. This is due to the large amount of available habitat and large-scale stocking program that includes smolt, parr, fry, and restocking of captured sea-run adults after spawning at the Craig Brook National Fish Hatchery (CBNFH). Roughly 600,000 smolts are stocked in the Penobscot River watershed annually. In addition, over two million fry and parr are stocked in the Penobscot River watershed annually. As such, all lifestages of Atlantic salmon could be present in the action area of this consultation.

Upstream migrating adults

All adults returning to the Penobscot River are collected at the Veazie Dam fishway. Adults captured at the fishway are either taken to CBNFH for captive breeding or returned to the river upstream of the Veazie Dam. Since the initial listing of the GOM DPS of Atlantic salmon in 2000, the number of returning adults (both naturally-reared and conservation hatchery stocked) captured at the fishway trap at the Veazie Dam has ranged from as low as 534 in 2000 to as many as 3,123 in 2011(USASAC 2012). The majority of adult returns to the Penobscot River are of hatchery origin (Fay *et al.* 2006). In 2011, 92% of adult Atlantic salmon returns were of hatchery smolt origin, and the balance (8%) originated from fry stocking or natural reproduction (USASAC 2012).

The Veazie fishway trap is operated each year from May 1 to October 31 (MDMR, MDIFW 2009). The majority of the adult salmon captures at Veazie occur in June, with the median capture date occurring around the last week of June (MDMR 2008). Use of the rubber dam system at the Veazie spillway has led to improved, and earlier captures of adult salmon in the river (MDMR 2007). Although the overall size of the salmon run differs from year to year, the monthly breakdown and median capture dates are similar (Table 2)(MDMR 2007, MDMR 2008, Dube *et al.* 2011).

Table 2. Monthly total and median capture dates of Atlantic salmon collected at the Veazie Trap during 2007-2010.

	2007		2008		2009		2010		Mean
Month	**No.**	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**	**Distribution**
May	48	5%	267	13%	173	9%	344	26%	13%
June	458	50%	1465	69%	1382	71%	782	59%	65%
July	268	29%	236	11%	370	19%	141	11%	16%
August	79	9%	111	5%	14	1%	18	1%	4%
September	45	5%	18	1%	11	1%	27	2%	2%

October	18	2%	15	1%	8	0%	4	0%	1%
Total Run	**916**	**100%**	**2112**	**100%**	**1958**	**100%**	**1316**	**100%**	**100%**
Median Capture Date	23-Jun-07		26-Jun-08		18-Jun-09		9-Jun-10		

According to current broodstock management plans, 650 adult salmon are typically collected each year at Veazie Dam for transport to the federal salmon hatcheries in Maine (MDMR 2007). Because of the goal of providing an equal ratio of male and female spawners for hatchery, as well as a proportion of 1-sea winter returns ("grilse"), the goal of 650 spawners is rarely achieved. Table 3 below presents broodstock targets and number of broodstock collected at the Veazie Dam since 2000.

Table 3. Atlantic salmon broodstock collected at the Veazie Trap during (2000-2011).

Year	Broodstock Target	Total Broodstock Collected
2000	600	328
2001	600	502
2002	600	377
2003	600	605
2004	600	606
2005	600	475
2006	650	537
2007	650	590
2008	650	650
2009	650	679
2010	650	700
2011	650	739

Adult salmon that are collected at Veazie and not transported to the hatchery for broodstock are put back in the river above the dam and allowed to continue their upstream migration. Although there are fishways at dams above Veazie, including Milford and West Enfield, there are no annual counts of salmon using those fish passage facilities. Studies have shown, however, that upstream migration beyond Veazie proceeds relatively quickly unless dam flashboards are down (which in the case of Great Works makes the fishways inoperable) or water temperature is elevated (Shepard 1995, Gorsky 2005).

Post-spawned adults

Following spawning in the fall, Atlantic salmon kelts may immediately return to the sea, or over-winter in freshwater habitat and migrate in the spring, typically April or May (Baum 1997). Spring flows resulting in spillage at the dams facilitate out-migration of adult salmon (Shepard 1988). Downstream passage success of kelts was assessed as part of radio tag studies conducted for smolts in the Penobscot (GNP 1989, Shepard 1989a, Hall and Shepard 1990). Kelts tended to move downstream early in the spring (mostly mid-April through late May), regardless of whether fish were tagged in the spring or fall (i.e., most radio-tagged study fish generally stayed in the river near where they were placed until the following spring). Because kelt passage occurred during periods of spill at most dams, a large portion of study fish (90%) passed dams via spillage (i.e., over the dam). Kelt attraction to, and use of, downstream passage facilities was highly variable depending on facility, year of study, and hydrological conditions (e.g., spill or not). At the upstream confluences (i.e., the Stillwater Branch and the main stem), kelts followed the routes in approximate proportion to flow in the two channels.

Downstream migrating smolts

Out-migrating Atlantic salmon smolts in the Penobscot River watershed are the result of wild production following natural spawning and juvenile rearing, or from stocking fry, parr, and smolts (Fay *et al.* 2006). The majority of the salmon run on the Penobscot are the result of stocked smolts; current management plans call for stocking 600,000 hatchery reared smolts at various locations in the main stem above Veazie Dam and in the Pleasant River (Piscataquis River sub-drainage) (MDMR, MDIFW 2009). Based on unpublished data from smolt-trapping studies in 2000 – 2005 by NMFS, smolts migrate from the Penobscot between late April and early June. The majority of the smolt migration appears to take place over a three to five week period after water temperatures rise to 10°C.

Rotary screw traps (RSTs) were used by NMFS during 2000-2005 to monitor downstream migrating smolts in the Penobscot River (Figure 4). Traps were deployed 0.87, 1.54, and 1.77 kilometers below the Veazie Dam. During the sampling period, the number of smolts captured in RSTs ranged from 72 to 3,165 annually. RST sampling in the Piscataquis River by MDMR in 2004 and 2005 captured 497 and 315 smolts, respectively. It is not currently possible to estimate the total number (wild and stocked) of smolts emigrating in the Penobscot or Piscataquis River, but the run is certainly related to the number of fish stocked annually.

Atlantic salmon utilize free-flowing rivers and streams for spawning and juvenile rearing. The lake-like condition of the impoundments at the Milford, West Enfield, Medway, Orono and Stillwater Projects do not provide suitable spawning or rearing habitat for Atlantic salmon.

State fishery agencies have estimated juvenile Atlantic salmon production in the Penobscot watershed, using habitat surveys and suitability modeling (MDMR, MDIFW 2009). According to the model, there are 4,070 rearing units (each rearing unit consists of 100 square meters) identified in the reach of the Penobscot River between Milford and West Enfield. However, the state's modeling estimated that the production of salmon parr for this reach was only 388. This is likely due to the fact that parr production is highest in smaller streams in the Penobscot watershed (less than 12 meters wide) and becomes negligible in river segments wider than 100 meters due to factors such as increased water temperatures and biological community composition (MDMR, MDIFW 2009).

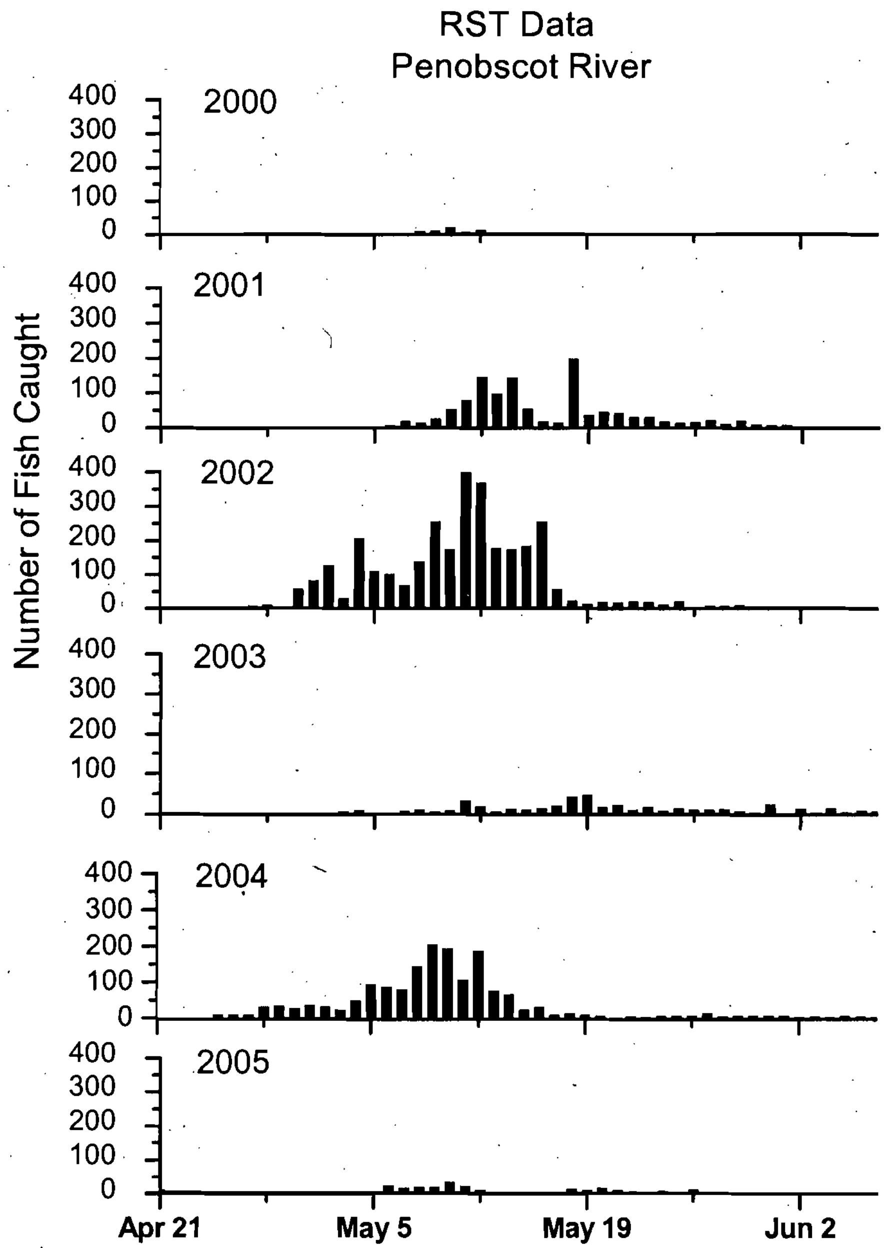

Figure 4. Total number of smolts collected using rotary screw traps in the Penobscot River from 2000 to 2005.

3.1.4. Factors Affecting Atlantic Salmon in the Action Area

3.1.4.1. Hydroelectric Facilities

The Penobscot River Basin has been extensively developed for hydroelectric power production. There are approximately 116 dams in the Penobscot River watershed; 24 of these dams operate under a FERC hydropower license or exemption (Fay *et al.* 2006). Hydroelectric dams are known to impact Atlantic salmon through habitat alteration, fish passage delays, and entrainment and impingement.

Habitat Alteration

While over 200,000 units of rearing habitat remains accessible in the Penobscot River watershed, historical and present day dams have eliminated or degraded vast, but to date unquantified, reaches of suitable rearing habitat. FERC (1997) estimated that 27% (19 miles) of main stem habitat (i.e., not including the Stillwater Branch segment) is impounded by the five dams between head-of-tide and the confluence of the East and West Branches in Medway. On the West Branch, approximately 57% of the 98 river miles is impounded (USACOE 1990). Approximately 11% of the approximately 74 miles of the Piscataquis River main stem, 28% of the approximately 43 miles of the Sebec River tributary to the Piscataquis, and 8% of the approximately 25 miles of the Passadumkeag River (below natural barrier at Grand Falls) is impounded (USACOE 1990).

Impoundments created by these dams limit access to habitat, alter habitat, and degrade water quality through increased temperatures and lowered dissolved oxygen levels. Furthermore, because hydropower dams are typically constructed in reaches with moderate to high underlying gradients, approximately 50% of available gradient in the main stem, and 41% in the West Branch, is impounded (USACOE 1990, FERC 1997). Coincidently, these moderate to high gradient reaches, if free-flowing, would likely constitute the highest value as Atlantic salmon spawning, nursery, and adult resting habitat within the context of all potential salmon habitat within these reaches.

Compared to a natural hydrograph, the operation of dams in a store-and-release mode on the East Branch, and especially on the West Branch of the Penobscot River, results in reduced spring runoff flows, less severe flood events, and augmented summer and early fall flows. Such operations in turn reduce sediment flushing and transport and physical scouring of substrates, and increase surface area and volume of summer and early fall habitat in the main stem. Water drawn from impoundments in the West Branch often constitutes half or more of the streamflow in the main stem during the otherwise drier summer months (data analyzed from FERC 1996a).

The extent to which these streamflow modifications in the upper Penobscot watershed impact salmon populations, habitat (including migratory corridors during applicable seasons), and restoration efforts is unknown. However, increased embeddedness of spawning and invertebrate colonization substrates, diminished flows during smolt and kelt outmigration, and enhanced habitat quantity and, potentially, "quality" for non-native predators such as smallmouth bass, are likely among the adverse impacts to salmon. Conversely, higher summer and early fall stream flows may provide some benefits to Atlantic salmon or their habitat within affected reaches, and may also help mitigate certain potential water quality impacts (e.g., dilution of harmful industrial and municipal discharges).

Habitat Connectivity

Pre-spawn adults

Among rivers within the range of the GOM DPS with hydropower dams that have one or more formal passage facility, most of the current understanding of fish passage efficiency comes from studies on the Penobscot River. Radio telemetry and other tracking studies by the MDMR and various hydropower project licensees have shown wide variation in site-specific upstream passage success, depending on the dam location and the environmental conditions (e.g., temperature, hydrology) during the year of study. For example, at the Veazie Dam, the percentage of radio tagged Atlantic salmon adults using the fishway ranged from 44% in 1990 to 89% in 1992, and averaged 68% over five years of study in the late 1980s and early 1990s (Dube 1988, Shepard 1989b, Shepard and Hall 1991, Shepard 1995). Shepard (1995) hypothesized that warm water temperatures during certain study years contributed to some of the low passage success rates observed at Veazie.

MDMR (formerly the Maine Atlantic Salmon Comission (MASC)) tagged several hundred Atlantic salmon adults captured at the Veazie Dam fishway trap with Passive Integrated Transponder (PIT) tags from 2002 to 2004. This study monitored the date and time of passage with tag detectors located at the entrance and exit of the upstream fishway(s) at five main stem and five major tributary hydropower dams in the Penobscot watershed (Beland and Gorsky 2004, MASC unpublished data). Of the 379 total salmon tagged at Veazie in 2002, only 21% (78 fish) also passed the Mattaceunk Project fishway on the main stem, some 50 miles and four additional dams upstream. Less than 1% (3 fish) passed above the Guilford Dam on the Piscataquis River tributary, which is six additional dams upstream. The percentages in 2003 were 9% (41 of 461) and less than 1% (1 of 461) for Mattaceunk and Guilford Dam passages, respectively. In 2004, 19% (142) of the 709 PIT tagged salmon passed Mattaceunk and less that 1% (6) passed Guilford Dam. Many factors affect these results; the most important factor is homing motivation. As many of the study fish were hatchery smolts stocked below Mattaceunk or Guilford Dams, these fish would not be expected to pass the most upstream dams. Nevertheless, proportions of adults reaching two key upriver spawning reaches (East Branch Penobscot River and Piscataquis River above Guilford) are less than would be expected based on the proportion of available production habitat and numbers of fry stocked in those reaches.

At Milford Dam, upstream passage success ranged from 86% in 1987 to 100% in 1990, and averaged 90% (56 of 62) over five years of study using Carlin and radio tags (Dube 1988, Shepard 1995). Similarly, a three year study that was conducted between 2002 and 2004 that looked at migratory movements of adult Atlantic salmon using PIT tags indicated passage success at Milford ranging between 86% and 94% (Beland and Gorsky 2004, MASC unpublished data). In 2005 and 2006, Holbrook *et al.* (2009) conducted acoustic telemetry studies to assess upstream passage of adult salmon in the Penobscot River from the Veazie Dam upstream to the Howland and West Enfield Dams. Passage at Milford was 100% in 2005 (3 of 3) and 67% in 2006 (2 of 3). Based on all of these studies, Holbrook *et al.* (2009) calculated that passage at the Milford Project ranged between 67% and 100%, with an average of 90% and a median passage rate of 93%.

Upstream passage efficiency ranged between 85% and 100% over four years of study at the West Enfield and Howland Projects, 20 miles upriver from Milford. Based upon radio telemetry studies conducted from 1989-1992, Shepard (1995) estimated pooled upstream passage rates for adult Atlantic salmon at the Howland and West Enfield at 88% for fish released below the

Milford Dam and 89% for fish released above the dam. The pooled result for fish released above and below the Milford Dam over those years was 89% (41 out of 46). As part of a PIT tag study in 2002, Beland and Gorsky (2003) determined that 94% (290 of 308) of the Atlantic salmon that passed the Milford Project successfully passed either the Howland or West Enfield Projects. Of the fish that passed the Milford Project in the study conducted by Holbrook *et al.* (2009), 100% (3 of 3 in 2005; 2 of 2 in 2006) continued upriver and passed either the West Enfield or Howland Projects. It is difficult to assess passage rates at the West Enfield Project and the Howland Project separately, as passage at these dams is strongly influenced by the homing behavior of the migrating fish. As such, many of the salmon that pass upstream of the Milford Project are homing to the Piscataquis River and are not motivated to pass the West Enfield Project in the mainstem.

Migratory Delay

Early migration is an adaptive trait that ensures adult Atlantic salmon have sufficient time to effectively reach spawning areas despite the occurrence of temporarily unfavorable conditions that naturally occur within rivers (Bjornn and Reiser 1991). Gorsky (2005) found that migration in Atlantic salmon was significantly affected by flow and temperature conditions in the Penobscot River. He found that high flow led to a decrease in the rate of migration and that rates increased with temperature up to a point (around 23 degrees C) where they declined rapidly. To avoid high flows and warmer temperatures in the river, Atlantic salmon have adapted to migrating in the late spring and early summer, even though spawning does not occur until October and November. Between 2007 and 2010, 78% of migrating Atlantic salmon migrated past the Veazie Dam in May and June. According to USGS temperature data from Eddington, Maine, the 12-year median daily temperature in the Penobscot River exceeds 23 C in the first week of July.

To access high quality summer holding areas close to spawning areas in the Penobscot River watershed, Atlantic salmon must migrate past multiple dams. Delay at these dams can, individually and cumulatively, affect an individual's ability to access suitable spawning habitat within the narrow window when conditions in the river are suitable for migration. In addition, delays in migration can cause overripening of eggs, increased chance of egg retention, and reduced egg viability in pre-spawn female salmonids (deGaudemar and Beall 1998). It is not known what level of delay at each of these dams would significantly affect a migrant's ability to access suitable spawning habitat, as it would be different for each individual, and would vary from year to year depending on environmental conditions. We believe that 48 hours provide adequate opportunity for pre-spawn adult Atlantic salmon to locate and utilize well-designed upstream fishways at hydroelectric dams.

Available empirical data indicate a wide range in time needed for individual adult salmon to pass upstream of various dams in the Penobscot River once detected in the vicinity of a spillway or tailrace. The yearly pooled median passage time for adults at Milford Dam ranged from 1.0 days to 5.3 days over five years of study, while the total range of individual passage times over this study period was 0.1 days to 25.0 days. The yearly pooled median passage time for adults at the West Enfield or Howland Dam ranged from 1.1 days to 3.1 days over four years of study, while the total range of individual passage times over this study period was 0.9 days to 61.1 days (Shepard 1995).

Adult migrating salmon are attracted to the discharge of the existing powerhouse at the Orono Project, where they can be significantly delayed (greater than 48 hours). The Orono Project is in the Stillwater Branch, but the powerhouse discharges into the mainstem of the river, adjacent to the confluence with the Stillwater. Over a two year period (1988-1989), Shepard (1995) indicated that 46% (56% in 1988 and 37% in 1989) of tagged salmon were attracted to this discharge and delayed for a median of 8.30 hours in 1988 and 2.18 hours in 1989, prior to continuing upstream migration in the mainstem. The duration of the delay in 1988 ranged between 0.3 hours to 247.4 hours. Of the fish attracted to the discharge in that year, 33% were recorded spending more than 48 hours in the tailrace of the Project (S. Shepard, personal communication, 2012). Some of the salmon entered the Orono tailrace several times or were found to have migrated upstream prior to being attracted to the discharge at Orono. This behavior may be partially attributable to the fact that a proportion of the fish (56% in 1988 and 28% in 1989) were hatchery fish that were stocked as smolts in the mainstem of the Penobscot, rather than in the upper watershed. These fish may not have imprinted on upriver habitat and, therefore, may not have been highly motivated to continue migrating upstream. This would suggest that the proportion of Atlantic salmon that were attracted to the discharge at Orono may be greater than what would be expected for just wild fish. However, this study provides the best available information regarding what proportion of Atlantic salmon migrating through the Penobscot River could be attracted to, and delayed by, the discharge of the powerhouse at the Orono Project.

Outmigrating smolts

Smolts from the upper Penobscot River have to navigate through several dams on their migrations to the estuary every spring. Holbrook *et al.* (2011) found that migrating smolts split when encountering Orson and Marsh Islands, with >74% of smolts staying in the mainstem, and the remainder migrating through the Stillwater Branch. Hatchery smolts were found to use the Stillwater Branch less than wild smolts. In 2005, 14% of hatchery smolts and 26% of wild smolts chose to migrate through the Stillwater Branch. Based on Holbrook's data, NMFS's Northeast Fisheries Science Center (NEFSC) calculated median smolt usage of the Stillwater Branch as 19.7% (NMFS 2012). Smolts in the mainstem currently must navigate through the Milford, Great Works and Veazie Dams, while those in the Stillwater must navigate the Stillwater and Orono Dams. Multiple dam passage studies of smolts in the Penobscot River were conducted in 1989 and 1990. In 1989, net smolt survival past the three lower river mainstem dams (Milford, Great Works, Veazie) and the intervening habitat was between 30.5% and 61% (Shepard 1991). The wide range in these figures reflects the uncertainty as to how to classify tagged smolts that are detected at one or more upstream detection arrays, but then are not detected at the lowermost array at the last dam, where gaps in detection coverage were reported. In 1990, the net smolt survival past four dams (West Enfield, Milford, Great Works and Veazie for those choosing the mainstem route, or West Enfield, Stillwater, Orono, and Veazie for those choosing the Stillwater Branch route) and the intervening habitat was between 38% and 92% (Shepard 1991), again depending on the manner in which undetected fish were treated along the course of the study reach. It should be noted that Shepard studies in 1989 and 1990 were not designed to determine smolt mortality specifically due to turbine passage.

Smolt studies conducted by Holbrook (2007) documented significant losses of smolts in the vicinity of mainstem dams in the Penobscot River. Of the 355 radio tagged smolts released in 2005, 43% were lost in the vicinity of the West Enfield, Howland, and Milford Dams. In 2006, 60% of tagged smolts (n=291) were lost in the vicinity of the West Enfield, Howland, and Milford Dams. Although these data do not definitively reveal sources of mortality, these losses are likely attributable to the direct and indirect effects of the dams (e.g., physical injury, predation).

Very few studies have been conducted in Maine to directly assess fish entrainment and mortality on Atlantic salmon at hydroelectric facilities. In the only known study addressing turbine-passage mortality at a Penobscot River hydropower dam, Shepard (1993) estimated acute mortality of hatchery smolts passing through the two horizontal Kaplan turbines at the West Enfield Dam at 2.3% (n = approximately 410). Delayed mortality of the control group (smolts exposed to similar conditions except turbine passage) was quite high ranging from 20% in 1993 to 40% in 1992. Delayed mortality of turbine-passed smolts was considerably higher, ranging from 42% in 1993 to 77% in 1992. The high observed delayed mortality in the control group lead Shepard (1993) to conclude that any comparisons of delayed mortality between the control and treatment would be unreliable.

Studies conducted by NMFS in 2003 reported a much higher rate of dead smolts in the Penobscot smolt traps (5.2%) compared to parallel studies on the Narraguagus (0.3%) where there are no operating hydroelectric dams (USASAC 2004). Although some of this difference could be due to the fact that most of the smolts in the Penobscot study were hatchery origin while all of the Narraguagus smolts were wild or naturally reared, the nature of injuries observed for the 22 Penobscot smolt mortalities indicated that more than 60% were the result of entrainment (USASAC 2004). Injuries attributed to turbine entrainment were also noted on smolts collected alive during the studies.

The route that a salmon smolt takes when passing a project is a major factor in its likelihood of survival. Fish that pass through a properly designed downstream bypass have a better chance of survival than a fish that goes over a spillway, which, in turn, has a better chance of survival than a fish swimming through the turbines. It can be assumed that close to 100% of smolts will survive when passing through a properly designed downstream bypass. However, based on the results of field trials looking at fish passage over spillways at five hydroelectric dams, only 97.1% of smolts are likely to survive passage via spillage (Normandeau Associates, Inc. 2011). Survival through turbines varies significantly based on numerous factors, but as described above can be significantly lower than the other two routes. A smolt study was conducted for Black Bear in 2010 to assess passage efficiency of the downstream bypass at the Orono Dam on the Stillwater Branch (Aquatic Science Associates, Inc. 2011). Radio and PIT tagged hatchery smolts were released under spill and non-spill conditions. Under spill conditions 13% of the smolts used the bypass, 17% went through the turbines, and 69% passed via spillage. Under non-spill conditions, 42% of smolts used the bypass and 58% went through the turbines.

Alden Research Laboratory, Inc. (Alden Lab 2012) has modeled current smolt survival rates at 15 dams on the Penobscot River, based on turbine entrainment, spill mortality estimates and bypass efficiency. Alden Lab conducted a literature review to estimate survival rates based on passage route. Based on that review, it was estimated that mortality through a properly designed bypass would not exceed 1%, whereas mortality via spillage would not exceed 3%. The estimates of mortality due to passage through the turbines was calculated based on the characteristics of individual turbines (such as type of turbine, number of blades and the speed of rotation) and were therefore project specific. In addition to these route-specific estimates, Alden Lab estimated a 5% indirect mortality rate (due primarily to predation and sublethal injuries during passage), regardless of passage route (Alden Lab 2012, Appendix A). Using these assumptions, Alden Lab estimated that the mean survival rates of all 15 dams ranged between 86% and 92% (Table 6).

Table 6. Modeled smolt survival rates under current conditions at May flows for 15 dams on the Penobscot River (Alden Lab 2012). Black Bear's projects on the Penobscot River are in bold.

Project	Mean	Min	Max
Veazie	89.7%	82.7%	91.3%
Great Works	86.1%	77.7%	89.6%
Milford	**91.6%**	**75.6%**	**92.0%**
West Enfield	**92.5%**	**92.3%**	**93.6%**
Mattaceunk	86.0%	77.2%	89.8%
Orono	**90.1%**	**81.6%**	**91.5%**
Stillwater	**91.9%**	**90.5%**	**92.1%**
Medway	**91.2%**	**88.4%**	**91.9%**
Howland	91.5%	89.6%	92.7%
Brown's Mill	86.5%	61.5%	91.8%
Lowell Tann.	88.7%	84.7%	94.9%
Moosehead	87.9%	66.0%	91.0%
Milo	89.0%	85.2%	90.9%
Sebec	88.7%	83.4%	90.9%
Frankfort	92.0%	90.8%	94.4%

The potential for delays in the timely passage of smolts encountering hydropower dams is also evident in some tracking studies. At the Mattaceunk Dam, the average time needed for hatchery smolts to pass the dam, after being detected in the forebay area, was 15.6 hours (range 0 to 72 hours), 39.2 hours (range 0 to 161 hours), 14.6 hours (range 0 to 59.4 hours) and 30 hours (range 0.2 to 226 hours) in four different study years (GNP 1995, GNP 1997, GNP 1998, GNP 1999). At the West Enfield Dam, the median delay was 0.86 hours (range 0.3 to 49.7 hours) for hatchery smolts in 1993 (BPHA 1993), and approximately 13 hours (range 0.2 to 102.9 hours) for wild smolts in 1994 (BPHA 1994). At the Orono Dam, the median delay between release and passage of smolts was 3.4 hours (range 0.6 to 33.3 hours) in 2010 (Aquatic Science Associates, Inc 2011). While these delays can lead to direct mortality of Atlantic salmon from increased predation (Blackwell *et al.* 1998), migratory delays can also reduce overall physiological health or physiological preparedness for seawater entry and oceanic migration (Budy *et al.* 2002). Various researchers have identified a "smolt window" or period of time in which smolts must reach estuarine waters or suffer irreversible effects (McCormick *et al.* 1999). Late migrants lose physiological smolt characteristics due to high water temperatures during spring migration (McCormick *et al.* 1999). Similarly, artificially induced delays in migration from dams can result in a progressive misalignment of physiological adaptation of smolts to seawater entry, smolt migration rates, and suitable environmental conditions and cues for migration. If so, then these delays may reduce smolt survival (McCormick *et al.* 1999).

Outmigrating kelts

Atlantic salmon kelts move downstream after spawning in November or, alternatively, overwinter in freshwater and outmigrate early in the spring (mostly mid-April through late May). Lévesque *et al.* (1985) and Baum (1997) suggest that 80% of kelts overwinter in freshwater habitat prior to returning to the ocean. Downstream passage success of kelts has been assessed in the Penobscot (GNP 1989, Shepard 1989a, Hall and Shepard 1990). Kelt passage occurred during periods of spill at most dams, and a large portion of study fish used the spillage. Success over mainstem Penobscot River dams was usually greater than 90% at any one site. Kelt attraction to, and use of, downstream passage facilities was highly variable depending on facility, year of study, and hydrological conditions (e.g., spill or not). At the upstream confluences (i.e., the Stillwater Branch and the mainstem), kelts followed the routes in approximate proportion to flow in the two channels (approximately 40%/60%). Shepard (1989a) documented that kelts relied on spillage flows to migrate past the Milford and Veazie Dams during a study conducted in 1988. In fact, some kelts spent hours to days searching for spillway flows to complete their downstream migration during the 1988 study.

Alden Lab (2012) has modeled the current survival rates of kelts at the dams on the Penobscot River, based on turbine entrainment, spill mortality estimates and bypass efficiency (Table 7). Alden Lab's analysis accounted for both immediate and delayed mortality associated with dam passage. Through the three months of outmigration, Alden Lab indicates that mean survival rates at 14 of the dams (Medway is excluded) on the Penobscot range between 61% and 93%.

Table 7. Modeled kelt survival rates under current conditions at May flows for Black Bear's projects on the Penobscot River (Alden Lab 2012). Black Bear's projects are indicated in bold.

Project	April			May			November		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Veazie	85.0%	80.6%	87.5%	80.8%	71.8%	86.1%	84.5%	71.8%	89.2%
Great Works	92.9%	92.5%	94.1%	93.0%	92.5%	94.1%	93.3%	92.6%	94.1%
Milford	**86.2%**	**69.3%**	**89.3%**	**84.7%**	**69.3%**	**89.5%**	**81.8%**	**65.8%**	**88.4%**
West Enfield	**91.0%**	**90.2%**	**91.6%**	**91.0%**	**90.2%**	**91.6%**	**90.8%**	**90.2%**	**94.1%**
Mattaceunk	82.7%	75.8%	87.7%	85.2%	75.8%	89.5%	85.0%	75.8%	89.5%
Orono	**87.9%**	**81.2%**	**90.1%**	**86.6%**	**65.8%**	**90.2%**	**83.6%**	**65.8%**	**89.4%**
Stillwater	**88.0%**	**65.8%**	**90.2%**	**85.7%**	**65.8%**	**90.3%**	**82.5%**	**65.8%**	**89.5%**
Medway	**31.0%**	**0.0%**	**60.0%**	**67.8%**	**0.0%**	**84.2%**	**66.6%**	**47.0%**	**79.8%**
Howland	92.6%	92.3%	94.1%	92.8%	92.3%	94.1%	92.9%	92.4%	94.1%
Brown's Mill	92.7%	92.4%	94.1%	92.9%	92.4%	94.1%	93.1%	92.4%	94.1%
Lowell Tannery	82.8%	74.9%	94.5%	83.3%	74.9%	94.5%	81.2%	47.0%	94.5%

Moosehead	92.2%	92.2%	92.2%	82.3%	0.0%	92.2%	76.3%	0.0%	92.2%
Milo	64.5%	43.6%	82.0%	66.8%	43.6%	83.2%	61.6%	0.0%	89.5%
Sebec	89.7%	86.0%	94.1%	89.8%	86.0%	92.3%	89.7%	86.0%	94.1%
Frankfort	68.4%	53.5%	90.8%	70.9%	53.5%	94.1%	71.6%	53.5%	94.1%

Delayed Effects of Downstream Passage

In addition to direct mortality sustained by Atlantic salmon at hydroelectric projects, Atlantic salmon in the Penobscot River will also sustain delayed mortality as a result of repeated passage events at multiple hydroelectric projects. Studies have investigated what is referred to as latent or delayed mortality, which occurs in the estuary or ocean environment and is associated with passage through one or more hydro projects (Budy *et al.* 2002, ISAB 2007, Schaller and Petrosky 2007, Haeseker *et al.* 2012). The concept describing this type of mortality is known as the hydrosystem-related, delayed-mortality hypothesis (Budy *et al.* 2002, Schaller and Petrosky 2007, Haeseker *et al.* 2012).

Budy *et al.* (2002) examined the influence of hydropower experience on estuarine and early ocean survival rates of juvenile salmonids migrating from the Snake River to test the hypothesis that some of the mortality that occurs after downstream migrants leave a river system may be due to cumulative effects of stress and injury associated with multiple dam passages. The primary factors leading to hydrosystem stress (and subsequent delayed mortality) cited by Budy *et al.* (2002) were dam passage (turbines, spillways, bypass systems), migration conditions (e.g., flow, temperature), and collection and transport around dams, all of which could lead to increased predation, greater vulnerability to disease, and reduced fitness associated with compromised energetic and physiological condition. In addition to linking hydrosystem experience to delayed mortality, Budy *et al.* (2002) cited evidence from mark-recapture studies that demonstrated differences in delayed mortality among passage routes (i.e., turbines, spillways, bypass and transport systems).

More recent studies have corroborated the indirect evidence for hydrosystem delayed mortality presented by Budy *et al.* (2002) and provided data on the effects of in-river and marine environmental conditions (Schaller and Petrosky 2007, Haeseker *et al.* 2012). Based on an evaluation of historical tagging data describing spatial and temporal mortality patterns of downstream migrants, Schaller and Petrosky (2007) concluded that delayed mortality of Snake River chinook salmon was evident and that it did not diminish with more favorable oceanic and climatic conditions. Estimates of delayed mortality reported in this study ranged from 0.75 to 0.95 (mean = 0.81) for the study years of 1991-1998 and 0.06 to 0.98 (mean = 0.64) for the period of 1975-1990. Haeseker *et al.* (2012) assessed the effects of environmental conditions experienced in freshwater and the marine environment on delayed mortality of Snake River chinook salmon and steelhead trout. This study examined seasonal and life-stage-specific survival rates of both species and analyzed the influence of environmental factors (freshwater: river flow spilled and water transit time; marine: spring upwelling, Pacific Decadal Oscillation, sea surface temperatures). Haeseker *et al.* (2012) found that both the percentage of river flow spilled and water transit time influenced in-river and estuarine/marine survival rates, whereas the Pacific Decadal Oscillation index was the most important factor influencing variation in marine and cumulative smolt-to-adult survival of both species. Also, freshwater and marine survival rates were shown to be correlated, demonstrating a relation between hydrosystem experience on estuarine and marine survival. The studies described above clearly support the delayed-mortality hypothesis proposed by Budy *et al.* (2002). However, only one of the studies quantified delayed mortality, and the estimates varied considerably.

Although delayed mortality following passage through a hydrosystem has been demonstrated by the studies discussed above, effectively quantifying such losses remains difficult, mainly because of practical limitations in directly measuring mortality after fish have left a river system (i.e., during time spent in estuaries and the marine environment). Evaluations of delayed mortality have generally produced indirect evidence to support the link between hydrosystem experience and estuary and marine survival rates (and smolt-to-adult returns). In fact, in a review of delayed mortality experienced by Columbia River salmon, ISAB (2007) recommended that attempts should not be made to provide direct estimates of absolute delayed mortality, concluding that measuring such mortality relative to a damless reference was not possible. Alternatively, it was suggested that the focus should be on estimating total mortality of in-river fish, which was considered more critical to the recovery of listed salmonids. Consequently, it is difficult to draw absolute or quantifiable inferences from the Columbia River studies to other river systems beyond the simple conclusion that delayed mortality likely occurs for most anadromous salmonid populations. Additionally, although there is evidence of differential mortality between upper and lower river smolts in the Columbia River basin (Schaller and Petrosky 2007), data are not available for estimating a cumulative mortality rate based on the number of dams passed by downstream migrants.

Given the difficulty in estimating this type of mortality at the present time, we do not have sufficient data to specifically assess the effect of hydrosystem-related mortality in the Penobscot River. Thus, we have not attempted to quantify the delayed (or delayed) loss of smolts or kelts attributed to Black Bear's projects in this Opinion. Nevertheless, considering that there are presently 15 FERC licensed hydroelectric projects in the Penobscot River watershed, it can be assumed that practically all smolts and kelts in the river must pass at least two hydroelectric dams during the downstream migrations and the resulting loss of endangered Atlantic salmon could be significant. According to a model developed by NMFS (2012; Figure 5), even a small cumulative mortality rate (1-10%) could have a significant effect on the number of returning 2 SW female Atlantic salmon in the Penobscot River watershed. It should be noted, however, that removal of the Veazie and Great Works Projects and decommissioning the Howland Project should significantly reduce the hydrosystem-related mortality of smolts and kelts in the river.

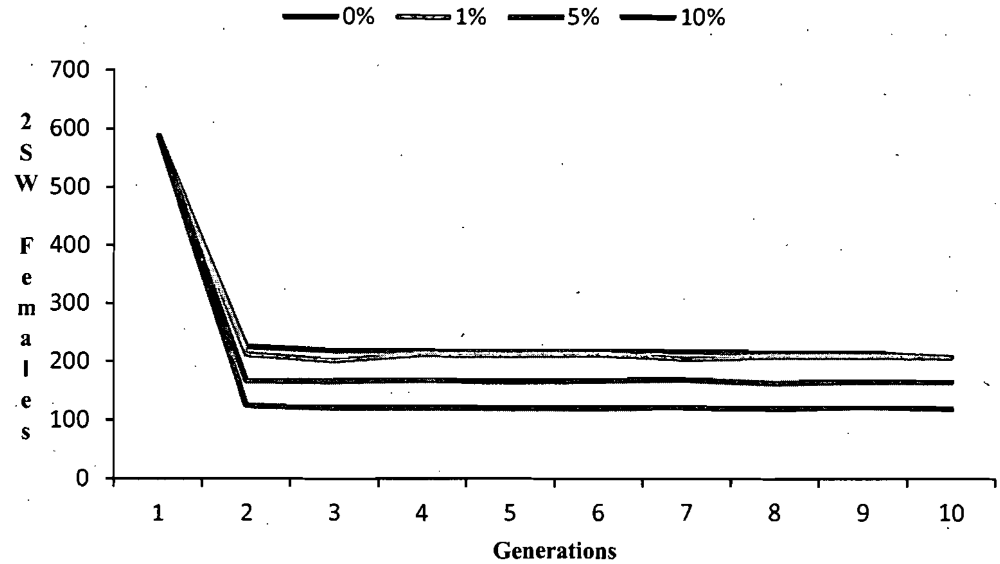

Figure 5. The potential effects of cumulative delayed mortality on the abundance of returning 2SW female Atlantic salmon over ten generations (NMFS 2012).

3.1.4.2. Predation

In addition to direct mortality during downstream passage, kelts and smolts are exposed to indirect mortality caused by sub-lethal injuries, increased stress, and/or disorientation. A large proportion of indirect mortality is a result of disorientation caused by downstream passage, which can lead to elevated levels of predation immediately downstream of the project (Mesa 1994).

Predation upon Penobscot River smolts has been studied by Blackwell (1996), as it relates to double crested cormorants, and by Van den Ende (1993) for certain fish species. In addition, the Penobscot River smolt migration studies described above have documented high smolt loss rates throughout the river system including free-flowing sections which implicate these same predators.

Smallmouth bass and chain pickerel are each important predators of Atlantic salmon within the range of the GOM DPS (Fay *et al.* 2006). Smallmouth bass are a warm-water species whose range now extends through north-central Maine and well into New Brunswick (Jackson 2002). Smallmouth bass are very abundant in the Penobscot River—smallmouth bass inhabit the entire main stem migratory corridor as well as many of the juvenile Atlantic salmon rearing habitats such as the East Branch Penobscot River and the Piscataquis River. Smallmouth bass likely feed on fry and parr though little quantitative information exists regarding the extent of bass predation upon salmon fry and parr. Smallmouth bass are important predators of smolts in main stem habitats, although bioenergetics modeling indicates that bass predation is insignificant at 5°C and increases with increasing water temperature during the smolt migration (Van den Ende 1993).

Chain pickerel are known to feed upon smolts within the range of the GOM DPS and certainly feed upon fry and parr, as well as smolts, given their piscivorous feeding habits (Van den Ende

1993). Chain pickerel feed actively in temperatures below 10°C (Van den Ende 1993, MDIFW 2002). Smolts were, by far, the most common item in the diet of chain pickerel observed by Barr (1962) and Van den Ende (1993). However, Van den Ende (1993) concluded that, "daily consumption was consistently lower for chain pickerel than that of smallmouth bass", apparently due to the much lower abundance of chain pickerel.

Northern pike were illegally stocked in Maine, and their range now includes Pushaw Lake which drains to the Lower Penobscot River (Fay *et al.* 2006). Northern pike have expanded their range in the Penobscot River to include the Pushaw Stream outlet, nearby Mud Pond and probably portions of the main stem Penobscot River, since there are no barriers to their movement. Northern pike are ambush predators that rely on vision and thus, predation upon smolts occurs primarily in daylight with the highest predation rates in low light conditions at dawn and dusk (Bakshtansky *et al.*1982). Hatchery smolts experience higher rates of predation by fish than wild smolts, particularly from northern pike (Ruggles 1980, Bakshtansky *et al.* 1982).

Many species of birds prey upon Atlantic salmon throughout their life cycle (Fay *et al.* 2006). Blackwell *et al.* (1997) reported that salmon smolts were the most frequently occurring food items in cormorant sampled at main stem dam foraging sites. Cormorants were present in the Penobscot River during the spring smolt migration as migrants, stopping to feed before resuming northward migrations, and as resident nesting birds using Penobscot Bay nesting islands (Blackwell 1996, Blackwell and Krohn 1997). The abundance of alternative prey resources such as upstream migrating alewife, likely minimizes the impacts of cormorant predation on the GOM DPS (Fay *et al.* 2006). Common mergansers and belted kingfishers are likely the most important predators of Atlantic salmon fry and parr in freshwater environments.

3.1.4.3.Contaminants and Water Quality

Pollutants discharged from point sources affect water quality within the action area of this consultation. Common point sources of pollutants include publicly operated waste treatment facilities, overboard discharges (OBD), a type of waste water treatment system), and industrial sites and discharges. The Maine Department of Environmental Protection (DEP) issues permits under the National Pollutant Discharge Elimination System (NPDES) for licensed point source discharges. Conditions and license limits are set to maintain the existing water quality classification. Generally, the impacts of point source pollution are greater in the larger rivers of the GOM DPS. The DEP has a schedule for preparing a number of TMDLs for rivers and streams within the Penobscot River watersheds. TMDLs allocate a waste load for a particular pollutant for impaired waterbodies. The main stem of the Penobscot River from its confluence with the Mattawamkeag River to Reeds Brook in Hampden has restricted fish consumption due to the presence of dioxin from industrial point sources. Combined sewer overflows from Milford, Old Town, Orono, Bangor, and Brewer produce elevated bacteria levels, thus inhibiting recreation uses of the river (primary contact). The lower area of the river south of Hampden to Verona Island is impaired due to contamination of mercury, PCBs, dioxin, and bacteria from industrial and municipal point sources. The West Branch of the Penobscot River is impaired due to hydro development and water withdrawals, thus creating aquatic life issues. Color inducing discharges in the West Branch of the Penobscot River are affecting water quality in the Penobscot River. Many small tributaries on the lower river in the Bangor area have aquatic life problems due to bacteria from both NPS and urban point sources. Parts of the Piscataquis River and its tributaries are impaired from combined sewer overflows and dissolved oxygen issues from agricultural NPS and municipal point sources. Approximately 160 miles of the Penobscot River and its tributaries are listed as impaired by the DEP.

3.1.5. Summary of Factors Affecting Recovery of Atlantic Salmon

There are a wide variety of factors that have and continue to affect the current status of the GOM DPS. The potential interactions among these factors are not well understood, nor are the reasons for the seemingly poor response of salmon populations to the many ongoing conservation efforts for this species.

Threats to the Species

The recovery plan for the previously designated GOM DPS (NMFS and USFWS 2005), the latest status review (Fay *et al.* 2006), and the 2009 listing rule all provide a comprehensive assessment of the many factors, including both threats and conservation actions, that are currently affecting the status and recovery of listed Atlantic salmon. The Services are writing a new recovery plan that will include the current, expanded GOM DPS and its designated critical habitat. The new recovery plan provides the most up to date list of significant threats affecting the GOM DPS. These are the following:

- Dams
- Inadequacy of existing regulatory mechanisms for dams
- Continued low marine survival rates for U.S. stocks of Atlantic salmon
- Lack of access to spawning and rearing habitat due to dams and road-stream crossings

In addition to these significant threats, there are a number of lesser stressors. These are the following:

- Degraded water quality
- Aquaculture practices, which pose ecological and genetic risks
- Climate change
- Depleted diadromous fish communities
- Incidental capture of adults and parr by recreational anglers
- Introduced fish species that compete or prey on Atlantic salmon
- Poaching of adults in DPS rivers
- Recovery hatchery program (potential for artificial selection/domestication)
- Sedimentation of spawning and rearing habitat
- Water extraction

Fay *et al.* (2006) examined each of the five statutory ESA listing factors and determined that each of the five listing factors is at least partly responsible for the present low abundance of the GOM DPS. The information presented in Fay *et al.* (2006) is reflected in and supplemented by the final listing rule for the new GOM DPS (74 FR 29344; June 19, 2009). The following gives a brief overview of the five listing factors as related to the GOM DPS.

1. **Present or threatened destruction, modification, or curtailment of its habitat or range** – Historically and, to a lesser extent currently, dams have adversely impacted Atlantic salmon by obstructing fish passage and degrading riverine habitat. Dams are considered to be one of the primary causes of both historic declines and the contemporary low abundance of the GOM DPS. Land use practices, including forestry and agriculture, have reduced habitat complexity (e.g., removal of large woody debris from rivers) and habitat connectivity (e.g., poorly designed road crossings) for Atlantic salmon. Water withdrawals, elevated sediment levels, and acid rain also degrade Atlantic salmon habitat.

2. **Overutilization for commercial, recreational, scientific, or educational purposes** – While most directed commercial fisheries for Atlantic salmon have ceased, the impacts from past fisheries are still important in explaining the present low abundance of the GOM DPS. Both poaching and by-catch in recreational and commercial fisheries for other species remain of concern, given critically low numbers of salmon.

3. **Predation and disease** – Natural predator-prey relationships in aquatic ecosystems in the GOM DPS have been substantially altered by introduction of non-native fishes (e.g., chain pickerel, smallmouth bass, and northern pike), declines of other native diadromous fishes, and alteration of habitat by impounding free-flowing rivers and removing instream structure (such as removal of boulders and woody debris during the log-driving era). The threat of predation on the GOM DPS is noteworthy because of the imbalance between the very low numbers of returning adults and the recent increase in populations of some native predators (e.g., double-crested cormorant), as well as non-native predators. Atlantic salmon are susceptible to a number of diseases and parasites, but mortality is primarily documented at conservation hatcheries and aquaculture facilities.

4. **Inadequacy of existing regulatory mechanisms** – The ineffectiveness of current federal and state regulations at requiring fish passage and minimizing or mitigating the aquatic habitat impacts of dams is a significant threat to the GOM DPS today. Furthermore, most dams in the GOM DPS do not require state or federal permits. Although the State of Maine has made substantial progress in regulating water withdrawals for agricultural use, threats still remain within the GOM DPS, including those from the effects of irrigation wells on salmon streams.

5. **Other natural or manmade factors** – Poor marine survival rates of Atlantic salmon are a significant threat, although the causes of these decreases are unknown. The role of ecosystem function among the freshwater, estuarine, and marine components of the Atlantic salmon's life history, including the relationship of other diadromous fish species in Maine (e.g., American shad, alewife, sea lamprey), is receiving increased scrutiny in its contribution to the current status of the GOM DPS and its role in recovery of the Atlantic salmon. While current state and federal regulations pertaining to finfish aquaculture have reduced the risks to the GOM DPS (including eliminating the use of non-North American Atlantic salmon and improving containment protocols), risks from the spread of diseases or parasites and from farmed salmon escapees interbreeding with wild salmon still exist.

Efforts to Protect the GOM DPS of Atlantic salmon

Efforts aimed at protecting Atlantic salmon and their habitats in Maine have been underway for well over one hundred years. These efforts are supported by a number of federal, state, and local government agencies, as well as many private conservation organizations. The 2005 recovery plan for the originally-listed GOM DPS (NMFS and USFWS 2005) presented a strategy for recovering Atlantic salmon that focused on reducing the most severe threats to the species and immediately halting the decline of the species to prevent extinction. The 2005 recovery program included the following elements:

1. Protect and restore freshwater and estuarine habitats;
2. Minimize potential for take in freshwater, estuarine, and marine fisheries;
3. Reduce predation and competition for all life-stages of Atlantic salmon;
4. Reduce risks from commercial aquaculture operations;
5. Supplement wild populations with hatchery-reared DPS salmon;
6. Conserve the genetic integrity of the DPS;
7. Assess stock status of key life stages;
8. Promote salmon recovery through increased public and government awareness; and
9. Assess effectiveness of recovery actions and revise as appropriate.

A wide variety of activities have focused on protecting Atlantic salmon and restoring the GOM DPS, including (but not limited to) hatchery supplementation; removing dams or providing fish passage; improving road crossings that block passage or degrade stream habitat; protecting riparian corridors along rivers; reducing the impact of irrigation water withdrawals; limiting effects of recreational and commercial fishing; reducing the effects of finfish aquaculture; outreach and education activities; and research focused on better understanding the threats to Atlantic salmon and developing effective restoration strategies. In light of the 2009 GOM DPS listing and designation of critical habitat, the Services are producing a new recovery plan for the expanded GOM DPS of Atlantic salmon.

3.2. Critical Habitat for Atlantic Salmon in the GOM DPS

Coincident with the June 19, 2009 endangered listing, NMFS designated critical habitat for the GOM DPS of Atlantic salmon (74 FR 29300; June 19, 2009) (Figure 6). The final rule was revised on August 10, 2009. In this revision, designated critical habitat for the expanded GOM DPS of Atlantic salmon was reduced to exclude trust and fee holdings of the Penobscot Indian Nation and a table was corrected (74 FR 39003; August 10, 2009).

Primary Constituent Elements of Atlantic Salmon Critical Habitat

Designation of critical habitat is focused on the known primary constituent elements (PCEs), within the occupied areas of a listed species that are deemed essential to the conservation of the species. Within the GOM DPS, the PCEs for Atlantic salmon are: 1) sites for spawning and rearing, and 2) sites for migration (excluding marine migration[1]). NMFS chose not to separate

1 Although successful marine migration is essential to Atlantic salmon, NMFS was not able to identify the essential features of marine migration and feeding habitat or their specific locations at the time critical habitat was designated.

spawning and rearing habitat into distinct PCEs, although each habitat does have distinct features, because of the GIS-based habitat prediction model approach that was used to designate critical habitat (74 FR 29300; June 19, 2009). This model cannot consistently distinguish between spawning and rearing habitat across the entire range of the GOM DPS.

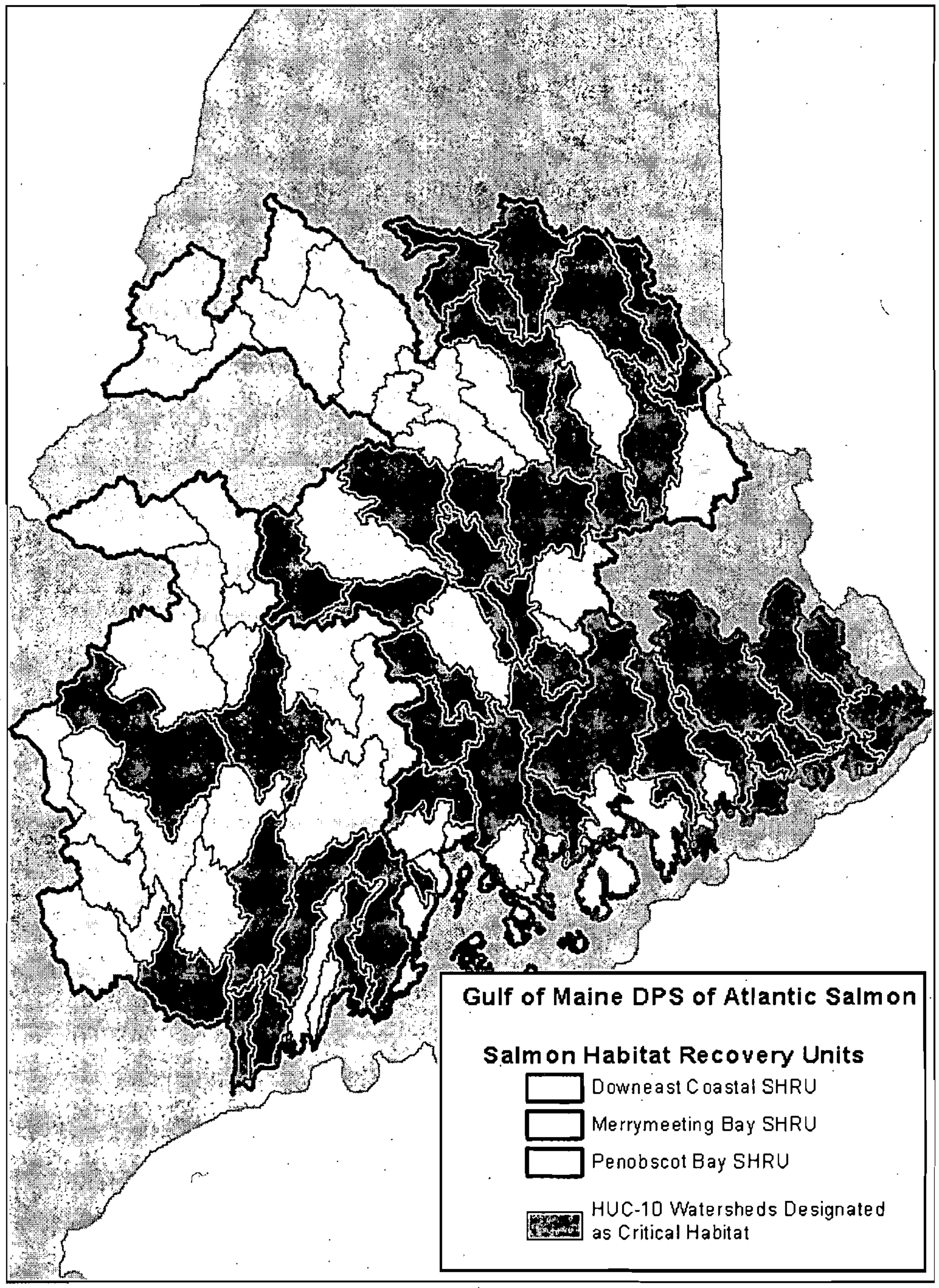

Figure 6. HUC-10 Watersheds Designated as Atlantic Salmon Critical Habitat within the GOM DPS.

The physical and biological features of the two PCEs for Atlantic salmon critical habitat are as follows:

Physical and Biological Features of the Spawning and Rearing PCE

1. Deep, oxygenated pools and cover (*e.g.*, boulders, woody debris, vegetation, etc.), near freshwater spawning sites, necessary to support adult migrants during the summer while they await spawning in the fall.
2. Freshwater spawning sites that contain clean, permeable gravel and cobble substrate with oxygenated water and cool water temperatures to support spawning activity, egg incubation, and larval development.
3. Freshwater spawning and rearing sites with clean, permeable gravel and cobble substrate with oxygenated water and cool water temperatures to support emergence, territorial development and feeding activities of Atlantic salmon fry.
4. Freshwater rearing sites with space to accommodate growth and survival of Atlantic salmon parr.
5. Freshwater rearing sites with a combination of river, stream, and lake habitats that accommodate parr's ability to occupy many niches and maximize parr production.
6. Freshwater rearing sites with cool, oxygenated water to support growth and survival of Atlantic salmon parr.
7. Freshwater rearing sites with diverse food resources to support growth and survival of Atlantic salmon parr.

Physical and Biological Features of the Migration PCE

1. Freshwater and estuary migratory sites free from physical and biological barriers that delay or prevent access of adult salmon seeking spawning grounds needed to support recovered populations.
2. Freshwater and estuary migration sites with pool, lake, and instream habitat that provide cool, oxygenated water and cover items (*e.g.*, boulders, woody debris, and vegetation) to serve as temporary holding and resting areas during upstream migration of adult salmon.
3. Freshwater and estuary migration sites with abundant, diverse native fish communities to serve as a protective buffer against predation.
4. Freshwater and estuary migration sites free from physical and biological barriers that delay or prevent emigration of smolts to the marine environment.
5. Freshwater and estuary migration sites with sufficiently cool water temperatures and water flows that coincide with diurnal cues to stimulate smolt migration.
6. Freshwater migration sites with water chemistry needed to support sea water adaptation of smolts.

Habitat areas designated as critical habitat must contain one or more PCEs within the acceptable range of values required to support the biological processes for which the species uses that habitat. Critical habitat includes all perennial rivers, streams, and estuaries and lakes connected to the marine environment within the range of the GOM DPS, except for those areas that have been specifically excluded as critical habitat. Critical habitat has only been designated in areas (HUC-10 watersheds) considered currently occupied by the species. Critical habitat includes the stream channels within the designated stream reach and includes a lateral extent as defined by the ordinary high-water line or the bankfull elevation in the absence of a defined high-water line. In estuaries, critical habitat is defined by the perimeter of the water body as displayed on standard 1:24,000 scale topographic maps or the elevation of extreme high water, whichever is greater.

For an area containing PCEs to meet the definition of critical habitat, the ESA also requires that the physical and biological features essential to the conservation of Atlantic salmon in that area "may require special management considerations or protections." Activities within the GOM DPS that were identified as potentially affecting the physical and biological features of salmon habitat and, therefore, requiring special management considerations or protections include agriculture, forestry, changing land-use and development, hatcheries and stocking, roads and road-stream crossings, mining, dams, dredging, and aquaculture.

Salmon Habitat Recovery Units within Critical Habitat for the GOM DPS

In describing critical habitat for the GOM DPS, NMFS divided the DPS into three Salmon Habitat Recovery Units or SHRUs. The three SHRUs include the Downeast Coastal, Penobscot Bay, and Merrymeeting Bay. The SHRU delineations were designed by NMFS 1) to ensure that a recovered Atlantic salmon population has widespread geographic distribution to help maintain genetic variability and 2) to provide protection from demographic and environmental variation. A widespread distribution of salmon across the three SHRUs will provide a greater probability of population sustainability in the future, as will be needed to achieve recovery of the GOM DPS.

Areas designated as critical habitat within each SHRU are described in terms of habitat units. One habitat unit represents 100 m^2 of salmon spawning or rearing habitat. The quantity of habitat units within the GOM DPS was estimated through the use of a GIS-based salmon habitat model (Wright *et al.* 2008). For each SHRU, NMFS determined that there were sufficient habitat units available within the currently occupied habitat to achieve recovery objectives in the future; therefore, no unoccupied habitat (at the HUC-10 watershed scale) was designated as critical habitat. A brief historical description for each SHRU, as well as contemporary critical habitat designations and special management considerations, are provided below.

Downeast Coastal SHRU

The Downeast Coastal SHRU encompasses fourteen HUC-10 watersheds covering approximately 747,737 hectares (1,847,698 acres) within Washington and Hancock counties. In this SHRU there are approximately 59,066 units of spawning and rearing habitat for Atlantic salmon among approximately 6,039 km of rivers, lakes and streams. Of the 59,066 units of spawning and rearing habitat, approximately 53,400 units of habitat in eleven HUC-10 watersheds are considered to be currently occupied. The Downeast SHRU has enough habitat units available within the occupied range that, in a restored state (*e.g.* improved fish passage or improved habitat quality), the Downeast SHRU could satisfy recovery objectives as described in the final rule for critical habitat (74 FR 29300; June 19, 2009). Certain tribal and military lands within the Downeast Coastal SHRU are excluded from critical habitat designation.

Penobscot Bay SHRU

The Penobscot Bay SHRU, which drains approximately 22,234,522 hectares (54,942,705 acres), contains approximately 315,574 units of spawning and rearing habitat for Atlantic salmon among approximately 17,440 km of rivers, lakes and streams. Of the 315,574 units of spawning and rearing habitat (within 46 HUC-10 watersheds), approximately 211,000 units of habitat are considered to be currently occupied (within 28 HUC-10 watersheds). Three HUC-10 watersheds (Molunkus Stream, Passadumkeag River, and Belfast Bay) are excluded from critical habitat designation due to economic impact. Certain tribal lands within the Penobscot Bay SHRU are also excluded from critical habitat designation.

Merrymeeting Bay SHRU

The Merrymeeting Bay SHRU drains approximately 2,691,814 hectares of land (6,651,620 acres) and contains approximately 339,182 units of spawning and rearing habitat for Atlantic salmon located among approximately 5,950 km of historically accessible rivers, lakes and streams. Of the 339,182 units of spawning and rearing habitat, approximately 136,000 units of habitat are considered to be currently occupied. There are forty-five HUC-10 watersheds in this SHRU, but only nine are considered currently occupied. Lands controlled by the Department of Defense within the Little Androscoggin HUC-10 and the Sandy River HUC-10 are excluded as critical habitat.

In conclusion, the June 19, 2009 final critical habitat designation for the GOM DPS (as revised on August 10, 2009) includes 45 specific areas occupied by Atlantic salmon that comprise approximately 19,571 km of perennial river, stream, and estuary habitat and 799 km^2 of lake habitat within the range of the GOM DPS and on which are found those physical and biological features essential to the conservation of the species. Within the occupied range of the GOM DPS, approximately 1,256 km of river, stream, and estuary habitat and 100 km^2 of lake habitat have been excluded from critical habitat pursuant to section 4(b)(2) of the ESA.

3.2.1. Status of Atlantic Salmon Critical Habitat in the Action Area

The environmental baseline of this Opinion describes the status of salmonid habitat, which is important for two reasons: a) because it affects the viability of the listed species within the action area at the time of the consultation; and b) because those habitat areas designated "critical" provide PCEs essential for the conservation (i.e., recovery) of the species. The environmental baseline also describes the status of critical habitat over the duration of the proposed action because it includes the persistent effects of past actions and the future effects of Federal actions that have not taken place but have already undergone section 7 consultation.

The complex life cycles exhibited by Atlantic salmon give rise to complex habitat needs, particularly during the freshwater phase (Fay *et al.* 2006). Spawning gravels must be a certain size and free of sediment to allow successful incubation of the eggs. Eggs also require cool, clean, and well-oxygenated waters for proper development. Juveniles need abundant food sources, including insects, crustaceans, and other small fish. They need places to hide from predators (mostly birds and bigger fish), such as under logs, root wads, and boulders in the stream, as well as beneath overhanging vegetation. They also need places to seek refuge from periodic high flows (side channels and off-channel areas) and from warm summer water temperatures (coldwater springs and deep pools). Returning adults generally do not feed in fresh water but instead rely on limited energy stores to migrate, mature, and spawn. Like juveniles, they also require cool water and places to rest and hide from predators. During all life stages, Atlantic salmon require cool water that is free of contaminants. They also need migratory corridors with adequate passage conditions (timing, water quality, and water quantity) to allow access to the various habitats required to complete their life cycle.

As discussed previously, critical habitat for Atlantic salmon has been designated in the Penobscot River, as well as in the Stillwater Branch. Both PCEs for Atlantic salmon (sites for spawning and rearing and sites for migration) are present in the action area as it was described in Section 2.6 of this Opinion (the entirety of the Penobscot River watershed). PCEs consist of the physical and biological elements identified as essential to the conservation of the species in the documents designating critical habitat. These PCEs include sites essential to support one or more life stages of Atlantic salmon (sites for spawning, rearing, and migration) and contain physical or biological features essential to the conservation of the species, for example, spawning gravels, water quality and quantity, unobstructed passage, and forage.

To facilitate and standardize determinations of effect for section 7 consultations involving Atlantic salmon critical habitat, we developed the "Matrix of PCEs and Essential Features for Designated Atlantic Salmon Critical Habitat in the GOM DPS" (Table 4). The matrix lists the PCEs, physical and biological features (essential features) of each PCE, and the potential conservation status of critical habitat within an action area. The two PCEs in the matrix (spawning and rearing, and migration) are described in regards to five distinct Atlantic salmon life stages: (1) adult spawning; (2) embryo and fry development; (3) parr development; (4) adult migration; and, (5) smolt migration. The conservation status of the essential features may exist in varying degrees of functional capacity within the action area. The three degrees of functional capacity used in the matrix are described in ascending order: (1) fully functioning; (2) limited function; and (3) not properly functioning. Using this matrix along with information presented in FERC's BA and site-specific knowledge of each project, NMFS determined that several essential features to Atlantic salmon in the action area have limited function or are not properly functioning currently (Table 5).

Table 4. Matrix of Primary Constituent Elements (PCEs) and essential features for assessing the environmental baseline of the action area.

		Conservation Status Baseline		
PCE	Essential Features	Fully Functioning	Limited Function	Not Properly Functioning
A) Adult Spawning: (October 1st - December 14th)				
	Substrate	highly permeable course gravel and cobble between 1.2 to 10 cm in diameter	40- 60% cobble (22.5-256 mm dia.) 40-50% gravel (2.2 – 22.2 mm dia.); 10-15% course sand (0.5 -2.2 mm dia.), and <3% fine sand (0.06-0.05mm dia.)	more than 20% sand (particle size 0.06 to 2.2 mm), no gravel or cobble
	Depth	17-30 cm	30 - 76 cm	< 17 cm or > 76 cm
	Velocity	31 to 46 cm/sec.	8 to 31cm/sec. or 46 to 83 cm/sec.	< 5-8 cm/sec. or > 83cm/sec.
	Temperature	7° to 10°C	often between 7° to 10°C	always < 7° or > 10°C
	pH	> 5.5	between 5.0 and 5.5	< 5.0
	Cover	Abundance of pools 1.8-3.6 meters deep (McLaughlin and Knight 1987). Large boulders or rocks, over hanging trees, logs, woody debris, submerged vegetation or undercut banks	Limited availability of pools 1.8-3.6 meters deep (McLaughlin and Knight 1987). Large boulders or rocks, over hanging trees, logs, woody debris, submerged vegetation or undercut banks	Absence of pools 1.8-3.6 meters deep (McLaughlin and Knight 1987). Large boulders or rocks, over hanging trees, logs, woody debris, submerged vegetation or undercut banks
	Fisheries Interactions	Abundant diverse populations of indigenous fish species	Abundant diverse populations of indigenous fish species, low quantities of non-native species present	Limited abundance and diversity of indigenous fish species, abundant populations of non-native species
B) Embryo and Fry Development: (October 1st - April 14th)				
	Temperature	0.5°C and 7.2°C, averages nearly 6oC from fertilization to eye pigmentation	averages < 4oC, or 8 to 10°C from fertilization to eye pigmentation	>10°C from fertilization to eye pigmentation
	D.O.	at saturation	7-8 mg/L	< 7 mg/L
	pH	> 6.0	6 - 4.5	< 4.5
	Depth	5.3-15cm	NA	<5.3 or >15cm
	Velocity	4 – 15cm/sec.	NA	<4 or > 15cm/sec.
	Fisheries Interactions	Abundant diverse populations of indigenous fish species	Abundant diverse populations of indigenous fish species, low quantities of non-native species present	Limited abundance and diversity of indigenous fish species, abundant populations of non-native species

TABLE 4 continued...

		Conservation Status Baseline		
PCE	Essential Features	Fully Functioning	Limited Function	Not Properly Functioning
C) Parr Development: (All year)				
	Substrate	gravel between 1.6 and 6.4 cm in diameter and boulders between 30 and 51.2 cm in diameter. May contain rooted aquatic macrophytes	gravel < 1.2cm and/or boulders > 51.2. May contain rooted aquatic macrophytes	no gravel, boulders, or rooted aquatic macrophytes present
	Depth	10cm to 30cm	NA	<10cm or >30cm
	Velocity	7 to 20 cm/sec.	< 7cm/sec. or > 20 cm/sec.	velocity exceeds 120 cm/sec.
	Temperature	15° to 19°C	generally between 7-22.5oC, but does not exceed 29oC at any time	stream temperatures are continuously <7oC or known to exceed 29oC
	D.O.	> 6 mg/l	2.9 - 6 mg/l	< 2.9 mg/l
	Food	Abundance of larvae of mayflies, stoneflies, chironomids, caddisflies, blackflies, aquatic annelids, and mollusks as well as numerous terrestrial invertebrates and small fish such as alewives, dace or minnows	Presence of larvae of mayflies, stoneflies, chironomids, caddisflies, blackflies, aquatic annelids, and mollusks as well as numerous terrestrial invertebrates and small fish such as alewives, dace or minnows	Absence of larvae of mayflies, stoneflies, chironomids, caddisflies, blackflies, aquatic annelids, and mollusks as well as numerous terrestrial invertebrates and small fish such as alewives, dace or minnows
	Passage	No anthropogenic causes that inhibit or delay movement	Presence of anthropogenic causes that result in limited inhibition of movement	barriers to migration known to cause direct inhibition of movement
	Fisheries Interactions	Abundant diverse populations of indigenous fish species	Abundant diverse populations of indigenous fish species, low quantities of non-native species present	Limited abundance and diversity of indigenous fish species, abundant populations of non-native species

TABLE 4 continued...

		Conservation Status Baseline		
PCE	Essential Features	Fully Functioning	Limited Function	Not Properly Functioning
D) Adult migration: (April 15th- December 14th)				
	Velocity	30 cm/sec to 125 cm/sec	In areas where water velocity exceeds 125 cm/sec adult salmon require resting areas with a velocity of < 61 cm/s	sustained speeds > 61 cm/sec and maximum speed > 667 cm/sec
	D.O.	> 5mg/L	4.5-5.0 mg/l	< 4.5mg/L
	Temperature	14 – 20°C	temperatures sometimes exceed 20oC but remain below 23°C.	> 23°C
	Passage	No anthropogenic causes that delay migration	Presence of anthropogenic causes that result in limited delays in migration	barriers to migration known to cause direct or indirect mortality of smolts
	Fisheries Interactions	Abundant diverse populations of indigenous fish species	Abundant diverse populations of indigenous fish species, low quantities of non-native species present	Limited abundance and diversity of indigenous fish species, abundant populations of non-native species
E) Juvenile Migration: (April 15th - June 14th)				
	Temperature	8 - 11oC	5 - 11°C.	< 5oC or > 11oC
	pH	> 6	5.5 - 6.0	< 5.5
	Passage	No anthropogenic causes that delay migration	Presence of anthropogenic causes that result in limited delays in migration	barriers to migration known to cause direct or indirect mortality of smolts

Table 5. Current conditions of essential features of Atlantic salmon critical habitat having limited function or not properly functioning as part of the environmental baseline of the action area.

Pathway/Indicator	Life Stages Affected	PCEs Affected	Effect	Population Viability Attributes Affected
Passage/Access to Historical Habitat	Adult, juvenile, smolt	Freshwater migration	Upstream passage delays and inefficiencies limit access to spawning habitat. Poor downstream passage causes direct and delayed mortality of smolts and kelts.	Adult abundance and productivity,
Habitat Elements, Channel Dynamics, Watershed Condition	Adult, incubating eggs, juvenile, smolt	Freshwater migration, spawning, and rearing	Impoundments degrade spawning and rearing habitat, increase predation, limit productivity, and delay migrations.	Adult abundance and productivity Juvenile growth rate
Water Quality	Adult, juvenile, incubating eggs	Freshwater spawning and rearing	Impoundments degrade spawning and rearing habitat.	Adult abundance and productivity Juvenile growth rate

3.2.2. Factors affecting Atlantic Salmon Critical Habitat in the Action Area

In Section 3.1.4, we present the factors affecting the GOM DPS of Atlantic salmon with the Penobscot River watershed. To the extent that these same factors (hydroelectric operations, predation, and water quality) affect the essential features of rearing, spawning and migration habitat in the Penobscot River watershed, they are also affecting Atlantic salmon critical habitat.

Threats to Critical Habitat within the GOM DPS

The final rule designating critical habitat for the GOM DPS identifies a number of activities that have and will likely continue to impact the biological and physical features of spawning, rearing, and migration habitat for Atlantic salmon. These include agriculture, forestry, changing land-use and development, hatcheries and stocking, roads and road-crossings and other instream activities (such as alternative energy development), mining, dams, dredging, and aquaculture. Most of these activities have or still do occur, at least to some extent, in each of the three SHRUs.

The Penobscot Bay SHRU once contained high quality Atlantic salmon habitat in quantities sufficient to support robust Atlantic salmon populations. The mainstem Penobscot has the highest biological value to the Penobscot Bay SHRU because it provides a central migratory corridor crucial for the entire Penobscot Bay SHRU. Dams, along with degraded substrate and cover, water quality, water temperature, and biological communities, have reduced the quality and quantity of habitat available to Atlantic salmon populations within the Penobscot Bay SHRU. A combined total of 24 FERC-licensed hydropower dams in the Penobscot Bay SHRU significantly impede the migration of Atlantic salmon and other diadromous fish to nearly 300,000 units of historically accessible spawning and rearing habitat. Agriculture and urban development largely affect the lower third of the Penobscot Bay SHRU below the Piscataquis River sub-basin by reducing substrate and cover, reducing water quality, and elevating water temperatures. Introductions of smallmouth bass and other non-indigenous species significantly degrade habitat quality throughout the mainstem Penobscot and portions of the Mattawamkeag, Piscataquis, and lower Penobscot sub-basins by altering predator/prey relationships. Similar to smallmouth bass, recent Northern pike introductions threaten habitat in the lower Penobscot River below the Great Works Dam.

Today, dams are the greatest impediment, outside of marine survival, to the recovery of salmon in the Penobscot, Kennebec and Androscoggin river basins (Fay *et al.* 2006). Hydropower dams in the Merrymeeting Bay SHRU significantly impede the migration of Atlantic salmon and other diadromous fish and either reduce or eliminate access to roughly 352,000 units of historically accessible spawning and rearing habitat. In addition to hydropower dams, agriculture and urban development largely affect the lower third of the Merrymeeting Bay SHRU by reducing substrate and cover, reducing water quality, and elevating water temperatures. Additionally, smallmouth bass and brown trout introductions, along with other non-indigenous species, significantly degrade habitat quality throughout the Merrymeeting Bay SHRU by altering natural predator/prey relationships.

Impacts to substrate and cover, water quality, water temperature, biological communities, and migratory corridors, among a host of other factors, have impacted the quality and quantity of habitat available to Atlantic salmon populations within the Downeast Coastal SHRU. Two hydropower dams on the Union river, and to a lesser extent the small ice dam on the lower Narraguagus River, limit access to roughly 18,500 units of spawning and rearing habitat within these two watersheds. In the Union River, which contains over 12,000 units of spawning and rearing habitat, physical and biological features have been most notably limited by high water temperatures and abundant smallmouth bass populations associated with impoundments. In the Pleasant River and Tunk Stream, which collectively contain over 4,300 units of spawning and rearing habitat, pH has been identified as possibly being the predominate limiting factor. The Machias, Narraguagus, and East Machias rivers contain the highest quality habitat relative to other HUC 10's in the Downeast Coastal SHRU and collectively account for approximately 40 percent of the spawning and rearing habitat in the Downeast Coastal SHRU.

3.3. Shortnose sturgeon

3.3.1. Species Description

Shortnose sturgeon are benthic fish that mainly occupy the deep channel sections of large rivers. They feed on a variety of benthic and epibenthic invertebrates including mollusks, crustaceans (amphipods, chironomids, isopods), and oligochaete worms (Vladykov and Greeley 1963, Dadswell 1979 *in* NMFS 1998). Shortnose sturgeon have similar lengths at maturity (45-55 cm fork length) throughout their range, but, because sturgeon in southern rivers grow faster than those in northern rivers, southern sturgeon mature at younger ages (Dadswell *et al.* 1984). Shortnose sturgeon are long-lived (30-40 years) and, particularly in the northern extent of their range, mature at late ages. In the north, males reach maturity at five to ten years, while females mature between seven and thirteen years. Based on limited data, females spawn every three to five years while males spawn approximately every two years. The spawning period is estimated to last from a few days to several weeks. Spawning begins from late winter/early spring (southern rivers) to mid to late spring (northern rivers)[2] when the freshwater temperatures increase to 8-9°C. Several published reports have presented the problems facing long-lived species that delay sexual maturity (Crouse *et al.* 1987, Crowder *et al.* 1994, Crouse 1999). In general, these reports concluded that animals that delay sexual maturity and reproduction must have high annual survival as juveniles through adults to ensure that enough juveniles survive to reproductive maturity and then reproduce enough times to maintain stable population sizes.

Total instantaneous mortality rates (Z) are available for the Saint John River (0.12 - 0.15; ages 14-55; Dadswell 1979), Upper Connecticut River (0.12; Taubert 1980b), and Pee Dee-Winyah River (0.08-0.12; Dadswell *et al.* 1984). Total instantaneous natural mortality (M) for shortnose sturgeon in the lower Connecticut River was estimated to be 0.13 (T. Savoy, Connecticut Department of Environmental Protection, personal communication). There is no recruitment information available for shortnose sturgeon because there are no commercial fisheries for the species. Estimates of annual egg production for this species are difficult to calculate because females do not spawn every year (Dadswell *et al.* 1984). Further, females may abort spawning attempts, possibly due to interrupted migrations or unsuitable environmental conditions (NMFS 1998). Thus, annual egg production is likely to vary greatly in this species. Fecundity estimates have been made and range from 27,000 to 208,000 eggs/female (Dadswell *et al.* 1984).

At hatching, shortnose sturgeon are blackish-colored, 7-11mm long and resemble tadpoles (Buckley and Kynard 1981). In 9-12 days, the yolk sac is absorbed and the sturgeon develops into larvae which are about 15mm total length (TL; Buckley and Kynard 1981). Sturgeon larvae are believed to begin downstream migrations at about 20mm TL. Laboratory studies suggest that young sturgeon move downstream in a 2-step migration; a 2- to 3-day migration by larvae followed by a residency period by young of the year (YOY), then a resumption of migration by yearlings in the second summer of life (Kynard 1997). Juvenile shortnose sturgeon (between 3-10 years of age) reside in the interface between saltwater and freshwater in most rivers (NMFS 1998).

In populations that have free access to the total length of a river (e.g., no dams within the species' range in a river: Saint John, Kennebec, Altamaha, Savannah and Delaware Rivers), spawning areas are located at the farthest upstream reach of the river (NMFS 1998). In the northern extent of their range, shortnose sturgeon exhibit three distinct movement patterns. These migratory movements are associated with spawning, feeding, and overwintering activities. In spring, as water temperatures rise above 8°C, pre-spawning shortnose sturgeon move from overwintering grounds to spawning areas. Spawning occurs from mid/late March to mid/late May depending upon location and water temperature. Sturgeon spawn in upper, freshwater areas and feed and overwinter in both fresh and saline habitats. Shortnose sturgeon spawning migrations are characterized by rapid, directed and often extensive upstream movement (NMFS 1998).

Shortnose sturgeon are believed to spawn at discrete sites within their natal river (Kieffer and

2 For purposes of this consultation, Northern rivers are considered to include tributaries of the Chesapeake Bay northward to the St. John River in Canada. Southern rivers are those south of the Chesapeake Bay.

Kynard 1996). In the Merrimack River, males returned to only one reach during a four year telemetry study (Kieffer and Kynard 1996). Squires *et al.* (1982) found that during the three years of the study in the Androscoggin River, adults returned to a 1-km reach below the Brunswick Dam and Kieffer and Kynard (1996) found that adults spawned within a 2-km reach in the Connecticut River for three consecutive years. Spawning occurs over channel habitats containing gravel, rubble, or rock-cobble substrates (Dadswell *et al.* 1984, NMFS 1998). Additional environmental conditions associated with spawning activity include decreasing river discharge following the peak spring freshet, water temperatures ranging from 8 - 12°, and bottom water velocities of 0.4 to 0.7 m/sec (Dadswell *et al.* 1984, NMFS 1998). For northern shortnose sturgeon, the temperature range for spawning is 6.5-18.0°C (Kieffer and Kynard in press). Eggs are separate when spawned but become adhesive within approximately 20 minutes of fertilization (Dadswell *et al.* 1984). Between 8° and 12°C, eggs generally hatch after approximately 13 days. The larvae are photonegative, remaining on the bottom for several days. Buckley and Kynard (1981) found week old larvae to be photonegative and form aggregations with other larvae in concealment.

Adult shortnose sturgeon typically leave the spawning grounds soon after spawning. Non-spawning movements include rapid, directed post-spawning movements to downstream feeding areas in spring and localized, wandering movements in summer and winter (Dadswell *et al.* 1984, Buckley and Kynard 1985, O'Herron *et al.* 1993). Kieffer and Kynard (1993) reported that post-spawning migrations were correlated with increasing spring water temperature and river discharge. Young-of-the-year shortnose sturgeon are believed to move downstream after hatching (Dovel 1981) but remain within freshwater habitats. Older juveniles tend to move downstream in fall and winter as water temperatures decline and the salt wedge recedes. Juveniles move upstream in spring and feed mostly in freshwater reaches during summer.

Juvenile shortnose sturgeon generally move upstream in spring and summer and move back downstream in fall and winter; however, these movements usually occur in the region above the saltwater/freshwater interface (Dadswell *et al.* 1984, Hall *et al.* 1991). Adult sturgeon occurring in freshwater or freshwater/tidal reaches of rivers in summer and winter often occupy only a few short reaches of the total length (Buckley and Kynard 1985). Summer concentration areas in southern rivers are cool, deep, thermal refugia, where adult and juvenile shortnose sturgeon congregate (Flournoy *et al.* 1992, Rogers *et al.* 1994, Rogers and Weber 1995, Weber 1996).

The temperature preference for shortnose sturgeon is not known (Dadswell *et al.* 1984) but shortnose sturgeon have been found in waters with temperatures as low as 2-3°C (Dadswell *et al.* 1984) and as high as 34°C (Heidt and Gilbert 1978). However, temperatures above 28°C are thought to adversely affect shortnose sturgeon. In the Altamaha River, temperatures of 28-30°C during summer months create unsuitable conditions and shortnose sturgeon are found in deep cool water refuges.

Shortnose sturgeon are known to occur at a wide range of depths. A minimum depth of 0.6 meters is necessary for the unimpeded swimming by adults. Shortnose sturgeon are known to occur at depths of up to 30 meters but are generally found in waters less than 20 meters (Dadswell *et al.* 1984, Dadswell 1979). Shortnose sturgeon have also demonstrated tolerance to a wide range of salinities. Shortnose sturgeon have been documented in freshwater (Taubert

1980, Taubert and Dadswell 1980) and in waters with salinity of 30 parts-per-thousand (ppt) (Holland and Yeverton 1973). McCleave *et al.* (1977) reported adults moving freely through a wide range of salinities, crossing waters with differences of up to 10ppt within a two hour period. The tolerance of shortnose sturgeon to increasing salinity is thought to increase with age (Kynard 1996). Shortnose sturgeon typically occur in the deepest parts of rivers or estuaries where suitable oxygen and salinity values are present (Gilbert 1989). Shortnose sturgeon were listed as endangered on March 11, 1967 (32 FR 4001), and the species remained on the endangered species list with the enactment of the ESA in 1973.

Although the original listing notice did not cite reasons for listing the species, a 1973 Resource Publication, issued by the U.S. Department of the Interior, stated that shortnose sturgeon were "in peril...gone in most of the rivers of its former range [but] probably not as yet extinct" (USDOI 1973). Pollution and overfishing, including bycatch in the shad fishery, were listed as principal reasons for the species' decline. In the late nineteenth and early twentieth centuries, shortnose sturgeon commonly were taken in a commercial fishery for the closely related and commercially valuable Atlantic sturgeon (*Acipenser oxyrinchus*). More than a century of extensive fishing for sturgeon contributed to the decline of shortnose sturgeon along the east coast. Heavy industrial development during the twentieth century in rivers inhabited by sturgeon impaired water quality and impeded these species' recovery; possibly resulting in substantially reduced abundance of shortnose sturgeon populations within portions of the species' ranges (e.g., southernmost rivers of the species range: Santilla, St. Marys and St. Johns Rivers). A shortnose sturgeon recovery plan was published in December 1998 to promote the conservation and recovery of the species (see NMFS 1998). Shortnose sturgeon are listed as "vulnerable" on the IUCN Red List.

Although shortnose sturgeon are listed as endangered range-wide, in the final recovery plan NMFS recognized 19 separate populations occurring throughout the range of the species. These populations are in New Brunswick Canada (1); Maine (2); Massachusetts (1); Connecticut (1); New York (1); New Jersey/Delaware (1); Maryland and Virginia (1); North Carolina (1); South Carolina (4); Georgia (4); and Florida (2). NMFS has not formally recognized distinct population segments (DPS)[3] of shortnose sturgeon under the ESA. The 1998 Recovery Plan indicates that while genetic information may reveal that interbreeding does not occur between rivers that drain into a common estuary, at this time, such river systems are considered a single population compromised of breeding subpopulations (NMFS 1998).

Studies conducted since the issuance of the Recovery Plan have provided evidence that suggests that years of isolation between populations of shortnose sturgeon have led to morphological and genetic variation. Walsh *et al.* (2001) examined morphological and genetic variation of shortnose sturgeon in three rivers (Kennebec, Androscoggin, and Hudson). The study found that the Hudson River shortnose sturgeon population differed markedly from the other two rivers for most morphological features (total length, fork length, head and snout length, mouth width,

3 The definition of species under the ESA includes any subspecies of fish, wildlife, or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature. To be considered a DPS, a population segment must meet two criteria under NMFS policy. First, it must be discrete, or separated, from other populations of its species or subspecies. Second, it must be significant, or essential, to the long-term conservation status of its species or subspecies. This formal legal procedure to designate DPSs for shortnose sturgeon has not been undertaken.

interorbital width and dorsal scute count, left lateral scute count, right ventral scute count). Significant differences were found between fish from Androscoggin and Kennebec rivers for interorbital width and lateral scute counts which suggests that even though the Androscoggin and Kennebec rivers drain into a common estuary, these rivers support largely discrete populations of shortnose sturgeon. The study also found significant genetic differences among all three populations indicating substantial reproductive isolation among them and that the observed morphological differences may be partly or wholly genetic.

Grunwald *et al.* (2002) examined mitochondrial DNA (mtDNA) from shortnose sturgeon in eleven river populations. The analysis demonstrated that all shortnose sturgeon populations examined showed moderate to high levels of genetic diversity as measured by haplotypic diversity indices. The limited sharing of haplotypes and the high number of private haplotypes are indicative of high homing fidelity and low gene flow. The researchers determined that glaciation in the Pleistocene Era was likely the most significant factor in shaping the phylogeographic pattern of mtDNA diversity and population structure of shortnose sturgeon. The Northern glaciated region extended south to the Hudson River while the southern non-glaciated region begins with the Delaware River. There is a high prevalence of haplotypes restricted to either of these two regions and relatively few are shared; this represents a historical subdivision that is tied to an important geological phenomenon that reflects historical isolation. Analyses of haplotype frequencies at the level of individual rivers showed significant differences among all systems in which reproduction is known to occur. This implies that although higher level genetic stock relationships exist (i.e., southern vs. northern and other regional subdivisions), shortnose sturgeon appear to be discrete stocks, and low gene flow exists between the majority of populations.

Waldman *et al.* (2002) also conducted mtDNA analysis on shortnose sturgeon from 11 river systems and identified 29 haplotypes. Of these haplotypes, 11 were unique to northern, glaciated systems and 13 were unique to the southern non-glaciated systems. Only five were shared between them. This analysis suggests that shortnose sturgeon show high structuring and discreteness and that low gene flow rates indicated strong homing fidelity.

Wirgin *et al.* (2005) also conducted mtDNA analysis on shortnose sturgeon from 12 rivers (St. John, Kennebec, Androscoggin, Upper Connecticut, Lower Connecticut, Hudson, Delaware, Chesapeake Bay, Cooper, Peedee, Savannah, Ogeechee and Altamaha). This analysis suggested that most population segments are independent and that genetic variation among groups was high.

In 2007, we initiated a five-year status review to assess the status of shortnose sturgeon rangewide. The status review team was specifically charged with analyzing new genetic data to inform the current understanding of shortnose sturgeon genetics rangewide. Although these analyses are not yet available, life history studies indicate that shortnose sturgeon populations from different river systems are substantially reproductively isolated (Kynard 1997),.

The best available information demonstrates differences in life history and habitat preferences between northern and southern river systems and given the species' anadromous breeding habits, the rare occurrence of migration between river systems, and the documented genetic differences between river populations, it is unlikely that populations in adjacent river systems interbreed with any regularity. This behavior likely accounts for the failure of shortnose sturgeon to repopulate river systems from which they have been extirpated, despite the geographic closeness of persisting populations. This particular characteristic of shortnose sturgeon also complicates recovery and persistence of this species in the future because, if a river population is extirpated in the future, it is unlikely that this river will be recolonized. Consequently, this Opinion will treat the nineteen separate populations of shortnose sturgeon as subpopulations (one of which occurs in the action area) for the purposes of this analysis.

3.3.2. Status and Trends of Shortnose Sturgeon Rangewide

Historically, shortnose sturgeon are believed to have inhabited nearly all major rivers and estuaries along nearly the entire east coast of North America. The range extended from the Saint John River in New Brunswick, Canada to the Indian River in Florida. Today, only 19 populations remain ranging from the St. Johns River, Florida (possibly extirpated from this system) to the Saint John River in New Brunswick, Canada. Shortnose sturgeon are large, long lived fish species. The present range of shortnose sturgeon is disjunct, with northern populations separated from southern populations by a distance of about 400 km. The species is anadromous in the southern portion of its range (i.e., south of Chesapeake Bay), while northern populations are amphidromous (NMFS 1998). Population sizes vary across the species' range. From available estimates, the smallest populations occur in the Cape Fear (~8 adults; Moser and Ross 1995) and Merrimack Rivers (~100 adults; M. Kieffer, United States Geological Survey, personal communication), while the largest populations are found in the Saint John (~100,000; Dadswell 1979) and Hudson Rivers (~61,000; Bain *et al.* 1998). As indicated in Kynard (1996), adult abundance is less than the minimum estimated viable population abundance of 1000 adults for five of 11 surveyed northern populations and all natural southern populations. Kynard (1996) indicates that all aspects of the species' life history indicate that shortnose sturgeon should be abundant in most rivers. As such, the expected abundance of adults in northern and north-central populations should be thousands to tens of thousands of adults. Expected abundance in southern rivers is uncertain, but large rivers should likely have thousands of adults. The only river systems likely supporting populations of these sizes are the Saint John, Hudson and possibly the Delaware and the Kennebec, making the continued success of shortnose sturgeon in these rivers critical to the species as a whole. While no reliable estimate of the size of either the total species or the shortnose sturgeon population in the northeastern United States exists, it is clearly below the size that could be supported if the threats to shortnose sturgeon were removed; however, overall the species trend is considered to be stable.

3.3.3. Status and Distribution of Shortnose Sturgeon in the Action Area

On June 30, 1978, one shortnose sturgeon was captured in Penobscot Bay during finfish sampling conducted by the MDMR (Squiers and Smith 1979). As shortnose sturgeon were thought to rarely participate in coastal migrations and are known to complete their entire life history in their natal river, researchers concluded that this sturgeon was a member of a previously undocumented Penobscot River population of shortnose sturgeon. The river had long been suspected of supporting a shortnose sturgeon population based on anecdotal evidence of shortnose sturgeon capture and observation in combination with archeological data which suggested that sturgeon from the Penobscot River were used by native peoples (Knight 1985 and Petersen and Sanger 1986 in NMFS 1998; see also Fernandes *et al.* 2010).

In 1994 and 1995, researchers attempted to document the use of the Penobscot River by shortnose sturgeon. Nets were set near the head of tide in both years with the goal of capturing spawning adults. This was the only area of the river targeted by the researchers. Researchers fished for approximately 409 net hours. No shortnose sturgeon were captured. However, even in rivers with relatively large populations with intense sampling programs (*i.e.*, the Connecticut River), it is not uncommon for there to be a year when no migration to the spawning grounds and subsequently no spawning occurs.

The 1978 capture, in conjunction with historical and anecdotal evidence and the habitat characteristics of the river, led us to conclude that there was a small persistent population of shortnose sturgeon in the Penobscot River (NMFS 1998).

In May 2006, the University of Maine (UM), in conjunction with NMFS and the U.S. Geological Survey (USGS), began a study of the distribution, abundance, and movements of adult and sub-adult Atlantic sturgeon in the Penobscot River. These research efforts confirmed the presence of shortnose sturgeon in the river. In 2006, 62 individual shortnose sturgeon were captured by UM in the Penobscot River from Frankfort upstream to Bangor. Between May 21, 2007, and September 10, 2007, an additional 99 individual shortnose sturgeon were captured and tagged in the river (Fernandes 2008, Fernandes *et al.* 2010). A total of 185 shortnose sturgeon were captured in the river in 2008 and 221 in 2009. To date, a total of 662 shortnose sturgeon have been captured in the Penobscot River (Dionne 2010b in MDMR 2010). All sturgeon captured during the study were adults or large juveniles as the type of gear used for sampling (large mesh gill nets of six inch and 12 inch stretch) is not designed to capture sturgeon less than two feet in length.

Using the 2006 and 2007 mark-recapture data, UM researchers used two different calculation methods to obtain a preliminary population estimate for the Penobscot River (Fernandes *et al.* 2008). Using a Lincoln/Peterson Index, an estimate of 1,049 fish was calculated (95% confidence interval of 673 and 6,939). A Schnabel estimate was also calculated yielding an estimate of 1710 shortnose sturgeon. It must be noted that both models assume a closed population (no mortality, birth or migration takes place). Fernandes (2008) used capture data from 2006 and 2007 to calculate Peterson and Schnabel estimates of abundance. The Peterson estimate of shortnose sturgeon abundance was 1,425 with a confidence interval of 203-2,647. The Schnabel estimate was 1,531 with a confidence interval of 885-5,681. As reported by Fernandes (2008), these two methods require a large number of recaptures for a precise estimate of abundance, and were likely affected by the low number of recaptures in this study. Additionally, several of the assumptions of these tests were violated, including the lack of a closed population and random sampling. A POPAN Jolly-Seber open population model completed in 2010 estimated approximately 1654 (95%CI: 1,108-2,200) adult shortnose sturgeon using the Penobscot River. Similarly, a more robust design analysis with closed periods in the summer and late fall, estimated seasonal adult abundance ranging from 636-1,285 (weighted mean), with a low estimate of 602 (95%CI: 409.6-910.8) and a high of 1,306 (95% CI: 795.6-2,176.4).

As noted above, several population estimates have been made for the Penobscot River, ranging from 602-1654 adult shortnose sturgeon (Fernandes 2008, Fernandes *et al.* 2010, Zydlewski *et al.* 2010 in MDMR 2010). It is currently unknown whether spawning is occurring in the Penobscot River or whether shortnose sturgeon present in the Penobscot River spawn in the Kennebec and/or Androscoggin River. Tracking data has shown that there is at least limited exchange between the Penobscot River and the Kennebec River. The most recent estimate of the number of shortnose sturgeon in the Kennebec complex is 9,488 and successful spawning has been confirmed in both the Kennebec and Androscoggin Rivers. The MDMR conducted studies of shortnose sturgeon in the Kennebec River from 1996 through 2001. A Schnabel estimate using tagging and recapture data from 1998, 1999 and 2000 indicates a population estimate of 9,488 (95% CI: 6,942 to 13,358) for the estuarine complex. Based on comparison to older population estimates, we believe that the Kennebec River population is increasing slightly or is stable. Without historical data to compare to the current Penobscot River population estimate, it is not possible to assess the population trend.

Currently, shortnose sturgeon are limited to the area below Veazie Dam. Existing fish passage facilities at the Veazie Dam are not used by shortnose sturgeon, and no shortnose sturgeon are known to occur upstream of the dam. Historically, the first natural obstacle to sturgeon migration on the Penobscot River may have been the falls at Milford, approximately rkm 70 (L. Flagg, MDMR, pers. comm 1998, Houston *et al.* 2007). If sturgeon were able to ascend the falls at Milford, they could have migrated without obstruction to Mattaseunk (rkm 171). The currently available information on the distribution of shortnose sturgeon in the Penobscot River is summarized below.

Recaptures of tagged fish and telemetry studies indicate that while shortnose sturgeon are present in the river and estuary throughout the year, their movements vary by season in response to water temperature and flow. From mid-October to mid-April most tagged shortnose sturgeon concentrate in a relatively small section of river in the Bangor area. Following this overwintering period they move downstream into the estuary, until returning upstream in summer during low flows. Tagged fish were observed to move as far upstream as two kilometers (1.2 miles) below the Veazie Dam by August. At the end of summer, shortnose sturgeon moved downstream to the location of the overwintering site in the Bangor area (Fernandes 2008, Zydlewski 2009b).

UM researchers captured 17 shortnose sturgeon in the reach of the Penobscot River between Sedgeunkedunk Stream (river kilometer 36.4) and an asphalt plant in Bangor (river kilometer 38.5) from September 28 to October 19, 2006. Additionally, in 2006, 12 of 14 (86%) shortnose sturgeon tagged with hydroacoustic transmitters were detected during the winter months in an approximately 7,500 foot section of the Penobscot River from the confluence of Sedgeunkedunk Stream upstream to the City of Bangor's waste water treatment facility. In 2011, sturgeon moved further upstream immediately above the old Bangor dam site into an area referred to as the Bangor headpond located in Ecozone 1 (river kilometer 43). Tracking data indicate that sturgeon begin moving into this reach of the Penobscot River in October and depart in April. Some adults start moving back into the vicinity of this area in June. This information indicates that the area around the Bangor water treatment facility and Sedgeunkedunk Stream is likely used as an overwintering area for shortnose sturgeon. These movements are consistent with movements of shortnose sturgeon in other river systems, including the Delaware and Kennebec Rivers. In these river systems, the majority of shortnose sturgeon have moved to the overwintering area by the time water temperatures reach 10°C in the fall, although some move to the overwintering area much sooner and others do not appear to move to the primary overwintering area at all.

The preliminary telemetry data collected by UM suggests that sub-adult and adult shortnose sturgeon move extensively within the river system during spring and early summer and often can be found over mudflats outside the main river channel (Fernandes *et al.* 2008b).

Based on life history information from other rivers, adult shortnose sturgeon in the Penobscot River would likely spawn downstream of the Veazie Dam when water temperatures are between 8 and 18°C. Based on studies of spawning shortnose sturgeon in other rivers, spawning areas likely have depths of 1-5m with water velocity between 50-125 cm/s and cobble/rubble substrate (101-300 mm diameter). In 2009, spawning mats and ichthyoplankton nets were used to detect potential spawning below Veazie Dam (Zydlewski 2009a). While no actual spawning activity was detected, suitable spawning areas were described, using data on bathymetry, water temperature and velocity (Zydlewski 2009a). Although spawning areas have not yet been identified, researchers suspect that based on the literature, spawning likely occurs as far upriver as sturgeon can migrate. This allows larvae and juveniles the most freshwater habitat downriver before they enter estuarine conditions. Accordingly, spawning habitat suitability (based on data on substrate and water velocity during predicted spawning periods) was much higher downstream in the vicinity of the former Bangor Dam, and essentially non-existent immediately below Veazie Dam (Zydlewski 2009a).

Adults are known to rapidly leave the area after spawning and move to downstream foraging areas. Adults may also briefly visit more saline reaches of the estuary as is seen in the Connecticut and Merrimack Rivers. Typically, in the fall when water temperatures drop to 10°C, shortnose sturgeon move to upstream overwintering areas. In the Penobscot, water temperatures of approximately 13°C seem to trigger movement to upstream concentration areas. In some river systems (Hudson, Connecticut), individual overwintering areas are segregated between spawners and non-spawners. In the Penobscot River, the distance to be traveled to the presumed spawning grounds is relatively short and in close proximity to overwintering areas as is seen in other rivers with small amounts of available habitat (*e.g.*, the Merrimack River). Eggs and larvae are likely concentrated near the spawning area for up to four weeks post-spawning, after which larvae disperse into the tidal river. As juvenile sturgeon are believed to remain upstream of the salt wedge until they are about 45 cm long (Crance 1986), it is likely that juvenile sturgeon would occur in the Penobscot River from the Veazie Dam downstream to the Town of Hampden, a stretch of river approximately 16 km long.

Based upon data collected by UM, known life history characteristics of shortnose sturgeon, and habitat availability in the Penobscot River, juvenile and adult shortnose sturgeon have the potential to occur in the action area at various times of the year.

Outside of spawning, shortnose sturgeon typically occur over soft substrates consisting of mud, silt or sand, and commonly in deeper channels or over tidal mud flats (NMFS 1998). Such habitat is extensive in the Penobscot River from the estuary upstream to the area around Bangor and Brewer (Fernandes 2008, Zydlewski 2009a, Zydlewski 2009b). Much of this soft sediment consists of bark, sawdust or wood chips, which were deposited as a result of log-driving and operation of saw mills and pulp and paper operations on the river. These soft sediment areas were found to be used by shortnose sturgeon throughout the year in recent UM studies (Fernandes 2008).

Recent data collected by UM and MDMR indicate that migration between river systems in Maine is more extensive than was previously thought. As summarized by Dionne (2010a in MDMR 2010), between 2006 and 2009 a total of 68 shortnose sturgeon were implanted with coded acoustic transmitters. Of the 46 active acoustically tagged individuals, 13 remained within the Penobscot River system. These fish demonstrated an in-river migration pattern that involved downriver movement from the wintering area in the spring, followed by gradual upriver movement throughout the summer prior to returning to the wintering area in the fall (Fernandes *et al.* 2010). Eleven individuals were characterized as "spring emigrants." These fish followed a similar in-river movement pattern to resident fish but made a single migration out of the Penobscot River system in the spring (April 12 – May 11) while the resident fish remained in the estuary. These fish largely returned to the Penobscot River within two months (May 25 – July 7); with one fish remaining outside the Penobscot River for approximately one year. Fifteen tagged fish were determined to be "fall emigrants." These fish followed the typical in-river migration pattern while in the river, with the exception of using the Kennebec River overwintering site. These fish utilized the Penobscot River from mid-spring through early fall (entering between April 19 and June 19 and leaving between September 9 and November 4). The remaining seven tagged fish were classified as "summer emigrants." The movements of these fish were not as well defined; these fish were observed leaving the Penobscot between June 1 and July 1 with some individuals overwintering in the Penobscot and some in the Kennebec. Returns to the Penobscot were made between April 26 and June 8. At least one of these fish spent over three months in coastal river systems between the Penobscot and Kennebec Rivers.

Research has been conducted by the New York University School of Medicine involving mitochondrial DNA (mtDNA) analysis of shortnose sturgeon populations, including fish caught in the Penobscot River (Wirgin *et al.* in progress). Information available to date for the Penobscot samples indicates that haplotype frequencies in this population were almost identical to that in the Kennebec River system. Additionally, the Penobscot River samples did not exhibit any haplotypes that were not seen elsewhere. It is unknown at this time whether shortnose sturgeon in the Penobscot River are the descendants of recent migrants from the Kennebec River, migrants themselves or whether they represent a remnant naturally reproducing Penobscot River population. It is possible that the adults captured to date are representatives of all three scenarios. As the sample size is very small and as mtDNA represents only a fraction (less than 1%) of the genetic material and is maternally inherited, it is difficult to make conclusive statements regarding the potential for fish in the Penobscot River to be genetically distinct from other fish in the Kennebec complex. However, as there were no unique haplotypes in the Penobscot River fish and unique haplotypes are seen in almost every other population, the best available information suggests that fish occurring in the Penobscot River are not genetically unique and are not genetically distinct from other fish in the Kennebec River. Nuclear DNA analysis (King *et al.* 2001) finds that the Kennebec, Androscoggin, and Penobscot Rives form a metapopulation that are genetically indistinguishable from each other; reflecting a panmictic population.

3.3.4. Factors Affecting Shortnose Sturgeon in the Action Area

3.3.4.1.Dams and Hydroelectric Facilities

As noted above, the range of shortnose sturgeon in the Penobscot River has been restricted by the Veazie Dam. In rivers where shortnose sturgeon have free access (*i.e.*, there are no dams), the species typically has a 100-200 kilometer range. In the Penobscot River, this range is restricted to only 40 kilometers of mainstem river, with an additional 32 kilometers of estuary available below the mouth of the river. The Veazie Dam and Great Works dam prevent shortnose sturgeon from accessing historically available habitat above the dams, which is thought to have extended to at least Milford Falls (approximately rkm 70). These dams have also likely prevented the species from spawning at their preferred spawning habitat, which is likely located upstream of the Veazie Dam. The lack of accessibility to this habitat has likely had a significant negative effect on shortnose sturgeon in this river system and will continue to delay recovery of this species in the Penobscot River. Because no shortnose sturgeon are known to occur upstream of any hydroelectric projects in the Penobscot River, passage over hydroelectric dams or through hydroelectric turbines is not a source of injury or mortality in the action area. The extent that shortnose sturgeon are affected by operations of hydroelectric facilities in the Penobscot River is currently unknown. Additionally, to the extent that upstream hydroelectric projects affect conditions below Veazie Dam, shortnose sturgeon are affected by the operation of these projects as well. The Veazie Dam is slated for removal within the timeframe of this action.

3.3.4.2.Contaminants and Water Quality

Shortnose sturgeon are vulnerable to effects from contaminants and water quality over their entire life history. In addition, their long life span increases the potential for environmental contaminants to build up in the tissue which may affect the development of the individual or its gametes. Point source discharges (*i.e.*, municipal wastewater, paper mill effluent, industrial or power plant cooling water or waste water) and compounds associated with discharges (*i.e.*, metals, dioxins, dissolved solids, phenols, and hydrocarbons) contribute to poor water quality that may also impact the health of individual sturgeon. The compounds associated with discharges can alter the chemistry and temperature of receiving waters, which may lead to mortality, changes in fish behavior, deformations, and reduced egg production and survival. Contaminants including heavy metals, PAHs, pesticides, and PCBs, can have serious, deleterious effects on aquatic life and are associated with the production of acute lesions, growth retardation, and reproductive impairment (Ruelle and Keenlyne 1993). Contaminants introduced into the water column or through the food chain eventually become associated with the benthos where bottom dwelling species like shortnose sturgeon are particularly vulnerable. In 2000, the US Environmental Protection Agency (EPA) delegated authority for the NPDES permit program to the State of Maine. Currently, we review and comment on all NPDES issued for discharges to the Penobscot River occurring below the Veazie Dam. In general, water quality has improved in the Penobscot River and Gulf of Maine over the past decades (Lichter *et al.* 2006, USEPA 2008). However, water quality issues that derive from wastewater treatment plants and power plants are still a concern for all life stages of shortnose sturgeon as effects may be long-lasting.

3.3.4.3.Summary of factors affecting Recovery of Shortnose Sturgeon

The Shortnose Sturgeon Recovery Plan (NMFS 1998) identifies habitat degradation or loss (resulting, for example, from dams, bridge construction, channel dredging, and pollutant discharges) and mortality (resulting, for example, from impingement on cooling water intake screens, dredging and incidental capture in other fisheries) as principal threats to the species' survival.

Several natural and anthropogenic factors continue to threaten the recovery of shortnose sturgeon rangewide. Shortnose sturgeon continue to be taken incidentally in fisheries along the east coast and are probably targeted by poachers throughout their range (Dadswell 1979, Dovel *et al.* 1992, Collins *et al.* 1996). Bridge construction and demolition projects may interfere with normal shortnose sturgeon migratory movements and disturb sturgeon concentration areas. Unless appropriate precautions are taken, internal damage and/or death may result from blasting projects with powerful explosives. Hydroelectric dams may affect shortnose sturgeon by restricting habitat, altering river flows or temperatures necessary for successful spawning and/or migration and causing mortalities to fish that become entrained in turbines. Maintenance dredging of Federal navigation channels and other areas can adversely affect or jeopardize shortnose sturgeon populations. Hydraulic dredges can lethally take sturgeon by entraining sturgeon in dredge dragarms and impeller pumps. Mechanical dredges have also been documented to lethally take shortnose sturgeon. In addition to direct effects, dredging operations may also impact shortnose sturgeon by destroying benthic feeding areas, disrupting spawning migrations, and filling spawning habitat with re-suspended fine sediments. Shortnose sturgeon are susceptible to impingement on cooling water intake screens at power plants. Electric power and nuclear power generating plants can affect sturgeon by impinging larger fish on cooling water intake screens and entraining larval fish. The operation of power plants can have unforeseen and extremely detrimental impacts to water quality which can affect shortnose sturgeon. For example, the St. Stephen Power Plant near Lake Moultrie, South Carolina was shut down for several days in June 1991 when large mats of aquatic plants entered the plant's intake canal and clogged the cooling water intake gates. Decomposing plant material in the tailrace canal coupled with the turbine shut down (allowing no flow of water) triggered a low dissolved oxygen water condition downstream and a subsequent fish kill. The South Carolina Wildlife and Marine Resources Department reported that twenty shortnose sturgeon were killed during this low dissolved oxygen event.

Contaminants, including toxic metals, polychlorinated aromatic hydrocarbons (PAHs), pesticides, and polychlorinated biphenyls (PCBs) can have substantial deleterious effects on aquatic life including production of acute lesions, growth retardation, and reproductive impairment (Cooper 1989, Sinderman 1994). Ultimately, toxins introduced to the water column become associated with the benthos and can be particularly harmful to benthic organisms (Varanasi 1992) like sturgeon. Heavy metals and organochlorine compounds are known to accumulate in fat tissues of sturgeon, but their long term effects are not yet known (Ruelle and

Henry 1992, Ruelle and Kennlyne 1993). Available data suggests that early life stages of fish are more susceptible to environmental and pollutant stress than older life stages (Rosenthal and Alderdice 1976).

Although there is little information available comparing the levels of contaminants in shortnose sturgeon tissues rangewide, some research on other related species indicates that concern about the effects of contaminants on the health of sturgeon populations is warranted. Detectible levels of chlordane, DDE (1,1-dichloro-2, 2-bis(p-chlorophenyl)ethylene), DDT (dichlorodiphenyl-trichloroethane), and dieldrin, and elevated levels of PCBs, cadmium, mercury, and selenium were found in pallid sturgeon tissue from the Missouri River (Ruelle and Henry 1994). These compounds were found in high enough levels to suggest they may be causing reproductive failure and/or increased physiological stress (Ruelle and Henry 1994). In addition to compiling data on contaminant levels, Ruelle and Henry also determined that heavy metals and organochlorine compounds (i.e., PCBs) accumulate in fat tissues. Although the long term effects of the accumulation of contaminants in fat tissues is not yet known, some speculate that lipophilic toxins could be transferred to eggs and potentially inhibit egg viability. In other fish species, reproductive impairment, reduced egg viability, and reduced survival of larval fish are associated with elevated levels of environmental contaminants including chlorinated hydrocarbons. A strong correlation that has been made between fish weight, fish fork length, and DDE concentration in pallid sturgeon livers indicates that DDE increases proportionally with fish size (NMFS 1998).

Contaminant analysis was conducted on two shortnose sturgeon from the Delaware River in the fall of 2002. Muscle, liver, and gonad tissue were analyzed for contaminants (ERC 2003). Sixteen metals, two semivolatile compounds, three organochlorine pesticides, one PCB Aroclor, as well as polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) were detected in one or more of the tissue samples. Levels of aluminum, cadmium, PCDDs, PCDFs, PCBs, DDE (an organochlorine pesticide) were detected in the "adverse affect" range. It is of particular concern that of the above chemicals, PCDDs, DDE, PCBs and cadmium, were detected as these have been identified as endocrine disrupting chemicals. Contaminant analysis conducted in 2003 on tissues from a shortnose sturgeon from the Kennebec River revealed the presence of fourteen metals, one semivolatile compound, one PCB Aroclor, PCDDs and PCDFs in one or more of the tissue samples. Of these chemicals, cadmium and zinc were detected at concentrations above an adverse effect concentration reported for fish in the literature (ERC 2003). While no directed studies of chemical contamination in shortnose sturgeon have been undertaken, it is evident that the heavy industrialization of the rivers where shortnose sturgeon are found is likely adversely affecting this species.

During summer months, especially in southern areas, shortnose sturgeon must cope with the physiological stress of water temperatures that may exceed 28°C. Flournoy *et al.* (1992) suspected that, during these periods, shortnose sturgeon congregate in river regions which support conditions that relieve physiological stress (i.e., in cool deep thermal refuges). In southern rivers where sturgeon movements have been tracked, sturgeon refrain from moving during warm water conditions and are often captured at release locations during these periods (Flournoy *et al.*, 1992, Rogers and Weber 1995, Weber 1996). The loss and/or manipulation of these discrete refuge habitats may limit or be limiting population survival, especially in southern river systems.

Pulp mill, silvicultural, agricultural, and sewer discharges, as well as a combination of non-point source discharges, which contain elevated temperatures or high biological demand, can reduce dissolved oxygen levels. Shortnose sturgeon are known to be adversely affected by dissolved oxygen levels below five milligrams per liter. Shortnose sturgeon may be less tolerant of low dissolved oxygen levels in high ambient water temperatures and show signs of stress in water temperatures higher than 28°C (Flournoy *et al.* 1992). At these temperatures, concomitant low levels of dissolved oxygen may be lethal.

3.4. Atlantic Sturgeon

The section below describes the Atlantic sturgeon listing, provides life history information that is relevant to all DPSs of Atlantic sturgeon and then provides information specific to the status of each DPS of Atlantic sturgeon likely to occur in the action area. Below, we also provide a description of which Atlantic sturgeon DPSs likely occur in the action area and provide information on the use of the action area by Atlantic sturgeon.

3.4.1. Species Description

The Atlantic sturgeon *(Acipenser oxyrinchus oxyrinchus)* is a subspecies of sturgeon distributed along the eastern coast of North America from Hamilton Inlet, Labrador, Canada to Cape Canaveral, Florida, USA (Scott and Scott 1988, ASSRT 2007, T. Savoy, CT DEP, pers. comm.). We have delineated U.S. populations of Atlantic sturgeon into five DPSs (77 FR 5880 and 77 FR 5914). These are: the Gulf of Maine (GOM), New York Bight (NYB), Chesapeake Bay, Carolina, and South Atlantic DPSs (Figure 7). The results of genetic studies suggest that natal origin influences the distribution of Atlantic sturgeon in the marine environment (Wirgin and King 2011). However, genetic data as well as tracking and tagging data demonstrate sturgeon from each DPS and Canada occur throughout the full range of the subspecies. Therefore, sturgeon originating from any of the five DPSs can be affected by threats in the marine, estuarine and riverine environment that occur far from natal spawning rivers.

On February 6, 2012, we published notice in the *Federal Register* listing the New York Bight (NYB), Chesapeake Bay, Carolina, and South Atlantic DPSs as "endangered," and the GOM DPS as "threatened" (77 FR 5880 and 77 FR 5914). The effective date of the listings was April 6, 2012. The DPSs do not include Atlantic sturgeon that are spawned in Canadian rivers. Therefore, Canadian spawned fish are not included in the listings.

As described below, individuals originating from two of the five listed DPSs are likely to occur in the action area. Information general to all Atlantic sturgeon as well as information specific to each of the relevant DPSs is provided below.

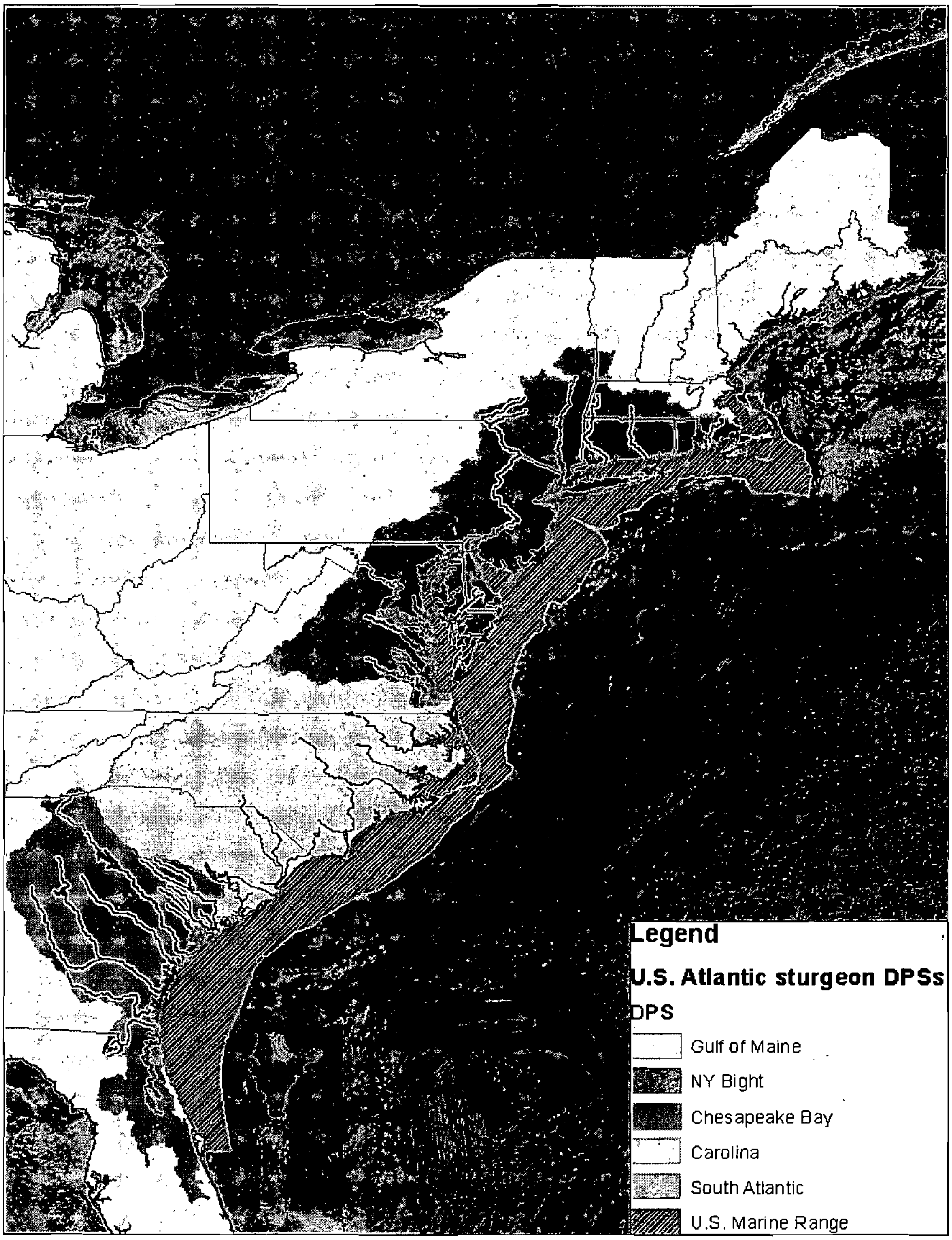

Figure 7. Map Depicting the Boundaries of the five Atlantic sturgeon DPSs

Atlantic sturgeon life history

Atlantic sturgeon are long lived (approximately 60 years), late maturing, estuarine dependent, anadromous fish (Bigelow and Schroeder 1953, Vladykov and Greeley 1963, Mangin 1964; Pikitch *et al.* 2005, Dadswell 2006, ASSRT 2007). The life history of Atlantic sturgeon can be divided up into five general categories (Table 8).

Table 8. Descriptions of Atlantic sturgeon life history stages (adapted from Mohler 2003, Atlantic Sturgeon Status Review Team 2007).

Age Class	**Size**	**Description**
Egg		Fertilized or unfertilized
Larvae		Negative photo-taxic, nourished by yolk sac
Young of Year (YOY)	**0.3 grams <41 cm TL**	Fish that are > 3 months and < one year; capable of capturing and consuming live food
Sub-adults	**>41 cm and <150 cm TL**	Fish that are at least age 1 and are not sexually mature
Adults	**>150 cm TL**	Sexually mature fish

Atlantic sturgeon are a relatively large fish, even amongst sturgeon species (Pikitch *et al.* 2005). Atlantic sturgeon are bottom feeders that suck food into a ventrally-located protruding mouth (Bigelow and Schroeder 1953). Four barbels in front of the mouth assist the sturgeon in locating prey (Bigelow and Schroeder 1953). Diets of adult and migrant subadult Atlantic sturgeon include mollusks, gastropods, amphipods, annelids, decapods, isopods, and fish such as sand lance (Bigelow and Schroeder 1953, ASSRT 2007, Guilbard *et al.*2007, Savoy 2007). Juvenile Atlantic sturgeon feed on aquatic insects, insect larvae, and other invertebrates (Bigelow and Schroeder 1953, ASSRT 2007, Guilbard *et al.* 2007).

Rate of maturation is affected by water temperature and gender. In general: (1) Atlantic sturgeon that originate from southern systems grow faster and mature sooner than Atlantic sturgeon that originate from more northern systems; (2) males grow faster than females; (3) fully mature females attain a larger size (i.e., length) than fully mature males; and (4) the length of Atlantic sturgeon caught since the mid-late 20th century have typically been less than three meters (Smith *et al.*1982, Smith *et al.* 1984, Smith 1985, Scott and Scott 1988, Young *et al.* 1998, Collins *et al.* 2000, Caron *et al.* 2002, Dadswell 2006, ASSRT 2007, Kahnle *et al* 2007, DFO 2011). The largest recorded Atlantic sturgeon was a female captured in 1924 that measured approximately

4.26 meters (Vladykov and Greeley 1963). Dadswell (2006) reported seeing seven fish of comparable size in the St. John River estuary from 1973 to 1995. Observations of large sized sturgeon are particularly important given that egg production is correlated with age and body size (Smith *et al.* 1982, Van Eenennaam *et al.* 1996, Van Eenennaam and Doroshov 1998, Dadswell 2006). However, while females are prolific with egg production ranging from 400,000 to 4,000,000 eggs per spawning year, females spawn at intervals of two to five years (Vladykov and Greeley 1963, Smith *et al.* 1982, Van Eenennaam *et al.* 1996, Van Eenennaam and Doroshov 1998, Stevenson and Secor 1999, Dadswell 2006). Given spawning periodicity and a female's relatively late age to maturity, the age at which 50 percent of the maximum lifetime egg production is achieved is estimated to be 29 years (Boreman 1997). Males exhibit spawning periodicity of one to five years (Smith 1985, Collins *et al.* 2000, Caron *et al.* 2002). While long-lived, Atlantic sturgeon are exposed to a multitude of threats prior to achieving maturation and have a limited number of spawning opportunities once mature.

Water temperature plays a primary role in triggering the timing of spawning migrations (ASMFC 2009). Spawning migrations generally occur during February-March in southern systems; April-May in Mid-Atlantic systems, and May-July in Canadian systems (Murawski and Pacheco 1977, Smith 1985, Bain 1997, Smith and Clugston 1997, Caron *et al.* 2002). Male sturgeon begin upstream spawning migrations when waters reach approximately 6° C (43° F) (Smith *et al.* 1982, Dovel and Berggren 1983, Smith 1985, ASMFC 2009), and remain on the spawning grounds throughout the spawning season (Bain 1997). Females begin spawning migrations when temperatures are closer to 12° C to 13° C (54° to 55° F) (Dovel and Berggren 1983, Smith 1985, Collins *et al.* 2000), make rapid spawning migrations upstream, and quickly depart following spawning (Bain1997).

The spawning areas in most U.S. rivers have not been well defined. However, the habitat characteristics of spawning areas have been identified based on historical accounts of where fisheries occurred, tracking and tagging studies of spawning sturgeon, and physiological needs of early life stages. Spawning is believed to occur in flowing water between the salt front of estuaries and the fall line of large rivers, when and where optimal flows are 46-76 cm/s and depths are 3-27 meters (Borodin 1925, Dees 1961, Leland 1968, Scott and Crossman 1973, Crance 1987, Shirey *et al.* 1999, Bain *et al.* 2000, Collins *et al.* 2000, Caron *et al.* 2002, Hatin *et al.* 2002, ASMFC 2009). Sturgeon eggs are deposited on hard bottom substrate such as cobble, coarse sand, and bedrock (Dees 1961, Scott and Crossman 1973, Gilbert 1989, Smith and Clugston 1997, Bain *et al.* 2000, Collins *et al.* 2000, Caron *et al.* 2002, Hatin *et al.* 2002, Mohler 2003, ASMFC 2009), and become adhesive shortly after fertilization (Murawski and Pacheco 1977, Van den Avyle 1983, Mohler 2003). Incubation time for the eggs increases as water temperature decreases (Mohler 2003). At temperatures of 20° and 18° C, hatching occurs approximately 94 and 140 hours, respectively, after egg deposition (ASSRT 2007).

Larval Atlantic sturgeon (i.e. less than four weeks old, with total lengths (TL) less than 30 mm; Van Eenennaam *et al.* 1996) are assumed to undertake a demersal existence and inhabit the same riverine or estuarine areas where they were spawned (Smith *et al.* 1980, Bain *et al.* 2000, Kynard and Horgan 2002, ASMFC 2009). Studies suggest that age zero (i.e., young-of-year), age one, and age two juvenile Atlantic sturgeon occur in low salinity waters of the natal estuary (Haley 1999, Hatin *et al.* 2007, McCord *et al.* 2007, Munro *et al.* 2007) while older fish are more salt tolerant and occur in higher salinity waters as well as low salinity waters (Collins *et al.* 2000). Atlantic sturgeon remain in the natal estuary for months to years before emigrating to open ocean as subadults (Holland and Yelverton 1973, Dovel and Berggen 1983, Waldman *et al.* 1996, Dadswell 2006, ASSRT 2007).

After emigration from the natal estuary, subadults and adults travel within the marine environment, typically in waters less than 50 meters in depth, using coastal bays, sounds, and ocean waters (Vladykov and Greeley 1963, Murawski and Pacheco 1977, Dovel and Berggren 1983, Smith 1985, Collins and Smith 1997, Welsh *et al.* 2002, Savoy and Pacileo 2003, Stein *et al.* 2004, USFWS 2004, Laney *et al.* 2007, Dunton *et al.* 2010, Erickson *et al.* 2011, Wirgin and King 2011). Tracking and tagging studies reveal seasonal movements of Atlantic sturgeon along the coast. Satellite-tagged adult sturgeon from the Hudson River concentrated in the southern part of the Mid-Atlantic Bight at depths greater than 20 meters during winter and spring, and in the northern portion of the Mid-Atlantic Bight at depths less than 20 meters in summer and fall (Erickson *et al.* 2011). Shirey (Delaware Department of Fish and Wildlife, unpublished data reviewed in ASMFC 2009) found a similar movement pattern for juvenile Atlantic sturgeon based on recaptures of fish originally tagged in the Delaware River. After leaving the Delaware River estuary during the fall, juvenile Atlantic sturgeon were recaptured by commercial fishermen in nearshore waters along the Atlantic coast as far south as Cape Hatteras, North Carolina from November through early March. In the spring, a portion of the tagged fish reentered the Delaware River estuary. However, many fish continued a northerly coastal migration through the Mid-Atlantic as well as into southern New England waters where they were recovered throughout the summer months. Movements as far north as Maine were documented. A southerly coastal migration was apparent from tag returns reported in the fall. The majority of these tag returns were reported from relatively shallow near shore fisheries with few fish reported from waters in excess of 25 meters (C. Shirey, Delaware Department of Fish and Wildlife, unpublished data reviewed in ASMFC 2009). Areas where migratory Atlantic sturgeon commonly aggregate include the Bay of Fundy (e.g., Minas and Cumberland Basins), Massachusetts Bay, Connecticut River estuary, Long Island Sound, New York Bight, Delaware Bay, Chesapeake Bay, and waters off of North Carolina from the Virginia-North Carolina border to Cape Hatteras at depths up to 24 meters (Dovel and Berggren1983, Dadswell *et al.*1984, Johnson *et al.* 1997, Rochard *et al.* 1997, Kynard *et al.* 2000, Eyler *et al.* 2004, Stein *et al.* 2004, Wehrell 2005, Dadswell 2006, ASSRT 2007, Laney *et al.* 2007). These sites may be used as foraging sites and/or thermal refuge.

3.4.2. Determination of DPS Composition in the Action Area

As explained above, the range of all five DPSs overlaps and extends from Canada through Cape Canaveral, Florida. We have considered the best available information to determine from which DPSs individuals in the action area are likely to have originated. We have determined that Atlantic sturgeon in the action area are likely to originate from two of the five ESA listed DPSs as well as from the St. John River in Canada. Fish originating from the St. John River are not listed under the ESA. Currently, if the fish does not have an identifying tag, the only way to tell the river (or DPS) of origin for a particular individual is by genetic sampling. The distribution of Atlantic sturgeon is influenced by geography, with Atlantic sturgeon from a particular DPS becoming less common the further you are from the river of origin. Areas that are geographically close are expected to have a similar composition of individuals. The nearest area to the action area for which mixed stock analysis is available is the Bay of Fundy, Canada. In this area, 63% of individuals are Canadian (St. John River) origin, 36% are GOM DPS origin and 1% are NYB origin. We do not currently have a mixed stock analysis for the action area. In the Penobscot River, we expect the composition to be similar to that in the Bay of Fundy; however, we expect that GOM DPS individuals will be more frequent than Canadian origin individuals. Therefore, in the action area, we expect Atlantic sturgeon to occur at the following frequencies: St. John River (Canada) 36%, Gulf of Maine DPS 63% and New York Bight DPS 1%. This assumption is supported by some preliminary genetic analyses of fish caught in rivers within the Gulf of Maine; these results demonstrate that the fish are predominantly of Gulf of Maine origin with some St. John River and Hudson River fish present. The genetic assignments have a plus/minus 5% confidence interval; however, for purposes of section 7 consultation, we have selected the reported values above, which approximate the mid-point of the range, as a reasonable indication of the likely genetic makeup of Atlantic sturgeon in the action area. These assignments and the data from which they are derived are described in detail in Damon-Randall *et al.* (2012).

3.4.3. Status and Trends of Atlantic Sturgeon Rangewide

Distribution and Abundance

Atlantic sturgeon underwent significant range-wide declines from historical abundance levels due to overfishing in the mid to late 19th century when a caviar market was established (Scott and Crossman 1973, Taub 1990, Kennebec River Resource Management Plan 1993, Smith and Clugston 1997, Dadswell 2006, ASSRT 2007). Abundance of spawning-aged females prior to this period of exploitation was predicted to be greater than 100,000 for the Delaware, and at least 10,000 females for other spawning stocks (Secor and Waldman 1999, Secor 2002). Historical records suggest that Atlantic sturgeon spawned in at least 38 rivers prior to this period. Currently, only 20 U.S. rivers are known to support spawning based on available evidence (i.e., presence of young-of-year or gravid Atlantic sturgeon documented within the past 15 years) (ASSRT 2007). While there may be other rivers supporting spawning for which definitive evidence has not been obtained (e.g., in the Penobscot and York Rivers), the number of rivers supporting spawning of Atlantic sturgeon are approximately half of what they were historically. In addition, only four rivers (Kennebec, Hudson, Delaware, James) are known to currently support spawning from Maine through Virginia where historical records support there used to be fifteen spawning rivers (ASSRT 2007). Thus, there are substantial gaps in the range between Atlantic sturgeon spawning rivers amongst northern and mid-Atlantic states which could make recolonization of extirpated populations more difficult.

There are no current, published population abundance estimates for any of the currently known spawning stocks. Therefore, there are no published abundance estimates for any of the five DPSs of Atlantic sturgeon. An estimate of 863 mature adults per year (596 males and 267 females) was calculated for the Hudson River based on fishery-dependent data collected from 1985-1995 (Kahnle *et al.* 2007). An estimate of 343 spawning adults per year is available for the Altamaha River, GA, based on fishery-independent data collected in 2004 and 2005 (Schueller and Peterson 2006). Using the data collected from the Hudson River and Altamaha River to estimate the total number of Atlantic sturgeon in either subpopulation is not possible, since mature Atlantic sturgeon may not spawn every year (Vladykov and Greeley 1963, Smith 1985, Van Eenennaam *et al.* 1996, Stevenson and Secor 1999, Collins *et al.* 2000, Caron *et al.* 2002), the age structure of these populations is not well understood, and stage to stage survival is unknown. In other words, the information that would allow us to take an estimate of annual spawning adults and expand that estimate to an estimate of the total number of individuals (e.g., yearlings, subadults, and adults) in a population is lacking.

3.4.4. Threats Faced by Atlantic sturgeon throughout their range

Atlantic sturgeon are susceptible to over exploitation given their life history characteristics (e.g., late maturity, dependence on a wide-variety of habitats). Similar to other sturgeon species (Vladykov and Greeley, 1963, Pikitch *et al.*, 2005), Atlantic sturgeon experienced range-wide declines from historical abundance levels due to overfishing (for caviar and meat) and impacts to habitat in the 19th and 20th centuries (Taub 1990, Smith and Clugston 1997, Secor and Waldman 1999).

Based on the best available information, we have concluded that unintended catch of Atlantic sturgeon in fisheries, vessel strikes, poor water quality, water availability, dams, lack of regulatory mechanisms for protecting the fish, and dredging are the most significant threats to Atlantic sturgeon (77 FR 5880 and 77 FR 5914; February 6, 2012). While all of the threats are not necessarily present in the same area at the same time, given that Atlantic sturgeon subadults and adults use ocean waters from the Labrador, Canada to Cape Canaveral, FL, as well as estuaries of large rivers along the U.S. East Coast, activities affecting these water bodies are likely to impact more than one Atlantic sturgeon DPS. In addition, given that Atlantic sturgeon depend on a variety of habitats, every life stage is likely affected by one or more of the identified threats.

An ASMFC interstate fishery management plan for sturgeon (Sturgeon FMP) was developed and implemented in 1990 (Taub 1990). In 1998, the remaining Atlantic sturgeon fisheries in U.S. state waters were closed per Amendment 1 to the Sturgeon FMP. Complementary regulations were implemented by us in 1999 that prohibit fishing for, harvesting, possessing or retaining Atlantic sturgeon or its parts in or from the Exclusive Economic Zone in the course of a commercial fishing activity.

Commercial fisheries for Atlantic sturgeon still exist in Canadian waters (DFO 2011). Sturgeon belonging to one or more of the DPSs may be harvested in the Canadian fisheries. In particular, the Bay of Fundy fishery in the Saint John estuary may capture sturgeon of U.S. origin given that sturgeon from the Gulf of Maine and the New York Bight DPSs have been incidentally captured in other Bay of Fundy fisheries (DFO 2011, Wirgin and King 2011). Because Atlantic sturgeon are listed under Appendix II of the Convention on International Trade in Endangered Species (CITES), the U.S. and Canada are currently working on a conservation strategy to address the potential for captures of U.S. fish in Canadian directed Atlantic sturgeon fisheries and of Canadian fish incidentally in U.S. commercial fisheries. At this time, there are no estimates of the number of individuals from any of the DPSs that are captured or killed in Canadian fisheries each year.

Based on geographic distribution, most U.S. Atlantic sturgeon that are intercepted in Canadian fisheries are likely to originate from the Gulf of Maine DPS, with a smaller percentage from the New York Bight DPS.

Fisheries bycatch in U.S. waters is one of the primary threats faced by all 5 DPSs. At this time, we have an estimate of the number of Atlantic sturgeon captured and killed in sink gillnet and otter trawl fisheries authorized by Federal FMPs (NMFS NEFSC 2011) in the Northeast Region but do not have a similar estimate for Southeast fisheries. We also do not have an estimate of the number of Atlantic sturgeon captured or killed in state fisheries. At this time, we are not able to quantify the effects of other significant threats (e.g., vessel strikes, poor water quality, water availability, dams, and dredging) in terms of habitat impacts or loss of individuals. While we have some information on the number of mortalities that have occurred in the past in association with certain activities (e.g., mortalities in the Delaware and James rivers that are thought to be due to vessel strikes), we are not able to use those numbers to extrapolate effects throughout one or more DPS. This is because of (1) the small number of data points and, (2) lack of information on the percent of incidences that the observed mortalities represent.

As noted above, the NEFSC prepared an estimate of the number of encounters of Atlantic sturgeon in fisheries authorized by Northeast FMPs (NEFSC 2011). The analysis prepared by the NEFSC estimates that from 2006 through 2010 there were 2,250 to 3,862 encounters per year in observed gillnet and trawl fisheries, with an average of 3,118 encounters. Mortality rates in gillnet gear are approximately 20%. Mortality rates in otter trawl gear are believed to be lower at approximately 5%.

3.4.5. Gulf of Maine DPS of Atlantic sturgeon

The GOM DPS of Atlantic sturgeon includes the following: all anadromous Atlantic sturgeon that are spawned in the watersheds from the Maine/Canadian border and, extending southward, all watersheds draining into the Gulf of Maine as far south as Chatham, MA. Within this range, Atlantic sturgeon historically spawned in the Androscoggin, Kennebec, Merrimack, Penobscot, and Sheepscot Rivers (ASSRT 2007). Spawning still occurs in the Kennebec River, and it is also possible that it still occurs in the Androscoggin and Penobscot Rivers as well. The capture of a larval Atlantic sturgeon during the 2011 spawning season below the Brunswick Dam by MDMR suggests that spawning may be occurring in the Androscoggin River. There is no evidence of recent spawning in the remaining rivers.

In the 1800s, construction of the Essex Dam on the Merrimack River at river kilometer (rkm) 49 blocked access to 58 percent of Atlantic sturgeon habitat in the river (Oakley 2003, ASSRT 2007). However, the accessible portions of the Merrimack seem to be suitable habitat for Atlantic sturgeon spawning and rearing (i.e., nursery habitat) (Keiffer and Kynard 1993). Therefore, the availability of spawning habitat does not appear to be the reason for the lack of observed spawning in the Merrimack River.

Studies are on-going to determine whether Atlantic sturgeon are spawning in these rivers. Atlantic sturgeon that are spawned elsewhere continue to use habitats within all of these rivers as part of their overall marine range (ASSRT 2007). The movement of subadult and adult sturgeon between rivers, including to and from the Kennebec River and the Penobscot River, demonstrates that coastal and marine migrations are key elements of Atlantic sturgeon life history for the GOM DPS as well as likely throughout the entire range (ASSRT 2007, Fernandes *et al.* 2010).

Bigelow and Schroeder (1953) surmised that Atlantic sturgeon likely spawned in Gulf of Maine Rivers in May-July. More recent captures of Atlantic sturgeon in spawning condition within the Kennebec River suggest that spawning more likely occurs in June-July (Squiers *et al.* 1981, ASMFC 1998, NMFS and USFWS 1998). Evidence for the timing and location of Atlantic sturgeon spawning in the Kennebec River includes: (1) the capture of five adult male Atlantic sturgeon in spawning condition (i.e., expressing milt) in July 1994 below the (former) Edwards Dam; (2) capture of 31 adult Atlantic sturgeon from June 15,1980, through July 26,1980, in a small commercial fishery directed at Atlantic sturgeon from the South Gardiner area (above Merrymeeting Bay) that included at least four ripe males and one ripe female captured on July 26,1980; and, (3) capture of nine adults during a gillnet survey conducted from 1977-1981, the majority of which were captured in July in the area from Merrymeeting Bay and upriver as far as Gardiner, ME (NMFS and USFWS 1998, ASMFC 2007). The low salinity values for waters above Merrymeeting Bay are consistent with values found in other rivers where successful Atlantic sturgeon spawning is known to occur.

Several threats play a role in shaping the current status of GOM DPS Atlantic sturgeon. Historical records provide evidence of commercial fisheries for Atlantic sturgeon in the Kennebec and Androscoggin Rivers dating back to the 17th century (Squiers *et al.* 1979). In 1849, 160 tons of sturgeon were caught in the Kennebec River by local fishermen (Squiers *et al.* 1979). Following the 1880's, the sturgeon fishery was almost non-existent due to a collapse of the sturgeon stocks. All directed Atlantic sturgeon fishing in all states has been prohibited since 1998, and retention of Atlantic sturgeon bycatch in and from the Exclusive Economic Zone (EEZ) has been prohibited since 1999. Nevertheless, mortalities associated with bycatch in fisheries occurring in state and federal waters still occurs. In the marine range, GOM DPS Atlantic sturgeon are incidentally captured in federal and state managed fisheries, reducing survivorship of subadult and adult Atlantic sturgeon (Stein *et al.* 2004, ASMFC 2007). As explained above, we have estimates of the number of subadults and adults that are killed as a result of bycatch in fisheries authorized under Northeast FMPs. At this time, we are not able to quantify the impacts from other threats or estimate the number of individuals killed as a result of other anthropogenic threats. Habitat disturbance and direct mortality from anthropogenic sources are the primary concerns.

Riverine habitat may be impacted by dredging and other in-water activities, disturbing spawning habitat and also altering the benthic forage base. Many rivers in the GOM DPS have navigation channels that are maintained by dredging. Dredging outside of Federal channels and in-water construction occurs throughout the GOM DPS. While some dredging projects operate with observers present to document fish mortalities, many do not. To date, we have not received any reports of Atlantic sturgeon killed during dredging projects in the Gulf of Maine region; however, as noted above, not all projects are monitored for interactions with fish. At this time, we do not have any information to quantify the number of Atlantic sturgeon killed or disturbed during dredging or in-water construction projects are also not able to quantify any effects to habitat.

Connectivity is disrupted by the presence of dams on several rivers in the Gulf of Maine region, including the Penobscot and Merrimack Rivers. While there are also dams on the Kennebec, Androscoggin and Saco Rivers, these dams are near the site of natural falls and likely represent the maximum upstream extent of sturgeon occurrence even if the dams were not present. Because no Atlantic sturgeon occur upstream of any hydroelectric projects in the Gulf of Maine region, passage over hydroelectric dams or through hydroelectric turbines is not a source of injury or mortality in this area. The extent that Atlantic sturgeon are affected by operations of dams in the Gulf of Maine region is currently unknown; however, as noted above, the documentation of an Atlantic sturgeon larva downstream of the Brunswick Dam in the Androscoggin River suggests that Atlantic sturgeon spawning may be occurring in the vicinity of at least that project and therefore, may be affected by project operations. The range of Atlantic sturgeon in the Penobscot River is limited by the presence of the Veazie and Great Works Dams. Together these dams prevent Atlantic sturgeon from accessing approximately 29 km of habitat, including the presumed historical spawning habitat located downstream of Milford Falls, the site of the Milford Dam. While removal of the Veazie and Great Works Dams is anticipated to occur in the near future, the presence of these dams is currently preventing access to significant habitats within the Penobscot River. While Atlantic sturgeon are known to occur in the Penobscot River, it is unknown if spawning is currently occurring or whether the presence of the Veazie and Great Works Dams affects the likelihood of spawning occurring in this river. The Essex Dam on the Merrimack River blocks access to approximately 58% of historically accessible habitat in this river. Atlantic sturgeon occur in the Merrimack River, but spawning has not been documented. Like the Penobscot, it is unknown how the Essex Dam affects the likelihood of spawning occurring in this river.

GOM DPS Atlantic sturgeon may also be affected by degraded water quality. In general, water quality has improved in the Gulf of Maine over the past decades (Lichter *et al.* 2006, USEPA 2008). Many rivers in Maine, including the Androscoggin River, were heavily polluted in the past from industrial discharges from pulp and paper mills. While water quality has improved and most discharges are limited through regulations, many pollutants persist in the benthic environment. This can be particularly problematic if pollutants are present on spawning and nursery grounds as developing eggs and larvae are particularly susceptible to exposure to contaminants.

There are no empirical abundance estimates for the GOM DPS. The Atlantic sturgeon SRT (2007) presumed that the GOM DPS was comprised of less than 300 spawning adults per year, based on abundance estimates for the Hudson and Altamaha River riverine populations of Atlantic sturgeon. Surveys of the Kennebec River over two time periods, 1977-1981 and 1998-2000, resulted in the capture of nine adult Atlantic sturgeon (Squiers 2004). However, since the surveys were primarily directed at capture of shortnose sturgeon, the capture gear used may not have been selective for the larger-sized, adult Atlantic sturgeon; several hundred subadult Atlantic sturgeon were caught in the Kennebec River during these studies.

Summary of the Gulf of Maine DPS

Spawning for the GOM DPS is known to occur in only one river (Kennebec). Although it may be occurring in other rivers, such as the Sheepscot or Penobscot, it has not been confirmed. There are indications of increasing abundance of Atlantic sturgeon belonging to the GOM DPS. Atlantic sturgeon continue to be present in the Kennebec River; in addition, they are captured in directed research projects in the Penobscot River, and are observed in rivers where they were unknown to occur or had not been observed to occur for many years (e.g., the Saco, Presumpscot, and Charles rivers). These observations suggest that abundance of the GOM DPS of Atlantic sturgeon is sufficient such that recolonization to rivers historically suitable for spawning may be occurring. However, despite some positive signs, there is not enough information to establish a trend for this DPS.

Some of the impacts from the threats that contributed to the decline of the GOM DPS have been removed (e.g., directed fishing), or reduced as a result of improvements in water quality and removal of dams (e.g., the Edwards Dam on the Kennebec River in 1999). There are strict regulations on the use of fishing gear in Maine state waters that incidentally catch sturgeon. In addition, there have been reductions in fishing effort in state and federal waters, which most likely would result in a reduction in bycatch mortality of Atlantic sturgeon. A significant amount of fishing in the Gulf of Maine is conducted using trawl gear, which is known to have a much lower mortality rate for Atlantic sturgeon caught in the gear compared to sink gillnet gear (ASMFC 2007). Atlantic sturgeon from the GOM DPS are not commonly taken as bycatch in areas south of Chatham, MA, with only eight percent (e.g., 7 of the 84 fish) of interactions observed in the Mid Atlantic/Carolina region being assigned to the GOM DPS (Wirgin and King 2011). Tagging results also indicate that GOM DPS fish tend to remain within the waters of the Gulf of Maine and only occasionally venture to points south. However, data on Atlantic sturgeon incidentally caught in trawls and intertidal fish weirs fished in the Minas Basin area of the Bay of Fundy (Canada) indicate that approximately 35 percent originated from the GOM DPS (Wirgin *et al.*, in draft).

As noted previously, studies have shown that in order to rebuild, Atlantic sturgeon can only sustain low levels of bycatch and other anthropogenic mortality (Boreman 1997, ASMFC 2007, Kahnle *et al.* 2007, Brown and Murphy 2010). We have determined that the GOM DPS is at risk of becoming endangered in the foreseeable future throughout all of its range (i.e., is a threatened species) based on the following: (1) significant declines in population sizes and the protracted period during which sturgeon populations have been depressed; (2) the limited amount of current spawning; and, (3) the impacts and threats that have and will continue to affect recovery.

3.4.6. New York Bight DPS of Atlantic sturgeon

The NYB DPS includes the following: all anadromous Atlantic sturgeon spawned in the watersheds that drain into coastal waters from Chatham, MA to the Delaware-Maryland border on Fenwick Island. Within this range, Atlantic sturgeon historically spawned in the Connecticut, Delaware, Hudson, and Taunton Rivers (Murawski and Pacheco 1977, Secor 2002, ASSRT 2007). Spawning still occurs in the Delaware and Hudson Rivers, but there is no recent evidence (within the last 15 years) of spawning in the Connecticut and Taunton Rivers (ASSRT 2007). Atlantic sturgeon that are spawned elsewhere continue to use habitats within the Connecticut and

Taunton Rivers as part of their overall marine range (ASSRT 2007, Savoy 2007, Wirgin and King 2011).

The Hudson River and Estuary extend 504 kilometers from the Atlantic Ocean to Lake Tear of-the-Clouds in the Adirondack Mountains (Dovel and Berggren 1983). The estuary is 246 km long, beginning at the southern tip of Manhattan Island (rkm 0) and running north to the Troy Dam (rkm 246) near Albany (Sweka *et al.* 2007). All Atlantic sturgeon habitats are believed to occur below the dam. Therefore, presence of the dam on the river does not restrict access of Atlantic sturgeon to necessary habitats (e.g., for spawning, rearing, foraging, over wintering) (NMFS and USFWS 1998, ASSRT 2007).

Use of the river by Atlantic sturgeon has been described by several authors. Briefly, spawning likely occurs in multiple sites within the river from approximately rkm 56 to rkm 182 (Dovel and Berggren 1983, Van Eenennaam *et al.* 1996, Kahnle *et al.* 1998, Bain *et al.* 2000). Selection of sites in a given year may be influenced by the position of the salt wedge (Dovel and Berggren 1983, Van Eenennaam *et al.* 1996, Kahnle *et al.* 1998). The area around Hyde Park (approximately rkm134) has consistently been identified as a spawning area through scientific studies and historical records of the Hudson River sturgeon fishery (Dovel and Berggren 1983, Van Eenennaam *et al.* 1996, Kahnle *et al.* 1998, Bain *et al.* 2000). Habitat conditions at the Hyde Park site are described as freshwater year round with bedrock, silt and clay substrates and waters depths of 12-24 m (Bain *et al.* 2000). Bain *et al.* (2000) also identified a spawning site at rkm 112 based on tracking data. The rkm 112 site, located to one side of the river, has clay, silt and sand substrates, and is approximately 21-27 m deep (Bain *et al.* 2000).

Young-of-year (YOY) have been recorded in the Hudson River between rkm 60 and rkm 148, which includes some brackish waters; however, larvae must remain upstream of the salt wedge because of their low salinity tolerance (Dovel and Berggren 1983, Kahnle *et al.* 1998, Bain *et al.* 2000). Catches of immature sturgeon (age 1 and older) suggest that juveniles utilize the estuary from the Tappan Zee Bridge through Kingston (rkm 43- rkm 148) (Dovel and Berggren 1983, Bain *et al.* 2000). Seasonal movements are apparent with juveniles occupying waters from rkm 60 to rkm 107 during summer months and then moving downstream as water temperatures decline in the fall, primarily occupying waters from rkm 19 to rkm 74 (Dovel and Berggren 1983, Bain *et al.* 2000). Based on river-bottom sediment maps (Coch 1986) most juvenile sturgeon habitats in the Hudson River have clay, sand, and silt substrates (Bain *et al.* 2000). Newburgh and Haverstraw Bays in the Hudson River are areas of known juvenile sturgeon concentrations (Sweka *et al.* 2007). Sampling in spring and fall revealed that highest catches of juvenile Atlantic sturgeon occurred during spring in soft-deep areas of Haverstraw Bay even though this habitat type comprised only 25% of the available habitat in the Bay (Sweka *et al.* 2007). Overall, 90% of the total 562 individual juvenile Atlantic sturgeon captured during the course of this study (14 were captured more than once) came from Haverstraw Bay (Sweka *et al.* 2007). At around three years of age, Hudson River juveniles exceeding 70 cm total length begin to migrate to marine waters (Bain *et al.* 2000).

In general, Hudson River Atlantic sturgeon mature at approximately 11 to 21 years of age (Dovel and Berggren 1983, ASMFC 1998, Young *et al.* 1998). A sample of 94 pre-spawning adult Atlantic sturgeon from the Hudson River was comprised of males 12 to 19 years old, and females that were 14 to 36 years old (Van Eenennaam *et al.* 1996). The majority of males were 13 to 16 years old while the majority of females were 16 to 20 years old (Van Eenennaam *et al.* 1996). These data are consistent with the findings of Stevenson and Secor (1999) who noted that, amongst a sample of Atlantic sturgeon collected from the Hudson River fishery from 1992-1995, growth patterns indicated males grew faster and, thus, matured earlier than females. The spawning season for Hudson River Atlantic sturgeon extends from late spring to early summer (Dovel and Berggren 1983, Van Eenennaam *et al.* 1996).

The abundance of the Hudson River Atlantic sturgeon riverine population prior to the onset of expanded exploitation in the 1800's is unknown but, has been conservatively estimated at 10,000 adult females (Secor 2002). Current abundance is likely at least one order of magnitude smaller than historical levels (Secor 2002, ASSRT 2007, Kahnle *et al.* 2007). As described above, an estimate of the mean annual number of mature adults (863 total; 596 males and 267 females) was calculated for the Hudson River riverine population based on fishery-dependent data collected from 1985-1995 (Kahnle *et al.* 2007). Kahnle *et al.* (1998, 2007) also showed that the level of fishing mortality from the Hudson River Atlantic sturgeon fishery during the period of 1985-1995 exceeded the estimated sustainable level of fishing mortality for the riverine population and may have led to reduced recruitment. All available data on abundance of juvenile Atlantic sturgeon in the Hudson River Estuary indicate a substantial drop in production of young since the mid 1970's (Kahnle *et al.* 1998). A decline appeared to occur in the mid to late 1970's followed by a secondary drop in the late 1980's (Kahnle *et al.* 1998, Sweka *et al.* 2007, ASMFC 2010). Catch-per-unit-effort data suggest that recruitment has remained depressed relative to catches of juvenile Atlantic sturgeon in the estuary during the mid-late 1980's (Sweka *et al.* 2007, ASMFC 2010). In examining the CPUE data from 1985-2007, there are significant fluctuations during this time. There appears to be a decline in the number of juveniles between the late 1980s and early 1990s and while the CPUE is generally higher in the 2000s as compared to the 1990s, given the significant annual fluctuation it is difficult to discern any trend. Despite the CPUEs from 2000-2007 being generally higher than those from 1990-1999, they are low compared to the late 1980s. There is currently not enough information regarding any life stage to establish a trend for the Hudson River population.

In the Delaware River and Estuary, Atlantic sturgeon occur from the mouth of the Delaware Bay to the fall line near Trenton, NJ, a distance of 220 km (NMFS and USFWS 1998, Simpson 2008). As is the case in the Hudson River, all historical Atlantic sturgeon habitats appear to be accessible in the Delaware (NMFS and USFWS 1998, ASSRT 2007). Recent multi-year studies have provided new information on the use of habitats by Atlantic sturgeon within the Delaware River and Estuary (Simpson 2008, Brundage and O'Herron 2009, Calvo *et al.* 2010, Fox and Breece 2010).

Historical records from the 1830's indicate Atlantic sturgeon may have spawned as far north as Bordentown, just below Trenton, NJ (Pennsylvania Commission of Fisheries 1897). Cobb (1899) and Borodin (1925) reported spawning occurring between rkm 77 and 130 (Delaware City, DE to Chester City, PA). Based on recent tagging and tracking studies carried out from 2009-2011, Breece (2011) reports likely spawning locations at rkm 120-150 and rkm 170-190. Mature adults have been tracked in these areas at the time of year when spawning is expected to occur and movements have been consistent with what would be expected from spawning adults.

Based on tagging and tracking studies, Simpson (2008) suggested that spawning habitat also exists from Tinicum Island (rkm 136) to the fall line in Trenton, NJ (rkm 211). To date, eggs and larvae have not been documented to confirm that actual spawning is occurring in these areas. However, as noted below, the presence of young of the year in the Delaware River provides confirmation that spawning is still occurring in this river.

Sampling in 2009 that targeted YOY resulted in the capture of more than 60 YOY in the Marcus Hook anchorage (rkm 127) area during late October-late November 2009 (Fisher 2009, Calvo *et al.* 2010). Twenty of the YOY from one study and six from the second study received acoustic tags that provided information on habitat use by this early life stage (Calvo *et al.* 2010, Fisher 2011). YOY used several areas from Deepwater (rkm 105) to Roebling (rkm 199) during late fall to early spring. Some remained in the Marcus Hook area while others moved upstream, exhibiting migrations in and out of the area during winter months (Calvo *et al.* 2010, Fisher 2011). At least one YOY spent some time downstream of Marcus Hook (Calvo *et al.* 2010, Fisher 2011). Downstream detections from May to August between Philadelphia (rkm 150) and New Castle (rkm 100) suggest non-use of the upriver locations during the summer months (Fisher 2011). By September 2010, only three of 20 individuals tagged by DE DNREC persisted with active tags (Fisher 2011). One of these migrated upstream to the Newbold Island and Roebling area (rkm 195), but was back down in the lower tidal area within three weeks and was last detected at Tinicum Island (rkm 141) when the transmitter expired in October (Fisher 2011). The other two remained in the Cherry Island Flats (rkm 113) and Marcus Hook Anchorage area (rkm130) until their tags transmissions also ended in October (Fisher 2011).

The Delaware Estuary is known to be a congregation area for sturgeon from multiple DPSs. Generally, non-natal late stage juveniles (sometimes also referred to as subadults) immigrate into the estuary in spring, establish home range in the summer months in the river, and emigrate from the estuary in the fall (Fisher 2011). Subadults tagged and tracked by Simpson (2008) entered the lower Delaware Estuary as early as mid-March but, more typically, from mid-April through May. Tracked sturgeon remained in the Delaware Estuary through the late fall departing in November (Simpson 2008). Previous studies have found a similar movement pattern of upstream movement in the spring-summer and downstream movement to overwintering areas in the lower estuary or nearshore ocean in the fall-winter (Brundage and Meadows 1982, Shirey *et al.* 1997, 1999, Brundage and O'Herron 2009, Brundage and O'Herron in Calvo *et al.* 2010).

Brundage and O'Herron (in Calvo *et al.* 2010) tagged 26 juvenile Atlantic sturgeon, including six young of the year. For non YOY fish, most detections occurred in the lower tidal Delaware River from the middle Liston Range (rkm 70) to Tinicum Island (rkm 141). For non YOY fish, these researchers also detected a relationship between the size of individuals and the movement pattern of the fish in the fall. The fork length of fish that made defined movements to the lower bay and ocean averaged 815 mm (range 651-970 mm) while those that moved towards the bay but were not detected below Liston Range averaged 716 mm (range 505-947 mm), and those that appear to have remained in the tidal river into the winter averaged 524 mm (range 485-566 mm) (Calvo *et al.* 2010). During the summer months, concentrations of Atlantic sturgeon have been located in the Marcus Hook (rkm 123-129) and Cherry Island Flats (rkm 112-118) regions of the river (Simpson 2008, Calvo *et al.* 2010) as well as near Artificial Island (Simpson 2008). Sturgeon have also been detected using the Chesapeake and Delaware Canal (Brundage 2007, Simpson 2008).

Adult Atlantic sturgeon captured in marine waters off of Delaware Bay in the spring were tracked in an attempt to locate spawning areas in the Delaware River, (Fox and Breece 2010). Over the period of two sampling seasons (2009-2010) four of the tagged sturgeon were detected in the Delaware River. The earliest detection was in mid-April while the latest departure occurred in mid-June (Fox and Breece 2010). The sturgeon spent relatively little time in the river each year, generally about four weeks, and used the area from New Castle, DE (rkm 100) to Marcus Hook (rkm 130) (Fox and Breece 2010). A fifth sturgeon tagged in a separate study was also tracked and followed a similar timing pattern but traveled farther upstream (to rkm 165) before exiting the river in early June (Fox and Breece 2010).

There is no abundance estimate for the Delaware River population of Atlantic sturgeon. Harvest records from the 1800's indicate that this was historically a large population with an estimated 180,000 adult females prior to 1890 (Secor and Waldman 1999, Secor 2002). Sampling in 2009 to target young-of- the year (YOY) Atlantic sturgeon in the Delaware River (i.e., natal sturgeon) resulted in the capture of 34 YOY, ranging in size from 178 to 349 mm TL (Fisher 2009) and the collection of 32 YOY Atlantic sturgeon in a separate study (Brundage and O'Herron in Calvo *et al.* 2010). Genetics information collected from 33 of the 2009 year class YOY indicates that at least three females successfully contributed to the 2009 year class (Fisher 2011). Therefore, while the capture of YOY in 2009 provides evidence that successful spawning is still occurring in the Delaware River, the relatively low numbers suggest the existing riverine population is limited in size.

Several threats play a role in shaping the current status and trends observed in the Delaware River and Estuary. In-river threats include habitat disturbance from dredging, and impacts from historical pollution and impaired water quality. A dredged navigation channel extends from Trenton seaward through the tidal river (Brundage and O'Herron 2009), and the river receives significant shipping traffic. Vessel strikes have been identified as a threat in the Delaware River; however, at this time we do not have information to quantify this threat or its impact to the population or the NYB DPS. Similar to the Hudson River, there is currently not enough information to determine a trend for the Delaware River population.

Summary of the New York Bight DPS

Atlantic sturgeon originating from the NYB DPS spawn in the Hudson and Delaware rivers. While genetic testing can differentiate between individuals originating from the Hudson or Delaware river the available information suggests that the straying rate is high between these rivers. There are no indications of increasing abundance for the NYB DPS (ASSRT 2009 & 2010). Some of the impact from the threats that contributed to the decline of the NYB DPS have been removed (e.g., directed fishing) or reduced as a result of improvements in water quality since passage of the Clean Water Act (CWA). In addition, there have been reductions in fishing effort in state and federal waters, which may result in a reduction in bycatch mortality of Atlantic sturgeon. Nevertheless, areas with persistent, degraded water quality, habitat impacts from dredging, continued bycatch in state and federally-managed fisheries, and vessel strikes remain significant threats to the NYB DPS.

In the marine range, NYB DPS Atlantic sturgeon are incidentally captured in federal and state managed fisheries, reducing survivorship of subadult and adult Atlantic sturgeon (Stein *et al.* 2004, ASMFC 2007). Based on mixed stock analysis results presented by Wirgin and King (2011), over 40 percent of the Atlantic sturgeon bycatch interactions in the Mid Atlantic Bight region were sturgeon from the NYB DPS. Individual-based assignment and mixed stock analysis of samples collected from sturgeon captured in Canadian fisheries in the Bay of Fundy indicated that approximately 1-2% were from the NYB DPS. At this time, we are not able to quantify the impacts from other threats or estimate the number of individuals killed as a result of other anthropogenic threats.

Riverine habitat may be impacted by dredging and other in-water activities, disturbing spawning habitat and also altering the benthic forage base. Both the Hudson and Delaware rivers have navigation channels that are maintained by dredging. Dredging is also used to maintain channels in the nearshore marine environment. Dredging outside of Federal channels and in-water construction occurs throughout the New York Bight region. While some dredging projects operate with observers present to document fish mortalities, many do not. We have reports of one Atlantic sturgeon entrained during hopper dredging operations in Ambrose Channel, New Jersey. At this time, we do not have any information to quantify the number of Atlantic sturgeon killed or disturbed during dredging or in-water construction projects and, additionally, are unable to quantify any effects to habitat.

In the Hudson and Delaware Rivers, dams do not block access to historical habitat. The Holyoke Dam on the Connecticut River blocks further upstream passage; however, the extent that Atlantic sturgeon would historically have used habitat upstream of Holyoke is unknown. Connectivity may be disrupted by the presence of dams on several smaller rivers in the New York Bight region. Because no Atlantic sturgeon occur upstream of any hydroelectric projects in the New York Bight region, passage over hydroelectric dams or through hydroelectric turbines is not a source of injury or mortality in this area. The extent that Atlantic sturgeon are affected by operations of dams in the New York Bight region is currently unknown.

NYB DPS Atlantic sturgeon may also be affected by degraded water quality. In general, water quality has improved in the Hudson and Delaware over the past decades (Lichter *et al.* 2006, USEPA 2008). Both the Hudson and Delaware rivers, as well as other rivers in the New York Bight region, were heavily polluted in the past from industrial and sanitary sewer discharges. While water quality has improved and most discharges are limited through regulations, many pollutants persist in the benthic environment. This can be particularly problematic if pollutants are present on spawning and nursery grounds as developing eggs and larvae are particularly susceptible to exposure to contaminants.

Vessel strikes occur in the Delaware River. Twenty-nine mortalities believed to be the result of vessel strikes were documented in the Delaware River from 2004 to 2008, and at least 13 of these fish were large adults. Given the time of year in which the fish were observed (predominantly May through July, with two in August), it is likely that many of the adults were migrating through the river to the spawning grounds. Because we do not know the percent of total vessel strikes that the observed mortalities represent, we are not able to quantify the number of individuals likely killed as a result of vessel strikes in the NYB DPS.

Studies have shown that to rebuild, Atlantic sturgeon can only sustain low levels of anthropogenic mortality (Boreman 1997, ASMFC 2007, Kahnle *et al.* 2007, Brown and Murphy 2010). There are no empirical abundance estimates of the number of Atlantic sturgeon in the NYB DPS. We have determined that the NYB DPS is currently at risk of extinction due to: (1) precipitous declines in population sizes and the protracted period in which sturgeon populations have been depressed; (2) the limited amount of current spawning; and (3) the impacts and threats that have and will continue to affect population recovery.

3.4.7. Factors Affecting Atlantic Sturgeon in Action Area

3.4.7.1. Dams and Hydroelectric Facilities

Connectivity is disrupted by the presence of dams on several rivers in the Gulf of Maine region, including the Penobscot River. The range of Atlantic sturgeon in the Penobscot River is limited by the presence of the Veazie and Great Works Dams. Together these dams prevent Atlantic sturgeon from accessing approximately 29 km of habitat, including the presumed historical spawning habitat located downstream of Milford Falls, the site of the Milford Dam. While removal of the Veazie and Great Works Dams is anticipated to occur in the near future, the presence of these dams is currently preventing access to significant habitats within the Penobscot River. While Atlantic sturgeon are known to occur in the Penobscot River, it is unknown if spawning is currently occurring or whether the presence of the Veazie and Great Works Dams affects the likelihood of spawning occurring in this river. Because no Atlantic sturgeon occur upstream of any hydroelectric projects in the Penobscot River, passage over hydroelectric dams or through hydroelectric turbines is not a source of injury or mortality in the action area. The extent that Atlantic sturgeon are affected by operations of hydroelectric facilities in the Penobscot River is currently unknown.

3.4.7.2. Contaminants and Water Quality

Atlantic sturgeon are vulnerable to effects from contaminants and water quality over their entire life history. In addition, their long life span increases the potential for environmental contaminants to build up in the tissue which may affect the development of the individual or its gametes. Point source discharges (i.e., municipal wastewater, paper mill effluent, industrial or power plant cooling water or waste water) and compounds associated with discharges (i.e., metals, dioxins, dissolved solids, phenols, and hydrocarbons) contribute to poor water quality that may also impact the health of individual sturgeon. The compounds associated with discharges can alter the chemistry and temperature of receiving waters, which may lead to mortality, changes in fish behavior, deformations, and reduced egg production and survival. Contaminants including heavy metals, polychlorinated aromatic hydrocarbons (PAHs), pesticides, and polychlorinated biphenyls (PCBs), can have serious, deleterious effects on aquatic life and are associated with the production of acute lesions, growth retardation, and reproductive impairment (Ruelle and Keenlyne 1993). Contaminants introduced into the water column or through the food chain eventually become associated with the benthos where bottom dwelling species like Atlantic sturgeon are particularly vulnerable.

3.5 Summary of Information on Listed Species and Critical Habitat in the Action Area

3.5.1. Summary of Information on Atlantic Salmon in the Action Area

Adult returns for the GOM DPS remain well below conservation spawning escapement (CSE). For all GOM DPS rivers in Maine, current Atlantic salmon populations (including hatchery contributions) are well below CSE levels required to sustain themselves (Fay *et al.* 2006), which is further indication of their poor population status. The abundance of Atlantic salmon in the GOM DPS has been low and either stable or declining over the past several decades. The proportion of fish that are of natural origin is very small (approximately 6% over the last ten years) and is continuing to decline. The conservation hatchery program has assisted in slowing the decline and helping to stabilize populations at low levels, but has not contributed to an increase in the overall abundance of salmon and has not been able to halt the decline of the naturally reared component of the GOM DPS.

3.5.2. Summary of Information on Critical Habitat in the Action Area

A number of activities within the Penobscot Bay SHRU will likely continue to impact the biological and physical features of spawning, rearing, and migration habitat for Atlantic salmon. These include agriculture, forestry, changing land-use and development, hatcheries and stocking, roads and road-crossings and other instream activities (such as alternative energy development), mining, dams, dredging, and aquaculture. Dams, along with degraded substrate and cover, water quality, water temperature, and biological communities, have reduced the quality and quantity of habitat available to Atlantic salmon populations within the Penobscot Bay SHRU. The removal of the two lowermost dams on the Penobscot is anticipated to significantly improve upstream passage and downstream survival, and will likely lead to an increase in the abundance of returning Atlantic salmon.

3.5.3. Summary of Information on Shortnose Sturgeon in the Action Area

As noted above, several population estimates have been made for the Penobscot River, ranging from several 602-1654 adult shortnose sturgeon (Fernandes 2008, Fernandes *et al.* 2010, Zydlewski *et al.* 2010 in MDMR 2010). Telemetry studies indicate that while shortnose sturgeon are present in the river and estuary throughout the year, their movements vary by season in response to water temperature and flow. From mid-October to mid-April most tagged shortnose sturgeon concentrate in a relatively small section of river in the Bangor area. Following this overwintering period they move downstream into the estuary, until returning upstream in summer during low flows. Tagged fish were observed to move as far upstream as two km (1.2 mi.) below the Veazie Dam by August. At the end of summer, shortnose sturgeon moved downstream to the location of the overwintering site in the Bangor area (Fernandes 2008, Zydlewski 2009b). Without information on historical abundance, it is difficult to make determinations regarding the stability of the population or about the long term survival and recovery of this population. Due to uncertainties regarding population size and genetic diversity, it is difficult to predict how likely the population would rebound from catastrophic events (*e.g.*, oil or chemical spill, weather event etc.) that affect habitat quality, prey availability or result in direct mortality of a number of individuals. However, as there are likely several hundred adults in this population and the adults captured so far are likely several decades old, the available information indicates that this population is long lived and currently, relatively unexploited by fisheries. As such, we believe that this population is likely stable but low when compared to historic population levels in the Penobscot River.

Historically, shortnose sturgeon are believed to have inhabited nearly all major rivers and estuaries along nearly the entire East Coast of North America. Today, only 19 spawning populations are known to persist. Population sizes range from under 100 adults in the Cape Fear and Merrimack Rivers to tens of thousands in the St. John and Hudson Rivers. As indicated in Kynard 1996, adult abundance is less than the minimum estimated viable population abundance of 1000 adults for five of 11 surveyed northern populations and all natural southern populations. The only river systems likely supporting healthy populations are the St John, Hudson and possibly the Delaware and the Kennebec (Kynard 1996), making the continued success of shortnose sturgeon in these rivers critical to the species as a whole.

While no reliable estimate of the total size of the taxon exists, it is clearly below the size that could be supported if the threats to shortnose sturgeon were removed. Based on the number of adults in populations for which estimates are available, there are at least 104,662 adult shortnose sturgeon, including 18,000 in the Saint John River in Canada. Based on the best available information, we believe that the abundance of shortnose sturgeon throughout their range is increasing with population growth continuing in the Hudson, Delaware and Kennebec. Some southern river populations are continuing to decline and other populations are stable, but at low levels. Overall, while the status of shortnose sturgeon throughout their range has improved since the time of listing, abundance and distribution are believed to be well below historic levels. Any conclusions on the status of individual populations or the species as a whole is complicated by a lack of information on juveniles in nearly all river systems, limited genetic information, and limited data on historical abundance.

3.5.4. Summary of Information on Atlantic Sturgeon in the Action Area

Atlantic sturgeon adults and subadults are likely to be present in the action area in the spring as they move from oceanic overwintering sites to upstream foraging and resting sites and then migrate back out of the area as they move to lower reaches of the estuary or oceanic areas in the late summer. During other times of the year, individuals are likely migrating within the marine environment or transitioning from and to overwintering and foraging areas within larger rivers along the coast (e.g., Kennebec and Androscoggin). Tracking data from tagged Atlantic sturgeon indicates that during the spring and summer, individuals are most likely to occur within rkm 21-24.5 (Fernandes *et al.* 2010). During this time, most Atlantic sturgeon are located between a 1.5 km stretch from rkm 23 to rkm 24.5. During the winter months, subadult Atlantic sturgeon are most likely to occur over a two km stretch around rkm 36.5 (Fernandes *et al.* 2010). However, in 2011 the overwintering site moved further upstream into the Bangor headpond area within Ecozone one at approximately rkm 43. As explained above, Atlantic sturgeon in the action area are likely to have originated from the GOM DPS and NYB DPS with the majority of individuals originating from the GOM DPS, and all of those individuals originating from the Kennebec River.

4. ENVIRONMENTAL BASELINE OF THE ACTION AREA

Environmental baselines for biological opinions include the past and present impacts of all state, federal or private actions and other human activities in the action area, the anticipated impacts of all proposed federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of state or private actions that are contemporaneous with the consultation in process (50 CFR 402.02). The environmental baseline for this Opinion includes the effects of several activities that may affect the survival and recovery of the listed species and may affect critical habitat in the action area.

4.1. Formal or Early Section 7 Consultations

In the Environmental Baseline section of an Opinion, we discuss the anticipated impacts of all proposed Federal actions in the action area that have already undergone formal or early section 7 consultation. Effects of Federal actions that have been completed are encompassed in the Status of the Species section of the Opinion.

On April 25, 2012, we issued an Opinion to the NMFS Northeast Fisheries Science Center, Maine Field Station on the impacts to listed species from the proposed Penobscot Estuarine Fish Community and Ecosystem Survey. The NEFSC is continuing to develop and refine a long term study plan to evaluate the feasibility of various capture methods with the goal of establishing a comprehensive ecosystem survey to document the distribution and relative abundance of aquatic species in estuarine and nearshore environments of the Penobscot River. The purpose of the proposed research survey is to develop consistent sampling methods and test efficacy of a variety of sampling techniques and gear types at numerous sites to measure estuary fish communities with a focus on diadromous fish species. We concluded that the proposed action was not likely to jeopardize the continued existence of listed Atlantic salmon, shortnose sturgeon or Atlantic sturgeon. The ITS accompanying the Opinion exempted the incidental take of up to 15 Atlantic sturgeon juveniles and/or subadults (4 St. John River (Canada), nine GOM DPS and two NYB DPS) and up to 32 shortnose sturgeon juveniles and/or adults. We hold an ESA section 10 (a)(l)(A) research permit (ESA permit 697823) from the USFWS. As all effects to Atlantic salmon resulting from the estuary study will be considered and authorized under this permit, take of Atlantic salmon was not exempted as part of the consultation.

Penobscot River Restoration Project

On December 23, 2009, we issued an Opinion to FERC on the surrender of licenses for the Veazie, Great Works and Howland Projects. The projects were decommissioned and purchased by the Penobscot River Restoration Trust. The Trust's intent is to restore migratory access and habitat for multiple species of diadromous fish in the Penobscot River. To accomplish these goals, the Trust proposes to decommission and remove the Veazie and Great Works Projects and decommission and build a nature-like fishway at the Howland Project. The Opinion considered take associated with the 6-year interim period prior to the dam removals, during which time listed fish would be affected by the presence of the dams. In the Opinion, we concluded that the proposed action was not likely to jeopardize the continued existence of listed Atlantic salmon or shortnose sturgeon. The ITS accompanying the Opinion exempted the incidental take of not more than 5.8% of Atlantic salmon smolts in the Penobscot River would be delayed[4], injured, or killed during interim operations of the Great Works Project for 2-years. At Veazie and Howland, we anticipated that not more than 6% and 1.5%, respectively, of the Penobscot River population of Atlantic salmon would be delayed, injured, or killed during the 6-year interim operation period. Regarding upstream passage during interim operations, we expect that each facility will be at least 75% effective at passing upstream migrating adults; therefore, no more than 25% of the entire run of adults would be delayed during the period of interim operations. The proposed action is also likely to result in the harm of all adult shortnose sturgeon attempting to spawn in the Penobscot River over the six year interim operation period, since they will not be able to access the upriver extent of their historic range near Milford. Similarly, the proposed action will result in the harm of all larvae and juveniles produced in the six year interim operation period as it will impair their ability to develop normally by decreasing the amount of low salinity habitat necessary for successful development of these life stages of shortnose sturgeon.

The dam removals associated with the PRRP will occur at the beginning of the term covered by the proposed action (likely between 2012 and 2014). The removal of the Great Works Dam is already underway. Therefore, the condition of the river after the removal of the dams will be considered as the Environmental Baseline for this consultation. The schedule for the implementation of the dam removals is 1) removal of the Great Works Project will be completed by November 2012, 2) the Veazie Project will be removed in 2013 or 2014, and 3) the bypass around the Howland Dam will be constructed in 2014, at the earliest.

Once the Veazie and Great Works Projects are removed, the Milford Project, located on the eastern side of Marsh Island in Milford, will be the lowermost dam on the mainstem Penobscot River (Figure 1).

The removal of the dams associated with the PRRP is anticipated to have significant effects on the survival of Atlantic salmon migrating in the mainstem of the Penobscot River. Two modeling efforts have been undertaken, one by USFWS and one by us, to predict the effect of this project on Atlantic salmon in the Penobscot River. The models only considered the effect of the components of the PRRP that have already undergone section 7 consultation (i.e. the removal of the Great Works and Veazie Dams, and a new upstream fish bypass at the Howland Project).

NMFS's Northeast Fisheries Science Center (NEFSC) has constructed a Dam Impact Analysis (DIA) model that will facilitate the determination of the effects of the proposed action on Atlantic salmon survival and recovery in the Penobscot Bay SHRU (NMFS 2012; Appendix C). Using estimates of smolt survival at dams provided by Alden Lab (2012) (Table 6), the DIA model estimates survival (both survival of downstream migrating smolts, as well as passage success of upstream migrants) at the West Enfield, Milford, Orono and Stillwater Projects under current operations, post-PRRP (the dam removals and fishway around Howland), and under the proposed action (new powerhouses, improved fish passage facilities and upstream and downstream passage performance standards); in addition to relating the results to survival and recovery of Atlantic salmon in the Penobscot Bay SHRU. The model's predictions for the

4 Delays to fish migrations due to ineffective fishways are considered "harm" to the species pursuant to 64 FR 60727 November 8, 1999.

environmental baseline (both before and after the dam removals) condition are considered here; whereas the analysis that addresses the result of the proposed action will be considered in Section 6 and Section 8.

According to the DIA model (NMFS 2012), the removal of the dams will increase both the proportion of outmigrating smolts surviving to Verona Island at the mouth of Penobscot Bay, and the proportion of returning 2SW females. The model predicts that the dam removals will lead to a 68% relative reduction in the proportion of outmigrating salmon smolts that are killed prior to reaching the estuary when compared to the existing conditions. The DIA model also predicts a 79% relative increase in the number of returning 2SW female Atlantic salmon when compared to existing conditions (Figure 8).

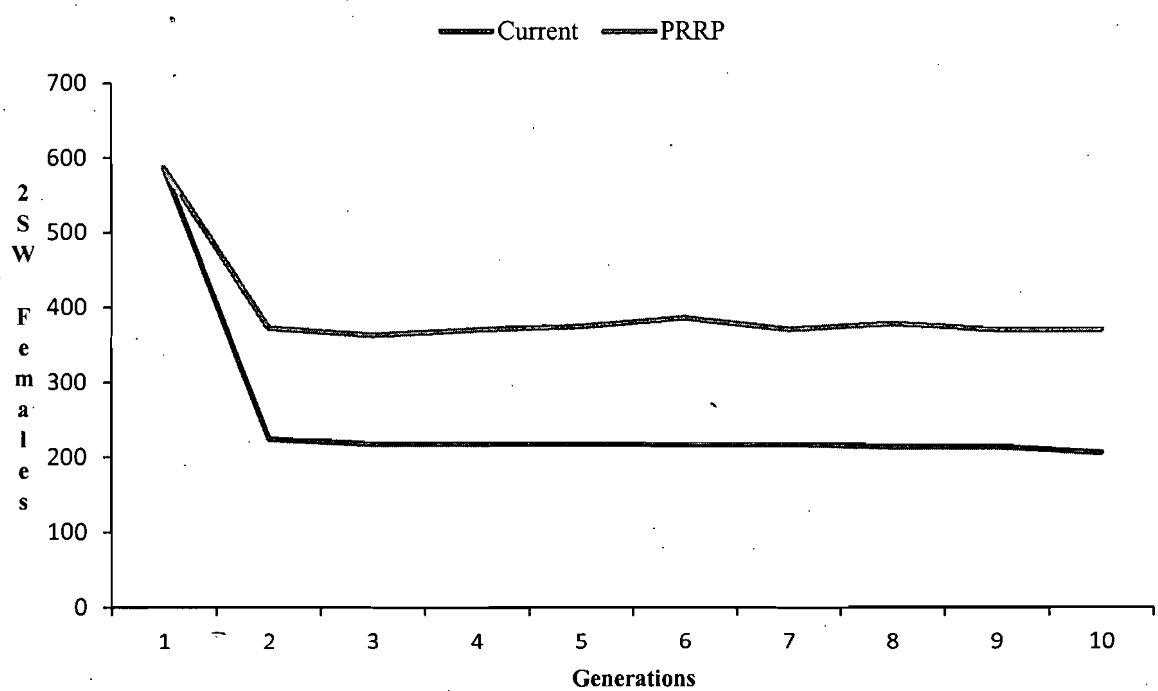

Figure 8. Comparison of the simulated number of returning 2SW female Atlantic salmon over ten generations according to the DIA model under existing conditions and conditions expected after the removal of the Veazie and Great Works Dams, as well as the construction of a bypass around the Howland Dam (PRRP).

USFWS (2012) conducted a separate life history model to assess the adequacy of the performance standards proposed by Black Bear and, in so doing, also looked at the effects of the dam removals on total smolt survival and adult returns (Appendix D). The USFWS (2012) model shows similar results to the DIA model, indicating that the dam removals would increase total smolt survival from 64% to 74%, as well as increase cumulative upstream passage success through the Penobscot River dams from 72% to 95%. The USFWS model calculated a population growth rate (λ or lambda) for the various scenarios, and determined that the dam removals associated with the PRRP will increase λ in the Penobscot River from 0.65 to 0.82, assuming low marine survival. A population that has a λ below 1 is a declining population that is below the replacement rate; however, the PRRP under poor marine survival conditions still shows a significant increase in the population's rate of growth. USFWS (2012) also calculated λ under high marine survival conditions and determined that the dam removals associated with the PRRP would cause it to increase from 0.85 to 1.07. Lambda values above 1.0 indicate that a population has a positive growth rate.

The DIA model (NMFS 2012) also predicted the effect that the dam removals will have on the distribution of Atlantic salmon in the Penobscot River. The metric used for distribution was the proportion of Atlantic salmon runs where at least one 2SW female successfully migrated past the West Enfield Project in the mainstem of the Penobscot, or the Howland Project in the Piscataquis River. These landmarks were chosen as 92% of high quality spawning and rearing habitat in the Penobscot River watershed occurs upriver of these locations (NMFS 2009). Access to this habitat is critical to the survival and recovery of the species in the Penobscot Bay SHRU. The model indicates that after ten generations under existing conditions only 64% of runs will have individuals accessing the habitat in the Upper Penobscot and the Piscataquis Rivers. After the dam removals have been completed, however, the DIA model predicts that the proportion of successful runs could increase to 90%, a 41% relative increase over existing conditions (Table 9).

Table 9. The proportion of runs anticipated where 2SW female Atlantic salmon are able to access high quality habitat in the upper Penobscot River (above West Enfield) and in the Piscataquis River (above Howland) over ten generations.

	Upper Penobscot		**Piscataquis**	
Generation	**Current**	**PRRP**	**Current**	**PRRP**
1	100%	100%	100%	100%
2	68%	91%	68%	91%
3	64%	90%	65%	90%
4	64%	90%	65%	91%
5	63%	90%	64%	90%
6	64%	90%	65%	90%
7	64%	91%	64%	91%
8	63%	90%	64%	91%
9	64%	91%	65%	91%
10	64%	90%	64%	90%

Given the results of the NMFS and USFWS models, it is anticipated that the PRRP could significantly decrease the mortality of downstream migrating smolts, as well as increase the proportion of pre-spawn Atlantic salmon that can successfully migrate to suitable spawning habitat in the upper Penobscot River and Piscataquis River. Both models also indicate a corresponding increase in the population growth rate over the next several generations due to the dam removal activities associated with the PRRP.

Atlantic and shortnose sturgeon

In addition to the anticipated effects on listed Atlantic salmon, it is expected that the dam removals associated with the PRRP will restore a significant amount of habitat to Atlantic and shortnose sturgeon in the Penobscot River. Currently, shortnose and Atlantic sturgeon are limited to the area below Veazie Dam. Existing fish passage facilities at the Veazie Dam are not used by sturgeon, and no sturgeon are known to occur upstream of the dam. Historically, the first natural obstacle to sturgeon migration on the Penobscot River may have been the falls at the existing location of the Milford Project (L. Flagg, MDMR, pers. comm. 1998). Therefore, the removal of the Veazie and Great Works Projects will allow both shortnose and Atlantic sturgeon to access habitat all the way up to the base of the Milford Dam, fourteen river kilometers upstream of Veazie on the mainstem, and the Orono Dam at the mouth of the Stillwater Branch. It is anticipated that the removal of the dams will provide natural passage to all historic spawning and rearing habitat for sturgeon downriver of these two projects.

4.2. Scientific Studies

Atlantic salmon

MDMR is authorized under the USFWS' endangered species blanket permit (No. 697823) to conduct monitoring, assessment, and habitat restoration activities for listed Atlantic salmon populations in Maine. The extent of take from MDMR activities during any given year is not expected to exceed 2% of any life stage being impacted; for adults, it would be less than 1%. MDMR will continue to conduct Atlantic salmon research and management activities in Cove Brook, Ducktrap River, Penobscot River, and the Kenduskeag Stream watershed while the proposed action is carried out. The information gained from these activities will be used to further salmon conservation actions in the GOM DPS.

We are also a sub-permittee under USFWS' ESA section 10 endangered species blanket permit. Research authorized under this permit is currently ongoing with respect to Atlantic salmon in the Penobscot River. The goal of current research is to document changes in fish populations resulting from both the removal of the Veazie and Great Works Projects as well as the construction of the fish bypass at the Howland Project. The study is utilizing boat electrofishing techniques to document baseline conditions in the river prior to construction at the dams. Following dam removal and construction of the fish bypass, researchers will re-sample the river. We are also monitoring biomass and species composition in the estuary to look at system-wide effects of PRRP projects. Although these activities will result in some take of Atlantic salmon, adverse impacts are expected to be minor and such take is authorized by an existing ESA permit. The information gained from these activities will be used to further salmon conservation actions in the GOM DPS.

USFWS is also authorized under an ESA section 10 endangered species blanket permit to conduct the conservation hatchery program at the Craig Brook and Green Lake National Fish Hatcheries. The mission of the hatcheries is to raise Atlantic salmon parr and smolts for stocking into selected Atlantic salmon rivers in Maine. Over 90% of adult returns to the GOM DPS are currently provided through production at the hatcheries. Approximately 600,000 smolts are stocked annually in the Penobscot River. The hatcheries provide a significant buffer from extinction for the species.

Shortnose sturgeon

Research activities for shortnose sturgeon conducted by UM scientists are authorized through a scientific research permit (No. 1595) issued by us in 2007. This permit allows the capture of up to 100 shortnose sturgeon annually in the Penobscot River from 2007-2012 using gill nets and trammel nets. This permit has been modified several times, most recently on January 13 2011. The current permit allows the capture of up to 200 shortnose sturgeon annually. The permit also allows tagging, tissue sampling, and boroscoping of a subset of individuals. Permit No. 1595 also authorizes UM to collect and preserve thirty shortnose sturgeon eggs to verify spawning in the Penobscot River. Mortalities of two adult or juvenile shortnose sturgeon are authorized annually. A Biological Opinion on the effects of research authorized under this permit was issued on March 27 2007. In this Opinion, we concluded that the research to be authorized under Permit No. 1595 was not likely to jeopardize the continued existence of any ESA-listed species under our jurisdiction. To date, approximately 893 individuals have been captured and only one mortality has been recorded. This research will continue through at least 2017.

Atlantic sturgeon

The MDMR, in collaboration with scientists at UM and others, proposes to conduct studies on the Atlantic sturgeon population in the GOM DPS. The research proposed to be conducted through a scientific research permit (NMFS No. 16526) would include determining movement patterns and rate of exchange between coastal river systems, characterizing the population structure (i.e., sex ratios and aging), and generating estimates of population abundance. The proposed action would involve several major river systems in Maine, including the Penobscot, Kennebec, Androscoggin and Sheepscot rivers. Smaller coastal rivers throughout Maine would also be targeted. The applicant would use gill nets to capture up to 975 juvenile and adult Atlantic sturgeon, and D-nets to sample 200 early life stage (ELS) annually. Atlantic sturgeon captured by gill nets, trammel nets, trawls, and beach seines would be measured, weighed, photographed, PIT tagged, Floy/T-bar tagged, tissue sampled, boroscoped, apical spine sampled, blood sampled, anesthetized, fin ray sectioned, and implanted with an acoustic telemetry tag. The applicant would use MS-222 as an anesthetic or on occasion, electronarcosis; see the application for further details. Not all Atlantic sturgeon would undergo all procedures. In total, up to 200 ELS, plus two annual incidental mortalities of juvenile Atlantic sturgeon and up to one adult Atlantic sturgeon over the life of the permit would be anticipated as the result of research. Research conducted prior to issuance of this permit has demonstrated a low mortality rate using similar gear types; approximately 120 Atlantic sturgeon were captured over a five year study with four incidental mortalities occurring to juvenile fish. This research would take place concurrently with authorized shortnose sturgeon research conducted in the Penobscot River under current Permit No. 1595.

4.3. Other Federally Authorized Activities in the Action Area

We have completed several informal consultations on effects of in-water construction activities in the Penobscot River permitted by the ACOE. This includes several dock, pier, and bank stabilization and dredging projects. No interactions with Atlantic salmon, shortnose or Atlantic sturgeon have been reported in association with any of these projects.

4.4. State or Private Activities in the Action Area

Information on the number of sturgeon captured or killed in state fisheries is extremely limited and as such, efforts are currently underway to obtain more information on the numbers of sturgeon captured and killed in state water fisheries. We are currently working with the Atlantic States Marine Fisheries Commission (ASMFC) and the coastal states to assess the impacts of state authorized fisheries on sturgeon. We anticipate that some states are likely to apply for ESA section 10(a)(1)(B) Incidental Take Permits to cover their fisheries; however, to date, no applications have been submitted.

In 2007, the MDMR authorized a limited catch-and-release fall fishery (September 15 to October 15) for Atlantic salmon in the Penobscot River upstream of the former Bangor Dam. The fishery was closed prior to the 2009 season. There is no indication that the fishery will be reinstated in the future.

4.5. Impacts of Other Human Activities in the Action Area

Other human activities that may affect listed species and critical habitat include direct and indirect modification of habitat due to hydroelectric facilities and the introduction of pollutants from paper mills, sewers, and other industrial sources. Pollution has been a major problem for this river system, which continues to receive discharges from sewer treatment facilities and paper production facilities (metals, dioxin, dissolved solids, phenols, and hydrocarbons). Hydroelectric facilities can alter the river's natural flow pattern and temperatures. In addition, the release of silt and other fine river sediments during dam maintenance can be deposited in sensitive spawning habitat nearby. These facilities also act as barriers to normal upstream and downstream movements, and block access to important habitats. Passage through these facilities may result in the mortality of downstream migrants.

5. CLIMATE CHANGE

The discussion below presents background information on global climate change and information on past and predicted future effects of global climate change throughout the range of the listed species considered here. Climate change is relevant to the Status of the Species, Environmental Baseline and Cumulative Effects sections of this Opinion; rather than include partial discussion in several sections of this Opinion, we are synthesizing this information into one discussion. Consideration of effects of the proposed action in light of predicted changes in environmental conditions due to anticipated climate change are included in the Effects of the Action section below (Section 6.0).

5.1. Background Information on Global climate change

The global mean temperature has risen 0.76°C (1.36°F) over the last 150 years, and the linear trend over the last 50 years is nearly twice that for the last 100 years (IPCC 2007) and precipitation has increased nationally by 5%-10%, mostly due to an increase in heavy downpours (NAST 2000). There is a high confidence, based on substantial new evidence, that observed changes in marine systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels, and circulation. Ocean acidification resulting from massive amounts of carbon dioxide and other pollutants released into the air can have major adverse impacts on the calcium balance in the oceans. Changes to the marine ecosystem due to climate change include shifts in ranges and changes in algal, plankton, and fish abundance (IPCC 2007); these trends are most apparent over the past few decades. Information on future impacts of climate change in the action area is discussed below.

Climate model projections exhibit a wide range of plausible scenarios for both temperature and precipitation over the next century. Both of the principal climate models used by the National Assessment Synthesis Team (NAST) project warming in the southeast by the 2090s, but at different rates (NAST 2000): the Canadian model scenario shows the southeast U.S. experiencing a high degree of warming, which translates into lower soil moisture as higher temperatures increase evaporation; the Hadley model scenario projects less warming and a significant increase in precipitation (about 20%). The scenarios examined, which assume no major interventions to reduce continued growth of world greenhouse gases (GHG), indicate that temperatures in the U.S. will rise by about 3°-5°C (5°-9°F) on average in the next 100 years which is more than the projected global increase (NAST 2000). A warming of about 0.2°C (0.4°F) per decade is projected for the next two decades over a range of emission scenarios (IPCC 2007). This temperature increase will very likely be associated with more extreme precipitation and faster evaporation of water, leading to greater frequency of both very wet and very dry conditions. Climate warming has resulted in increased precipitation, river discharge, and glacial and sea-ice melting (Greene *et al.* 2008).

The past three decades have witnessed major changes in ocean circulation patterns in the Arctic, and these were accompanied by climate associated changes as well (Greene *et al.* 2008). Shifts in atmospheric conditions have altered Arctic Ocean circulation patterns and the export of freshwater to the North Atlantic (Greene *et al.* 2008, IPCC 2006). With respect specifically to the North Atlantic Oscillation (NAO), changes in salinity and temperature are thought to be the result of changes in the earth's atmosphere caused by anthropogenic forces (IPCC 2006). The NAO impacts climate variability throughout the northern hemisphere (IPCC 2006). Data from the 1960s through the present show that the NAO index has increased from minimum values in the 1960s to strongly positive index values in the 1990s and somewhat declined since (IPCC 2006). This warming extends over 1000m (0.62 miles) deep and is deeper than anywhere in the world oceans and is particularly evident under the Gulf Stream/ North Atlantic Current system (IPCC 2006). On a global scale, large discharges of freshwater into the North Atlantic subarctic seas can lead to intense stratification of the upper water column and a disruption of North Atlantic Deepwater (NADW) formation (Greene *et al.* 2008, IPCC 2006). There is evidence that the NADW has already freshened significantly (IPCC 2006). This in turn can lead to a slowing down of the global ocean thermohaline (large-scale circulation in the ocean that transforms low-density upper ocean waters to higher density intermediate and deep waters and returns those waters back to the upper ocean), which can have climatic ramifications for the whole earth system (Greene *et al.* 2008).

While predictions are available regarding potential effects of climate change globally, it is more difficult to assess the potential effects of climate change over the next few decades on coastal and marine resources on smaller geographic scales, such as the Penobscot River, especially as climate variability is a dominant factor in shaping coastal and marine systems. The effects of future change will vary greatly in diverse coastal regions for the U.S. Warming is very likely to continue in the U.S. over the next 25 to 50 years regardless of reduction in GHGs, due to emissions that have already occurred (NAST 2000). It is very likely that the magnitude and frequency of ecosystem changes will continue to increase in the next 25 to 50 years, and it is possible that the rate of change will accelerate. Climate change can cause or exacerbate direct stress on ecosystems through high temperatures, a reduction in water availability, and altered frequency of extreme events and severe storms. Water temperatures in streams and rivers are likely to increase as the climate warms and are very likely to have both direct and indirect effects on aquatic ecosystems. Changes in temperature will be most evident during low flow periods when they are of greatest concern (NAST 2000). In some marine and freshwater systems, shifts in geographic ranges and changes in algal, plankton, and fish abundance are associated with high confidence with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation (IPCC 2007).

A warmer and drier climate is expected to result in reductions in stream flows and increases in water temperatures. Expected consequences could be a decrease in the amount of dissolved oxygen in surface waters and an increase in the concentration of nutrients and toxic chemicals due to reduced flushing rate (Murdoch *et al.* 2000). Because many rivers are already under a great deal of stress due to excessive water withdrawal or land development, and this stress may be exacerbated by changes in climate, anticipating and planning adaptive strategies may be critical (Hulme 2005). A warmer-wetter climate could ameliorate poor water quality conditions in places where human-caused concentrations of nutrients and pollutants other than heat currently degrade water quality (Murdoch *et al.* 2000). Increases in water temperature and changes in seasonal patterns of runoff will very likely disturb fish habitat and affect recreational uses of lakes, streams, and wetlands. Surface water resources in the southeast are intensively managed with dams and channels and almost all are affected by human activities; in some systems water quality is either below recommended levels or nearly so. A global analysis of the potential effects of climate change on river basins indicates that due to changes in discharge and water stress, the area of large river basins in need of reactive or proactive management interventions in response to climate change will be much higher for basins impacted by dams than for basins with free-flowing rivers (Palmer *et al.* 2008). Human-induced disturbances also influence coastal and marine systems, often reducing the ability of the systems to adapt so that systems that might ordinarily be capable of responding to variability and change are less able to do so. Because stresses on water quality are associated with many activities, the impacts of the existing stresses are likely to be exacerbated by climate change. Within 50 years, river basins that are impacted by dams or by extensive development may experience greater changes in discharge and water stress than unimpacted, free-flowing rivers (Palmer *et al.* 2008).

While debated, researchers anticipate: 1) the frequency and intensity of droughts and floods will change across the nation; 2) a warming of about 0.2°C (0.4°F) per decade; and 3) a rise in sea level (NAST 2000). A warmer and drier climate will reduce stream flows and increase water temperature resulting in a decrease of DO and an increase in the concentration of nutrients and toxic chemicals due to reduced flushing. Sea level is expected to continue rising: during the 20th century global sea level has increased 15 to 20 cm (6-8 inches).

5.2. Species Specific Information on Climate Change Effects

5.2.1. Effects to Atlantic Salmon and Critical Habitat

Atlantic salmon may be especially vulnerable to the effects of climate change in New England, since the areas surrounding many river catchments where salmon are found are heavily populated and have already been affected by a range of stresses associated with agriculture, industrialization, and urbanization (Elliot *et al.* 1998). Climate effects related to temperature regimes and flow conditions determine juvenile salmon growth and habitat (Friedland1998). One study conducted in the Connecticut and Penobscot rivers, where temperatures and average discharge rates have been increasing over the last 25 years, found that dates of first capture and median capture dates for Atlantic salmon have shifted earlier by about 0.5 days/ year, and these consistent shifts are correlated with long-term changes in temperature and flow (Juanes *et al.* 2004). Temperature increases are also expected to reduce the abundance of salmon returning to home waters, particularly at the southern limits of Atlantic salmon spatial distribution (Beaugrand and Reid 2003).

One recent study conducted in the United Kingdom that used data collected over a 20-year period in the Wye River found Atlantic salmon populations have declined substantially and this decline was best explained by climatic factors like increasing summer temperatures and reduced discharge more than any other factor (Clews *et al.* 2010). Changes in temperature and flow serve as cues for salmon to migrate, and smolts entering the ocean either too late or too early would then begin their post-smolt year in such a way that could be less optimal for opportunities to feed, predator risks, and/or thermal stress (Friedland 1998). Since the highest mortality affecting Atlantic salmon occurs in the marine phase, both the temperature and the productivity of the coastal environment may be critical to survival (Drinkwater *et al.* 2003). Temperature influences the length of egg incubation periods for salmonids (Elliot *et al.* 1998) and higher water temperatures could accelerate embryo development of salmon and cause premature emergence of fry.

Since fish maintain a body temperature almost identical to their surroundings, thermal changes of a few degrees Celsius can critically affect biological functions in salmonids (NMFS and USFWS 2005). While some fish populations may benefit from an increase in river temperature for greater growth opportunity, there is an optimal temperature range and a limit for growth after which salmonids will stop feeding due to thermal stress (NMFS and USFWS 2005). Thermally stressed salmon also may become more susceptible to mortality from disease (Clews *et al.* 2010). A study performed in New Brunswick found there is much individual variability between Atlantic salmon and their behaviors and noted that the body condition of fish may influence the temperature at which optimal growth and performance occur (Breau *et al.* 2007).

The productivity and feeding conditions in Atlantic salmon's overwintering regions in the ocean are critical in determining the final weight of individual salmon and whether they have sufficient energy to migrate upriver to spawn (Lehodey *et al.* 2006). Survival is inversely related to body size in pelagic fishes, and temperature has a direct effect on growth that will affect growth-related sources of mortality in post-smolts (Friedland 1998). Post-smolt growth increases in a linear trend with temperature, but eventually reaches a maximum rate and decreases at high temperatures (Brett 1979 in Friedland 1998). When at sea, Atlantic salmon eat crustaceans and small fishes, such as herring, sprat, sand-eels, capelin, and small gadids, and when in freshwater, adults do not feed but juveniles eat aquatic insect larvae (FAO 2012). Species with calcium carbonate skeletons, such as the crustaceans that salmon sometimes eat, are particularly susceptible to ocean acidification, since ocean acidification will reduce the carbonate availability necessary for shell formation (Wood *et al.* 2008). Climate change is likely to affect the abundance, diversity, and composition of plankton, and these changes may have important consequences for higher trophic levels like Atlantic salmon (Beaugrand and Reid 2003).

In addition to temperature, stream flow is also likely to be impacted by climate change and is vital to Atlantic salmon survival. In-stream flow defines spatial relationships and habitat suitability for Atlantic salmon and since climate is likely to affect in-stream flow, the physiological, behavioral, and feeding-related mechanisms of Atlantic salmon are also likely to be impacted (Friedland 1998). With changes in in-stream flow, salmon found in smaller river systems may experience upstream migrations that are confined to a narrower time frame, as small river systems tend to have lower discharges and more variable flow (Elliot *et al.* 1998). The changes in rainfall patterns expected from climate change and the impact of those rainfall patterns on flows in streams and rivers may severely impact productivity of salmon populations (Friedland 1998). More winter precipitation falling as rain instead of snow can lead to elevated winter peak flows which can scour the streambed and destroy salmon eggs (Battin *et al.* 2007, Elliot *et al.* 1998). Increased sea levels in combination with higher winter river flows could cause degradation of estuarine habitats through increased wave damage during storms (NSTC 2008). Since juvenile Atlantic salmon are known to select stream habitats with particular characteristics, changes in river flow may affect the availability and distribution of preferred habitats (Riley *et al.* 2009). Unfortunately, the critical point at which reductions in flow begin to have a damaging impact on juvenile salmonids is difficult to define, but generally flow levels that promote upstream migration of adults are likely adequate to encourage downstream movement of smolts (Hendry *et al.* 2003).

Humans may also seek to adapt to climate change by manipulating water sources, for example in response to increased irrigation needs, which may further reduce stream flow and biodiversity (Bates *et al.* 2008).Water extraction is a high level threat to Atlantic salmon, as adequate water quantity and quality are critical for all life stages of Atlantic salmon (NMFS and USFWS 2005). Climate change will also affect precipitation, with northern areas predicted to become wetter and southern areas predicted to become drier in the future (Karl *et al.* 2009). Droughts may further exacerbate poor water quality and impede or prevent migration of Atlantic salmon (Riley *et al.* 2009).

It is anticipated that these climate change effects could significantly affect the functioning of the Atlantic salmon critical habitat. Increased temperatures will affect the timing of upstream and downstream migration and make some areas unsuitable as temporary holding and resting areas. Higher temperatures could also reduce the amount of time that conditions are appropriate for migration (<23 degrees Celsius), which could affect an individual's ability to access suitable spawning habitat. In addition, elevated temperatures will make some areas unsuitable for spawning and rearing due to effects to egg and embryo development.

5.2.2. Shortnose sturgeon

Global climate change may affect shortnose sturgeon in the future. Rising sea level may result in the salt wedge moving upstream in affected rivers. Shortnose sturgeon spawning occurs in fresh water reaches of rivers because early life stages have little to no tolerance for salinity. Similarly, juvenile shortnose sturgeon have limited tolerance to salinity and remain in waters with little to no salinity. If the salt wedge moves further upstream, shortnose sturgeon spawning and rearing habitat could be restricted. In river systems with dams or natural falls that are impassable by sturgeon, the extent that spawning or rearing may be shifted upstream to compensate for the shift in the movement of the saltwedge would be limited. While there is an indication that an increase in sea level rise would result in a shift in the location of the salt wedge, for most spawning rivers there are no predictions on the timing or extent of any shifts that may occur; thus, it is not possible to predict any future loss in spawning or rearing habitat. However, in all river systems, spawning occurs miles upstream of the saltwedge. It is unlikely that shifts in the location of the saltwedge would eliminate freshwater spawning or rearing habitat. If habitat was severely restricted, productivity or survivability may decrease.

The increased rainfall predicted by some models in some areas may increase runoff and scour spawning areas and flooding events could cause temporary water quality issues. Rising temperatures predicted for all of the U.S. could exacerbate existing water quality problems with DO and temperature. While this occurs primarily in rivers in the southeast U.S. and the Chesapeake Bay, it may start to occur more commonly in the northern rivers. Shortnose sturgeon are tolerant to water temperatures up to approximately 28°C (82.4°F); these temperatures are experienced naturally in some areas of rivers during the summer months. If river temperatures rise and temperatures above 28°C are experienced in larger areas, sturgeon may be excluded from some habitats.

Increased droughts (and water withdrawal for human use) predicted by some models in some areas may cause loss of habitat including loss of access to spawning habitat. Drought conditions in the spring may also expose eggs and larvae in rearing habitats. If a river becomes too shallow or flows become intermittent, all shortnose sturgeon life stages, including adults, may become susceptible to strandings. Low flow and drought conditions are also expected to cause additional water quality issues. Any of the conditions associated with climate change are likely to disrupt river ecology causing shifts in community structure and the type and abundance of prey. Additionally, cues for spawning migration and spawning could occur earlier in the season causing a mismatch in prey that are currently available to developing shortnose sturgeon in rearing habitat; however, this would be mitigated if prey species also had a shift in distribution or if developing sturgeon were able to shift their diets to other species.

5.2.3. Atlantic sturgeon

Global climate change may affect all DPSs of Atlantic sturgeon in the future; however, effects of increased water temperature and decreased water availability are most likely to effect the South Atlantic and Carolina DPSs. Rising sea level may result in the salt wedge moving upstream in affected rivers. Atlantic sturgeon spawning occurs in fresh water reaches of rivers because early life stages have little to no tolerance for salinity. Similarly, juvenile Atlantic sturgeon have limited tolerance to salinity and remain in waters with little to no salinity. If the salt wedge moves further upstream, Atlantic sturgeon spawning and rearing habitat could be restricted. In river systems with dams or natural falls that are impassable by sturgeon, the extent that spawning or rearing may be shifted upstream to compensate for the shift in the movement of the saltwedge would be limited. While there is an indication that an increase in sea level rise would result in a shift in the location of the salt wedge, at this time there are no predictions on the timing or extent of any shifts that may occur; thus, it is not possible to predict any future loss in spawning or rearing habitat. However, in all river systems, spawning occurs miles upstream of the saltwedge. It is unlikely that shifts in the location of the saltwedge would eliminate freshwater spawning or rearing habitat. If habitat was severely restricted, productivity or survivability may decrease.

The increased rainfall predicted by some models in some areas may increase runoff and scour spawning areas and flooding events could cause temporary water quality issues. Rising temperatures predicted for all of the U.S. could exacerbate existing water quality problems with DO and temperature. While this occurs primarily in rivers in the southeast U.S. and the Chesapeake Bay, it may start to occur more commonly in the northern rivers. Atlantic sturgeon prefer water temperatures up to approximately 28°C (82.4°F); these temperatures are experienced naturally in some areas of rivers during the summer months. If river temperatures rise and temperatures above 28°C are experienced in larger areas, sturgeon may be excluded from some habitats.

Increased droughts (and water withdrawal for human use) predicted by some models in some areas may cause loss of habitat including loss of access to spawning habitat. Drought conditions in the spring may also expose eggs and larvae in rearing habitats. If a river becomes too shallow or flows become intermittent, all Atlantic sturgeon life stages, including adults, may become susceptible to strandings or habitat restriction. Low flow and drought conditions are also expected to cause additional water quality issues. Any of the conditions associated with climate change are likely to disrupt river ecology causing shifts in community structure and the type and abundance of prey. Additionally, cues for spawning migration and spawning could occur earlier in the season causing a mismatch in prey that are currently available to developing sturgeon in rearing habitat.

6. EFFECTS OF THE ACTION

This section of an Opinion assesses the direct and indirect effects of the proposed action on threatened and endangered species or critical habitat, together with the effects of other activities that are interrelated or interdependent (50 CFR 402.02). Indirect effects are those that are caused later in time, but are still reasonably certain to occur. Interrelated actions are those that are part of a larger action and depend upon the larger action for their justification. Interdependent actions are those that have no independent utility apart from the action under consideration (50 CFR 402.02). The trapping of Atlantic salmon broodstock by MDMR will occur at the Milford and Orono fish traps after the proposed action has occurred. This activity would not occur but for the construction of the fish traps. However, as this activity has already been authorized under a research and recovery blanket permit with USFWS (permit number 697823); its effects will not be addressed in this Opinion. We have not identified any other interrelated or interdependent actions.

These activities will affect the GOM DPS of Atlantic salmon, shortnose sturgeon, the GOM DPS of Atlantic sturgeon and the New York Bight DPS of Atlantic sturgeon as well as critical habitat designated from the GOM DPS of Atlantic salmon. The sections that follow present our analysis of the following: (1) construction of new powerhouses and fish passage facilities; (2) hydroelectric operations under the terms of the revised licenses; and (3) implementation of upstream and downstream fish passage efficiency and survival studies required by the licenses.

6.1. Effects of Powerhouse and Fishway Construction

Effects of the construction of powerhouses and fishways at the Orono, Stillwater and Milford Projects are likely to be restricted to the area between the Milford and Veazie Dams on the mainstem, and the Stillwater Branch downstream of the Stillwater Dam. As shortnose and Atlantic sturgeon do not use the fish passage facilities at Veazie, they are restricted to habitat below the Veazie Dam. The Veazie Dam is approximately 4.5 miles downriver from the Orono Project and nearly 9 miles downriver of Milford Dam. The Veazie Dam is proposed for removal in 2013-2014. The Great Works Dam which is the next dam on the river is in the process of being removed. After Veazie and Great Works are removed, sturgeon will be able to reach the Orono project on the Stillwater Branch and the Milford Project on the Penobscot River mainstem. Powerhouse and fishway construction at Orono is scheduled to be completed in 2013, prior to the removal of the Veazie Dam. Fishway construction at Milford is scheduled to be completed in 2012, also prior to removal of the Veazie Dam. Effects of powerhouse and fishway construction will not be experienced below the Veazie Dam; as such, no shortnose or Atlantic sturgeon will be exposed to effects of any of the proposed powerhouse and fishway construction.

The mainstem Penobscot River serves as an important migratory corridor for adult Atlantic salmon migrating upriver to spawning habitat between May and October, as well as to outmigrating smolts between April and June and outmigrating kelts in early winter and spring. The potential effects associated with the construction of powerhouses at Orono and Stillwater and fishways at Orono and Milford include inhibiting fish passage during construction, increasing noise and suspended sediment levels, causing direct injury and mortality during construction, and potentially spilling toxic substances (e.g., equipment leaks). The effects of construction on Atlantic salmon are considered below.

6.1.1. Fish Passage

Activities associated with the construction of new powerhouses at the Orono and Stillwater Projects, as well as the fishway improvements at the Milford, Orono and Stillwater Projects, have the potential to affect Atlantic salmon in the lower Penobscot River by increasing turbidity and noise levels. To minimize exposure, in-water construction activities have been timed to avoid smolt and kelt outmigration periods. As such, no Atlantic salmon smolts or kelts are expected to be affected by these activities. Therefore, only passage of upstream migrating Atlantic salmon adults could be affected by construction activities.

Construction is anticipated to commence in late summer of 2012, and will be completed by the end of 2013.. The majority of in-water construction is anticipated to occur in 2012. The Penobscot River Restoration Trust (PRRT) has arranged for MDMR to trap and truck migrating adult Atlantic salmon that have been trapped at the Veazie Dam upriver of the Milford Project during the removal of the Great Works Dam, which began in June 2012. However, it is likely that trucking will have ceased by late summer when construction at the Orono, Stillwater and Milford Projects is expected to commence. At that point all upstream migrants will be released into the Veazie headpond. Based on Atlantic salmon returns between 2007 and 2010, 7% of the run passes the Veazie Project between August and October. Therefore, it is expected that at least 7% of the Atlantic salmon run in the Penobscot could be migrating through the project area during construction activities in the late summer and fall of 2012. As Great Works Dam will have been breached, and the Denil fishway at Milford will be operational, it is anticipated that these fish will be able to migrate successfully through the River.

In 2013, the Great Works Dam will have been removed and trucking of Atlantic salmon upriver of Milford will not be conducted. Therefore, the entirety of the salmon run will be migrating through the mainstem of the Penobscot River and could be exposed to the effects of the remaining in-water construction activities (primarily cofferdam removal).

Adult migrating salmon are attracted to the discharge of the existing powerhouse at the Orono project, where they can be significantly delayed. The powerhouse discharges into the mainstem of the River, adjacent to the confluence with the Stillwater Branch. Shepard (1995) determined that 46% (56% in 1988 and 37% in 1989) of tagged salmon were attracted to this discharge and delayed for a median of 8.30 hours in 1988 and 2.18 hours in 1989. The duration of the delay in 1988 ranged between 0.3 hours to 247.4 hours. Shepard (1995) indicated that all of these fish eventually continued their upstream migration in the mainstem. Of the fish attracted to the discharge, only 33% were recorded spending more than 48 hours in the tailrace of the Project (S. Shepard, personal communication, 2012). Many of the salmon tracked during this study were originally stocked in the mainstem, and, therefore, may not have been motivated to migrate any further upriver. This would suggest that the proportion of Atlantic salmon that were attracted to the discharge at Orono may be larger than what would be expected for wild fish, or for fish that were stocked as smolts further upriver. However, this study provides the best available information regarding what proportion of Atlantic salmon migrating through the Penobscot River could be attracted to the discharge of the powerhouse in Orono. Therefore, the level of delay observed by Shepard (1995) is a conservative estimate of what would be expected at the Orono Project during the 2012 construction season.

While the intake cofferdam is in place in 2013 (July to October) Black Bear proposes to pass all flows over the spillway, which will temporarily eliminate the discharge from the existing powerhouse. Therefore, salmon will be attracted to spillage in the bypass rather than to discharge from the powerhouse during this stage of construction. Based on Atlantic salmon returns between 2007 and 2010, 23% of the run passes the Veazie Project between July and October. As the spillway is more than 800 feet from the confluence with the mainstem, it is possible that the decrease in attraction to the river will lead to increased delay at the Orono Project during construction. However, it is impossible to predict what level of increased delay would occur. Therefore, it is assumed that 33% of the salmon that are attracted to the increased spillage will be significantly delayed during the period when the intake cofferdam is in place in 2013. This equates to approximately 3% of the entire run in 2013 (23% of the run between July and October x 46% attracted to discharge x 33% of the fish delayed by more than 48 hours= 3%).

As there is no upstream passage into the Stillwater Branch, it is anticipated that very few Atlantic salmon will be able to access the construction area between the Orono and Stillwater Projects. However, a proportion of Atlantic salmon are known to drop back in the river during their upstream migration. In 2002-2004 and 2010, the proportion of Atlantic salmon that were released into the Veazie headpond that dropped downriver and were recaptured in the Veazie trap ranged between 0.8% and 9.4%, with an average of 5.9% (Holbrook *et al.* 2009, MDMR unpublished data). Fall back over Veazie is a conservative estimate of fall back into the Stillwater Branch; however, it is the best available information of fall back rates in the lower Penobscot River. Therefore, based on this recapture rate, and assuming that the fish fall back into the mainstem Penobscot and Stillwater Branch in equal proportion, it can be estimated that no more than 0.3% (7% of the salmon run x maximum 9.4% fall back x 50% split between Stillwater and mainstem) of the salmon run in 2012 will fall back into the Stillwater Branch and, therefore, could be exposed to effects associated with construction at the Stillwater Project.

6.1.2. Cofferdam Construction

As discussed previously, construction activities will likely commence between August and October in 2012, when approximately 7% of the salmon run could be expected to be migrating through the mainstem of the Penobscot River. In this timeframe, enclosed cofferdams will be constructed at the Orono, Stillwater and Milford Projects to create a dry work area for construction of the new powerhouses, tailraces and fishways. The construction of cofferdams can entrap fish within the cofferdam, and expose fish to elevated sediment and noise levels. The cofferdams at the Stillwater and Orono Projects will temporarily isolate a combined 2.6 acres of habitat in the Stillwater Branch of the Penobscot River. In addition, the Milford Dam will require the isolation of approximately 500 square feet of habitat in the mainstem Penobscot River for the construction of the new fishways.

Isolation of a work area within a cofferdam minimizes the overall adverse effects of construction activities on Atlantic salmon and their habitat because it reduces exposure to in-water construction activities. However, isolating the work area within a cofferdam could lead to negative impacts on fish if any are trapped within the isolated work area. Given the level of instream activity associated with setting up the cofferdams and other construction-related activities along the stream banks, any adult salmon present in the project area are expected to move away from the work zone. Given that the majority of construction activity is in the Stillwater Branch and not in the mainstem, which is the primary migratory corridor, this movement away from the construction area is not likely to halt or hinder migration through the Penobscot. However, it is still possible that salmon could become entrapped within the cofferdams, if they are constructed in the wet. Therefore, in order to minimize the probability of entrapping an adult Atlantic salmon within the work area, a visual survey of these areas will be conducted by qualified personnel to verify that there are no salmon within the project area prior to and during the installation and removal of any in-water bypass structure, including cofferdams. If Atlantic salmon are found within a cofferdam, they will be removed and returned to the River prior to dewatering. The implementation of such an evacuation plan will minimize the effect so that entrapped fish would not be anticipated to be injured or killed by the construction and dewatering of the proposed cofferdams.

Capturing and handling salmon causes physiological stress and can cause physical injury although these effects can be kept to a minimum through proper handling procedures. The fish evacuation plan should minimize such stresses by requiring minimal handling time; minimal time that fish are held out of the water; and using transfer containers with aerated stream water of ambient temperature. Impacts to Atlantic salmon will be further minimized by requiring that only qualified biologists handle the fish. Given these minimization efforts, it is not expected that there will be any injury or mortality associated with cofferdam construction.

6.1.3. Water Quality Effects

Sediments and Turbidity

Construction of new powerhouses, fishways and associated features would require the use of extensive heavy equipment in the Penobscot River. Construction activities associated with the proposed project, including cofferdam construction and removal and access road construction, will temporarily introduce sediment and increase turbidity in the Penobscot River. While Black Bear will employ erosion and sedimentation BMPs to prevent and minimize erosion and sedimentation during construction, some release of fine materials and turbidity is likely to occur as a result of these in-water activities.

Elevated TSS concentrations have the potential to adversely affect adult Atlantic salmon in the Penobscot River. According to Herbert and Merkens (1961), the most commonly observed effects of exposure to elevated TSS concentrations on salmonids include: 1) avoidance of turbid waters in homing adult anadromous salmonids, 2) avoidance or alarm reactions by juvenile salmonids, 3) displacement of juvenile salmonids, 4) reduced feeding and growth, 5) physiological stress and respiratory impairment, 6) damage to gills, 7) reduced tolerance to disease and toxicants, 8) reduced survival, and 9) direct mortality. Fine sediment deposited in salmonid spawning gravel can also reduce interstitial water flow, leading to depressed DO concentrations, and can physically trap emerging fry on the gravel.

Studies of the effects of turbid waters on fish suggest that concentrations of suspended solids can reach thousands of milligrams per liter before an acute toxic reaction is expected (Burton 1993). The studies reviewed by Burton demonstrated lethal effects to fish at concentrations of 580mg/L to 700,000 mg/L depending on species. However, sublethal effects have been observed at substantially lower turbidity levels. Behavioral avoidance of turbid waters may be one of the most important effects of suspended sediments (DeVore *et al.* 1980, Birtwell *et al.* 1984, Scannell 1988). Salmonids have been observed to move laterally and downstream to avoid turbid plumes (McLeay *et al.* 1984, 1987, Sigler *et al.* 1984, Lloyd 1987, Scannell 1988, Servizi and Martens 1991). Juvenile salmonids tend to avoid streams that are chronically turbid, such as glacial streams or those disturbed by human activities, except when the fish need to traverse these streams along migration routes (Lloyd *et al.* 1987).

Exposure duration is a critical determinant of the occurrence and magnitude of physical or behavioral effects (Newcombe and MacDonald 1991). Salmonids have evolved in systems that periodically experience short-term pulses (days to weeks) of high suspended sediment loads, often associated with flood events, and are adapted to such high pulse exposures. Adult and larger juvenile salmonids appear to be little affected by the high concentrations of suspended sediments that occur during storm and snowmelt runoff episodes (Bjornn and Reiser 1991). However, research indicates that chronic exposure can cause physiological stress responses that can increase maintenance energy and reduce feeding and growth (Redding *et al.* 1987, Lloyd 1987, Servizi and Martens 1991). In a review of the effects of sediment loads and turbidity on fish, Newcomb and Jensen (1996) concluded that more than six days exposure to total suspended solids (TSS) greater than ten milligrams per liter is a moderate stress for juvenile and adult salmonids and that a single day exposure to TSS in excess of 50 mg/l is a moderate stress.

At moderate levels, turbidity has the potential to adversely affect primary and secondary productivity, and at high levels has the potential to injure and kill adult and juvenile fish. Turbidity might also interfere with feeding (Spence *et al.* 1996). Newly emerged salmonid fry may be vulnerable to even moderate amounts of turbidity (Bjornn and Reiser 1991). Other behavioral effects on fish, such as gill flaring and feeding changes, have been observed in response to pulses of suspended sediment (Berg and Northcote 1985). Fine redeposited sediments also have the potential to adversely affect primary and secondary productivity (Spence *et al.* 1996), and to reduce incubation success (Bell 1991) and cover for juvenile salmonids (Bjornn and Reiser 1991). Larger juvenile and adult salmon appear to be little affected by ephemeral high concentrations of suspended sediments that occur during most storms and episodes of snowmelt. However, other research demonstrates that feeding and territorial behavior can be disrupted by short-term exposure to turbid water.

In-water work will primarily be conducted on ledge within dewatered bypass reaches or within the confines of dewatered cofferdams; therefore, sediment releases are only anticipated during the installation and removal of these cofferdams. Single day TSS levels in excess of 50 mg/l are not anticipated during these activities because: 1) BMPs for erosion and sedimentation control will be employed throughout construction; 2) flow will be managed at the Projects to minimize flow into the work area; and, 3) the majority of excavation will occur on ledge. Therefore, we do not expect any Atlantic salmon to be injured or killed due to exposure to elevated TSS or sediments during construction activities. Atlantic salmon may experience behavioral avoidance of turbid waters during construction, which could cause a change in migratory route. As there is ample space available in the river for migration, a minor change in route should not adversely affect upriver migration for salmon. It is unlikely that any significant number of parr would be present below each project during construction since the area is not stocked with fry or parr and natural reproduction in these areas is not known to occur. Construction will occur outside of the smolt outmigration period so it is not anticipated that any smolts will be affected by sediments released by construction.

Contaminants

Use of heavy equipment near a water body introduces the risk that toxic contaminants (e.g., fuel, oil, etc.) could enter the Penobscot River. Chemical contaminants can be introduced into waterbodies through direct contact with contaminated surfaces or by the introduction of storm or washwater runoff and can remain in solution in the water column or deposit on the existing bed material. Research has shown that exposure to contaminants can reduce reproductive capacity, growth rates, and resistance to disease, and may lead to lower survival rates for salmon (Arkoosh 1998a, 1998b). The risk for contaminants entering the Penobscot River would increase during construction, possibly degrading habitat condition.

To reduce the potential for introducing contaminants into the river during construction activities, Black Bear will require the contractor to follow several BMPSs including: a) no equipment, materials, or machinery shall be stored, cleaned, fueled or repaired within any wetland or watercourse; b) dumping of oil or other deleterious materials on the ground will be forbidden; c) the contractor shall provide a means of catching, retaining, and properly disposing of drained oil, removed oil filters, or other deleterious material; and d) all oil spills shall be reported immediately to the appropriate regulatory body. These BMPs will reduce the likelihood of any contaminant releases into the river during construction activities. Based on implementation of this plan, it is extremely unlikely that there would be a release of contaminants into the river. As such, any effects to Atlantic salmon as a result of contaminants from heavy equipment in the action area would be discountable.

6.1.4. Ledge Removal Effects

Ledge removal is proposed to occur in the tailraces of the new powerhouses at the Orono and Stillwater Projects (Table 10). Ledge will be removed by drilling and blasting. Holes will be drilled into the bedrock down to a specified depth and then blast charges will be installed in the resulting cavities. Upon blasting the fractured bedrock will be removed by mechanical means such as an excavator or a crane.

Table 10. Volume of ledge that will be removed via drilling and blasting at the Orono and Stillwater Projects.

	Blasting Impacts (cy)	
	Orono	Stillwater
Powerhouse	1900	1500
Forebay	50	0
Tailrace 1	1100	590
Tailrace 2	500	2320
Total	3550	4410

Blasting

The use of explosives in or near water produces a post-detonation compression shock wave with a rapid rise to a peak pressure followed by a rapid decay to below ambient hydrostatic pressure (Wright and Hopky 1998). This final pressure deficit causes most of the known adverse effects to fish from blasting by damaging the swim bladder, kidney, liver, spleen, and circulatory system (sinus venous). Any of these organs may rupture or hemorrhage as a result of blasting, with the swim bladder being the most sensitive. The effects on fish are variable and relate to the type of explosive; size and pattern of charges; method of detonation; distance from the point of detonation; water depth; and species, size and life stage of fish. Small fish, including juvenile salmon, are more likely to be injured by an explosion than large fish (ADFG 1991). Shock waves generated by in-water explosions generally have more adverse effects on fish than underground explosions, in part because some energy is reflected and lost at the ground-water interface. Underwater explosions that are contained (e.g., explosive placed within a pier for demolition by drilling and covering), however, reduce the capacity of the water-borne shock wave to cause fish mortality when compared to an unconfined underwater explosion (Keevin 1998).

In 2010, monitoring was conducted in association with the installation of the Old Town Fuel and Fiber plant water intake structures on the Penobscot River in Old Town, Maine. As part of the project blasting was conducted within a dry earthen and portable fabric cofferdam to remove rock from the river bottom. No other means of noise mitigation (passive or active) were addressed or employed. Based on SPL waveform measurements taken ten meters from the source, unmitigated sound levels ranged from < 196.8 dB re: 1 μPa $_{PEAK}$ to 221.5 dB re: 1 μPa $_{PEAK}$. This is a similar technique to what Black Bear is proposing for the work at the Orono and Stillwater Projects; however, as the blasting will be occurring more than ten meters from the river the noise levels are anticipated to be lower.

Wright (1982) has demonstrated that effects on fish from blasting occur when the overpressure exceeds 100 kPa (kilopascals), or 14.5 pounds per square inch (which is equivalent to approximately 220 dB re: 1 μPa). This is the pressure limit used in guidelines developed by the Canadian Department of Fisheries and Oceans to protect fishery resources from explosions in or near water bodies (Wright and Hopky 1998). Black Bear has proposed to keep noise levels in the river below 187 dB_{SEL} re: 1 μPa and 206 dB $_{PEAK}$ re: 1 μPa. They have proposed to do this by limiting charge weights, delaying individual blasts to reduce detonation related sound pressures, and by blasting within a dewatered cofferdam (Black Bear Amendment Applications 2011). These noise thresholds are based on the Fisheries Hydroacoustic Working Group (FHWG 2008) thresholds for injury to fish due to pile driving noise. The extent to which these thresholds apply to blasting is unknown; however, when compared to the threshold for blasting reported by Wright and Hopky (1998), the FHWG guidelines appear to be conservative.

As blasting will occur at the end of the adult salmon migration period (August to October), only 7% of the salmon run could be exposed to this activity. The blasting will occur in the dry within an earthen cofferdam that has been dewatered, and fish will not be able to get any closer to blasting and drilling activities than approximately 30 meters due to the location of the new tailraces within the cofferdams. Given the distance from the source, as well as the other minimization techniques proposed by Black Bear (blasting in the dry, limiting charge weights, delaying individual blasts, sound monitoring) we anticipate that no Atlantic salmon will be injured or killed due to the activities associated with tailrace excavation at the Orono and Stillwater Projects. However, it is anticipated that construction noise will lead to avoidance behavior in Atlantic salmon in the vicinity that may lead to minor migratory delays (less than 48 hours). As delay is anticipated to be brief, the noise effects associated with the construction of the powerhouses and tailraces will be insignificant.

As described above, adult Atlantic salmon may be exposed to changes in water quality and increased underwater noise associated with certain construction activities. In the worst case, Atlantic salmon in the project area will be exposed to increases in sediment and noise that could lead to an avoidance response, which could potentially lead to a minor delay in migration. As Black Bear has proposed several minimization techniques to keep noise levels from blasting and drilling below thresholds for injury to fish, no injuries or mortalities are anticipated from these activities. In addition, erosion and sedimentation control BMPs will be implemented to minimize the amount of sediment that enters the river, and will therefore, not lead to any lethal or injurious effects to fish. Therefore, all effects associated with the construction of new powerhouses and fishways at the Orono, Stillwater and Milford Projects are anticipated to be insignificant.

Drilling

Drills generate noise and vibrations when in operation as a result of friction between the drill bit face and the material it is boring through (i.e., rock is denser than sand or silt, so there is greater friction resulting in higher noise and vibration levels than for softer materials) (Transit Link Consultants 2008). The generated noise and vibration from the drill produces sound waves that transverse the substrate. Detailed data on the underwater noise associated with the exact drill to be used is not available, but information on underwater noise from geotechnical drills is available. As these drills work in the same fashion, it is reasonable to use the source levels associated with geotechnical drills as a surrogate for the specific drill to be used for this project. Unmitigated sound levels from underwater geotechnical drills have been estimated at 118-145 dB re 1uPa at 1 meter, with noise decreasing to 101.5 dB re 1uPa at 150 meters, 97.0 dB re 1uPa at 250 meters, and 94.1 dB re 1uPa at 350 meters. As noise produced by drilling in water is relatively low, and the proposed activity will occur within a dewatered cofferdam, it is expected that drilling will have an insignificant effect on Atlantic salmon.

6.1.5. Atlantic Salmon Critical Habitat

Proposed construction activities will temporarily reduce the status of several habitat indicators relative to Atlantic salmon critical habitat. We expect these activities to cause temporary adverse effects to the migratory PCE of critical habitat by reducing water quality due to increased noise and turbidity and the filling of habitat. The habitat in the Stillwater Branch does not currently function for upstream migration of pre-spawn adult Atlantic salmon due to the lack of fish passage facilities at both the Stillwater and Orono projects. However, the habitat does function as a migration corridor for outmigrating smolts and kelts in the spring as they make their way to the estuary. In addition, temporary effects (turbidity and noise) of the construction at the Orono and Stillwater Projects are anticipated to extend into the mainstem of the Penobscot River, which functions as migratory habitat for both pre-spawn adults and outmigrating smolts and kelts. Construction has been timed so that in-water effects to the habitat (turbidity, noise and the presence of temporary fill) will not coincide with the smolt outmigration period. However, construction effects may still reduce the functioning of the habitat for adult Atlantic salmon in the mainstem for short intervals.

The construction of the new powerhouses will place temporary and permanent fill below the ordinary high water (OHW) line in the Stillwater Branch of the Penobscot River (Table 11). The total temporary fill is 2.6 acres (115,470 square feet), while the permanent fill (new penstocks, powerhouses and site work) will eliminate 0.66 acres (28,999 square feet) of migratory habitat. As previously indicated, the majority of the temporary fill will be placed and removed in the Stillwater Branch outside of the spring outmigration period. Therefore, the placement of this fill is anticipated to have an insignificant effect on the migration PCE. However, the placement of permanent fill will negatively affect the functioning of the habitat in the bypass reach at both projects by precluding the use of the habitat for migration. However, as the permanent fill associated with the new structures will only occupy 0.02% of the migratory habitat in the Stillwater Branch, it is not anticipated that it will substantially alter the functioning of the habitat for Atlantic salmon.

There will be no permanent fill associated with the new fishway at Milford, although a small area (509 square feet) will be temporarily cofferdammed in the tailrace during construction. The cofferdam will be placed on ledge, so it is not anticipated that there will be a significant sediment release when it is removed. There will be no blasting or excavation associated with the project at Milford. As the Denil fishway at Milford will be maintained and operated during construction, it is anticipated that the effect of construction activities on these fish would be insignificant.

Table 11. Areas of effect associated with construction at the Orono, Stillwater and Milford Projects.

		Temporary (sf)	Permanent (sf)
Orono	Cofferdams	41,870	
	Penstock		10,985
	Site Work		7,607
	Powerhouse		3,300
	Total	**41,870**	**21,892**
Stillwater	Cofferdams	73,600	
	Site Work		2,982
	Powerhouse		4,125
	Total	**73,600**	**7,107**
Milford	Cofferdams	509	0
	Total	**509**	**0**

Construction of the new powerhouses without pass-through upstream fishways will continue to impair critical habitat for adults in the Stillwater branch. The installation of a fish trap at the Orono project will help to minimize these effects to critical habitat but will not completely eliminate them. If it is found that a significant number of adult Atlantic salmon are attracted to the Stillwater Branch, Black Bear will develop reasonable solutions for minimizing the effects to the PCE.

6.2. Effects of Hydroelectric Operations

Hydroelectric dams can impact Atlantic salmon, shortnose sturgeon and Atlantic sturgeon through habitat alteration, fish passage delays, entrainment in turbines and impingement on screens and/or racks. Currently, the Medway, West Enfield, Milford, Stillwater and Orono Projects are operated pursuant to the terms and conditions of existing FERC licenses. Existing FERC license articles require the projects to be operated in a run-of-river mode with minimal impoundment fluctuations. The license amendments will not alter the run-of-river requirement.

6.2.1. Atlantic salmon

The modified licenses proposed by FERC implement protection measures described in the SPP to achieve specified performance standards (96% downstream survival of smolts and 95% upstream passage efficiency) in order to minimize the effect of operations of Black Bear's hydroelectric facilities on migrating Atlantic salmon. The SPP involves the sequential implementation of three protective measures, interspersed with monitoring studies. Once the performance standards have been met no further measures will need to be implemented. However, it is possible that all three of the measures will need to be implemented and studied prior to the performance standards being achieved. Therefore, it is possible that there will be a ten year period between when the licenses are amended and the final study year where the performance standards are achieved. Since we cannot accurately predict the survival of Atlantic salmon achieved through each of the individual protection measures, it will be assumed that survival and passage efficiency at these projects will be maintained at existing levels throughout this period. Thereafter, it will be assumed that the performance standards have been achieved.

6.2.1.1. Upstream Passage Effects

To complete their upstream migration, all pre-spawn Atlantic salmon in the Penobscot River must navigate past numerous hydroelectric projects via fishways. Fishways collect motivated fish into human-made structures that allow them to proceed in their migration. These fish are necessarily crowded together into a narrow channel or trap, which exposes them to increased levels of injury and delay, as well as to stress from elevated water temperatures, energetic exhaustion and disease. Forcing fish to alter their migratory behavior and potentially exposing them to the corresponding stress and injury negatively affects 100% of the Atlantic salmon motivated to migrate past a hydroelectric project.

Atlantic salmon are known to successfully utilize upstream fishways at the Milford and West Enfield Projects. However, none of the fishways are 100% effective at passing Atlantic salmon. At Milford Dam, upstream passage success ranged from 86% in 1987 to 100% in 1990, and averaged 90% (56 of 62) over five years of study (Dube 1988, Shepard 1989a, Shepard and Hall 1991, Shepard 1995). Upstream passage efficiency ranged between 85% and 100% over four years of study at the West Enfield and Howland Projects, 20 miles upriver from Milford. Based upon radio telemetry studies conducted from 1989-1992, Shepard (1995) estimated pooled upstream passage rates for adult Atlantic salmon at the Howland and West Enfield from 88-89%.

The amended project licenses will require Black Bear to enhance fish passage through the lower Penobscot River by constructing new fish lifts at the Milford and Orono Projects. The new lift at the Milford Project will replace the existing Denil fishway and is intended to lead to higher upstream passage rates. The Denil may be deactivated while the fish lift is functioning, but can be reactivated if there are problems with the lift, or to provide volitional passage for Atlantic salmon in the future. The construction of the new fish trap at the Orono Project, where none has previously existed, should provide passage for Atlantic salmon that are attracted to the Orono bypass reach. As no passage will be provided at the Stillwater Project, salmon trapped at the Orono fish trap will be trapped and trucked upriver of the Milford Project. It is anticipated that a portion of the annual run of Atlantic salmon will be attracted to the spill at the Orono Dam, but that most individuals will migrate through the mainstem.

Adult salmon that are not passed at the Milford and West Enfield Projects will either spawn in downstream areas, return to the ocean without spawning, or die in the river. These salmon are significantly affected by the presence of fishways at the Milford and West Enfield Projects. Although no studies have looked directly at the fate of fish that fail to pass through upstream fish passage facilities on the Penobscot River, we convened an expert panel in 2010 to provide the best available information on the fate of these fish. The panel was comprised of state, federal, and private sector Atlantic salmon biologists and engineers with expertise in Atlantic salmon biology and behavior at fishways. The group estimated a baseline mortality rate of 1% for Atlantic salmon that fail to pass a fishway at a given dam on the Penobscot River (NMFS 2011, Appendix B). Dams that do not have fishways were not considered to have baseline mortality. Additional mortality was assumed based on project specific factors, such as predation, fish handling, high fall back rates, lack of thermal refugia, etc. The panel assumed an additional 1% mortality due to fall back at the Veazie Project caused by handling associated with the trapping and handling facilities. The proposed project includes the construction of a similar facility at the Milford Project. Therefore, the proposed project will increase the mortality rate of fish that fail to pass the Milford fishway by 1%. Therefore, it is assumed that under SPP conditions (post fishway construction) 2% of the Atlantic salmon that fail to pass the Milford Project will die; 1% due to baseline mortality and 1% due to increased fall back. Likewise, it is assumed for both the environmental baseline and SPP conditions at West Enfield that 2% of the Atlantic salmon that fail to pass the Project will be killed; 1% due to baseline mortality and 1% due to high fallback rates at that dam. The mortality rate at West Enfield is not expected to change after the implementation of the proposed project as there are no structural changes proposed to the Project. Under the baseline conditions, there is no mortality associated with attempted passage at the Orono Project as no upstream fish passage facilities currently exist. However, after the proposed fish trap has been constructed, it is assumed that 1% of the fish that enter the bypass reach and fail to find the fish trap may be killed.

Migratory Delay

In addition to documenting passage success, past studies at Milford and West Enfield have documented delays in upstream migrations for Atlantic salmon. The yearly pooled median passage time for adults at Milford Dam ranged from 1.0 days to 5.3 days over five years of study, while the total range of individual passage times over this study period was 0.1 days to 25.0 days. The yearly pooled median passage time for adults at the West Enfield or Howland Dam ranged from 1.1 days to 3.1 days over four years of study, while the total range of individual passage times over this study period was 0.9 days to 61.1 days (Shepard 1995).

To access high quality spawning and rearing habitat in the Penobscot River watershed, Atlantic salmon must migrate past multiple dams. Delay at these dams can, individually and cumulatively, affect an individual's ability to access suitable spawning habitat within the narrow window when conditions in the River are suitable for migration. In addition, delays in migration can cause overripening of eggs, increased chance of egg retention, and reduced egg viability in pre-spawn female salmonids (deGaudemar and Beal 1998). It cannot be known what level of delay at each of these dams would significantly affect a migrant's ability to access suitable spawning habitat, as it would be different for each individual, and would vary from year to year depending on environmental conditions. NMFS believes that 48 hours provide adequate opportunity for pre-spawn adult Atlantic salmon to locate and utilize well-designed upstream fishways at hydroelectric dams. Once the Veazie and Great Works Dams have been removed, keeping delay at each individual project below 48 hours would ensure a cumulative delay of under a week due to dams in the River (four days for fish migrating to the Piscataquis and Mattawamkeag Rivers, and six days for fish migrating to the East Branch of the Penobscot). Passage times in excess of 48 hours per project would result in unnatural delay for migrants that could make the suitable spawning habitat to which the salmon is migrating inaccessible. Therefore, we consider any adult salmon documented to take longer than 48 hours to pass an upstream passage facility to have been significantly delayed.

Performance Standard

Exact upstream fish passage efficiency and survival rates are not known at the Milford and West Enfield Projects under all operational and environmental conditions. However, based on the minimum passage rate cited in the available empirical studies, NMFS expects that the Milford and West Enfield Projects are at least 86% and 85% effective, respectively, at passing adult Atlantic salmon that are homing to areas in the Penobscot River above each facility. Under the performance standards described in the SPP, operations of the projects pursuant to the amended licenses will require Black Bear to achieve an upstream performance standard of 95% at both of these facilities. Studies will be conducted to evaluate that the performance standard has been met. If the project does not achieve the 95% performance standard, the facility will be modified to increase efficiency and/or survival, and evaluated again and repeated as necessary to achieve the performance standard.

The increase in passage efficiency associated with the performance standard will benefit the species by allowing more individuals to locate suitable spawning habitat and successfully spawn. Currently, the range of passage efficiencies for existing and future conditions (under the SPP) overlap, meaning that in years with higher passage success, the performance standard is already being met. However, in years where passage success is low under current conditions, it is expected that Black Bear will need to alter operations in order to meet the performance standard of 95%. Therefore, in the years where passage rates would otherwise be low, the performance standard would increase passage rates at both the Milford and West Enfield Projects by approximately 10% by increasing passage rates from 85-86% to 95%. Increasing passage rates at the Milford and West Enfield Projects to 95% will increase cumulative passage through both dams from 73% (based on minimum passage rates of 86% and 85%, respectively) to 90%.

Upstream Impediments to Passage

Stillwater Branch of the Penobscot River

The Projects on the Stillwater Branch, the Orono and Stillwater Projects, currently lack upstream passage facilities for diadromous fish. Although a fish lift and trap are proposed for the Orono Project, the amended licenses will not require Black Bear to release any trapped fish into the headpond. The Stillwater Branch runs along the west side of Orson and Marsh Islands before flowing back into the mainstem. The Stillwater primarily functions as a migration corridor for outmigrating smolts and kelts, and would be used by Atlantic salmon migrating to upstream spawning habitat if there weren't any barriers.

A proportion of the annual Atlantic salmon run in the Penobscot migrate to the base of the Orono Project every year. Shepard (1995) determined that in 1988 and 1989, 46% of adult salmon that were passed upriver of the Veazie Dam were attracted to the existing powerhouse discharge at the Orono Project for a median of 8.30 hours in 1988 and 2.18 hours in 1989. The duration of the delay in 1988 ranged between 0.3 hours to 247.4 hours. As there was still attraction flow to the mainstem Penobscot at this location, however, 100% of the delayed fish eventually continued their migrations in the mainstem. Although the Orono Project may not cause migration to cease, delay hinders the timing for reaching suitable spawning habitat and may eventually result in a 'dead end' where fish stop migrating. In addition, it may lead to spawning in unsuitable habitat, increased predation and an inefficient expenditure of energetics (Glebe and Leggett 1981, Larinier 2000, Schilt 2007). Given the location of the proposed powerhouse, it is expected that fish attracted to the new powerhouse will need to travel the additional 250 to 300 feet up the proposed tailrace channel, which dead ends at the draft tube discharge. At this location, unlike at the existing powerhouse, there will be less attraction back to the mainstem Penobscot River. In addition, Black Bear is proposing to route more water down the Stillwater Branch (up to 10%) and concentrate the flow with additional generating facilities. This change in flow characteristics will increase attraction flow, and will likely increase the delay of upstream migrating Atlantic salmon, as well. Fish that are attracted to the bypass reach are expected to be drawn to the proposed fish trap and trucked upstream; however, there are no provisions for trapping fish attracted to the existing or proposed powerhouse tailraces. Therefore, it is likely that some proportion of Atlantic salmon will be significantly delayed (more than 48 hours) at the powerhouses at the Orono Project. In 1988, Shepard (1995) determined that 33% (three out of nine) of the fish that were delayed by the discharge of the powerhouse at the Orono Project were in the tailrace for more than 48 hours. As we consider delay of more than 48 hours as significant, this equates to 15% of upstream migrating adults currently being significantly delayed (33% x the 46% of Atlantic salmon attracted to the discharge of the Orono powerhouse=15%) by the powerhouse discharge at the Orono Project.

According to Black Bear, fish migrations in the lower Penobscot River will not be affected by the new flow reallocation between the Stillwater Branch and mainstem river (BBHP October 7, 2011 letter to FERC). While we believe that the flow reallocation and installation of an additional powerhouse at the Orono Project may increase delay for upstream migrating adults in the lower Penobscot River, we do not have any information to validate this assumption. Therefore, we will assume that significant delay of adults following construction of the new powerhouse at the Orono Project will continue at existing levels. Therefore, we assume that no more than 15% of Atlantic salmon will be delayed significantly (more than 48 hours) by the discharge of the powerhouses at the Orono Project.

Black Bear will deploy telemetry receivers in the tailrace of the new Orono powerhouse, as well as in the bypass reach, to evaluate levels of significant delay. If information is collected during upstream passage studies that indicates that more than 15% of upstream migrating Atlantic salmon are being significantly delayed by the powerhouse discharge at the Orono Project, and Black Bear cannot effectively and expeditiously remedy the situation, then consultation will need to be reinitiated.

As there is no upstream passage into the Stillwater Branch it is anticipated that very few Atlantic salmon will be able to access the area downstream of the Stillwater Project. However, a proportion of Atlantic salmon are known to drop back into the river during their upstream migration. In 2002-2004 and 2010, the proportion of Atlantic salmon that were released into the Veazie headpond that dropped downriver and were recaptured in the Veazie trap ranged between 0.8% and 9.4%, with an average of 5.9% (Holbrook *et al.* 2009, MDMR unpublished data). As much of this fall back may be associated with the handling effects at Veazie, it is a conservative estimate of the proportion of the run that falls back during migration. As there are no upstream passage facilities at Stillwater, all of the salmon that fall back over the Project will need to navigate downstream past the Orono Project in order to either continue their upstream migration in the mainstem, or drop out of the River. Due to the delay associated with the attraction to the discharge at both the Stillwater and Orono Projects, as well as with having to swim down the Stillwater Branch prior to continuing upstream migration in the mainstem, it is expected that 100% of the fish that fall over the Stillwater Project will be significantly delayed (more than 48 hours).

West Branch of the Penobscot River

The West Branch of the Penobscot River is currently inaccessible to anadromous fish because there is no fish passage at the four lowermost dams. This unoccupied watershed is not designated as critical habitat for Atlantic salmon as it was not deemed essential for the recovery of the species (50 CFR Part 226). However, the impassable dams exclude Atlantic salmon from approximately 80,000 units of spawning and rearing habitat within the West Branch (NMFS 2009), or 25% of the potential rearing habitat within the Penobscot drainage. The lower-most of the dams on the West Branch is the Medway Project, which is operated by Black Bear and is one of the projects considered in this Opinion. No upstream passage facilities exist at the Medway Dam, and Black Bear is not proposing to incorporate any into this project as part of this action. Rather, Black Bear has proposed to incorporate a new license article that requires them to meet with us every five years "to ensure that operation of the Medway Project is consistent with the listing determinations for such species and with the then-current recovery objectives for such species" (Filed with FERC on May 15, 2012).

The West Branch above the Medway Project is managed by the State of Maine for resident fishes and catadromous eels. The East Millinocket Dam is 2.9 kilometers upriver of the Medway Project and is the next upstream barrier to migrating fish. The approximately 0.46 square kilometers of habitat between the two projects has been made inaccessible to Atlantic salmon by the lack of passage at the Medway Dam. The habitat is impounded and is, therefore, not currently suitable as rearing or spawning habitat. This reach of river is not currently stocked with Atlantic salmon so there should be no homing of salmon to it. The presence of the dam forces any migrating Atlantic salmon approaching the dam to stray into downstream habitat. NMFS (2012) estimated that approximately 7% of the Atlantic salmon that are returning to their natal habitat in the East Branch of the Penobscot will stray into the West Branch. Due to the lack of upstream passage facilities at the Medway Project, 100% of these fish will be forced to stray back into the East Branch or into the segment of the mainstem between the Medway and Mattaceunk Projects. Between 2002 and 2011, the number of Atlantic salmon passed at the Mattaceunk Project ranged between 37 and 345 (USASAC 2010, 2008, 2005, 2004, 2003). Although no studies exist, some proportion of these fish are attracted to the flow coming out of the West Branch, and will, therefore be subject to some amount of delay downstream of the Medway Project prior to dropping back downriver. Based on the level of delay measured by Shepard (1995) at the Orono Project, it can be estimated that approximately 33% of the fish that approach within 200 meters of the Medway Project may be delayed significantly. Therefore, it can be estimated that 2% (33% x 7%=2%) of the Atlantic salmon that successfully pass the Mattaceunk Project will be delayed significantly in the tailrace of the Medway Project. Black Bear will deploy telemetry receivers at the Medway Project to evaluate levels of significant delay.

While the loss of connectivity to the West Branch is important from the perspective of production potential, the fact that an entire major sub-drainage has been eliminated may further elevate the significance of this loss when viewed from the metapopulation perspective. As with many major tributaries of the Penobscot, the West Branch likely represented a unique combination of watershed level factors (e.g., topography, hydrology, basic water chemistry, and nutrient supply) that distinguished it from the East Branch, Piscataquis, or Mattawamkeag. The importance of having the West Branch available to the GOM DPS metapopulation of salmon, while unknown, could be significant at this broader scale.

6.2.1.2.Downstream Passage Effects

The projects currently affect outmigrating juvenile salmon and kelts by: 1) injury and mortality associated with entrainment through project facilities, 2) delayed outmigration influencing outmigrating timing, 3) potential to increase predation on outmigrating juveniles in project reservoirs, and 4) increasing stress levels, which leads to a subsequent decrease in saltwater tolerance. Under the proposed action, the projects would continue to cause some mortality and injury to downstream migrating smolts and kelts. Although the measures described in the SPP are anticipated to improve downstream fish passage conditions compared to the current conditions, fish mortality and injury would still be lower if the river was free flowing. Reservoirs that are part of the projects alter the conditions that juvenile salmon face as compared to a free flowing condition. The reservoirs alter water quality, eliminate stream channel migratory routes, and alter timing and behavior of outmigrating fish.

The West Enfield, Milford, Stillwater and Orono Projects all operate with some form of downstream fish passage and protection for outmigrating smolts and kelts, including reduced spacing of the trashracks for protection against turbine entrainment and sluice gates or other openings for downstream passage. Since none of the fishways are 100% effective, turbine entrainment, impingement and migratory delays of Atlantic salmon are expected at each dam (Section 3). Therefore, continuing to operate the West Enfield, Milford, Stillwater and Orono Projects will affect downstream movements of Atlantic salmon in the Penobscot River watershed.

Estimates of downstream passage efficiency and smolt survival for projects in the Penobscot vary widely depending on operational and environmental conditions. In 1989, net smolt survival over the three lower river mainstem dams (Milford, Great Works, Veazie) and the intervening habitat was between 30.5% and 61% (Shepard 1991). Smolt studies conducted by Holbrook (2007) documented significant losses of smolts in the vicinity of mainstem dams in the Penobscot River. Of the 355 radio tagged smolts released in 2005, 43% were lost in the vicinity of the West Enfield, Howland, and Milford Dams. In 2006, 60% of tagged smolts (n=291) were lost in the vicinity of the West Enfield, Howland, and Milford Dams.

Estimates of downstream passage efficiency and survival for smolts and kelts through all of the dams on the Penobscot have been modeled by Alden Lab (2012) (Tables 6 and 7). Survival rates were calculated for the range of possible flow conditions. Mean smolt survival rates at Milford, West Enfield, Orono and Stillwater were 91.6%, 92.5%, 90.1% and 91.9%, respectively. Alden Lab also reported minimum smolt survival rates at these projects as 75.6%, 92.3%, 81.6% and 90.5%, respectively. Through the three months of outmigration, Alden indicates that mean survival rates of kelts at all four dams are between 82% and 91%, with the lower values occurring in the month of November. However, kelt survival rates at three of the projects (all except West Enfield) are predicted to fall as low as 65-69%.

Performance Standard

Exact downstream survival rates for smolts and kelts are not known at the Milford, West Enfield, Stillwater and Orono Projects under all operational and environmental conditions. However, the survival rates calculated by Alden Lab (2012) provide an estimate of baseline mortality at these projects under a variety of flows. Under the performance standards described in the SPP, Black Bear will need to achieve a downstream performance standard of 96%, based on a 75% confidence interval, for both smolts and kelts at each of these facilities. In order to be considered to have met the performance standard, downstream passage of a smolt or kelt must occur within 24 hours of approaching within 200 meters of a project's trashracks. Studies will be conducted to evaluate that the performance standard has been met. If the project does not achieve the 96% performance standard, the facility will be modified to increase efficiency, and evaluated again and repeated as necessary to achieve the performance standard. It is assumed that the standard will not be met immediately and that it may take several years before it can be achieved. Therefore, it is assumed that the existing survival rates will persist for a period, not to exceed ten years.

The improvement in survival rates associated with the performance standard will benefit the species by increasing the number of smolts and kelts surviving their outmigration, which in turn will increase the number of adult returns in future years. Meeting the performance standard will increase the minimum survival rate of both smolts and kelts considerably at each individual project (Table 12). The standard will also have a corresponding effect on the total survival of smolts and kelts that migrate through multiple dams in the system (either West Enfield-Stillwater-Orono if the Stillwater Branch path is chosen; or West Enfield-Milford if the mainstem path is chosen). Meeting the performance standard will increase total survival for smolts and kelts swimming through multiple Black Bear Projects by 37.87% and 68.20%, respectively.

Table 12. Anticipated changes in smolt and kelt minimum survival rates due to the implementation of a downstream performance standard. The differences are relative to existing mortality, rather than absolute differences. The mortality rate for fish that swim through multiple dams is based on a median split between the Stillwater Branch and the mainstem Penobscot of 19.7%/80.3% (NMFS 2012, based on Holbrook *et al.* 2011). Existing kelt survival is based on data from Alden Lab (2012), but has been weighted based on 80% of outmigration occurring in the spring and 20% in the fall (Lévesque *et al.* 1985, Baum 1997).

Project	Smolts			Kelts		
	Existing	*SPP*	*Difference*	*Existing*	*SPP*	*Difference*
Milford	75.60%	96.00%	26.98%	68.59%	96.00%	39.97%
West Enfield	92.30%	96.00%	4.01%	90.18%	96.00%	6.45%
Orono	81.60%	96.00%	17.65%	72.00%	96.00%	33.34%
Stillwater	90.50%	96.00%	6.08%	65.84%	96.00%	45.82%
All 4 Dams	**66.15%**	**91.20%**	**37.87%**	**54.22%**	**91.20%**	**68.20%**

As mentioned previously, a proportion of adult pre-spawn Atlantic salmon are known to drop back into the river during their upstream migration. In 2002-2004 and 2010, the proportion of Atlantic salmon that were released into the Veazie headpond that dropped downriver and were recaptured in the Veazie trap ranged between 0.8% and 9.4%, with an average of 5.9% (Holbrook *et al.* 2009, MDMR unpublished data). As much of this fall back may be associated with the handling effects at Veazie, 9.4% represents a conservative estimate of the proportion of the run that falls back during migration. Although Black Bear has not proposed a downstream performance standard for upstream migrants that fall back over a project, it is assumed that the mortality rates associated with downstream passage (Table 12) for the Milford, West Enfield, Stillwater and Orono Projects will apply to these salmon, as well.

6.2.2. Atlantic Salmon Critical Habitat

As discussed in Section 3.2, critical habitat for Atlantic salmon has been designated in the Penobscot River including the sections of river in the vicinity of the Orono, Stillwater, Milford and West Enfield Projects. Within the action area of this consultation, the PCEs for Atlantic salmon include: 1) sites for spawning and rearing; and, 2) sites for migration (excluding marine migration). The analysis presented in the environmental baseline shows several habitat indicators are not properly functioning, and biological requirements of Atlantic salmon are not being met in the action area. We expect that the proposed project would continue to harm these already impaired habitat characteristics. We expect the continued operations of these projects to cause adverse effects to some essential features of critical habitat, including water quality, substrate, migration conditions, and forage in a similar manner as present in the environmental baseline. However, designated critical habitat in the Penobscot River watershed is anticipated to improve for Atlantic salmon with the implementation of the performance standards outlined in the proposed SPP. Operation of the projects pursuant to the amended licenses is expected to achieve these performance standards by 2023. At this time, effects of hydroelectric operations to the migration PCE will be reduced by improving survival rates and reducing delay for both upstream and downstream migrating Atlantic salmon.

The Stillwater Branch has been designated as critical habitat for the GOM DPS of Atlantic salmon. It runs along the west side of Orson and Marsh Islands before flowing back into the mainstem. Although there is a small amount of spawning and rearing habitat in this branch of the river, the Stillwater primarily functions as a migration corridor for outmigrating smolts and kelts, and would be used by Atlantic salmon migrating to upstream spawning habitat if there weren't any barriers. Therefore, the continuation of the impassable conditions at the Orono and Stillwater Projects significantly affects the migratory PCE within the Stillwater Branch. Although migration upriver is not halted, the lack of passage facilities contributes to migratory delay by forcing migrating salmon attracted to the flow out of the Stillwater Branch to drop back into the mainstem before continuing their migration.

The lack of upstream passage at the Orono Project prevents access to the Stillwater Branch, not only for Atlantic salmon, but also for other diadromous fish species, such as alewives, blueback herring and shad. One of the essential features that is described for the migration PCE refers to the need for diverse native fish communities that serve as a protective buffer against predation. Thus, the lack of upstream passage for these species at the projects on the Stillwater Branch diminishes the functioning of the habitat within the Stillwater Branch of the River. The proposed project will not reduce this effect.

6.2.3. Shortnose and Atlantic Sturgeon

It is believed that, historically, prior to dam construction, shortnose and Atlantic sturgeon ranged only as far as the site of the Orono Project on the Stillwater Branch and the Milford Project on the mainstem Penobscot River (L. Flagg, MDMR, personal communication 1998, Houston *et al.* 2007). Since historical data on sturgeon habitat use in the river is lacking, NMFS assumes that Penobscot River sturgeon have migration patterns and habitat uses consistent with other northeastern rivers. As such, spawning would occur at the most upstream accessible area, which in the Penobscot will be Milford Falls. In many rivers, shortnose sturgeon have two overwintering concentration areas, with an upstream site closest to the spawning grounds used by pre-spawners and a more downstream site used by non-spawning adults and juveniles. Juvenile shortnose sturgeon are typically concentrated in the area above the freshwater-saltwater interface, which prior to dam construction occurred above the Veazie Dam. Atlantic sturgeon are more tolerant of salinity and, thus, overwinter in the lower estuary or coastal ocean, while the juveniles tend to occur in low salinity waters of the natal estuary.

6.2.3.1. Upstream Passage

As explained above, the Veazie Dam currently represents the first barrier to upstream migration to shortnose and Atlantic sturgeon. After the removal of the Veazie and Great Works Projects, the Milford Dam, on the mainstem, and the Orono Dam, on the Stillwater Branch, will be the lowermost dams on the Penobscot, and will be accessible to sturgeon. Some proportion of

Atlantic and shortnose sturgeon are anticipated to be trapped at the new fish lifts being constructed at these projects. Pursuant to the requirements of the amended operating licenses, all shortnose and Atlantic sturgeon that are trapped will be handled according to Black Bear's sturgeon handling plan, and will be released downstream of the projects.

Limited information is available on the use of fish passage facilities by sturgeon generally. Ladders are installed at several hydroelectric facilities in the northeast where shortnose and Atlantic sturgeon are known to occur, including the Brunswick Dam on the Androscoggin River, Cabot Station on the Connecticut River and the Veazie Dam on the Penobscot River. Despite extensive monitoring programs at these facilities, no shortnose or Atlantic sturgeon have ever been documented using the ladders. The only documented use of a fish ladder by a sturgeon in the northeast is one shortnose sturgeon that was documented in the Denil ladder at the DSI dam on the Deerfield River, a tributary to the Connecticut River.

Fish lifts may be more successful at passing sturgeon. The fish lift at the Holyoke Dam on the Connecticut River passed 127 shortnose sturgeon over a 31- year period (1980-2011) (Ducheney *et al.* 2006, R. Murray, Holyoke Gas and Electric, personal communication, 2012). Between 0 and 16 shortnose sturgeon were trapped per year throughout that period, averaging approximately four fish per year. As many more shortnose sturgeon were observed annually downriver of the Holyoke Dam, the trapping of so few fish indicates poor passage efficiency and/or a lack of motivation to move upriver. As spawning habitat in the Connecticut River occurs upriver of the Holyoke Dam, the fish are likely more motivated to move upriver of the dam than they would be in a river where they have full access to their historic spawning habitat. Comparatively, shortnose sturgeon have never been trapped at the lowermost dam (Lockwood) in the Kennebec River where sturgeon have access to the entirety of their historic habitat.

Given sturgeon capture rates at fish lifts on the Kennebec and Connecticut Rivers, it is anticipated that very few shortnose sturgeon will be trapped at the Milford and Orono Projects. An average of four fish per year were trapped at the Holyoke Dam over a thirty-one year period. As shortnose sturgeon population estimates for the lower Connecticut River and the Penobscot River are similar (Connecticut: 1000 (Savoy 2005); Penobscot: 602-1654) it is anticipated that a similar number of fish will be captured at the Milford and Orono Dams. Four shortnose sturgeon a year is a conservative estimate given that, unlike in the Connecticut, sturgeon in the Penobscot will have access to their historic range in the Penobscot River after the removal of the Great Works and Veazie Dams and, thus, may be less motivated to move upriver. As sturgeon prefer deeper water for their migrations most will likely stay in the mainstem, rather than enter the Stillwater Branch. Therefore, it is expected that three of the four sturgeon captured every year would become trapped in the Milford fish trap, whereas only one per year would be expected to be trapped at the Orono Project.

Similar to shortnose sturgeon, Atlantic sturgeon are rarely found to use fishways. In the 31 years that records have been kept at the Holyoke Project, only a single Atlantic sturgeon has ever been trapped in the fishway. This may not be representative of what would occur at the proposed Orono and Milford fish traps, because, unlike in the Penobscot, it is not thought that Atlantic sturgeon would spawn in the Connecticut River. However, the fact that no Atlantic sturgeon have ever been trapped at the Lockwood Project on the Kennebec River, where there is a spawning population, would support the conclusion that few would be caught in fish traps on the Penobscot River. Given the low usage of fish traps by Atlantic sturgeon in the northeast, it is anticipated that no more than one Atlantic sturgeon will be trapped at the Milford and Orono Projects per project per year, which equates to 25 and 35 fish, respectively, over the term of the existing licenses.

As sturgeon do not occur in the vicinity of the Stillwater, West Enfield and Medway Projects, operations at these projects will not affect upstream movements of either species of sturgeon.

6.2.3.2.Downstream Effects

With the removal of the Veazie and Great Works Dams, the range of shortnose and Atlantic sturgeon in the Penobscot River will extend to the foot of the Milford Dam, on the mainstem, and the Orono Dam, on the Stillwater Branch, which are likely the historic upstream limits for both species. Sturgeon will not be passed upstream of these projects; therefore, there will be no effects to the species associated with downstream passage. However, the operations of these projects could affect sturgeon occurring downstream of these facilities.

While spawning by shortnose and Atlantic sturgeon in the Penobscot River has not been confirmed, it is possible. Thus, it is thought that with the removal of the two lowermost dams, these species will regain access to their historic spawning grounds in the river. Optimal shortnose sturgeon spawning habitats are in freshwater, but usually within areas of tidal influence, in deep water where the predominate substrate type is a combination of gravel, rubble, and cobble and water velocities are between 30 and 76 centimeters per second (cm/s) (Crance 1986). In the Merrimack River, telemetry studies revealed that spawning males occurred in water 2.3-5.8 m deep (Kieffer and Kynard 1996) and in the Connecticut River, radio-tagged females used spawning depths of 1.2-10.4 m deep (Buckley and Kynard 1985, Kynard 1997). Spawning for Atlantic sturgeon is believed to occur in flowing water between the salt front of estuaries and the fall line of large rivers, when and where optimal flows are 46-76 cm/s and depths are 3-27 meters (Borodin 1925, Dees 1961, Leland 1968, Scott and Crossman 1973, Crance 1987, Shirey *et al.* 1999, Bain *et al.* 2000, Collins *et al.* 2000, Caron *et al.* 2002, Hatin *et al.* 2002, ASMFC 2009).

The habitat downstream of the Orono Project consists primarily of ledge with a relatively high gradient and relatively shallow water depths (one to two feet). Given these characteristics the bypass reach is an unlikely location for sturgeon spawning. Due to the presence of deeper water and more variable substrate types, however, portions of the habitat downriver of the Milford Project may be more suitable. Both the Milford and Orono Projects operate as run of river facilities, which will minimize the scouring of habitats and the likelihood of pulsed discharges that could result in the stranding of adult or early life stage Atlantic and shortnose sturgeon. Based on this, we do not expect that operations of Milford or Orono will affect the ability of shortnose or Atlantic sturgeon to spawn successfully in the vicinity of these projects or that the operation of these projects will affect the successful development of early life stages of shortnose or Atlantic sturgeon that may be present in the action area.

Once a year, the impoundments of Orono and Milford are lowered to a point where the flashboards can safely be replaced, resulting in a short period (a few hours) of receded flows downstream. This typically occurs in the month of June. Although minimum flows will still be maintained, there is potential during these low flow periods for sturgeon to become stranded in pools. The Milford Project does not have a bypass reach, which means that although water levels may decrease during this period there aren't any areas that are anticipated to dry out entirely and few pools, if any, are anticipated to become isolated. Therefore, no shortnose and Atlantic sturgeon are expected to become stranded at the Milford Project.

The Orono Project has a bypass reach that could become partially dewatered during flashboard replacement, which could result in the stranding of a small number of sturgeon. As the flashboards are typically replaced in June, and sturgeon spawning generally occurs between March and May, it is anticipated that no pre-spawn sturgeon are likely to be stranded. As sturgeon tend to move downstream once spawning is complete, very few adults are likely to be in the area when the flashboards are being replaced. Given that the habitat in the Orono bypass reach is not suitable for spawning, it is not expected that any sturgeon eggs or juveniles will occur in the affected area. However, it is possible that a small number of adult Atlantic and shortnose sturgeon could be attracted to the flow out of the Stillwater Branch and make their way into the Orono bypass reach, where they could potentially become stranded during flashboard replacement. It is expected that no more than one shortnose sturgeon or Atlantic sturgeon per year (equates to 35 individuals per species over the term of the license), will be affected by stranding. To minimize this effect, qualified staff from Black Bear will conduct surveys and will carefully transport any stranded sturgeon downriver as described in their proposed sturgeon handling plan. These fish would be subject to stress from stranding and handling similar to the sturgeon trapped in the proposed fish trap and lift at Orono; however, any injuries experienced are expected to be minor and consist of scrapes and abrasions. No significant injuries or mortalities are anticipated.

6.3. Effects of Fish Handling

6.3.1. Trapping and Handling of Atlantic Salmon

Trapping, handling and trucking fish causes them stress. The primary contributing factors to stress and death from handling are excessive doses of anesthetic, differences in water temperatures (between the river and wherever the fish are held), dissolved oxygen conditions, the amount of time that fish are held out of the water, and physical trauma. Stress on Atlantic salmon increases rapidly from handling if the water temperature is too warm or dissolved oxygen is below saturation. Fish that are transferred to holding tanks can experience trauma if care is not taken in the transfer process, and fish can experience stress and injury from overcrowding in traps that are not emptied on a regular basis. Debris buildup at traps can also kill or injure fish if the traps are not monitored and cleared on a regular basis.

With the removal of the fish trapping and handling facility at the Veazie Project, the majority of Atlantic salmon migrating upriver in the Penobscot River will swim through the upstream passage facilities at the Milford Project. These fish will be trapped and then released upstream of the Milford Project, or will be taken to Green Lake National Fish Hatchery to be used as broodstock. The handling and trucking of these fish will be conducted by MDMR, which holds a section 10(a)(1)(A) research permit under the USFWS's regional endangered species blanket permit (No. 697823) which authorizes the handling of listed Atlantic salmon. Therefore, the effects of handling and transporting are not considered as part of the proposed action. However, all migrating adult Atlantic salmon in the mainstem will be affected by the Project as they will be trapped and potentially delayed by the dam and its fish passage facilities.

Migrating Atlantic salmon are anticipated to be trapped at both the Milford and Orono Projects. The vast majority of migrating adult Atlantic salmon is anticipated to migrate up the mainstem and, thus, get trapped and passed at the Milford Project. However, we anticipate that a small proportion of the Atlantic salmon run will be attracted to and trapped within the proposed fish trap at the Orono Dam. The salmon trapped at Orono will be placed into trucks and transported upriver of the Milford Project on the mainstem. Black Bear is responsible for the handling and transport of fish over short distances. Long-distance transport, such as to the hatchery, will be conducted by MDMR. In either case, it is anticipated that Black Bear will be responsible for the operation and maintenance of the new fish lift, which is anticipated to affect every Atlantic salmon that enters the lift or that is delayed in its migration by the Project. MDMR maintains a database of adult Atlantic salmon mortalities attributable to trapping and trucking from the Veazie fish trap. Between 1978 and 2011, the median mortality rate for adult Atlantic salmon trapped at the Veazie Dam was 0.07%. In a typical year, between zero and four salmon are killed during trapping and transportation at the Veazie Project. Similar levels of mortality are anticipated at the Milford Project, while fewer are likely to be killed at the Orono Project. Although there are no records of injuries in the MDMR database, it is assumed that a larger proportion of trapped and trucked Atlantic salmon suffer from injuries than mortality and that some of these injuries may lead to delayed mortality.

6.3.2. Trapping and Handling of Sturgeon

Atlantic and shortnose sturgeon could be trapped in the fish lifts at the Milford and Orono Projects. Although the location of spawning habitat in the Penobscot is unknown, it is assumed that it would occur downriver of the Milford and Orono projects as these are the historic upstream limits for both species. As the spawning habitat in the Penobscot is anticipated to be below the Milford Falls (the site of the Milford Project), it is unlikely that sturgeon will be motivated to pass the projects. However, it is possible that a few sturgeon per year will be attracted to flow from the spillway at Orono, or the powerhouse discharge at Milford, and become trapped. These fish will be handled as proposed in the sturgeon handling plan (Sections 2.1.2.5 and 2.3.2.4), and will be released downriver of the projects as soon as possible. They will not be transported in trucks and the handling will be minimized to the extent possible.

As described above, when flashboards are replaced at the Orono and Milford Projects, or other operations cause no-spill or no-leakage conditions, there is a possibility that sturgeon may become stranded in pools below the dams. When these activities occur trained Black Bear staff will survey isolated pools downstream and transport trapped fish back into the river. Handling time is anticipated to be minimal; therefore, it is anticipated that all sturgeon will be moved back to the river without significant injury or mortality.

6.3.3. Effects of Aquatic Monitoring and Evaluation

Under the proposed action, numerous measures will be implemented to minimize project effects on Atlantic salmon passage in the Penobscot River. These measures include the construction of upstream and downstream fish passage facilities and performance standards that were incorporated in a SPP. In order to determine the effectiveness of the performance measures, Black Bear proposes to conduct downstream survival studies at the Orono, Stillwater, Milford and West Enfield Projects, as well as upstream effectiveness studies at the Milford and West Enfield Projects.

Proposed Studies

The downstream smolt survival studies will involve obtaining Atlantic salmon smolts from GLNFH, surgically implanting radio transmitter tags, and then conducting paired releases in groups up and downriver of each of the projects. The handling and implantation of radio tags will injure all of the fish used in the studies, and a small proportion will likely be killed.

Upstream passage efficiency studies will be conducted using adult Atlantic salmon trapped either at the Veazie Dam (prior to its removal) or at the Milford Dam. The adult fish will be gastrically implanted with a radio telemetry tag prior to being placed downstream of the project. The handling and implantation of radio tags will injure all of the fish used in the studies.

Under the SPP, Black Bear will monitor and evaluate the effectiveness of various measures outlined in the SPP to determine if performance standards for upstream and downstream passage have been met. Studies on outmigrating smolts will be conducted after each measure in Figure 2 is implemented. The study period after each measure is three years. An initial three-year study will be conducted, potentially followed by the sequential implementation of three different performance measures if the standard has not been met. This means that there is the potential for smolt studies to be conducted for ten consecutive years at the Orono, Stillwater, Milford and West Enfield Projects. After the downstream performance standard has been achieved at each project, a one year verification study will be conducted every ten years thereafter. Given the license terms of these projects, these verification studies will add an additional study year to Milford (license expires in 2038), and two more years to both the Stillwater and Orono Projects (license expires in 2048). After the first or second year of each three year study, Black Bear may decide to implement the next measure in the sequence, rather than completing the three year study. Therefore, it is anticipated that ten to twelve years represents a conservative estimate of the number of years under which the projects will be studied for downstream smolt passage. Table 13 shows the anticipated number of smolts used at each project per year of study. In addition to the fish being used in the survival studies, Black Bear has proposed to conduct tag life and retention studies on 40 smolts each year that monitoring occurs. Including these additional fish, it is conservatively estimated that 7,050 smolts will be tagged and released as part of monitoring downstream passage success at all four of the projects.

Table 13. The number of salmon smolts that are anticipated to be affected by downstream survival studies conducted to test the performance measures described in the SPP.

Project	Smolts Per Year	# Years	Total

	Experiment	*Control*		
Milford	102	60	11	1782
West Enfield	102	60	10	1620
Orono	0	60	12	720
Stillwater	102	102	12	2448
Tag life/Retention	40		12	480
Total				**7050**

During upstream monitoring of fishways at the Milford and West Enfield projects, 20 to 40 pre-spawn adults a year will have radio tags gastrically implanted prior to release downstream of Milford. The initial study (two years) will only test the Milford Project, however, a verification study will be conducted at both the Milford and West Enfield Projects every ten years after the project licenses have been amended until the expiration of their current licenses. Therefore, Milford (license expires in 2038) will be tested for four years (2013, 2014, 2024, 2034) during the term of this consultation, whereas, West Enfield (license expires in 2024) will only be tested for one year (2023). As a maximum of 40 fish will be used to study passage efficiency in four different years over the term of this consultation, it is expected that as many as 200 adult Atlantic salmon could be trapped, handled and tagged as part of the proposed studies.

Ten years after completion of the final enhancements for smolt outmigration outlined in the SPP, Black Bear will conduct a study to provide verification that kelts moving downstream meet the 96% downstream performance standard. Black Bear indicates that the study would coincide with smolt monitoring, would involve using tagged male kelts, and would evaluate monitoring passage at the Orono, Stillwater, Milford, and West Enfield Projects. We believe that a maximum of 40 post-spawn Atlantic salmon should be used per project per year over three years in order to verify that the performance standard has been achieved. Although a larger sample size would provide for a more statistically sound result, adult salmon are a critically valuable resource for restoring salmon populations and, therefore, the number of affected individuals should be minimized to the extent possible. The three year study would require the use of a maximum of 480 post-spawn male Atlantic salmon (four projects x 40 fish x three years = 480 fish). No follow-up studies have been proposed at this time.

Tagging

Techniques such as PIT tagging, coded wire tagging, fin-clipping, and the use of radio transmitters are common to many scientific research efforts using listed species. All sampling, handling, and tagging procedures have an inherent potential to stress, injure, or even kill the marked fish. Radio telemetry will be used as the primary technique for the proposed studies.

There are two techniques used to implant fish with radio tags and they differ in both their characteristics and consequences. First, a tag can be inserted into a fish's stomach by pushing it past the esophagus with a plunger. Stomach insertion does not cause a wound and does not interfere with swimming. This technique is benign when salmon are in the portion of their spawning migrations during which they do not feed (Nielsen 1992). In addition, for short-term studies, stomach tags allow faster post-tagging recovery and interfere less with normal behavior than do tags attached in other ways. This is the technique that Black Bear proposes to use on adult Atlantic salmon for the upstream passage studies.

The second method for implanting radio tags is to surgically place them within the body cavities of (usually juvenile) salmonids. These tags do not interfere with feeding or movement. However, the tagging procedure is difficult, requiring considerable experience and care (Nielsen 1992). Because the tag is placed within the body cavity, it is possible to injure a fish's internal organs. Infections of the sutured incision and the body cavity itself are also possible (Chisholm and Hubert 1985, Mellas and Haynes 1985). This is the technique that Black Bear proposes to use on Atlantic salmon smolts for the downstream passage studies.

Fish with internal radio tags often die at higher rates than fish tagged by other means because radio tagging is a complicated and stressful process. Mortality is both acute (occurring during or soon after tagging) and delayed (occurring long after the fish have been released into the environment). Acute mortality is caused by trauma induced during capture, tagging, and release. It can be reduced by handling fish as gently as possible. Delayed mortality occurs if the tag or the tagging procedure harms the animal in direct or subtle ways. Tags may cause wounds that do not heal properly, may make swimming more difficult, or may make tagged animals more vulnerable to predation (Howe and Hoyt 1982, Matthews and Reavis 1990, Moring 1990). Tagging may also reduce fish growth by increasing the energetic costs of swimming and maintaining balance.

All fish used in the proposed studies will be subject to handling by one or more people. There is an immediate risk of injury or mortality and a potential for delayed mortality due to mishandling. Those same fish that survive initial handling will also be subject to tag insertion for identification purposes during monitoring activities. It is assumed that a 100% of the fish that are handled and tagged will suffer injury, and some of these will die due to immediate and long term effects of being trucked, handled and tagged.

All 7,050 Atlantic salmon smolts used in the downstream survival studies will be harassed and injured. In addition, a proportion of the smolts are anticipated to be killed due to handling and tagging, as well as to the direct and indirect effects associated with dam passage. There is some variability in the reported level of mortality associated with tagging juvenile salmonids. NMFS did not document any immediate mortality while tagging 666 hatchery reared juvenile Atlantic salmon between 1997 and 2005 prior to their release into the Dennys River. After two weeks of being held in pools, only two (0.3%) of these fish were subject to delayed mortality. Over the same timeframe, NMFS surgically implanted tags into wild juvenile Atlantic salmon prior to their release into the Narraguagus River. Of the 679 fish tagged, 13, or 1.9%, died during surgery (NMFS, unpublished data). It is likely there were delayed mortalities as a result of the surgeries, but this could not be quantified because fish were not held for an extended period. In a study assessing tagging mortality in hatchery reared yearling Chinook salmon, Hockersmith *et al.* (2000) determined that 1.8% (20 out of 1,133) died after having radio tags surgically implanted. Given this range of mortality rates, it is anticipated that no more than 2% of Atlantic salmon smolts will be killed due to handling and tagging during the proposed downstream monitoring over ten years of study. The proportion of smolts anticipated to be injured and killed due to the effects of downstream passage is addressed in Section 6.2.1.2.

All adult salmon used in the upstream and downstream passage studies will be harassed and injured due to handling and tagging. However, long term effects of handling and tagging on adult salmon appear to be negligible. Bridger and Booth (2003) indicate that implanting tags gastrically does not affect the swimming ability, migratory orientation, and buoyancy of test fish. The primary disadvantage of gastrically implanted tags is that fish are often unable to feed while the tags are in their stomachs. As pre-spawn adult Atlantic salmon do not feed (Fay *et al.* 2006), this should not significantly affect the tagged individuals. Due to handling and tag insertion, it is possible that a small proportion of the study fish will be killed due to delayed effects. In a study of adult sockeye salmon in Alaska, it was determined that 2% (one out of 59 fish) of adults tagged with esophageal radio tags died within 33-days of tagging (Ramstad and Woody 2003). Assuming a similar rate with Atlantic salmon, it can be anticipated that 2% of the 200 study fish (or four fish) could be subject to mortality due to upstream passage monitoring activities at the West Enfield and Milford Projects over several years of study. Likewise, it is anticipated that 2% of the, at most, 480 kelts used in the downstream study (approximately three fish per project) could die due the effects of handling and tagging. Mortalities are expected to be minimized by having trained professionals conduct the procedures using established protocols.

7. CUMULATIVE EFFECTS

Cumulative effects are defined in 50 CFR §402.02 as those effects of future state or private activities, not involving Federal activities, that are reasonably certain to occur within the action area of the Federal action subject to consultation.

The effects of future state and private activities in the action area that are reasonably certain to occur are continuation of recreational fisheries, discharge of pollutants, and development and/or construction activities resulting in excessive water turbidity and habitat degradation.

Impacts to shortnose sturgeon, Atlantic sturgeon and Atlantic salmon from non-federal activities are largely unknown in the Penobscot River. It is possible that occasional recreational fishing for anadromous fish species may result in incidental takes of these species. There have been no documented takes of shortnose sturgeon from fisheries in the action area although one Atlantic sturgeon was captured by an angler in 2005. The operation of these hook and line fisheries and other fisheries could result in future sturgeon or Atlantic salmon mortality and/or injury.

In December 1999, the State of Maine adopted regulations prohibiting all angling for sea-run salmon statewide. A limited catch-and-release fall fishery (September 15 to October 15) for Atlantic salmon in the Penobscot River was authorized by the MASC for 2007. The fishery was closed prior to the 2009 season. Despite strict state and federal regulations, both juvenile and adult Atlantic salmon remain vulnerable to injury and mortality due to incidental capture by recreational anglers and incidental catch in commercial fisheries. The best available information indicates that Atlantic salmon are still incidentally caught by recreational anglers. Evidence suggests that Atlantic salmon are also targeted by poachers (NMFS 2005). Commercial fisheries for elvers (juvenile eels) and alewives may also capture Atlantic salmon as bycatch. No estimate of the numbers of Atlantic salmon caught incidentally in recreational or commercial fisheries exists.

Pollution from point and non-point sources has been a major problem in this river system, which continues to receive discharges from sewer treatment facilities and paper production facilities (metals, dioxin, dissolved solids, phenols, and hydrocarbons). Contaminants introduced into the water column or through the food chain, eventually become associated with the benthos where bottom dwelling and feeding species like shortnose and Atlantic sturgeon are particularly vulnerable. Atlantic salmon are also vulnerable to impacts from pollution and are also likely to continue to be impacted by water quality impairments in the Penobscot River and its tributaries.

Contaminants associated with the action area are directly linked to industrial development along the waterfront. PCBs, heavy metals, and waste associated with point source discharges and refineries are likely to be present in the future due to continued operation of industrial facilities. In addition many contaminants such as PCBs remain present in the environment for prolonged periods of time and thus would not disappear even if contaminant input were to decrease. It is likely that shortnose sturgeon, Atlantic sturgeon and Atlantic salmon will continue to be affected by contaminants in the action area in the future.

Industrialized waterfront development will continue to impact the water quality in and around the action area. Sewage treatment facilities, manufacturing plants, and other facilities present in the action area are likely to continue to operate. Excessive water turbidity, water temperature variations and increased shipping traffic are likely with continued future operation of these facilities. As a result, shortnose and Atlantic sturgeon foraging and/or distribution in the action area may be adversely affected.

Sources of contamination in the action area include atmospheric loading of pollutants, stormwater runoff from development, groundwater discharges, and industrial development. Chemical contamination may have an effect on listed species reproduction and survival.

As noted above, impacts to listed species from all of these activities are largely unknown. However, we have no information to suggest that the effects of future activities in the action area will be any different from effects of activities that have occurred in the past.

8. INTEGRATION AND SYNTHESIS OF EFFECTS

In the discussion below, we consider whether the effects of the proposed action reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of the listed species in the wild by reducing the reproduction, numbers, or distribution of the GOM DPS of Atlantic salmon, shortnose sturgeon and the NYB and GOM DPSs of Atlantic sturgeon. The purpose of this analysis is to determine whether the proposed action, in the context established by the status of the species, environmental baseline, and cumulative effects, would jeopardize the continued existence of the GOM DPS of Atlantic salmon, shortnose sturgeon and the NYB and GOM DPSs of Atlantic sturgeon. In addition, the analysis will determine whether the proposed action will adversely modify designated critical habitat for Atlantic salmon.

In the NMFS/USFWS Section 7 Handbook, for the purposes of determining jeopardy, survival is defined as, "the species' persistence as listed or as a recovery unit, beyond the conditions leading to its endangerment, with sufficient resilience to allow for the potential recovery from endangerment. Said in another way, survival is the condition in which a species continues to exist into the future while retaining the potential for recovery. This condition is characterized by a species with a sufficient population, represented by all necessary age classes, genetic heterogeneity, and number of sexually mature individuals producing viable offspring, which exists in an environment providing all requirements for completion of the species' entire life cycle, including reproduction, sustenance, and shelter."

Recovery is defined as, "Improvement in the status of listed species to the point at which listing is no longer appropriate under the criteria set out in section 4(a)(1) of the Act." Below, for the GOM DPS of Atlantic salmon, shortnose sturgeon and the NYB and GOM DPSs of Atlantic sturgeon, the listed species that may be affected by the proposed action, we summarize the status of the species and consider whether the proposed action will result in reductions in reproduction, numbers or distribution of that species and then considers whether any reductions in reproduction, numbers or distribution resulting from the proposed action would reduce appreciably the likelihood of both the survival and recovery of that species, as those terms are defined for purposes of the Federal Endangered Species Act.

We have determined that the proposed action will result in harm or harassment to Atlantic salmon, shortnose sturgeon and Atlantic sturgeon in the action area. While lethal injuries and/or mortalities are being reduced by adhering to construction BMPs and the provisions of the SPP, it is anticipated that some Atlantic salmon will be injured or killed as a result of the continued operations of the five hydroelectric projects considered in this Opinion. Whereas, no Atlantic sturgeon or shortnose sturgeon are expected to be injured or killed by the action.

8.1. Atlantic Salmon

GOM DPS Atlantic salmon currently exhibit critically low spawner abundance, poor marine survival, and are confronted with a variety of additional threats. The abundance of GOM DPS Atlantic salmon has been low and either stable or declining over the past several decades. The proportion of fish that are of natural origin is extremely low (approximately 6% over the last ten years) and is continuing to decline. The conservation hatchery program assists in slowing the decline and helps stabilize populations at low levels, but has not contributed to an increase in the overall abundance of salmon and has not been able to halt the decline of the naturally reared component of the GOM DPS.

We recognize that the operation of the Orono, Stillwater, Milford, West Enfield and Medway Projects pursuant to amended licenses that incorporate the proposed SPP and its associated performance measures will lead to an improvement in upstream and downstream passage for Atlantic salmon as compared to current operations. However, the projects will continue to affect the abundance, reproduction and distribution of salmon in the Penobscot River by delaying, injuring and killing upstream migrating pre-spawn adults, as well as outmigrating smolts and kelts. While FERC will require that Black Bear implement several measures to reduce adverse impacts of project operation, all Atlantic salmon in the Penobscot River watershed will be adversely affected by continued operations of these facilities.

Summary of Construction Effects

The construction of new powerhouses at the Stillwater and Orono Projects, as well as new fish lifts at the Orono and Milford Projects, will cause short-term impacts to Atlantic salmon when exposed to increased suspended sediments concentrations and increased underwater noise levels in the action area. The proposed action includes certain measures that should reduce the adverse effects of instream work on listed species and critical habitat; including erosion and sedimentation control BMPs, noise minimization techniques, and the timing of in-water work to avoid the smolt migration.

The isolation of riverine habitat within a cofferdam minimizes the overall adverse effects of construction activities on Atlantic salmon and their habitat because it reduces exposure to in-water construction activities. However, isolating the work area within a cofferdam could lead to negative impacts on fish if any are trapped within the isolated work area. In order to minimize the probability of entrapping an adult Atlantic salmon within the work area, a visual survey of these areas will be conducted by qualified personnel to verify that there are no salmon within the project area prior to and during the installation and removal of any in-water bypass structure, including cofferdams. If Atlantic salmon are found within a cofferdam, they will be removed and returned to the River prior to dewatering. As the cofferdams will be 1) constructed at the end of the upstream migration period in 2012 when only a small proportion of the salmon run will still be migrating through the mainstem of the Penobscot, and 2) constructed within the Stillwater Branch where very few salmon are likely to occur, it is expected that no more than one adult salmon per project will be harmed due to capture and handling at the Orono and Stillwater Projects. Capturing and handling salmon causes physiological stress and can cause physical injury although these effects can be kept to a minimum through proper handling procedures. The fish evacuation plan should minimize such stresses by requiring minimal handling time; minimal time that fish are held out of the water; and using transfer containers with aerated stream water of ambient temperature. Impacts to Atlantic salmon will be further minimized by requiring that only qualified biologists handle the fish. Given these minimization efforts, it is not expected that there will be any injury or mortality associated with cofferdam construction.

Summary of Upstream Passage Effects

Atlantic salmon are known to successfully utilize upstream fishways in the Penobscot River. However, even when operated pursuant to the amended licenses, none of the projects will be 100% effective at passing all Atlantic salmon that are motivated to access habitat upriver. Adult salmon that are not passed at the Milford and West Enfield Projects will either spawn in downstream areas, return to the ocean without spawning, or die in the river. These salmon are significantly affected by the stress, injury and mortality associated with locating and successfully passing fishways at the Milford, Orono and West Enfield Projects. Although no studies have looked directly at the fate of fish that fail to pass through upstream fish passage facilities on the Penobscot River, we convened an expert panel in 2010 to provide the best available information on the fate of these fish. The panel was comprised of state, federal, and private sector Atlantic salmon biologists and engineers with expertise in Atlantic salmon biology and behavior at fishways. The group estimated a baseline mortality rate of 1% for Atlantic salmon that fail to pass a fishway at a given dam on the Penobscot River (NMFS 2011, Appendix B). Dams that do not have fishways were not considered to have baseline mortality, as fish are not subject to the stresses of upstream passage (although they may be subjected to significant delays). Additional mortality was assumed based on project specific factors, such as predation, fish handling, high fall back rates, lack of thermal refugia, etc. Based on these assumptions, the panel estimated existing mortality rates for Atlantic salmon that fail to pass the Milford, West Enfield and Orono Projects of 1%, 2% and 0%, respectively. Due to the proposal to install a handling facility at Milford and a trap at Orono, the proposed project is anticipated to increase those rates to 2% and 1%, respectively.

Based on the expert panel's conclusions, it is anticipated that a small proportion of pre-spawn Atlantic salmon that currently approach the Milford and West Enfield Projects are killed while attempting passage. It is assumed for this analysis that the existing passage rates will be maintained until the achievement of the performance standard has been demonstrated through passage studies. Therefore, the projects will be considered to operate under two conditions: the current condition, and the SPP performance standard condition (i.e., operations pursuant to the amended licenses). The upstream performance standard, once achieved, is anticipated to significantly decrease the proportion of salmon killed in their passage attempt, as proportionally more salmon are passed.

As they currently lack upstream fish passage facilities, it is assumed that 100% of Atlantic salmon that approach the Stillwater, Medway and Orono Projects experience significant adverse effects due to delay or alteration in spawning behavior. As no upstream passage facilities are proposed at the Stillwater or Medway Projects, these conditions will continue to be experienced even when FERC issues amended licenses. Therefore, these adverse effects will continue during the entirety of the period that the Stillwater and Medway Projects will operate. The construction of a new fish trap may minimally alleviate these effects in the Orono Project's bypass reach. However, the purpose of the Orono fish trap is not to serve as a traditional fishway, but rather as an evacuation device that will remove fish that are attracted to the spillage in the Orono bypass reach. We will consider the Orono trap to be effective if 95% of the Atlantic salmon that enter the bypass reach are either trapped by the new fish trap or migrate volitionally out of the bypass reach within 48 hours. As described above, up to 1% of the fish that fail to exit the bypass reach within 48 hours will die. The remaining fish will suffer from the effects of significant delay, but are expected to eventually drop down into the mainstem and will either continue their upstream migration or will drop downriver and spawn in potentially less suitable habitat.

The existence of all of Black Bear's projects in the Penobscot River results in a certain amount of delay in upstream migration. Numerous studies collectively report a wide range in time needed for individual adult salmon to pass upstream of various dams once detected in the vicinity of a spillway or tailrace. The yearly pooled median passage time for adults at Milford Dam ranged from 1.0 days to 5.3 days over five years of study, while the total range of individual passage times over this study period was 0.1 days to 25.0 days. The yearly pooled median passage time for adults at the West Enfield or Howland Dam ranged from 1.1 days to 3.1 days over four years of study, while the total range of individual passage times over this study period was 0.9 days to 61.1 days (Shepard 1995). When the projects are operating pursuant to the amended licenses, delay at the Milford and West Enfield projects should be reduced. When operating in compliance with the upstream performance standard, 95% of salmon will pass these projects within 48 hours of approaching within 200 meters of either of these projects; thus, only 5% will experience significant delays (*i.e.*, greater than 48 hours).

There is no upstream performance standard proposed for the Orono Project on the Stillwater Branch. As addressed previously, Shepard (1995) determined that in 1988 and 1989, 46% of adult salmon that were passed upriver of the Veazie Dam were attracted to the existing powerhouse discharge at the Orono Project for a median of 8.30 hours in 1988 and 2.18 hours in 1989. The duration of the delay in 1988 ranged between 0.3 hours to 247.4 hours. This delay is not expected to be reduced when project operations are modified under the terms of the amended license. In fact, the construction of a new powerhouse and tailrace, as well as an increase in the amount of flow being channeled through the Stillwater Branch, may lead to both an increase in the proportion of fish delayed, and in the duration of that delay. This will be caused by the potential additive effects of multiple discharges (*i.e*,. a fish is attracted to and delayed by the existing powerhouse, and is subsequently attracted to and delayed by discharge from the new powerhouse). The proposed fish trap at the Orono Project is intended to minimize the amount of delay in the bypass reach by providing a method for the removal of Atlantic salmon and transport back to the mainstem. However, as the trap will be located in the bypass reach and not at either of the powerhouses, we do not know how effective it will be at reducing the overall delay experienced by Atlantic salmon at the Project. Under current conditions, it is estimated that 33% of the Atlantic salmon that are attracted to the discharge of the existing powerhouse will be harassed due to significant delay (in excess of 48 hours) in migration. We believe that a delay in migration of more than two days per project could affect a salmon's ability to migrate successfully to suitable spawning habitat. Black Bear will monitor delay at the Orono Project and if a significant number of fish are delayed for more than 48 hours they will discuss solutions with state and federal fisheries agencies.

It is not known how many adult Atlantic salmon are attracted to the West Branch of the Penobscot and are delayed due to the lack of passage at the Medway Project. Likewise, the duration of the delay is not known. As there is currently no spawning in the West Branch, it is not anticipated that salmon will be motivated to migrate into the river to spawn. However, it is anticipated that some proportion of the Atlantic salmon that are homing to the East Branch will stray into the West Branch. These fish will be delayed for some amount of time prior to dropping back into the East Branch or the mainstem Penobscot. Based on the work conducted by Shepard (1995) at the Orono Project, it is estimated that 33% of the Atlantic salmon that are attracted to the discharge of the powerhouse at the Medway Project will be harassed due to significant delay (in excess of 48 hours) in migration. We believe that a delay in migration of more than two days per project could affect a salmon's ability to migrate successfully to suitable spawning habitat. Black Bear will monitor the number of salmon that come within 200 meters of the Medway Project, and will assess the level of delay that is resulting due to project operations. FERC is proposing to implement a license article requiring Black Bear to meet with us every five years to discuss the operation of the project in relation to listed species. If significant delay is occurring, possible solutions will be discussed at that time.

Upstream Distribution Effects

Of the surviving Atlantic salmon that fail to pass the upstream fishways at Milford, Orono and West Enfield, the vast majority are assumed to stray to other habitat and spawn. The expert panel convened by us in 2010 addressed this issue, and determined that the presence of the dams would cause the majority of straying Atlantic salmon to spawn in habitat downriver of the dam that halted their migration. For Milford and Orono, this would mean that 100% of the fish that stray would fall back into the habitat upriver of Verona Island, and would potentially spawn in the lower mainstem Penobscot, or in one of its tributaries. Of the Atlantic salmon that failed to pass West Enfield, the expert panel assumed that 60% would spawn in the Piscataquis River and that the remaining 40% would spawn either in the Passadumkeag River or in the mainstem Penobscot upriver of the Milford Project. This forced straying of a small proportion of migrating Atlantic salmon may lead to a gradual shift downriver in the distribution of the species in the Penobscot. The PRRP and the proposed performance standards are anticipated to reduce this effect, however, by increasing the proportion of fish that can migrate successfully in the Penobscot River watershed.

As noted previously, no upstream fish passage facilities are proposed for the Orono and Stillwater Projects, which will prevent Atlantic salmon from using the Stillwater Branch as a migratory corridor. Habitat is available and accessible to migrating adults in the mainstem of the river and all of the Atlantic salmon that were attracted to the discharge from the Stillwater Branch in 1988 and 1989 eventually strayed back to the mainstem where they continued their upstream migration (Shepard 1995). Therefore, while the continued blockage of the Stillwater Branch will continue to alter the distribution of migratory behavior, it will not preclude pre-spawn adults from accessing high quality spawning habitat upriver.

The Medway Project prevents Atlantic salmon from accessing approximately 80,000 habitat units in the West Branch of the Penobscot (NMFS 2009). This habitat represents approximately 25% of the potential spawning and rearing habitat within the Penobscot drainage. The Medway Project itself only prevents passage to the next upstream barrier, the East Millinocket Dam about two miles upriver and, on its own, is not preventing access to a significant quantity of habitat. However, the lack of passage at Medway does force all Atlantic salmon that are attracted to the flow in the West Branch to stray downriver into the East Branch, or into the mainstem. This straying leads to increased energy expenditure and delay, which could prevent salmon from accessing suitable spawning habitat.

Summary of Downstream Passage Effects

A significant proportion of Atlantic salmon smolts and kelts are injured or killed while passing dams during their downstream migration. It is assumed for this Opinion that the existing downstream passage rates will be maintained until the achievement of the performance standard has been demonstrated through passage studies. Therefore, over the life of the project licenses, we consider that the projects will operate under two conditions: the current condition and the conditions once the SPP performance standards are met. Once the projects are operating pursuant to the downstream performance standard, there will be a decrease in the proportion of salmon killed while attempting downstream passage.

Atlantic salmon smolts outmigrate to the estuary in the spring after rearing in freshwater streams. Under current operations, which may continue for up to ten years, Alden Lab (2012) reports that, due to the direct and indirect effects of dam passage, between 6.40% and 24.36% of smolts outmigrating through the Penobscot River are killed annually by the individual dams considered in this Opinion (Table 14). Therefore, cumulatively, between 15.3% and 32.9% of smolts migrating through the Projects in the lower Penobscot (West Enfield, Milford, Stillwater and Orono) will be subject to direct mortality associated with dam passage (assuming a median split of 80.3%/19.7% between the mainstem Penobscot and the Stillwater Branch (NMFS 2012, based on Holbrook *et al.* 2011). Pursuant to the terms of the proposed license amendments and consistent with the he SPP, we anticipate that the performance standard of 96%, based on a 75% confidence interval, will be met at all four projects no later than spring of 2023. At that point, the mortality rate is expected to be 4%, which will reduce the cumulative mortality rate through all four dams to 8.7%. This is a relative reduction of between 43% and 74%, when compared to the maximum and minimum survival rates reported by Alden Lab (2012).

Atlantic salmon kelts outmigrate in the fall after spawning, or in the spring after overwintering in freshwater. They are subject to the same challenges associated with dam passage as smolts but, due to their greater length, are more likely to be struck by a turbine blade (Alden Lab 2012). Under current operations, which may persist for up to ten years, Alden Lab (2012) reports that, due to the direct and indirect effects of dam passage, between 7.91% and 34.17% of kelts will be killed annually by the individual dams considered in this Opinion. Therefore, between 19.3% and 43.9% of kelts migrating past the West Enfield, Milford, Stillwater and Orono Projects in the lower Penobscot will be subject to mortality associated with dam passage (assuming that outmigrating kelts split between the Stillwater Branch and the mainstem Penobscot at the same rate as smolts). It is anticipated that the performance standard of 96%, based on a 75% confidence interval, will be met at all four projects no later than spring of 2023. At that point, the mortality rate is expected to be 4%, which will reduce the cumulative mortality rate through all four dams to 8.7%, which is a relative reduction of between 55% and 80%, when compared to the maximum and minimum survival rates reported by Alden Lab.

Table 14. The proportion of Atlantic salmon smolts and kelts that are anticipated to be killed annually due to direct and indirect effects due to present and future operations at the Milford, West Enfield, Orono and Stillwater Projects based on survival estimates provided by Alden Lab (2012), and a median split between the Stillwater Branch and the mainstem Penobscot of 19.7%/80.3% (NMFS 2012, based on Holbrook *et al.* 2011). Existing kelt survival numbers are based on Alden Lab's data, but has been weighted to account for 80% of outmigration occurring in the spring and 20% in the fall (Lévesque *et al.* 1985, Baum 1997).

	Project	**Smolts**		**Kelts**		
		Max	*Min*	*Max*	*Min*	*Duration*
Environmental Baseline	Milford	24.4%	8.0%	31.4%	10.8%	2013-2022
	West Enfield	7.7%	6.4%	9.8%	7.9%	
	Orono	18.4%	8.5%	28.0%	10.0%	
	Stillwater	9.5%	7.9%	34.2%	9.9%	
	All Four	**32.9%**	**15.3%**	**43.9%**	**19.3%**	
SPP Performance Standards	Milford	4.0%		4.0%		2023-2038
	West Enfield	4.0%		4.0%		2023-2024
	Orono	4.0%		4.0%		2023-2048
	Stillwater	4.0%		4.0%		2023-2048
	All Four	**8.7%**		**8.7%**		

Similar to migrating pre-spawn adults, outmigrating smolts and kelts are subject to delay by the presence of hydroelectric dams. While these delays can lead to mortality of Atlantic salmon from increased predation (Blackwell *et al.* 1998), migratory delays can also reduce overall physiological health or physiological preparedness for seawater entry and oceanic migration (Budy *et al.* 2002). Various researchers have identified a "smolt window" or period of time in which smolts must reach estuarine waters or suffer irreversible effects (McCormick *et al.* 1999). Late migrants lose physiological smolt characteristics due to high water temperatures during spring migration (McCormick *et al.* 1999). Similarly, artificially induced delays in migration from dams can result in a progressive misalignment of physiological adaptation of smolts to seawater entry, smolt migration rates, and suitable environmental conditions and cues for migration. If so, then these delays may reduce smolt survival (McCormick *et al.* 1999).

We expect that 24 hours provides adequate opportunity for smolts and kelts to locate and utilize well-designed downstream fishways at hydroelectric dams. A 24-hour period would allow these migrants an opportunity to locate and pass the fishway during early morning and dusk, a natural diurnal migration behavior of Atlantic salmon. Passage times in excess of 24 hours would result in unnatural delay for migrants leading to increased predation and reduced fitness in the freshwater to saltwater transition. Therefore, any smolt or kelt documented to take longer than 24 hours to pass a downstream passage facility will be considered to have failed in their passage attempt. Therefore, under the downstream performance standard, 96% of salmon smolts and kelts are expected to be passed within 24 hours of approaching within 200 meters of any of these projects; thus, only 4% will be potentially subjected to significant delays.

In addition to the direct and indirect mortality associated with dam passage for smolts and kelts, there is also the possibility of additional dam-related mortality occurring in the early marine phases of the salmon's life history. For Pacific salmon species, this concept is known as the hydrosystem-related delayed-mortality hypothesis (Budy *et al.* 2002, Schaller and Petrosky 2007). This delayed mortality is thought to be attributable to physiological stress associated with dam passage that affects smolts and post-smolts experiencing the challenges of transitioning to the marine environment (osmoregulation, novel predators, etc.). Very recently, Haeseker *et al.* (2012) provide clear evidence supporting this hypothesis for Snake River Chinook salmon and steelhead. At this time, it is impossible to quantify how much (if any) early marine mortality of Atlantic salmon may be attributable to similar mechanisms in the Penobscot River watershed. However, it is reasonable to assume that some level of delayed (and as yet undocumented) early marine mortality of Atlantic salmon is ultimately due to earlier hydrosystem experience.

8.1.1. Survival and Recovery Analysis

Jeopardy is defined as "an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species" (50 CFR 402.02). Therefore, to determine if the proposed action will jeopardize the GOM DPS of Atlantic salmon, we conduct an analysis of the effects of the proposed action on survival and recovery.

The first step in conducting this analysis is to assess the effects of the proposed action on the survival of the species. Survival is defined as the condition in which a species continues to exist into the future while retaining the potential for recovery. This condition is characterized by a species with a sufficient population, represented by all necessary age classes, genetic heterogeneity, and number of sexually mature individuals producing viable offspring, which exists in an environment providing all requirements for completion of the species' entire life cycle, including reproduction, sustenance, and shelter (USFWS and NMFS 1998).

There are three criteria that are evaluated under the survival analysis: reproduction, numbers and distribution. The number of returning adult Atlantic salmon, particularly 2SW females, to the Penobscot River is a measure of both the reproduction and numbers of the species. We consider the proportion of runs where pre-spawn Atlantic salmon are able to access high quality spawning and rearing habitat in the upper Penobscot watershed as a reasonable and appropriate measure of distribution. As 92% of high quality habitat in the Penobscot River exists upriver of the West Enfield Project on the mainstem, and the Howland Project on the Piscataquis River, we consider improved access past these locations to be critical to the survival and recovery of the species. The survival analysis assumes that the following conditions are maintained over the time period considered in this consultation: existing passage rates at all the dams in the Penobscot River, estimations of existing freshwater and marine survival rates, and existing hatchery stocking rates.

The second step in conducting this analysis is to assess the effects of the proposed project on the recovery of the species. Recovery is defined as the improvement in the status of listed species to the point at which listing is no longer appropriate under the criteria set out in section 4(a)(1) of the ESA (50 CFR 402.02). As with the survival analysis, there are three criteria that are evaluated under the recovery analysis: reproduction, numbers and distribution. In the recovery analysis, the same measures are used to evaluate these criteria as are used in the survival analysis. However, unlike with survival, the recovery analysis requires an adjustment to the existing freshwater and marine survival rates to allow for a population that has a positive growth rate, so that it can be determined how the proposed project will affect the species ability to achieve recovery. Such an analysis could not be conducted under existing freshwater and marine survival conditions, since they do not allow a population trending towards recovery. The recovery condition includes existing dam passage rates, but does not include hatchery supplementation as it is assumed that in a recovered population, stocking will not be necessary to sustain a viable population.

The proposed construction activities and passage studies are only anticipated to kill, injure, harm and harass a small number of Atlantic salmon and are, therefore, not anticipated to result in changes in abundance, reproduction and distribution that would reduce appreciably the likelihood of both the survival and recovery of the species. Therefore, this analysis only addresses the effects of future operations of Black Bear's hydroelectric facilities under the terms of the proposed SPP.

To facilitate this analysis, NMFS and USFWS have independently constructed models to determine how dams affect the GOM DPS of Atlantic salmon (NMFS 2012, Appendix C; USFWS 2012, Appendix D). The models utilize life history characteristics and estimated passage and survival rates at dams in the Penobscot River to determine how the proposed project will affect survival and recovery of Atlantic salmon. Both models use multiple inputs in their analyses that are documented and described in detail in Appendix C and D.

The NMFS Dam Impact Assessment (DIA) model evaluates the relative effect that changes in various inputs could have on the abundance of returning 2SW female Atlantic salmon to the Penobscot River under the survival and recovery conditions. The DIA model uses the following inputs in its analysis:

- Initial number of 2SW females spawners
- Eggs per female
- Freshwater Survival (Egg to smolt)
- In-River Survival (Outmigration)
- Smolt production caps
- Hatchery Stocking Levels and Location
- Downstream passage estimates (Alden)
- Downstream passage estimate correlation
- Path choice
- Hatchery discount
- Marine Survival
- Broodstock collection
- Natural Straying Rate
- Dam mortality
- Dam-induced Straying Rate
- Pre-spawn adult upstream passage efficiencies

The model compares baseline survival and recovery conditions to what would be anticipated with the implementation of the performance standards outlined in Black Bear's SPP. As described previously, dam passage rates, marine and freshwater survival, and hatchery supplementation are adjusted according to the condition (Table 15).

Table 15. The conditions considered in the NMFS's DIA model for the Penobscot River watershed, based on the proposed action of implementing upstream and downstream performance standards.

	Survival		**Recovery**	
	Baseline	*Proposed*	*Baseline*	*Proposed*
Dam Passage Rates	Existing+PRRP	SPP	Existing+PRRP	SPP
Hatchery	Stocking	Stocking	No stocking	No stocking
Marine Survival	Post-regime shift	Post-regime shift	Pre-regime shift	Pre-regime shift
Freshwater Survival	Contemporary	Contemporary	Improved	Improved

Survival Analysis

Abundance and Reproduction

Our DIA model compares baseline conditions with the conditions of the river once the proposed action has been implemented. The baseline condition of the Penobscot River in this comparison assumes the following: that the removal of the Veazie and Great Works Projects, as well as the new bypass around the Howland Project has occurred; that all remaining dams are functioning at their current passage rates; that stocking of hatchery smolts is occurring; and that marine survival is at contemporary levels. The project condition alters the passage rates at the West Enfield, Milford, Stillwater and Orono Projects to 96% downstream and 95% upstream. The baseline assumes a starting population in the Penobscot River that approximates current conditions. For the model, we calculated that the ten year (2002-2011) average of returning 2SW females is 587 individuals.

The model results indicate that the downstream performance standard is anticipated to reduce the proportion of salmon smolts that are killed by hydroelectric operations on the Penobscot by 52% when compared to baseline conditions, which includes completion of the PRRP. Similarly, the DIA model indicates that the standards will lead to an increase in the annual return rate of 2SW female Atlantic salmon by 11% in the tenth generation over the baseline conditions when the PRRP is completed (Figure 9). As the metric being assessed is the change in the abundance of pre-spawn 2SW female Atlantic salmon, we assume that the increase in abundance corresponds with an increase in reproduction.

As illustrated in Figure 9, the model indicates a significant decline in 2SW female returns between the first and second generations prior to leveling out for the next nine generations. Although in generation one the model allows for 587 females to spawn in the system, the majority of their progeny do not survive to the adult stage due to freshwater and marine mortality factors. As such, they have very little effect on the subsequent adult returns and generations two through ten are primarily being driven by the return rate for the stocked smolts. In short, the 'wild' spawners in generation one are providing very little benefit to the subsequent adult returns under the baseline survival conditions and any benefit provided quickly dissipates as the generations progress.

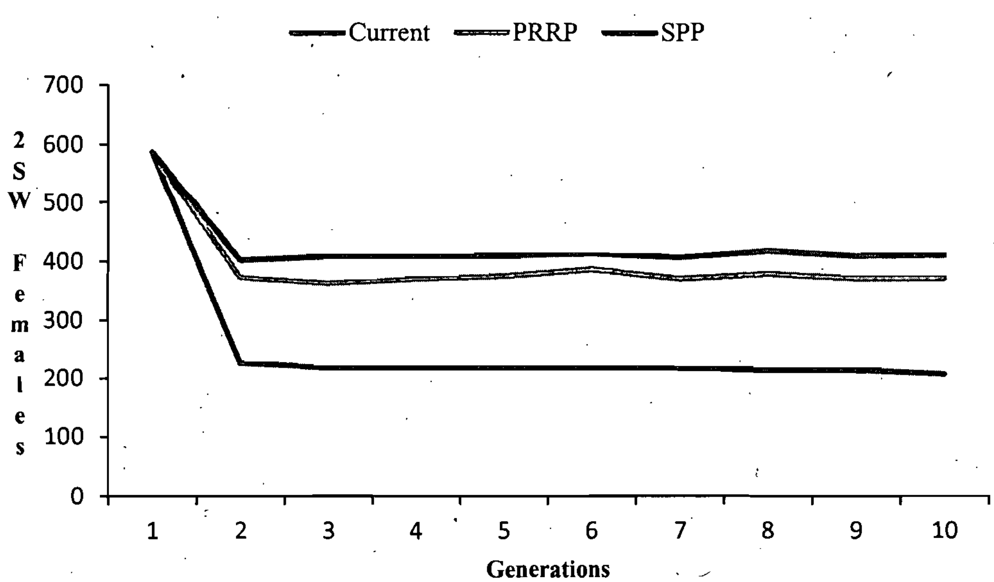

Figure 9. Comparison of the simulated number of returning 2SW female Atlantic salmon over ten generations according to the DIA model under current, environmental baseline (PRRP), and SPP passage conditions (NMFS 2012).

As mentioned above, USFWS (2012) constructed an independent life history model to assess how operations of the projects pursuant to the SPP would affect total smolt survival and adult returns in the Penobscot River (Appendix D). The USFWS (2012) model shows similar results to our DIA model, indicating that operations of the projects pursuant to the SPP's performance standards would result in a relative increase in cumulative smolt survival of 7% over the baseline conditions (which include the PRRP). Additionally, the model predicts that operations pursuant to the SPP will result in an increase in cumulative upstream passage success through the Penobscot River dams of 2%. The USFWS model also calculated a population growth rate (λ) for the various scenarios, and determined that the proposed performance standards will increase λ in the Penobscot River from 0.82 to 0.85, assuming existing marine survival rates are maintained over this period. A population that has a λ below 1 is a declining population that is below the replacement rate; however, the USFWS model indicates that under conditions where the projects operate pursuant to the SPP and under existing marine survival conditions, there will be an increase of 3.5% in the population's rate of growth.

Based on the results of the two models, it can be concluded that, although the Atlantic salmon population is still declining, the proposed project will lead to a slight increase in the abundance of returning 2SW female Atlantic salmon to the Penobscot River and the GOM DPS of Atlantic salmon. As the metric being measured is pre-spawn females, this increased abundance corresponds with an equal increase in reproduction.

Distribution

We conducted a separate analysis using the DIA model to assess the effects of project operations pursuant to the SPP on the distribution of Atlantic salmon in the Penobscot River watershed. In this analysis, the proportion of runs where salmon access habitat upstream of the West Enfield Project in the mainstem of the Penobscot and the Howland Dam on the Piscataquis River, is compared between the baseline condition and the condition after the implementation of the SPP. The DIA model indicates that the operation of the projects in a manner that achieves the performance standards in the SPP leads to a small increase in the proportion of runs where salmon pass the West Enfield or Howland Projects (Table 16). The model indicates that after ten generations the implementation of the SPP there will be a 2% relative increase when compared to baseline conditions. Therefore, the proposed project is anticipated to lead to a small improvement in the distribution of Atlantic salmon in the Penobscot River, and GOM DPS as a whole.

Table 16. The proportion of runs anticipated where 2SW female Atlantic salmon are able to access high quality habitat in the upper Penobscot River (above West Enfield) and in the Piscataquis River (above Howland) over ten generations.

	Upper Penobscot			Piscataquis		
Generation	**Current**	**PRRP**	**SPP**	**Current**	**PRRP**	**SPP**
1	100%	100%	100%	100%	100%	100%
2	68%	91%	92%	68%	91%	92%
3	64%	90%	92%	65%	90%	92%

4	64%	90%	92%	65%	91%	92%
5	63%	90%	92%	64%	90%	92%
6	64%	90%	92%	65%	90%	92%
7	64%	91%	92%	64%	91%	92%
8	63%	90%	92%	64%	91%	92%
9	64%	91%	92%	65%	91%	92%
10	64%	90%	92%	64%	90%	92%

The model results for the survival analysis indicate that the operation of Black Bear's Projects in the Penobscot River, under the terms of the proposed SPP, will lead to a slight increase in the abundance, reproduction and distribution of Atlantic salmon in the Penobscot River watershed, as well as the GOM DPS as a whole. Therefore, the proposed action will not appreciably reduce the likelihood that the GOM DPS of Atlantic salmon will survive.

Recovery Analysis

In certain instances an action may not appreciably reduce the likelihood of a species survival (persistence) but may affect its likelihood of recovery or the rate at which recovery is expected to occur. As explained above, we have determined that the proposed action will not appreciably reduce the likelihood that Atlantic salmon will survive in the wild. Here, we consider the potential for the action to reduce the likelihood of recovery. As noted above, recovery is defined as the improvement in status such that listing is no longer appropriate.

Section 4(a)(1) of the ESA requires listing of a species if it is in danger of extinction throughout all or a significant portion of its range (i.e., "endangered"), or likely to become in danger of extinction throughout all or a significant portion of its range in the foreseeable future (i.e., "threatened") because of any of the following five listing factors: (1) The present or threatened destruction, modification, or curtailment of its habitat or range, (2) overutilization for commercial, recreational, scientific, or educational purposes, (3) disease or predation, (4) the inadequacy of existing regulatory mechanisms, (5) other natural or manmade factors affecting its continued existence.

At existing freshwater and marine survival rates (the medians have been estimated by NMFS as 1.1% and 0.4%, respectively), it is unlikely that Atlantic salmon will be able to achieve recovery. As indicated in the survival analysis above, at current survival rates wild spawners are having a very small effect on the number of returning salmon. If hatchery supplementation were to cease, the population would decline rapidly, and recovery would not be possible. Therefore, a significant increase in either freshwater or marine survival (or a lesser increase in both) will be necessary to achieve recovery. The Atlantic Salmon Recovery Team (ASRT) created a conceptual model to indicate how marine and freshwater survival rates would need to change in order to recover Atlantic salmon (ASRT 2010). In Figure 10, the red dot represents current marine and freshwater survival rates; the blue line represents all possible combinations of marine and freshwater survival rates that would result in a stable population with a growth rate of zero. If survival conditions are above the blue line, the population is growing, and, thus, trending towards recovery (lambda greater than one). The red lines indicate the rates of freshwater survival that have been historically observed (Legault 2004). This model indicates that there are many potential routes to recovery; for example, recovery could be achieved by significantly increasing the existing marine survival rate while holding freshwater survival at existing levels, or, conversely, by significantly increasing freshwater survival while holding marine survival at today's levels. Conceptually, however, the figure makes clear that an increase in both freshwater and marine survival will lead to the shortest and, therefore, most likely to occur, path to achieving a self-sustaining population that is trending towards recovery.

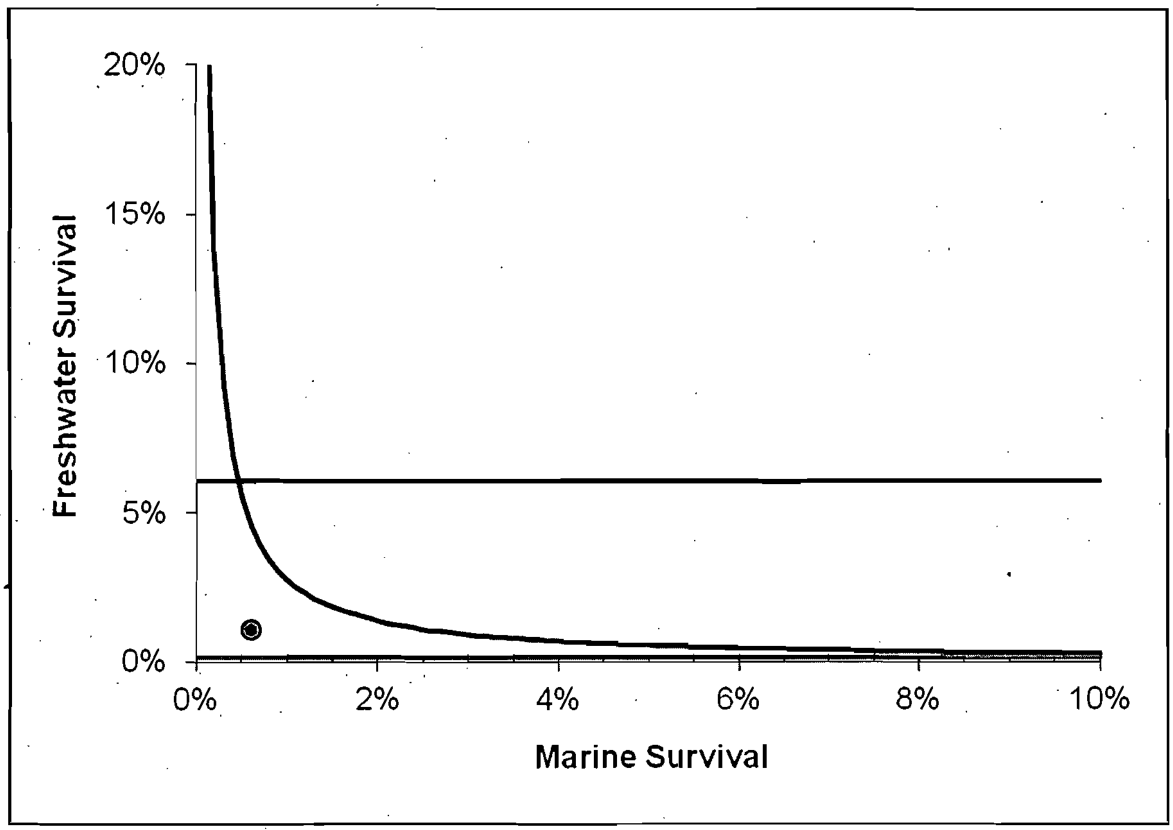

Figure 10. A conceptual model constructed by ASRT (2010) that demonstrates how changes in marine and freshwater survival will be necessary to recover the GOM DPS of Atlantic salmon. The red dot represents current conditions, the blue line represents recovery, and the red lines are the historic maximum and minimum freshwater survival.

In order to model the effect that the proposed action would have on recovery, marine and freshwater survival rates are increased to a point that will allow for the recovery of the species. To do this, assumptions are made about what constitutes a realistic increase in these parameters. In the mid-1980's to early 1990's there was a 50% to 70% decline in Atlantic salmon marine survival rates. This event is referred to as the regime shift (Chaput *et al.* 2005); the causes for which are unknown at this time (Windsor *et al.* 2012). Based on the smolt to adult return rate for wild fish in the Narraguagus River, USFWS (2012) estimated that the pre-regime shift marine survival rate ranged between 0.9% and 5.2%, with an average of 3.0%. A four-fold increase in the current median marine survival rate (from 0.4% to 1.7%) will allow for a rate that is within the range estimated to have existed prior to the regime shift.

Freshwater survival rates have historically ranged between 0.1% and 6.0%, with an average of

1.5% (Legault 2004). A two fold increase in the existing median freshwater survival rate (from 1.1% to 2.2%) creates a condition that is above the historical mean, but is within the range that has been observed and, when coupled with improved marine survival, will allow for a modest positive growth rate in the Atlantic salmon population.

This recovery analysis looks at two scenarios; one that sets the starting population at existing levels, and another that starts at an already recovered population. Using these scenarios, the analysis will address whether the proposed project will preclude or slow the existing population from achieving recovery (Scenario #1), as well as whether an already recovered population can sustain recovery under the conditions created by the proposed action (Scenario #2).

Recovery Scenario #1

Abundance and Reproduction

Like in the survival analysis, the baseline population under this scenario assumes a starting population in the Penobscot River that approximates current conditions. For the DIA model, NMFS calculated that the ten year average (2002-2011) of returning 2SW female Atlantic salmon is 587 individuals. As described above, in order to achieve recovery an increase in freshwater and marine survival will be necessary. We have determined that a doubling of freshwater survival and a quadrupling of marine survival will allow for a population that is increasing at a slow but steady rate, although other scenarios could be used to achieve the same increase in population growth rate.

To conduct the scenario #1 recovery analysis, we used the DIA model to compare the recovery baseline condition with the condition anticipated once the proposed action has been implemented. The current baseline condition of the Penobscot River in this comparison assumes that the PRRP (removal of the Veazie and Great Works Projects, as well as the new bypass around the Howland Project) has occurred; that all remaining dams, including Black Bear's projects, are functioning at their current passage rates; that stocking of hatchery smolts has been discontinued; and, as indicated above, that marine and freshwater survival has been increased to a point that recovery is achievable. The SPP condition improves the downstream and upstream passage rates at the West Enfield, Milford, Stillwater and Orono Projects to 96% and 95%, respectively. For comparison, the model also incorporated a hypothetical full passage condition, where all of Black Bear's projects in the Penobscot River, except for Medway, had their upstream and downstream passage rates set to 100%. The DIA model analysis predicts that operations of the projects pursuant to the SPP will lead to a relative increase in the number of returning 2SW female Atlantic salmon of 41% after ten generations. However, as anticipated, the proposed project will lead to 35% fewer returns than what would be expected under the full passage scenario (Figure 11).

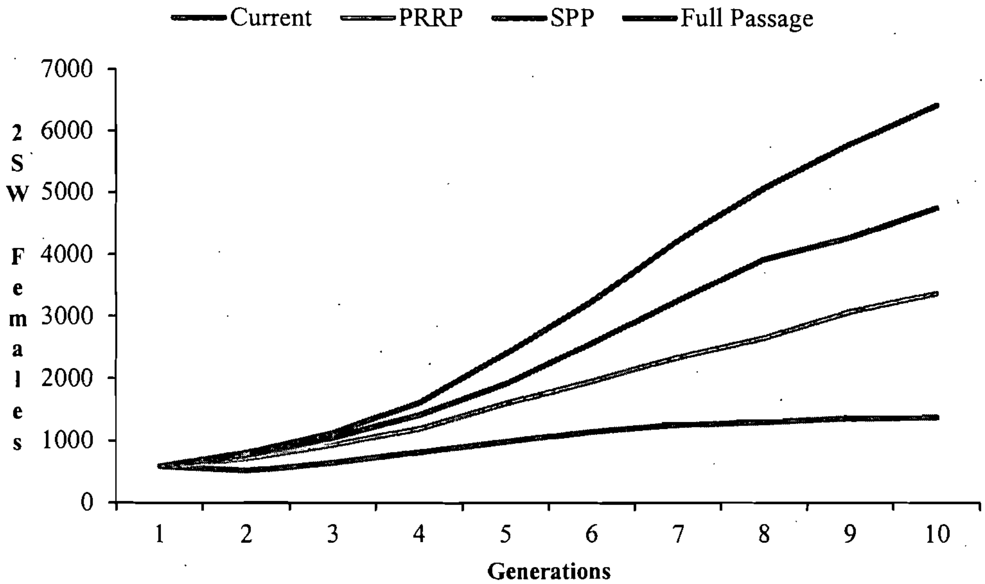

Figure 11. Comparison of the simulated number of returning 2SW female Atlantic salmon over ten generations under the first recovery scenario according to the DIA model under current, environmental baseline (PRRP), SPP and full passage conditions (NMFS 2012).

The draft Atlantic Salmon Recovery Plan, which is currently being developed by the Services, indicates that 2,000 wild adult returning salmon in each of the three SHRUs will be necessary for the species to achieve recovery. Two thousand adult returns equate to approximately 1,000 wild 2SW female Atlantic salmon. As can be seen in Table 17, both the SPP and the Full Passage condition achieve this threshold by the third generation under these survival rates. Although these numbers would vary under different freshwater and marine survival rates, this output suggests that under improved survival conditions the operation of the projects pursuant to the SPP likely does not appreciably reduce the rate of recovery. Therefore, this analysis indicates that the proposed action will likely not preclude the species from growing in a way that leads to recovery and that the action will not significantly reduce the rate at which it can occur should marine and freshwater survival rates increase sufficiently to allow for recovery.

Table 17. The simulated number (median) of returning 2SW female Atlantic salmon returns estimated by the DIA model under the recovery scenario #1 that incorporates a starting population that estimates the ten year (2002-2011) average return rate (NMFS 2012).

Generation	Current	PRRP	SPP	Full Passage
1	587	587	587	587
2	517	710	766	807
3	645	930	1045	1120
4	814	1195	1414	1613
5	980	1597	1908	2396
6	1144	1953	2569	3239
7	1253	2338	3256	4230

8	1303	2651	3929	5076
9	1360	3079	4280	5796
10	1378	3373	4755	6425

USFWS's (2012) life history model also assessed how the proposed SPP would affect the Penobscot Bay SHRU if marine survival was increased to pre-regime levels (Appendix D). The model calculated a population growth rate (λ or lambda) under this condition, and determined that the proposed performance standards will increase λ in the Penobscot River under the recovery scenario from 1.07 to 1.10. A population that has a λ greater than 1 is an increasing population trending towards recovery. The USFWS model indicates that the SPP, under increased marine survival conditions, would lead to an increase of 2.7% in the population's rate of growth.

Distribution

Under scenario #1 (starting population at existing levels), the DIA model was used to conduct a separate analysis to assess the effects of the SPP on the distribution of Atlantic salmon in the Penobscot River watershed under the baseline recovery conditions (hatchery off and increased freshwater and marine survival). In this analysis, the proportion of runs where salmon access habitat upstream of the West Enfield Project in the mainstem of the Penobscot and the Howland Dam on the Piscataquis River, is compared between the baseline condition and the condition after the implementation of the SPP. The DIA model indicates that with improved marine and freshwater survival the proportion of runs where individual 2SW female salmon access habitat upriver of the West Enfield and Howland Projects is between 97% and 100% regardless of dam passage rates. The model indicates that the SPP condition will allow 100% of salmon runs to have access to the upper Penobscot and Piscataquis after ten generations, which is essentially the same as the environmental baseline condition, where 99% and 100% of successful runs can access the habitat in the mainstem Penobscot and Piscataquis, respectively.

Recovery Scenario # 2

Abundance and Reproduction

The baseline for this analysis assumes that the population has achieved a sustainable level approximately at the threshold for recovery. The draft Atlantic Salmon Recovery Plan, which is currently being developed by the Services, indicates that 2,000 wild adult returning salmon in each of the three SHRUs will be necessary for the species to achieve recovery. Two thousand adult returns equates to approximately 1000 2SW female Atlantic salmon, which is the metric that was used in the DIA model. As described above, in order to achieve and sustain a recovery an increase in freshwater and marine survival will be necessary. We determined that a doubling of freshwater survival and a quadrupling of marine survival will allow for a population that is increasing at a slow but steady rate, although other scenarios could be used to achieve the same increase in population growth rate.

To conduct the scenario # 2 recovery analysis, we used the model to compare the recovery baseline condition with the conditions anticipated once the proposed action has been fully implemented. The baseline condition of the Penobscot River watershed in this comparison assumed that the removal of the Veazie and Great Works Projects, as well as the new bypass around the Howland Project, has occurred; that all remaining dams, including Black Bear's projects, are functioning at their current passage rates; that stocking of hatchery smolts has been discontinued; and, as indicated above, that marine survival has been increased to a point that recovery is sustainable. The post project implementation condition alters the downstream and upstream passage rates at the West Enfield, Milford, Stillwater and Orono Projects to 96% and 95%, respectively. For comparison, the model also incorporated a full passage condition, where all of Black Bear's projects in the Penobscot River, except for Medway, had their upstream and downstream passage rates set to 100%. Our analysis addressing the effect of the project on the abundance of returning adults indicates that the SPP will lead to an increase in the number of returning 2SW females of approximately 39% after ten generations (Figure 12). However, as anticipated, the proposed project will lead to 27% fewer returns than what would be expected under the full passage condition.

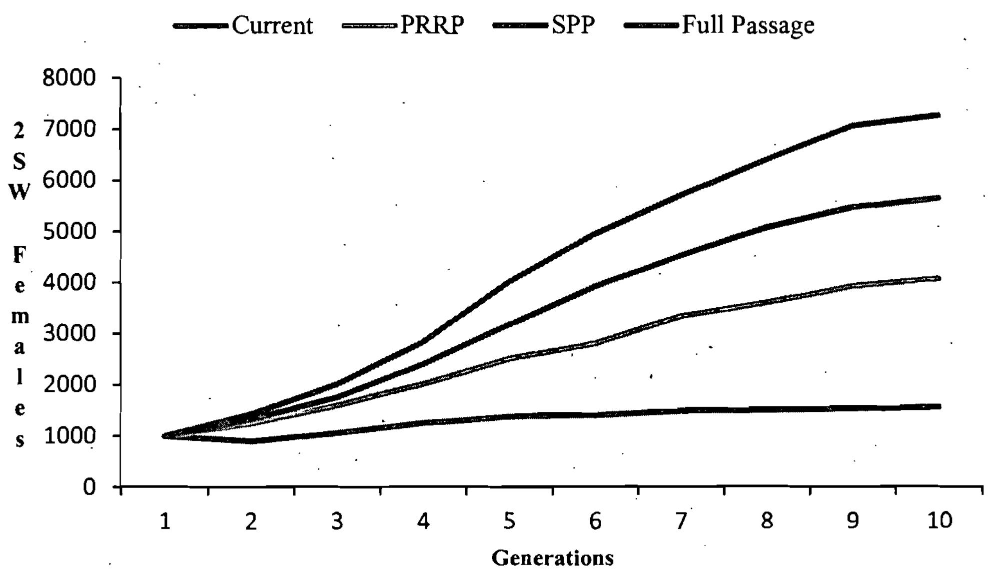

Figure 12. Comparison of the simulated number of returning 2SW female Atlantic salmon over ten generations under the second recovery scenario according to the DIA model under current, environmental baseline (PRRP), SPP and full passage conditions (NMFS 2012).

The intent of this analysis is to indicate whether or not a recovered Atlantic salmon population can sustain recovery (stay above the threshold) once the proposed action has been implemented. The results suggest that although the number of returning salmon is somewhat smaller under the SPP condition than under the full passage scenario, neither condition allows the population to drop below 1000, and both show a population growth rate that is increasing into the foreseeable future.

Distribution

Under scenario #2 (starting population at recovery threshold), the DIA model was used to conduct a separate analysis to assess the effects of the SPP on the distribution of Atlantic salmon in the Penobscot River watershed under the baseline recovery conditions (hatchery off and increased freshwater and marine survival). In this analysis, the proportion of runs where salmon access habitat upstream of the West Enfield Project in the mainstem of the Penobscot and the Howland Dam on the Piscataquis River, is compared between the baseline condition and the condition after the implementation of the SPP. The DIA model indicates that with improved marine and freshwater survival the proportion of runs where individual 2SW female salmon access habitat upriver of the West Enfield and Howland Projects is between 97% and 100% regardless of dam passage rates. The model indicates that the SPP condition will allow 100% of salmon runs to have access to the upper Penobscot and Piscataquis after ten generations, which is essentially the same as the environmental baseline condition, where 99% and 100% of successful runs can access the habitat in the mainstem Penobscot and Piscataquis, respectively.

Summary of Effects of the Proposed Action to Atlantic Salmon

In this section, we summarize the effects of the proposed action on the GOM DPS of Atlantic salmon in conjunction with the environmental baseline. Based on the information provided above, the proposed action will not appreciably reduce the likelihood of survival for Atlantic salmon in the wild (i.e., it will not decrease the likelihood that the species will continue to persist into the future with sufficient resilience to allow for the potential recovery from endangerment). Although the population growth rate of Atlantic salmon will still have a downward trend after the implementation of the proposed project, the increase in upstream and downstream passage rates as described in the SPP will lead to a slight improvement of the baseline condition of the species, and will make recovery more likely should other parameters, such as marine and freshwater survival, improve in the future. While juvenile and adult Atlantic salmon mortality associated with dam passage at the Milford, West Enfield, Orono, Stillwater and Medway Projects will continue to have an adverse effect on Atlantic salmon in the Penobscot River, the NMFS DIA (2012) and USFWS (2012) models indicate that the loss will not be sufficient to appreciably diminish the species ability to achieve recovery. As such, there is not likely to be an appreciable reduction in the likelihood of survival and recovery in the wild of the Penobscot River population or the species as a whole.

The proposed action will not affect Atlantic salmon in a way that prevents the species from having a sufficient population, represented by all necessary age classes, genetic heterogeneity, and number of sexually mature individuals producing viable offspring and it will not result in effects to the environment which would prevent Atlantic salmon from completing their entire life cycle, including reproduction, sustenance, and shelter. The above analysis predicts that the proposed project will lead to an improvement in the numbers, reproduction and distribution of Atlantic salmon. This is the case because: 1) the proposed performance standards result in an increase in the abundance of pre-spawn adult Atlantic salmon returning to the Penobscot River, 2) the increase in the number of returning Atlantic salmon due to the improved downstream survival and upstream passage rates at Black Bear's facilities will lead to an increase in reproduction in high quality spawning habitat in the upper Penobscot and Piscataquis Rivers, and 3) the increase in the number of returning Atlantic salmon due to the improved downstream survival and upstream passage rates at Black Bear's facilities will lead to a higher distribution of Atlantic salmon in the upper Penobscot watershed.

Despite the threats faced by individual Atlantic salmon inside and outside of the action area, the proposed action will not increase the vulnerability of individual Atlantic salmon to these additional threats and exposure to ongoing threats will not increase susceptibility to effects related to the proposed action.

While we are not able to predict with precision how climate change will impact Atlantic salmon in the action area or how the species will adapt to climate change-related environmental impacts, no additional effects related to climate change to Atlantic salmon in the action area are anticipated over the life of the proposed action (i.e., through the license period of the individual projects). We have considered the effects of the proposed action in light of cumulative effects explained above, including climate change, and have concluded that even in light of the ongoing impacts of these activities and conditions; the conclusions reached above do not change.

8.2. Atlantic Salmon Critical Habitat

Critical habitat for Atlantic salmon has been designated in the Penobscot River including the sections of river in the vicinity of the Orono, Stillwater, Milford and West Enfield Projects. Within the action area of this consultation, the PCEs for Atlantic salmon include: 1) sites for spawning and rearing; and, 2) sites for migration (excluding marine migration). Although there is a small amount of spawning and rearing habitat in the mainstem of the Penobscot and the Stillwater Branch, the habitat in the proposed project area primary functions as a migration corridor for migrating pre-spawn adults, as well as for outmigrating smolts and kelts

Summary of Construction Effects

The construction of the powerhouses and fishways on the Stillwater Branch will temporarily reduce the functioning of critical habitat in the vicinity of the Orono and Stillwater Projects between 2012 and 2013. These areas will be made unsuitable for Atlantic salmon migration due to elevated turbidity and noise levels associated with construction activities. The effects will be of short duration and, as all work will occur within dewatered cofferdams, it is expected that exposure to the effects will be minimal. It is expected that temporary construction effects will cause fish to avoid the project area for short periods of time.

The total temporary fill associated with the proposed project is 2.6 acres (115,470 square feet), while the permanent fill (new penstocks, powerhouses and site work) will eliminate 0.66 acres (28,999 square feet) of migratory habitat. The majority of the temporary fill will be placed and removed in the Stillwater Branch outside of the spring outmigration period. As the Stillwater does not function as an upstream migratory corridor due to a lack of passage facilities, the placement of this fill is anticipated to have an insignificant effect on the migration PCE. However, the placement of permanent fill will negatively affect the functioning of the habitat in the bypass reach at both projects by precluding the use of the habitat for migration. As the permanent fill associated with the new structures will only occupy 0.02% of the migratory habitat in the Stillwater Branch, it is not anticipated that it will substantially alter the functioning of the habitat for Atlantic salmon.

There will be no permanent fill associated with the new fishway at Milford, although a small area (509 square feet) will be temporarily cofferdammed in the tailrace during construction. The cofferdam will be placed on ledge, so it is not anticipated that there will be a significant sediment release when it is removed. There will be no blasting or excavation associated with the project at Milford. As the Denil fishway at Milford will be maintained and operated during construction, it is anticipated that the effect of construction activities on these fish would be insignificant.

Summary of Upstream Passage Effects

The proposed upstream performance standard will improve migratory conditions in the action area by allowing more Atlantic salmon to successfully migrate past the Milford and West Enfield Projects. As 95% of salmon will have to migrate past these dams within 48 hours of approaching within 200 meters of the tailrace, it is expected that the proposed standards will also reduce levels of significant delay associated with dam passage. It is expected that the operation of these fishways will still adversely affect the critical habitat by blocking passage to 5% of migrating salmon that are presumably motivated to pass each dam.

The proposed project will not improve passage into the Stillwater Branch of the Penobscot River. Although a new fish lift will be constructed at Orono, trapped Atlantic salmon will not be allowed to continue their migration in the Stillwater Branch; rather they will be released into the mainstem. Although the lack of passage adversely affects the migratory PCE in the Stillwater Branch, Atlantic salmon that are attracted to the Orono Project have been found to eventually continue their migration in the mainstem of the River (Shepard 1995). Thus, the presence of the Orono Project does not prevent migration to the high quality spawning and rearing habitat in the upper river, although it may lead to significant levels of migratory delay. As no performance standard has been proposed for the Orono Project, the SPP does not define the level of expected delay. Based on the results of a study conducted by Shepard (1995), 33% of Atlantic salmon that are attracted to the discharge of the Orono Project could be subject to significant delay (more than 48 hours).

Summary of Downstream Passage Effects

The proposed downstream performance standard will improve migratory conditions in the action area by allowing more Atlantic salmon smolts and kelts to survive downstream passage through the Stillwater, Orono, Milford and West Enfield Projects. A significant proportion of Atlantic salmon smolts and kelts are injured or killed while passing dams during their downstream migration. The proposed downstream performance standard will significantly reduce this effect by requiring that 96%, based on a 75% confidence interval, of outmigrating Atlantic salmon smolts and kelts survive passage. The performance standard will lead to a relative reduction in smolt mortality of between 43% and 74%, when compared to the maximum and minimum survival rates reported by Alden Lab (2012). Similarly, it is expected to be a relative reduction in kelt mortality of between 55% and 80%. It is also anticipated that the performance standard will lead to a reduction in delay as a smolt or kelt will only be considered to have met the standard if it safely passes the dam within 24 hours of approaching within 200 meters of the project trashracks.

We expect that the proposed project would continue to harm the PCEs in the action area. We expect the continued operations of these projects to cause adverse effects to some essential features of critical habitat, including water quality, substrate, migration conditions, and forage in a similar manner as present in the environmental baseline. However, designated critical habitat in the Penobscot River watershed is anticipated to improve for Atlantic salmon with the implementation of the upstream and downstream performance standards outlined in the proposed SPP. Operation of the projects pursuant to the amended licenses is expected to achieve these performance standards by 2023. At this time, effects of hydroelectric operations to the migration PCE will be reduced by improving passage rates and reducing delay for both upstream and downstream migrating Atlantic salmon. Therefore, the proposed project is not likely to adversely modify or destroy Atlantic salmon critical habitat.

8.3. Shortnose sturgeon

Historically, shortnose sturgeon are believed to have inhabited nearly all major rivers and estuaries along nearly the entire east coast of North America. Today, only 19 populations remain. The shortnose sturgeon residing in the Penobscot River come from one of these nineteen populations. The present range of shortnose sturgeon is disjunct, with northern populations separated from southern populations by a distance of about 400 km. Population sizes range from under 100 adults in the Cape Fear and Merrimack Rivers to tens of thousands in the St. John and Hudson Rivers. As indicated in Kynard (1996), adult abundance is less than the minimum estimated viable population abundance of 1,000 adults for five of 11 surveyed northern populations and all natural southern populations. The only river systems likely supporting populations close to expected abundance are the St John, Hudson and possibly the Delaware and the Kennebec (Kynard 1996), making the continued success of shortnose sturgeon in these rivers critical to the species as a whole.

Shortnose sturgeon will not be able to access the Milford, Orono, Stillwater, West Enfield and Medway Projects during construction as they cannot currently move upstream of the Veazie Dam, which will not be removed until 2013 at the earliest. Therefore, the species will not be exposed to any effects associated with the construction of the new powerhouses and fish lifts; and consequently, all construction related effects are likely to be insignificant and discountable.

Future operations of the Stillwater, West Enfield and Medway Projects are not likely to result in negative effects to shortnose sturgeon as they are located upstream of what is believed to be the historic range of shortnose sturgeon in the Penobscot River, and no shortnose sturgeon will be exposed to effects of project operations. The Milford and Orono Projects are located at what is believed to be the upstream extent of the historic range of shortnose sturgeon and, therefore, they are not considered barriers to upstream migration. It is anticipated that once the Great Works and Veazie Dams have been removed that shortnose sturgeon will utilize habitat downstream of these projects, potentially for spawning. Therefore, it is possible that the operation of the facilities could impact shortnose sturgeon and its habitat downriver of the project.

We have determined that the proposed action will affect shortnose sturgeon by resulting in the capture of four shortnose sturgeon in the fish lifts at the Orono and Milford Projects annually. It is expected that three of these fish will be captured at the Milford Project, while only one is expected to be captured at the Orono Project. Additionally, the stranding of one shortnose sturgeon at the Orono Project per year is expected in pools downstream of the dam during the replacement or maintenance of flashboards. Black Bear will adhere to a monitoring plan and handling plan to ensure that any shortnose sturgeon captured in the fish lifts, or in isolated pools, are removed promptly and returned safely downstream. It is possible that some captured shortnose sturgeon could experience minor injuries, such as abrasions, due to contact with the concrete surface of the fish lift. Shortnose sturgeon captured in the fish lifts will be temporarily delayed from carrying out spawning activities. However, given that monitoring will be continuous during the spawning season the amount of time that any shortnose sturgeon would spend in the fish traps, or in an isolated pool, is short and certainly less than 24 hours. As such, it is extremely unlikely that the fish would miss a spawning opportunity. Similarly, it is unlikely that the temporary capture in the traps, or in the pools, and subsequent removal and placement back downstream of the fish lift would cause an individual shortnose sturgeon to abandon their spawning attempt. Considering this analysis, the capture of four (three at the Milford Project and one at the Orono project) shortnose sturgeon in fish lifts, and an additional one stranded per project in pools during flashboard replacement, is not likely to result in any injury or mortality or affect the fitness of any individuals, or cause any reduction in the number of eggs spawned or in the successful development of those eggs and larvae.

The proposed action is not likely to reduce reproduction of shortnose sturgeon in the action area because: (1) there will be no reduction in the number of spawning adults; (2) there will be no reduction in fitness of spawning adults; (3) there is not anticipated to be any reduction in the number of eggs spawned or the fitness of any eggs or larvae; and (4) the project will continue to operate in run of river mode thus there is no potential for pulsed flows which could disrupt spawning or rearing.

The action is also not likely to reduce the numbers of shortnose sturgeon in the action area as there will be no mortality of any individuals and no reason shortnose sturgeon would abandon the action area during the spawning season. The distribution of shortnose sturgeon within the action area will not be affected by the action, as shortnose sturgeon will have access to the entirety of its historic range.

Based on the information provided above, the proposed action will not appreciably reduce the likelihood of survival for shortnose sturgeon in the wild (i.e., it will not decrease the likelihood that the species will continue to persist into the future with sufficient resilience to allow for the potential recovery from endangerment). The action will not affect shortnose sturgeon in a way that prevents the species from having a sufficient population, represented by all necessary age classes, genetic heterogeneity, and number of sexually mature individuals producing viable offspring and it will not result in effects to the environment which would prevent shortnose sturgeon from completing their entire life cycle, including reproduction, sustenance, and shelter. This is the case because: (1) the action will not result in the mortality of any shortnose sturgeon (2) as the action will not result in the mortality of any individuals, the action is not likely to have an effect on the levels of genetic heterogeneity in the population; (4) the temporary adverse effects to individuals captured in the fish lifts will not affect the reproductive output of any individual or the species as a whole; (5) the action will not affect the distribution of shortnose sturgeon in the action area or beyond the action area (i.e., throughout its range); (6) the action will not affect the reproductive fitness of any individual spawning adult or result in any reductions in the number of eggs spawned or the successful development of any eggs or larvae; (7) the operations of the project will not affect the ability of shortnose sturgeon to successfully spawn or for eggs and larvae to successfully develop and, (9) the action will have no effect on the ability of shortnose sturgeon to shelter or forage.

In certain instances an action may not appreciably reduce the likelihood of a species survival (persistence) but may affect its likelihood of recovery or the rate at which recovery is expected to occur. As explained above, we have determined that the proposed action will not appreciably reduce the likelihood that shortnose sturgeon will survive in the wild. Here, we consider the potential for the action to reduce the likelihood of recovery. As noted above, recovery is defined as the improvement in status such that listing is no longer appropriate.

Section 4(a)(1) of the ESA requires listing of a species if it is in danger of extinction throughout all or a significant portion of its range (i.e., "endangered"), or likely to become in danger of extinction throughout all or a significant portion of its range in the foreseeable future (i.e., "threatened") because of any of the following five listing factors: (1) The present or threatened destruction, modification, or curtailment of its habitat or range, (2) overutilization for commercial, recreational, scientific, or educational purposes, (3) disease or predation, (4) the inadequacy of existing regulatory mechanisms, (5) other natural or manmade factors affecting its continued existence.

The proposed action is not expected to modify, curtail or destroy the range of the species since it will not result in any reductions in the number of shortnose sturgeon in the action area and since it will not affect the overall distribution of shortnose sturgeon other than to cause temporary changes in movements throughout the action area. The proposed action will not utilize shortnose sturgeon for recreational, scientific or commercial purposes, affect the adequacy of existing regulatory mechanisms to protect this species, or affect their continued existence. The effects of the proposed action will not hasten the extinction timeline or otherwise increase the danger of extinction; further, the action will not prevent the species from growing in a way that leads to recovery and the action will not change the rate at which recovery can occur. Therefore, the proposed action will not appreciably reduce the likelihood that shortnose sturgeon can be brought to the point at which they are no longer listed as endangered or threatened.

Despite the threats faced by individual shortnose sturgeon inside and outside of the action area, the proposed action will not increase the vulnerability of individual shortnose sturgeon to these additional threats and exposure to ongoing threats will not increase susceptibility to effects related to the proposed action. While we are not able to predict with precision how climate change will impact shortnose sturgeon in the action area or how the species will adapt to climate change-related environmental impacts, no additional effects related to climate change to shortnose sturgeon in the action area are anticipated over the life of the proposed action (i.e., through the license period of the individual projects). We have considered the effects of the proposed action in light of cumulative effects explained above, including climate change, and has concluded that even in light of the ongoing impacts of these activities and conditions, the conclusions reached above do not change.

8.4. Atlantic sturgeon

We have estimated that the proposed project may interact with New York Bight and GOM DPSs of Atlantic sturgeon. As explained in the "Effects of the Action" section, the operation of fish traps at the Milford and Orono Projects and the lowering of water levels in the Orono bypass reach during flashboard maintenance is expected to directly affect adult Atlantic sturgeon. Because these activities are not selective for which populations may be captured, we anticipate that the effects from the proposed action could impact both the NYB and GOM DPSs of Atlantic sturgeon (Table 18). As described previously, we expect Atlantic sturgeon to occur at the following frequencies in the action area: St. John River (Canada) 36%; Gulf of Maine DPS 63% and New York Bight DPS 1%. Therefore, impacts from the anticipated interaction and capture of several individual Atlantic sturgeon that could originate from either the GOM DPS or NYB DPS are described below. Note that if you add the values in the table below for the individuals allocated among the DPSs, the value exceeds the total expected. This is an artifact of the mixed stock analysis information being applied to calculate a whole value by population. As an example, to calculate the number of GOM DPS fish affected at the Milford Project using the MSA, one would multiply the total number of affected fish (25) by the proportion anticipated to be from the GOM DPS (63%). This equals 15.75, which, since portions of an individual fish cannot be affected, is equal to 16 fish. In this case, no more than 25 Atlantic sturgeon are anticipated to be trapped at Milford, of which, up to 16 could come from the GOM DPS.

Table 18. Number of Atlantic Sturgeon expected to be affected by the proposed project.

Project	Source	Duration	Total	DPS		
				GOM (63%)	**St. John (36%)**	**NYB (1%)**
Milford	Trapping	2013-2038	25	16	9	1
	Stranding		0	0	0	0
Orono	Trapping	2013-2048	35	23	13	1
	Stranding		35	23	13	1

8.4.1 Gulf of Maine DPS of Atlantic Sturgeon

While Atlantic sturgeon occur in several rivers in the Gulf of Maine, recent spawning has only been documented in the Kennebec River and possibly in the Androscoggin River. However, Atlantic sturgeon are known to occur in the Penobscot River, and it is possible that a spawning population may persist in the River below Veazie Dam. The removal of Veazie Dam provides Atlantic sturgeon with access to what is believed to be the full range of their historic habitat in the river.

During construction, Atlantic sturgeon will not be able to access the Milford, Orono, Stillwater, West Enfield and Medway Projects as they cannot currently move upstream of the Veazie Dam, which will not be removed until 2013 at the earliest. Therefore, the species will not be exposed to any effects associated with the construction of the new powerhouses and fish lifts; and consequently, all construction related effects are likely to be insignificant and discountable.

Future operations of the Stillwater, West Enfield and Medway Projects are not likely to result in negative effects to GOM DPS Atlantic sturgeon as they are located upstream of their historic range in the Penobscot River. The Milford and Orono Projects are located near the upstream extent of the historic range of Atlantic sturgeon and, therefore, they are not considered barriers to upstream migration. It is anticipated that once the Great Works and Veazie Dams have been removed that GOM DPS Atlantic sturgeon will utilize habitat downstream of these projects. Therefore, it is possible that the operation of the facilities could impact GOM DPS Atlantic sturgeon and its habitat downriver of the project.

We have determined that the proposed action will affect Atlantic sturgeon by resulting in the capture of one adult per project per year in the new fish lifts at the Orono and Milford Projects. These fish are from the GOM DPS (threatened) and NYB DPS (endangered), as well as from the St. John River (Canada). As outlined in Table 18, over the term of the FERC license this equates to the capture of no more than 35 Atlantic sturgeon at the Orono Project, with up to 23 coming from the GOM DPS. Likewise, no more than 25 Atlantic sturgeon are expected to be captured at the Milford Project over the term of its license, with up to16 coming from the GOM DPS. An additional Atlantic sturgeon per year is expected to be stranded in pools downstream of the Orono Project during the replacement or maintenance of flashboards. This equates to the stranding of no more than 35 Atlantic sturgeon over the term of the license, with up to 23 coming from the GOM DPS. As all in-water work will occur prior to the removal of the Veazie Dam, no GOM DPS Atlantic sturgeon will be exposed to the effects of construction. Black Bear will adhere to a monitoring plan and handling plan to ensure that any GOM DPS Atlantic sturgeon captured in the fish lifts, or in isolated pools, are removed promptly and returned safely downstream. It is possible that some captured GOM DPS Atlantic sturgeon could experience minor injuries, such as abrasions, due to contact with the concrete surface of the fish lift. GOM DPS Atlantic sturgeon captured in the fish lifts will be temporarily delayed from carrying out spawning activities. However, given that monitoring will be continuous during the spawning season the amount of time that any Atlantic sturgeon would spend in the fish traps, or in an isolated pool, is short and certainly less than 24 hours. As such, it is extremely unlikely that the fish would miss a spawning opportunity. Similarly, it is unlikely that the temporary capture in the traps, or in the pools, and subsequent removal and placement back downstream of the fish lift would cause an individual Atlantic sturgeon to abandon their spawning attempt. Considering this analysis, the capture of GOM DPS Atlantic sturgeon at the Milford (15 adults trapped) and Orono (21 adults trapped, 21 stranded in pools) Projects, is not likely to result in any injury or mortality or affect the fitness of any individuals, or cause any reduction in the number of eggs spawned or in the successful development of those eggs and larvae.

The proposed action is not likely to reduce reproduction of GOM DPS Atlantic sturgeon in the action area because: (1) there will be no reduction in the number of spawning adults; (2) there will be no reduction in fitness of spawning adults; (3) there is not anticipated to be any reduction in the number of eggs spawned or the fitness of any eggs or larvae; and (4) the project will continue to operate in run of river mode thus there is no potential for pulsed flows which could disrupt spawning or rearing.

The action is also not likely to reduce the numbers of GOM DPS Atlantic sturgeon in the action area as there will be no mortality of any individuals and no reason they would abandon the action area during the spawning season. The distribution of GOM DPS Atlantic sturgeon within the action area will not be affected by the action, as they will have access to the entirety of their historic range.

Based on the information provided above, the proposed action will not appreciably reduce the likelihood of survival for GOM DPS Atlantic sturgeon in the wild (i.e., it will not decrease the likelihood that the species will continue to persist into the future with sufficient resilience to allow for the potential recovery from endangerment). The action will not affect GOM DPS Atlantic sturgeon in a way that prevents the species from having a sufficient population, represented by all necessary age classes, genetic heterogeneity, and number of sexually mature individuals producing viable offspring and it will not result in effects to the environment which would prevent Atlantic sturgeon from completing their entire life cycle, including reproduction, sustenance, and shelter. This is the case because: (1) the action will not result in the mortality of any GOM DPS Atlantic sturgeon (2) as the action will not result in the mortality of any individuals, the action is not likely to have an effect on the levels of genetic heterogeneity in the population; (4) the temporary adverse effects to individuals captured in the fish lifts will not affect the reproductive output of any individual or the species as a whole; (5) the action will not affect the distribution of Atlantic sturgeon in the action area or beyond the action area (i.e., throughout its range); (6) the action will not affect the reproductive fitness of any individual spawning adult or result in any reductions in the number of eggs spawned or the successful development of any eggs or larvae; (7) the operations of the project will not affect the ability of Atlantic sturgeon to successfully spawn or for eggs and larvae to successfully develop and, (9) the action will have no effect on the ability of Atlantic sturgeon to shelter or forage.

In certain instances an action may not appreciably reduce the likelihood of a species survival (persistence) but may affect its likelihood of recovery or the rate at which recovery is expected to occur. As explained above, we have determined that the proposed action will not appreciably reduce the likelihood that GOM DPS Atlantic sturgeon will survive in the wild. Here, we consider the potential for the action to reduce the likelihood of recovery. As noted above, recovery is defined as the improvement in status such that listing is no longer appropriate.

Section 4(a)(1) of the ESA requires listing of a species if it is in danger of extinction throughout all or a significant portion of its range (i.e., "endangered"), or likely to become in danger of extinction throughout all or a significant portion of its range in the foreseeable future (i.e., "threatened") because of any of the following five listing factors: (1) The present or threatened destruction, modification, or curtailment of its habitat or range, (2) overutilization for commercial, recreational, scientific, or educational purposes, (3) disease or predation, (4) the inadequacy of existing regulatory mechanisms, (5) other natural or manmade factors affecting its continued existence.

The proposed action is not expected to modify, curtail or destroy the range of the species since it will not result in any reductions in the number of GOM DPS Atlantic sturgeon in the action area and since it will not affect the overall distribution of Atlantic sturgeon other than to cause temporary changes in movements throughout the action area. The proposed action will not utilize Atlantic sturgeon for recreational, scientific or commercial purposes, affect the adequacy of existing regulatory mechanisms to protect this species, or affect their continued existence. The effects of the proposed action will not hasten the extinction timeline or otherwise increase the danger of extinction; further, the action will not prevent the species from growing in a way that leads to recovery and the action will not change the rate at which recovery can occur. Therefore, the proposed action will not appreciably reduce the likelihood that GOM DPS Atlantic sturgeon can be brought to the point at which they are no longer listed as endangered or threatened.

Despite the threats faced by individual Atlantic sturgeon inside and outside of the action area, the proposed action will not increase the vulnerability of individual GOM DPS Atlantic sturgeon to these additional threats and exposure to ongoing threats will not increase susceptibility to effects related to the proposed action. While we are not able to predict with precision how climate change will impact GOM DPS Atlantic sturgeon in the action area or how the species will adapt to climate change-related environmental impacts, no additional effects related to climate change to GOM DPS Atlantic sturgeon in the action area are anticipated over the life of the proposed action (i.e., through the license period of the individual projects). We have considered the effects of the proposed action in light of cumulative effects explained above, including climate change, and have concluded that even in light of the ongoing impacts of these activities and conditions; the conclusions reached above do not change.

8.4.2 New Your Bight DPS of Atlantic Sturgeon

NYB DPS Atlantic sturgeon will not be able to access the Milford, Orono, Stillwater, West Enfield and Medway Projects during construction as they cannot currently move upstream of the Veazie Dam, which will not be removed until 2013 at the earliest. Therefore, the species will not be exposed to any effects associated with the construction of the new powerhouses and fish lifts; and consequently, all construction related effects are likely to be insignificant and discountable.

Future operations of the Stillwater, West Enfield and Medway Projects are not likely to result in negative effects to NYB DPS Atlantic sturgeon as they are located upstream of their historic range in the Penobscot River. The Milford and Orono Projects are located near the upstream extent of the historic range of Atlantic sturgeon and, therefore, they are not considered barriers to upstream migration. It is anticipated that once the Great Works and Veazie Dams have been removed that Atlantic sturgeon will utilize habitat downstream of these projects. Therefore, it is possible that the operation of the facilities could impact NYB DPS Atlantic sturgeon and its habitat downriver of the project.

We have determined that the proposed action will affect Atlantic sturgeon by resulting in the capture of one Atlantic sturgeon per project per year in the new fish lifts at the Orono and Milford Projects. These fish are from the GOM and NYB DPSs, as well as from the St. John River (Canada). As outlined in Table 18, over the term of the FERC license this equates to the capture of no more than 35 Atlantic sturgeon at the Orono Project, with up to one coming from the NYB DPS. Likewise, no more than 25 Atlantic sturgeon are expected to be captured at the Milford Project over the term of its license, with up to one coming from the NYB DPS. An additional Atlantic sturgeon per year is expected to be stranded in pools downstream of the Orono Project during the replacement or maintenance of flashboards. This equates to the stranding of no more than 35 Atlantic sturgeon over the term of the license, with up to one coming from the NYB DPS. As all in-water work will occur prior to the removal of the Veazie

Dam, no Atlantic sturgeon will be exposed to the effects of construction. Black Bear will adhere to a monitoring plan and handling plan to ensure that any Atlantic sturgeon captured in the fish lifts, or in isolated pools, are removed promptly and returned safely downstream. It is possible that some captured Atlantic sturgeon could experience minor injuries, such as abrasions, due to contact with the concrete surface of the fish lift. Atlantic sturgeon captured in the fish lifts will be temporarily delayed from carrying out spawning activities. However, given that monitoring will be continuous during the spawning season the amount of time that any Atlantic sturgeon would spend in the fish traps, or in an isolated pool, is short and certainly less than 24 hours. As such, it is extremely unlikely that the fish would miss a spawning opportunity. Similarly, it is unlikely that the temporary capture in the traps, or in the pools, and subsequent removal and placement back downstream of the fish lift would cause an individual Atlantic sturgeon to abandon their spawning attempt. Considering this analysis, the capture of one NYB DPS Atlantic sturgeon in the fish lifts at the Milford and Orono Projects, and the additional stranding of one NYB DPS Atlantic sturgeon at the Orono Project due to flashboard replacement, is not likely to result in any injury or mortality or affect the fitness of any individuals, or cause any reduction in the number of eggs spawned or in the successful development of those eggs and larvae.

The proposed action is not likely to reduce reproduction of NYB DPS Atlantic sturgeon in the action area because: (1) there will be no reduction in the number of spawning adults; (2) there will be no reduction in fitness of spawning adults; (3) there is not anticipated to be any reduction in the number of eggs spawned or the fitness of any eggs or larvae; and (4) the project will continue to operate in run of river mode thus there is no potential for pulsed flows which could disrupt spawning or rearing.

The action is also not likely to reduce the numbers of NYB DPS Atlantic sturgeon in the action area as there will be no mortality of any individuals and no reason they would abandon the action area during the spawning season. The distribution of NYB DPS Atlantic sturgeon within the action area will not be affected by the action, as they will have access to the entirety of their historic range.

Based on the information provided above, the proposed action will not appreciably reduce the likelihood of survival for NYB DPS Atlantic sturgeon in the wild (i.e., it will not decrease the likelihood that the species will continue to persist into the future with sufficient resilience to allow for the potential recovery from endangerment). The action will not affect NYB DPS Atlantic sturgeon in a way that prevents the species from having a sufficient population, represented by all necessary age classes, genetic heterogeneity, and number of sexually mature individuals producing viable offspring and it will not result in effects to the environment which would prevent Atlantic sturgeon from completing their entire life cycle, including reproduction, sustenance, and shelter. This is the case because: (1) the action will not result in the mortality of any NYB DPS Atlantic sturgeon (2) as the action will not result in the mortality of any individuals, the action is not likely to have an effect on the levels of genetic heterogeneity in the population; (4) the temporary adverse effects to individuals captured in the fish lifts will not affect the reproductive output of any individual or the species as a whole; (5) the action will not affect the distribution of NYB DPS Atlantic sturgeon in the action area or beyond the action area (i.e., throughout its range); (6) the action will not affect the reproductive fitness of any individual spawning adult or result in any reductions in the number of eggs spawned or the successful development of any eggs or larvae; (7) the operations of the project will not affect the ability of NYB DPS Atlantic sturgeon to successfully spawn or for eggs and larvae to successfully develop and, (9) the action will have no effect on the ability of Atlantic sturgeon to shelter or forage.

In certain instances an action may not appreciably reduce the likelihood of a species survival (persistence) but may affect its likelihood of recovery or the rate at which recovery is expected to occur. As explained above, we have determined that the proposed action will not appreciably reduce the likelihood that Atlantic sturgeon will survive in the wild. Here, we consider the potential for the action to reduce the likelihood of recovery. As noted above, recovery is defined as the improvement in status such that listing is no longer appropriate.

Section 4(a)(1) of the ESA requires listing of a species if it is in danger of extinction throughout all or a significant portion of its range (i.e., "endangered"), or likely to become in danger of extinction throughout all or a significant portion of its range in the foreseeable future (i.e., "threatened") because of any of the following five listing factors: (1) The present or threatened destruction, modification, or curtailment of its habitat or range, (2) overutilization for commercial, recreational, scientific, or educational purposes, (3) disease or predation, (4) the inadequacy of existing regulatory mechanisms, (5) other natural or manmade factors affecting its continued existence.

The proposed action is not expected to modify, curtail or destroy the range of the species since it will not result in any reductions in the number of NYB DPS Atlantic sturgeon in the action area and since it will not affect their overall distribution other than to cause temporary changes in movements throughout the action area. The proposed action will not utilize NYB DPS Atlantic sturgeon for recreational, scientific or commercial purposes, affect the adequacy of existing regulatory mechanisms to protect this species, or affect their continued existence. The effects of the proposed action will not hasten the extinction timeline or otherwise increase the danger of extinction; further, the action will not prevent the species from growing in a way that leads to recovery and the action will not change the rate at which recovery can occur. Therefore, the proposed action will not appreciably reduce the likelihood that NYB DPS Atlantic sturgeon can be brought to the point at which they are no longer listed as endangered or threatened.

Despite the threats faced by individual NYB DPS Atlantic sturgeon inside and outside of the action area, the proposed action will not increase the vulnerability of individual sturgeon to these additional threats and exposure to ongoing threats will not increase susceptibility to effects related to the proposed action. While we are not able to predict with precision how climate change will impact NYB DPS Atlantic sturgeon in the action area or how the species will adapt to climate change-related environmental impacts, no additional effects related to climate change to shortnose sturgeon in the action area are anticipated over the life of the proposed action (i.e., through the license period of the individual projects). We have considered the effects of the proposed action in light of the cumulative effects explained above, including climate change, and have concluded that even in light of the ongoing impacts of these activities and conditions; the conclusions reached above do not change.

9. CONCLUSION

After reviewing the best available information on the status of endangered and threatened species under NMFS jurisdiction, the environmental baseline for the action area, the effects of the action, and the cumulative effects, it is our biological opinion that the proposed action may adversely affect but is not likely to jeopardize the continued existence of shortnose sturgeon, the GOM DPS of Atlantic sturgeon, the New York Bight DPS of Atlantic sturgeon or the GOM DPS of Atlantic salmon. Furthermore, the proposed action is not expected to result in the destruction or adverse modification of critical habitat designated for the GOM DPS.

10. INCIDENTAL TAKE STATEMENT

Section 9(a)(1) of the ESA prohibits any taking (harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, collect, or attempt to engage in any such conduct) of endangered species without a specific permit or exemption. We interpret the term ''harm'' as an act which actually kills or injures fish or wildlife. It is further defined to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing behavioral patterns such as spawning, rearing, feeding, and migrating (50 CFR §222.102; NMFS 1999b). We have not defined the term "harass"; however, it is commonly understood to mean to annoy or bother. In addition, legislative history helps elucidate Congress' intent that harassment would occur where annoyance adversely affects the ability of individuals of the species to carry out biological functions or behaviors: "[take] includes harassment, whether intentional or not. This would allow, for example, the Secretary to regulate or prohibit the activities of birdwatchers where the effect of those activities might disturb the birds and make it difficult for them to hatch or raise their young" (HR Rep. 93-412, 1973). Incidental take is defined as take that is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity by a Federal agency or applicant (50 CFR §402.02). Under the terms of section 7(b)(4) and section 7(o)(2), taking that is incidental to and not intended as part of the agency action is not considered to be prohibited under the ESA, provided that such taking is in compliance with the terms and conditions of the incidental take statement.

The prohibitions against incidental take are currently in effect for the GOM DPS of Atlantic salmon, shortnose sturgeon, and all DPSs of Atlantic sturgeon except the threatened GOM DPS. A final section 4(d) rule for the GOM DPS of Atlantic sturgeon, which we anticipate to be published in the *Federal Register* soon, will apply the appropriate take prohibitions. The proposed 4(d) rule for the GOM DPS was published on June 10, 2011 (76 FR 34023) and includes prohibitions on take with very limited exceptions. The appropriate prohibitions on take of GOM DPS Atlantic sturgeon will take effect on the date the final 4(d) rule is effective and at that time, the take provided in this ITS will apply to the GOM DPS.

An incidental take statement specifies the amount or extent of any incidental taking of endangered or threatened species. It also provides reasonable and prudent measures that are necessary and appropriate to minimize and/or monitor incidental take and sets forth terms and conditions with which the action agency must comply in order to implement the reasonable and prudent measures. The measures described in this section are nondiscretionary. If the FERC fails to include these conditions in the license articles or Black Bear fails to assume and carry out the terms and conditions of this incidental take statement, the protective coverage of section

7(a)(2) may lapse. To monitor the effect of incidental take, the FERC must require Black Bear to report the progress of the action and its effect on each listed species to NMFS, as specified in this incidental take statement (50 CFR §402.14(i)(3)).

10.1. Amount or Extent of Take

In Section 6, we described the mechanisms by which ESA-listed anadromous fish and designated critical habitat would likely be affected by the construction of new powerhouses at the Orono and Stillwater Projects, the construction of fishway enhancements at the Orono, Milford and Stillwater Projects, and the incorporation of protective measures and performance standards proposed in Black Bear's SPP at the Milford, West Enfield, Medway, Orono and Stillwater Projects. The following sections describe the amount or extent of take that we expect would result based on the anticipated effects of the proposed action.

If the proposed action results in take of a greater amount or extent than that described above, the FERC would need to reinitiate consultation. The exempted take includes only take incidental to the proposed action.

10.1.1. Amount or Extent of Incidental Take of Atlantic salmon

10.1.1.1. Construction Activities

Construction is anticipated to commence in late summer of 2012, and will be completed by the end of 2013. The majority of in-water construction is anticipated to occur in 2012 after the trapping and upriver trucking of salmon associated with the Great Works Dam removal has ceased. At that point all upstream migrants will be released into the Veazie headpond. Based on Atlantic salmon returns between 2007 and 2010, 7% of the run passes the Veazie Project between August and October. Therefore, it is expected that at least 7% of the Atlantic salmon run in the Penobscot could be migrating through the project area during construction activities in the late summer and fall of 2012. Due to the use of erosion and sedimentation BMPs, the rock and ledge composition of the substrate and the fact that all blasting and drilling will occur within dewatered cofferdams, it is not anticipated that there will be any take of Atlantic salmon due to turbidity and noise effects associated with construction. However, it is possible that a small number of salmon could become entrapped within the cofferdams constructed at the Stillwater and Orono Projects. It is anticipated that one Atlantic salmon could be temporarily trapped at each of these two projects (Table 19). As qualified fisheries biologists will conduct stranding surveys and remove trapped salmon prior to dewatering, the fish are not expected to be killed. However, capturing and handling fish causes physiological stress and can cause physical injury although these effects can be kept to a minimum through proper handling procedures. Therefore, the construction of cofferdams at the Stillwater and Orono Projects may potentially harm one adult Atlantic salmon per project.

In addition to the entrapment of migrating Atlantic salmon, it is likely that some salmon will be significantly delayed in their migration due to the construction at the Orono Project during 2013. As described previously, adult migrating salmon are attracted to the discharge of the existing powerhouse at the Orono project, where they can be significantly delayed. The installation of an intake cofferdam, and the rerouting of 100% of the flow over the spillway, will cause fish to be attracted to the spillway rather than to the powerhouse discharge. As the spillway is more than 800 feet from the confluence with the mainstem, it is possible that the decrease in attraction to the river will lead to increased delay at the Orono Project during construction. Although the increase in delay cannot be quantified, it is expected that at least 33% of the Atlantic salmon attracted to the spillage will be harassed due to significant delay caused by the installation of the intake cofferdam at the Orono Project between July and October 2013.

Table 19. Summary of Atlantic salmon incidental take associated with FERC's authorization of Black Bear's proposed project.

Project	Source of Effect	Lifestage	Type of Effect	Mechanism of Effect	Baseline Conditions		SPP Conditions	
					Timeframe	Extent	Timeframe	Extent
Milford	Upstream Passage	Adult	Harassment	Forced straying	2013-2014	9.90%	2015-2038	4.90%
			Mortality	Direct and Indirect		0.10%		0.10%
	Downstream Passage	Smolt	Mortality	Direct and Indirect	2013-2022	24.40%	2023-2038	4.00%
		Kelt		Direct and Indirect		31.40%		4.00%
		Adult		Due to fall back		31.40%		4.00%
	Trapping	Adult	Collect	Fishway	2013-2038	100%		
			Mortality	Handling		100 fish		
	Monitoring Studies	Smolt	Harm	Handling and Surgery	2013-2022 and 2032	1899 fish		
			Mortality			38 fish		
		Adult	Harm	Handling and Surgery	2013-2014, 2024 and 2034	160 fish		
			Mortality			3 fish		
		Kelt	Harm	Handling and Surgery	3 year study	120 fish		
			Mortality			3 fish		
Orono	Construction	Adult	Harm	Cofferdam	2012	1 fish		
			Harassment	Significant Delay	2013	33%		
	Upstream Passage	Adult	Harassment	Forced straying	2013-2014	100.00%	2015-2048	4.90%
			Mortality	Direct and Indirect		0.00%		0.05%
			Harassment	Significant Delay	2013-2048	33.00%		
	Downstream Passage	Smolt	Mortality	Direct and Indirect	2013-2022	18.40%	2023-2048	4.00%
		Kelt		Direct and Indirect		28.00%		4.00%
		Adult		Due to Fall back		28.00%		4.00%
	Trapping/Trucking	Adult	Mortality	Handling and Transport	2014-2048	34 fish		
			Collect	Fishway	2013-2048	100%		
	Monitoring Studies	Smolt	Harm	Handling and Surgery	2013-2022 and 2032 and 2042	720 fish		
			Mortality			15 fish		
		Kelt	Harm	Handling and Surgery	3 year study	120 fish		
			Mortality			3 fish		

Table 19. continued…

Project	Source of Effect	Lifestage	Type of Effect	Mechanism of Effect	Baseline Conditions		SPP Conditions	
					Timeframe	Extent	Timeframe	Extent
Stillwater	Construction	Adult	Harm	Cofferdam	2012	1 fish		
	Upstream Passage	Adult	Harassment	Stray and Delay	2013-2048	100.00%		
	Downstream Passage	Smolt	Mortality	Direct and Indirect	2013-2022	9.50%	2023-2048	4.00%
		Kelt		Direct and Indirect		34.20%		4.00%
		Adult		Due to fall back		34.20%		4.00%
	Monitoring Studies	Smolt	Harm	Handling and Surgery	2013-2022 and 2032 and 2042	2448 fish		
			Mortality			49 fish		
		Kelt	Harm	Handling and Surgery	3 year study	120 fish		
			Mortality			3 fish		
West Enfield	Upstream Passage	Adult	Harassment	Forced Straying	2013-2022	10.78%	2023-2024	4.90%
			Mortality			0.22%		0.10%
			Collect	Fishway	2013-2024	100.00%		
	Downstream Passage	Smolt	Mortality	Direct and Indirect	2013-2022	7.70%	2023-2038	4.00%
		Kelt		Direct and Indirect		9.80%		4.00%
		Adult		Due to fall back		9.80%		4.00%
	Monitoring Studies	Smolt	Harm	Handling and Surgery	2013-2022	1620 fish		
			Mortality			33 fish		
		Adult	Harm	Handling and Surgery	2023	40 fish		
			Mortality			1 fish		
		Kelt	Harm	Handling and Surgery	3 year study	120 fish		
			Mortality			3 fish		
Medway	Upstream Passage	Adult	Harassment	Forced Straying	2013-2029	100.00%		
				Significant Delay		33.00%		

*The 480 smolts used in the tag retention/survival studies were allocated to each project based on the number of years each will be studied over the term of the consultation.

10.1.1.2. Hydroelectric Operations

We anticipate that the continued operation of the Milford, West Enfield, Medway, Orono and Stillwater Projects could potentially harm Atlantic salmon adults and smolts in the mainstem and Stillwater Branch of the Penobscot River. However, Black Bear's proposal to implement the provisions of the SPP will reduce the number of takes associated with these Projects.

Upstream Passage

As described above, section 9(a)(1) of the ESA prohibits any taking (harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, collect, or attempt to engage in any such conduct) of endangered species without a specific permit or exemption. The Merriam-Webster Dictionary defines "collect" as "to bring together into one body or place". The dictionary further defines "capture" as "to take captive" and "trap" as "to place in a restricted position". The function of a fishway is to temporarily collect, capture and trap all migrating fish that are motivated to pass a dam, and to provide a mechanism for them to do so. Therefore, it is anticipated that 100% of the Atlantic salmon that use the upstream passage facilities at the Milford, West Enfield or Orono Projects are collected, captured and trapped and, therefore, could potentially be exposed to the stress, injury and delay associated with being forced into fishways.

Based on pooled passage rates (1987-1992 at Milford and 1989-1992 at West Enfield) calculated in a study conducted by Shepard (1995), it is anticipated that no more than 10% of the Atlantic salmon attempting to pass upstream of the Milford Project, or 11% attempting to pass West Enfield, are currently delayed[5], injured, or killed. Under the provisions of the SPP, passage efficiency is expected to be increased so that no more than 5% of pre-spawn adults will be delayed, injured or killed by either the Milford or the West Enfield Project. The upstream performance standard is anticipated to be achieved at the Milford Project no later than the migration season following the two year initial efficiency study. As no initial study is proposed at West Enfield, it will not be known if the performance standard is being met until the ten year verification study has been conducted in 2023. Therefore, it is assumed that no fewer than 89% of Atlantic salmon will achieve passage past the Project over the next ten years. Although no performance standard has been proposed for Orono, it is anticipated that the new fish lift and trap will perform similarly to the one proposed for the Milford Project for fish that enter the bypass reach.

We convened an expert panel in December 2010 to provide the best available information on what happens to the Atlantic salmon that fail to pass a project with an upstream fishway. The group estimated a baseline mortality rate of 1% for Atlantic salmon that fail to pass a fishway at a given dam on the Penobscot River (NMFS 2010, Appendix B). Additional mortality was assumed based on project specific factors, such as predation, high fallback rates, fish handling, lack of thermal refugia, etc. The panel assumed an additional 1% mortality due to fall back at the Veazie Project caused by handling associated with the trapping and handling facilities. The proposed project includes the construction of a similar facility at the Milford Project. Therefore, the proposed project will increase the mortality rate of fish that fail to pass the Milford fishway

5 Delays to fish migrations due to ineffective fishways are considered "harm" to the species pursuant to 64 FR 60727 November 8, 1999.

by 1%. Therefore, it is assumed that under SPP conditions (post fishway construction) 2% of the Atlantic salmon that fail to pass the Milford Project will die; 1% due to baseline mortality and 1% due to increased fall back. Likewise, it is assumed for both the environmental baseline and SPP conditions at West Enfield that 2% of the Atlantic salmon that fail to pass the Project will be killed; 1% due to baseline mortality and 1% due to high fallback rates at that dam. Under the environmental baseline, there is no mortality associated with attempted passage at the Orono Project as no upstream fish passage facilities currently exist. However, after the proposed fish trap has been constructed, it is assumed that 1% of the fish that enter the bypass reach and fail to enter the fish trap, or exit the reach of their own volition, may be killed. Fish that fail to pass the fishway, but do not die, are harassed, and potentially harmed, by being forced to change their natural reproductive behavior; either by spawning in potentially less suitable habitat downstream, or by dropping back into the ocean without spawning. We estimate that take will occur at all five of Black Bear's projects in the Penobscot River due to the effects associated with upstream passage (Table 20). As it is not possible to predict with any certainty the number of Atlantic salmon that will be motivated to pass each of the projects on the Penobscot River, the amount of take due to upstream dam passage is provided as a proportion of the upstream migrants that approach within 200 meters of each individual project.

Table 20. The proportion of pre-spawn Atlantic salmon adults that are anticipated to be killed or harassed due to present and future operations at the Milford, West Enfield, Orono, Stillwater and Medway Projects. These estimates are based on pooled passage rates under the baseline and SPP conditions, and input from the expert panel convened by NMFS in December 2010.

		Fate of Salmon Approaching Dam			**Effect Duration**
		Pass	*Mortality*	*Harass*	
Environmental Baseline	Milford	90.00%	0.10%	9.90%	2013-2014
	West Enfield	89.00%	0.22%	10.78%	2013-2022
	Orono	0.00%	0.00%	100.00%	2013-2014
	Stillwater	0.00%	0.00%	100.00%	2013-2048
	Medway	0.00%	0.00%	100.00%	2013-2029
SPP Performance Standards	Milford	95.00%	0.10%	4.90%	2015-2038
	West Enfield	95.00%	0.10%	4.90%	2023-2024
	Orono*	95.00%	0.05%	4.95%	2015-2048
	Stillwater	0.00%	0.00%	100.00%	2013-2048
	Medway	0.00%	0.00%	100.00%	2013-2029

*This applies only to the Atlantic salmon that enter the Orono bypass reach. It is expected that 95% of the Atlantic salmon that enter the bypass reach will either be trapped in the fish trap, or will migrate out of their own volition.

As stated previously, there is no upstream performance standard at the Orono Project that describes the amount of significant delay to be expected under future operations. However, based on information collected by Shepard (1995) it is assumed that no more than 33% of the migrating adult Atlantic salmon attracted to the discharge from either of the two powerhouses will be harassed due to significant delay (more than 48 hours). A similar level of delay is anticipated at the Medway Project, where it is estimated that 33% of the fish that stray from the East Branch (approximately 7%) and approach within 200 meters of the Project may be delayed significantly. The Stillwater Project is anticipated to directly affect very few adult Atlantic salmon as there is no upstream access to the Project due to the lack of upstream passage facilities at the Orono Project. However, it is likely that a small proportion of the salmon run will fall back into the Stillwater Branch and over the Stillwater Project. One hundred percent of the fish that fall back will be significantly delayed by the Project because of its lack of upstream passage facilities.

Downstream Passage

A significant proportion of Atlantic salmon smolts and kelts are injured or killed during dam passage every year. As it is not possible to predict with any certainty the number of Atlantic salmon smolts and kelts that will be outmigrating past each of the projects on the Penobscot River, the amount of take due to downstream dam passage is provided as a proportion of the smolts and kelts that attempt to pass each individual dam. Table 21 indicates the maximum proportion of smolts and kelts that are anticipated to be killed due to direct and indirect effects both before and after the full implementation of the SPP performance standards, based on estimates provided by Alden Lab (2012). It is anticipated that the performance standard of 96%, based on a 75% confidence interval, will be met at all four projects no later than 2023. At that point, the mortality rate is not expected to exceed 4% at any of the four projects in any year.

Table 21. The maximum proportion of Atlantic salmon smolts and kelts that are anticipated to be killed annually due to present and future operations at the Milford, West Enfield, Orono and Stillwater Projects based on survival estimates provided by Alden Lab (2012). Existing kelt survival numbers are based on Alden Labs data, but has been weighted to account for 80% of outmigration occurring in the spring and 20% in the fall (Lévesque *et al.* 1985, Baum 1997).

	Project	Smolts	Kelts	Effect Duration
Environmental Baseline	Milford	24.40%	31.40%	2013-2022
	West Enfield	7.70%	9.80%	2013-2022
	Orono	18.40%	28.00%	2013-2022
	Stillwater	9.50%	34.20%	2013-2022
SPP Performance Standards	Milford	4.00%	4.00%	2023-2038
	West Enfield	4.00%	4.00%	2023-2024
	Orono	4.00%	4.00%	2023-2048
	Stillwater	4.00%	4.00%	2023-2048

In addition to smolts and kelts, it is anticipated that a small number of pre-spawn adult Atlantic salmon that fall back into the Stillwater Branch and the mainstem Penobscot will be subject to mortality associated with downstream dam passage at the Milford, West Enfield, Orono and Stillwater Projects. It is anticipated that mortality for pre-spawn adults would be the same as for kelts under the Environmental Baseline and SPP performance standard conditions (Table 21).

Trapping and Trucking

The trapping and trucking of Atlantic salmon can lead to stress, injury and mortality of migrating

Atlantic salmon. Migrating Atlantic salmon are anticipated to be trapped at both the Milford and Orono Projects. All of the Atlantic salmon that are trapped, handled, or trucked at these facilities will be harassed, and potentially injured, but most of these fish are anticipated to continue their migrations once they have been returned to the River. MDMR maintains a database of adult Atlantic salmon mortalities attributable to trapping and trucking from the Veazie fish trap. Between 1978 and 2011, the median mortality rate for adult Atlantic salmon at the Veazie trap was 0.07%. In a typical year, between zero and four salmon are killed during trapping and transportation at the Veazie Project (O. Cox, MDMR, personal communication). Although the MDMR database does not account for incidences of injury, it is assumed that a larger proportion of trapped and trucked Atlantic salmon suffer from injuries than mortality and that some of these injuries may lead to delayed mortality.

It is anticipated that as many as four adult Atlantic salmon will be killed every year at the Milford Project due to trapping (100 fish over the term of the license). Although Black Bear is responsible for the operation of the fish trap, they are not responsible for the trucking of Atlantic salmon to GLNFH, which is conducted by MDMR. However, as the MDMR database does not indicate the source of salmon mortalities (trapping or trucking) it is assumed that four fish a year is a conservative estimate of the number of fish that could potentially be killed in the Milford fish trap.

We anticipate that a portion of the Atlantic salmon run will be attracted to the spillage in the bypass reach at the Orono Project. Black Bear is responsible for both trap operation and short-distance trucking at the Orono project. It is anticipated that no more than one Atlantic salmon a year will be killed due to trapping and trucking at that Project.

10.1.1.3. Fish Passage Monitoring

Black Bear will be conducting studies of upstream efficiency and downstream survival in order to test the efficacy of protective measures and to verify that the performance standards are being met. As described previously, to determine whether the downstream performance standard is being met, three year paired-release studies will be conducted after fish passage facilities have been improved per the SPP and, if performance measures are not being met, after the first two successive protective measures are implemented. The final measure (nighttime shutdowns of the turbines for two weeks during the smolt outmigration) will only require a single year of study. Therefore, it is possible that there could be up to ten years of downstream survival studies being conducted at the Milford, West Enfield, Orono and Stillwater Projects. Based on the proposed study plan and the potential for ten to twelve years of studies at each of the projects, a maximum of 7,050 Atlantic salmon smolts will be adversely affected by the proposed studies due to trapping, handling, and the implantation of radio tags (Table 13). All of these fish will be injured due to the surgery required for tag implantation, and up to 2% of the fish used at each project (or 141 fish total) may die as a result.

In addition to downstream smolt survival studies, Black Bear proposes to conduct upstream passage efficiency studies at the Milford and West Enfield Projects using adult Atlantic salmon. The Milford fish lift will be tested in two consecutive years; one study year prior to the removal of Veazie Dam, and one year after the dam has been removed. In addition, passage efficiency will be tested every ten years to ensure that the performance standard is still being met. Black Bear has proposed to tag 20 to 40 adult salmon for each year of the study. Therefore, given the length of the remaining license term at Milford (expires in 2038), there is potential for 160 adult Atlantic salmon to be affected ((2 year initial study + 2 one-year studies at ten year intervals) * a maximum of 40 fish per year = 160 total fish). Unlike the Milford project, Black Bear is not proposing to conduct an initial upstream passage efficiency study at the West Enfield Project. However, they have proposed to conduct a ten year verification study. It is assumed that up to 40 adult Atlantic salmon will be affected as part of this monitoring. Therefore, a total of 200 adult Atlantic salmon will be affected by upstream monitoring studies at the Milford and West Enfield Projects over the term of this consultation. All of these fish will be potentially harassed and harmed due to the handling and surgical procedures necessary to prepare them for the studies. As the procedures will be conducted by professional fisheries biologists using established protocols few mortalities are anticipated. Of the 200 adult Atlantic salmon being used for the upstream studies, no more than four are anticipated to be killed during monitoring of upstream fish passage (i.e. three during the monitoring of the Milford Project, and one during the monitoring of the West Enfield project).

In addition to the upstream studies, Black Bear proposes to conduct a downstream kelt study ten years after the implementation of the final enhancements for smolt outmigration. A three year study at the Milford, West Enfield, Orono and Stillwater Projects will require the take of no more than 480 male kelts (40 fish x 4 projects x 3 years = 480 fish). All of these fish will be potentially harassed and harmed due to the handling and surgical procedures necessary to prepare them for the studies. As the procedures will be conducted by professional fisheries biologists using established protocols few mortalities are anticipated. Of the 480 kelts being used in the three year kelt study, no more than 12 (three per project) are anticipated to be killed.

We believe this level of incidental take is a reasonable estimate of incidental take that will occur given the seasonal distribution and abundance of Atlantic salmon in the action area and the information provided by numerous empirical studies and models on the upstream and downstream survival rates of Atlantic salmon in the Penobscot River. In the accompanying biological opinion, we determined that this level of anticipated take is not likely to result in jeopardy to the species. We consider this incidental take level to be exceeded if more than the specified amount of smolts and adults are harmed or harassed during the specified timeframe over the term of the individual projects license.

10.1.2. Amount or Extent of Incidental Take of Shortnose sturgeon

The proposed action has the potential to directly affect shortnose sturgeon by capturing three shortnose sturgeon annually at the Milford Project, and one at the Orono Project, at the proposed upstream fish passage facilities. In addition, the project could result in the annual capture of one shortnose sturgeon at the Orono Project in isolated pools downriver of the dam during flashboard maintenance and replacement. All trapped individuals will be removed from the fish traps, or the isolated pools, and returned downstream. Any captured fish may be harmed by receiving minor injuries due to abrasions on the trap or the pool substrate. The capture of four shortnose sturgeon annually (three at Milford and one at Orono) in the upstream fish traps, as well as the stranding of one shortnose sturgeon in pools downstream of the Orono Project, is likely. Over the term of the amended license, this equates to 75 shortnose sturgeon being trapped at the Milford Project (license expires in 2038), and 70 being trapped or stranded at the Orono Project (license expires in 2048). Neither mortality nor major injuries of any shortnose sturgeon is anticipated or exempted.

We believe this level of incidental take is a reasonable estimate of incidental take that will occur given the seasonal distribution and abundance of shortnose sturgeon in the action area and the reports of shortnose sturgeon entering fish lifts, or being stranded, in other rivers. In the accompanying biological opinion, we determined that this level of anticipated take is not likely to result in jeopardy to the species. We consider this incidental take level to be exceeded if more than three shortnose sturgeon are captured in the fish trap at the Milford Project, or more than one shortnose sturgeon is captured at the Orono Project on an annual basis over the term of their licenses. Additionally, take will be considered exceeded if more than one shortnose sturgeon per year is trapped in isolated pools downstream of the Orono Project during flashboard maintenance.

10.1.3. Amount or Extent of Incidental Take of Atlantic sturgeon

The proposed action has the potential to directly affect Atlantic sturgeon by resulting in the capture of one Atlantic sturgeon per project per year at Black Bear's upstream fish passage facilities at the Orono and Milford Projects. In addition, the project could result in the capture of one Atlantic sturgeon per year in isolated pools downriver of the Orono Project during flashboard maintenance and replacement. All trapped individuals will be removed from the fish traps, or the isolated pools, and returned downstream. Any captured fish may be harmed by receiving minor injuries due to abrasions on the trap or the pool substrate. The capture of two Atlantic sturgeon annually (one each at the Milford and Orono Projects) in the upstream fish traps, as well as the stranding of one Atlantic sturgeon annually in pools downstream of the Orono Project, is likely. This equates to 70 Atlantic sturgeon affected by trapping and stranding at the Orono Project, and 25 affected by trapping at the Milford Project, over the terms of the amended licenses (Table 18). Based on a mixed stock analysis, we anticipate that no more than 62 of the Atlantic sturgeon (46 at Orono, 16 at Milford) will be GOM DPS origin and no more than three (two at Orono, one at Milford) will be NYB DPS origin. The remaining 35 Atlantic sturgeon (26 at Orono and 9 at Milford) will originate from St. John River Canada and are not protected under the US ESA. Neither mortality nor major injuries of any Atlantic sturgeon is anticipated or exempted.

We believe this level of incidental take is a reasonable estimate of incidental take that will occur given the seasonal distribution and abundance of Atlantic sturgeon in the action area and the reports of Atlantic sturgeon entering fish lifts, or being stranded, in other rivers. In the accompanying biological opinion, we determined that this level of anticipated take is not likely to result in jeopardy to the species. We consider this incidental take level to be exceeded if more than one Atlantic sturgeon per year is captured in the traps at either the Orono or Milford Projects, or if more than one Atlantic sturgeon per year is stranded in pools downstream of the Orono Project.

10.2. Reasonable and Prudent Measures

We believe the following reasonable and prudent measures are necessary and appropriate to minimize and monitor incidental take of Atlantic salmon, shortnose sturgeon and Atlantic sturgeon. These must be included as enforceable terms of any amended operating licenses issued by FERC to Black Bear. Please note that these reasonable and prudent measures and terms and conditions are in addition to the measures contained in the June 7, 2012 SPP that Black Bear has committed to implement and FERC is proposing to incorporate into the project licenses. As these measures will become mandatory requirements of any new licenses issued, we do not repeat them here as they are considered to be part of the proposed action.

1. FERC must ensure, through enforceable conditions of the project licenses, that Black Bear conduct all in-water and near-water construction activities in a manner that minimizes incidental take of ESA-listed or proposed species and conserves the aquatic resources on which ESA-listed species depend.

2. FERC must ensure, through enforceable conditions of the project licenses, that Black Bear minimize incidental take from all in-water and near-water activities by applying best management practices to the proposed action that avoid or minimize adverse effects to water quality and aquatic resources.

3. To minimize incidental take from project operations, FERC must require that Black Bear measure and monitor the performance standards contained in the June 7, 2012 Species Protection Plan (SPP) in a way that is adequately protective of listed Atlantic salmon.

4. FERC must ensure, through enforceable conditions of the project licenses, that Black Bear complete an annual monitoring and reporting program to confirm that Black Bear is minimizing incidental take and reporting all project-related observations of dead or injured salmon or sturgeon to NMFS.

5. If the new Milford upstream fish lift is not operational prior to the Veazie Dam removal, or if it is proven ineffective during upstream monitoring studies, FERC must require Black Bear to install a broodstock collection device at the existing Denil fishway.

10.3. Terms and Conditions

In order to be exempt from prohibitions of section 9 of the ESA, FERC must comply with the following terms and conditions, which implement the reasonable and prudent measures described above and which outline required reporting/monitoring requirements. These terms and conditions are non-discretionary. Any taking that is in compliance with the terms and conditions specified in this Incidental Take Statement shall not be considered a prohibited taking of the species concerned (ESA section 7(o)(2)). In carrying out all of these terms and conditions, FERC as lead Federal agency in this consultation, is responsible for coordinating with the other Federal agencies that are party to the consultation, as well as with the licensee. FERC must implement these terms and conditions through enforceable conditions of the project licenses.

Where appropriate, the ACOE must require these terms and conditions as enforceable conditions of any permits or authorizations.

1. To implement reasonable and prudent measure #1, FERC and ACOE must require Black Bear to do the following:

   a. Hold a pre-construction meeting with the contractor(s) to review all procedures and requirements for avoiding and minimizing impacts to Atlantic salmon and to emphasize the importance of these measures for protecting salmon.

   b. Black Bear must notify NMFS one week before in-water work begins.

   c. Use Best Management Practices that will minimize concrete products (dust, chips, larger chunks) mobilized by construction activities from entering flowing or standing waters. Best practicable efforts shall be made to collect and remove all concrete products prior to rewatering of construction areas.

   d. Employ erosion control and sediment containment devices at the Stillwater, Orono and Milford Dams construction sites. During construction, all erosion control and sediment containment devices shall be inspected weekly, at a minimum, to ensure that they are working adequately. Any erosion control or sediment containment inadequacies will be immediately addressed until the disturbance is minimized.

   e. Provide erosion control and sediment containment materials (e.g., silt fence, straw bales, aggregate) in excess of those installed, so they are readily available on site for immediate use during emergency erosion control needs.

   f. Ensure that vehicles operated within 150 feet (46 m) of the construction site waterways will be free of fluid leaks. Daily examination of vehicles for fluid leaks is required during periods operated within or above the waterway.

   g. During construction activities, ensure that BMPs are implemented to prevent pollutants of any kind (sewage, waste spoils, petroleum products, etc.) from contacting water bodies or their substrate.

   h. In any areas used for staging, access roads, or storage, be prepared to evacuate all materials, equipment, and fuel if flooding of the area is expected to occur within 24 hours.

   i. Perform vehicle maintenance, refueling of vehicles, and storage of fuel at least 150 feet (46 m) from the waterway, provided, however, that cranes and other semi-mobile equipment may be refueled in place.

   j. At the end of each work shift, vehicles will not be stored within, or over, the waterway.

k. Prior to operating within the waterway, all equipment will be cleaned of external oil, grease, dirt, or caked mud. Any washing of equipment shall be conducted in a location that shall not contribute untreated wastewater to any flowing stream or drainage area.

l. Use temporary erosion and sediment controls on all exposed slopes during any hiatus in work exceeding seven days.

m. Place material removed during excavation only in locations where it cannot enter sensitive aquatic resources.

n. Minimize alteration or disturbance of the streambanks and existing riparian vegetation to the greatest extent possible.

o. Remove undesired vegetation and root nodes by mechanical means only. No herbicide application shall occur.

p. Mark and identify clearing limits. Construction activity or movement of equipment into existing vegetated areas shall not begin until clearing limits are marked.

q. Retain all existing vegetation within 150 feet (46 m) of the edge of the bank to the greatest extent practicable.

2. To implement reasonable and prudent measure #2, FERC and ACOE must require Black Bear to do the following:

   a. Contact NMFS within 24 hours of any interactions with Atlantic salmon, Atlantic sturgeon or shortnose sturgeon, including non-lethal and lethal takes (Jeff Murphy: by email (Jeff.Murphy@noaa.gov) or phone (207) 866- 7379 and the Section 7 Coordinator (incidental.take@noaa.gov)

   b. In the event of any lethal takes, any dead specimens or body parts must be photographed, measured, and preserved (refrigerate or freeze) until disposal procedures are discussed with NMFS.

   c. Notify NMFS of any changes in project and fishway operations (including maintenance activities such as flashboard replacement and draft tube dewatering) at the Orono, Stillwater, Milford, West Enfield, and Medway Projects.

   d. Submit a fish evacuation protocol to NMFS at least two weeks prior to the commencement of in-water work. Daily visual surveys will be conducted by qualified personnel to verify that there are no Atlantic salmon within the project area during the installation and removal of any in-water cofferdam or bypass structure. If cofferdams overtop due a high flow event, the cofferdam will be resurveyed for adult Atlantic salmon prior to dewatering. If any Atlantic salmon are observed within the enclosed cofferdam they should be removed, either by herding or by capture. Handling should be minimized to the extent possible.

3. To implement reasonable and prudent measure #3, the FERC must require that Black Bear do the following:
   a. Require Black Bear to measure the survival performance standard for downstream migrating Atlantic salmon smolts and kelts at the Orono, Stillwater, Milford, and West Enfield Projects of 96% (within the lower and upper 75% confidence limit) using a scientifically acceptable methodology.
      i. That is, 96% of downstream migrating smolts and kelts approaching the dam structure survive passing the project, which would include from 200 meters upstream of the trashracks and continuing downstream to the point where delayed effects of passage can be quantified. Black Bear must coordinate with NMFS in selecting an adequate location for the downstream receivers.
      ii. Passage must occur within 24 hours of a smolt or kelt approaching within 200 meters of the trashracks for it to be considered a successful passage attempt that can be applied towards the performance standard.
      iii. The survival standard is considered achieved if each year of a three year study period achieves at least 96%, based on a 75% confidence interval, at each project. A Cormack-Jolly-Seber (CJS) model, or other acceptable approach, must be used to determine if the survival estimate and associated error bounds meet targets and efficiency/survival estimates are within scope of published telemetry work for salmon in the region.
      iv. Black Bear must consult with NMFS concerning the application of appropriate statistical methodology and must provide an electronic copy of model(s) and data to NMFS.

   b. All tags released in the system should have codes that are not duplicative of tags used by other researchers in the river, including university, state, federal and international tagging programs.

   c. Submit a study plan for a one year adult upstream study at the West Enfield Project to be conducted ten years post implementation of the SPP.

   d. Submit a study plan for a three year downstream kelt study at the Orono, Stillwater, Milford, and West Enfield Projects.

4. To implement reasonable and prudent measure #4, the FERC must require that Black Bear do the following:

   a. Require that Black Bear seek comments from NMFS on any fish passage design plans at the 30%, 60%, and 90% design phase. Also, allow NMFS to inspect fishways at the projects at least annually.

   b. Submit annual reports at the end of each calendar year summarizing the results of proposed action and any takes of listed sturgeon or Atlantic salmon to NMFS by mail (to the attention of the Section 7 Coordinator, NMFS Protected Resources Division, 55 Great Republic Drive, Gloucester, MA 01930 and to incidental.take@noaa.gov.

The reasonable and prudent measures, with their implementing terms and conditions, are designed to minimize and monitor the impact of incidental take that might otherwise result from the proposed action. If, during the course of the action, the level of incidental take is exceeded, immediate reinitiation of consultation and review of the reasonable and prudent measures are required. FERC must immediately provide an explanation of the causes of the taking and review with NMFS the need for possible modification of the reasonable and prudent measures.

Reasonable and prudent measures and their implementing terms and conditions may not alter the basic design, location, scope, duration, or timing of the action, and should involve only minor changes (50 CFR §402.14(i)(2)). The FERC and ACOE have reviewed the RPMs and Terms and Conditions outlined above and have agreed to implement all of these measures as described herein. The discussion below explains why each of these RPMs and Terms and Conditions are necessary and appropriate to minimize or monitor the level of incidental take associated with the proposed action and how they represent only a minor change to the action as proposed by the FERC.

RPM #1, #2, as well as Terms and Conditions (#1-2) are necessary and appropriate as they will require Black Bear and their contractors to use best management practices and best available technology for construction. This will ensure that take of listed Atlantic salmon is minimized to the extent practical. These procedures represent only a minor change to the proposed action as following these procedures should not increase the cost of the project or result in any delays or reduction of efficiency of the project.

RPM #3 as well as Term and Condition #3 are necessary and appropriate as they describe how Black Bear will be required to measure and monitor the success of the proposed performance standards. These procedures represent only a minor change to the proposed action as following these procedures should not increase the cost of the project or result in any delays or reduction of efficiency of the project.

RPM #4 as well as Term and Condition# 4 are necessary and appropriate to ensure the proper documentation of any interactions with listed species as well as requiring that these interactions are reported to NMFS in a timely manner with all of the necessary information. This is essential for monitoring the level of incidental take associated with the proposed action. This RPM and the Terms and Conditions represent only a minor change as compliance will not result in any increased cost, delay of the project or decrease in the efficiency of the project.

RPM #5 is necessary and appropriate as it will require Black Bear to minimize the effect of the operation of the Milford Project if the Veazie Dam is removed prior to the completion of the proposed fish lift, or in the event that the new fish lift is proven to be ineffective. The lack of a collection device on the Penobscot River, even temporarily, would threaten the recovery and survival of the species as broodstock could not be obtained to sustain the hatchery program at the Green Lake National Fish Hatchery. This will ensure that take of listed Atlantic salmon is minimized to the extent practical. This requirement represents only a minor change to the proposed action as following these procedures should not increase the cost of the project significantly or result in any delays or reduction of efficiency of the project.

11. CONSERVATION RECOMMENDATIONS

Section 7(a)(1) of the ESA directs Federal agencies to utilize their authorities to further the purposes of the ESA by carrying out conservation programs for the benefit of endangered and threatened species. Conservation recommendations are discretionary agency activities to minimize or avoid adverse effects of a proposed action on listed species or critical habitat, to help implement recovery plans, or to develop information. NMFS has determined that the proposed action is not likely to jeopardize the continued existence of shortnose sturgeon, the GOM DPS of Atlantic salmon and the GOM DPS and NYB DPS of Atlantic sturgeon. To further reduce the adverse effects of the proposed project on shortnose sturgeon, Atlantic sturgeon and Atlantic salmon, NMFS recommends that FERC implement the following conservation measures.

1. If any lethal take occurs, FERC should use its authorities to, and/or direct the licensee to, arrange for contaminant analysis of the specimen. If this recommendation is to be implemented, the fish should be frozen and NMFS should be contacted immediately to provide instructions on shipping and preparation.

2. FERC should use its authorities to implement license requirements for all FERC regulated projects in Maine to provide safe and effective upstream and downstream fish passage for listed Atlantic salmon and other diadromous fish species. For Atlantic salmon, this can be accomplished through station shutdowns during the smolt passage season (April to June) and kelt passage season (October to December and April to June) or the installation of highly effective fishways.

3. FERC should use its authorities to require all FERC regulated hydroelectric projects in Maine to document the effectiveness of station shutdowns or fishways in protecting listed Atlantic salmon.

4. FERC should use its authorities to require all FERC regulated hydroelectric projects in Maine to operate in a manner that is protective of NMFS listed species. This can be accomplished by requiring these facilities to operate in a run-of-river mode to simulate a natural stream hydrograph.

12. REINITIATION NOTICE

This concludes formal consultation concerning FERC's proposal to amend licenses to allow for new powerhouses at the Stillwater and Orono Projects, as well as incorporate the provisions of the proposed SPP at the Stillwater, Orono, Milford, West Enfield and Medway Projects located on the Penobscot River in Penobscot County, Maine. As provided in 50 CFR §402.16, reinitiation of formal consultation is required where discretionary federal agency involvement or control over the action has been retained (or is authorized by law) and if: (1) the amount or extent of taking specified in the incidental take statement is exceeded; (2) new information reveals effects of the action that may not have been previously considered; (3) the identified action is subsequently modified in a manner that causes an effect to listed species; or (4) a new species is listed or critical habitat designated that may be affected by the identified action. In instances where the amount or extent of incidental take is exceeded, section 7 consultation must be reinitiated immediately.

This Opinion assumes that the SPP will be implemented upon issuance of this document and performance standard deficiencies addressed and progress documented annually. If standards are not achieved within ten years of issuance, FERC must reinitiate consultation with NMFS.

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APPENDIX A

Atlantic Salmon Survival Estimates At Mainstem Hydroelectric Projects on the Penobscot River

Draft Phase 3 Final Report

Alden Research Laboratory, Inc.

APPENDIX B

Atlantic Salmon Fate and Straying at Upstream Fish Passage Facilities on the Penobscot River

February 2011

APPENDIX C

NMFS Dam Impact Assessment Model

Northeast Fisheries Science Center
Woods Hole, MA

2012

APPENDIX D

Technical Memorandum

Assumptions Used and Verification
Process for the Development of the
Black Bear Hydro Species Projection Plan

USFWS 2012

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Atlantic Salmon Survival Estimates at Mainstem Hydroelectric Projects on the Penobscot River

DRAFT

PHASE 3 FINAL REPORT

Prepared for

The National Marine Fisheries Service
National Oceanographic and Atmospheric Administration
U.S. Department of Commerce

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1 INTRODUCTION

The National Marine Fisheries Service (NMFS) is in the process of developing a population model for endangered Atlantic salmon populations to assist with the determination of acceptable levels of incidental "take" at hydro projects on the Penobscot River. The term "take" (as defined in section 3 of the Endangered Species Act) means to "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct." The term "harm" has been further clarified by NMFS and the United States Fish and Wildlife Service (FWS) to include any act which "actually kills or injures fish or wildlife, as well as acts that may include significant habitat modification or degradation that significantly impairs essential behavioral patterns of fish or wildlife (64 FR 607277, November 8, 1999)." Migration is a critical behavior for anadromous fishes and, therefore, merited specific mention in the definition. In the final rule clarifying the definition of "harm," NMFS and FWS specifically note the following form of take: "constructing or maintaining barriers that eliminate or impede a listed species' access to habitat or ability to migrate." Thus for anadromous species, juveniles and adults must be able to pass downstream from spawning grounds to the open ocean, and adults must be able to return from the ocean to spawning grounds in a timely manner. Atlantic salmon smolts and kelts migrating downstream may be subject to mortality at hydropower facilities due to injuries sustained during passage through turbines and fish bypasses, or over spillways. In addition to direct mortality associated with these passage routes, indirect mortality may result from increased predation rates or reduced fitness associated with the stress of downstream passage and migration delays at hydro projects. Cumulative effects from passage at multiple projects may also lead to increased mortality and reduced fitness during the in-river migration and after fish reach the estuary and marine environment.

A major component of the Atlantic salmon population model that is being developed by NMFS will be estimating the survival rates of smolts and kelts at each hydropower project during their downstream migration. To obtain this information, the NMFS contracted Alden Research Laboratory, Inc. (Alden) to estimate downstream passage survival of Atlantic salmon smolts and kelts at 15 hydroelectric projects on the Penobscot River and its tributaries. These desktop survival estimates focus on direct mortality attributable to passage at dams, but indirect and cumulative (delayed) mortality associated with multiple dam passage are also addressed. The primary goal of Alden's analysis was to effectively estimate the survival distributions of Atlantic salmon smolts and kelts passing downstream at each of the specified hydro projects. To achieve this goal, the study objectives were to estimate the proportion of fish (smolts and kelts) using available downstream passage routes and to estimate direct and indirect survival associated with each route. An established turbine blade strike probability and mortality model was used to estimate direct survival of fish passing through turbines at each project. Survival rates for fish that pass downstream over spillways or through fish bypass facilities was estimated based on existing site-specific data or from studies conductecd other hydro projects with similar species (i.e., anadromous salmonids). The proportion of fish using each available downstream passage route was based on flow distributions and bypass efficiency estimates (either site specific or developed from the literature).

NMFS established the following three project phases for completing the downstream passage survival analysis for Atlantic salmon in the Penobscot River:

- Phase 1: Define the term "survival" as it pertains to the loss of fish passing downstream at a given dam and gather and summarize all information and data that will be used to generate Atlantic salmon survival distributions at each of the specified projects.

- Phase 2: Calculate survival distributions for smolts and kelts passing downstream at each project.

- Phase 3: Finalize Phase 1 and 2 efforts and submit final report to NMFS.

The first task of Phase 1 was to consult with NMFS and mutually agree to the definition of the term "survival" with respect to downstream passage at each project and the proposed population model being developed by NMFS. This definition includes direct and indirect mortality associated with all passage routes, as well as cumulative mortality resulting from passage at multiple dams. The second task of Phase 1 focused on obtaining and summarizing existing information and data for each hydroelectric project that was needed for the estimation of downstream passage survival. Information that was sought for each project pertained to turbine design and operation, spillway design, debris/ice sluice design, and fish passage facility design and operation (including any existing bypasses). Obtaining information on project operation (e.g., turbine and spillway discharge, fish bypass discharge) and river flow (average monthly discharge) during specificed smolt and kelt migration periods and the effectiveness of any existing downstream passage facilities was also an important objective of this task.

Turbine design and operational data obtained during Phase 1 were used to calculate turbine passage survival of smolts and kelts at each project as part of Phase 2. For spillway and bypass survival, Alden reviewed literature from previous studies that have examined survival rates of smolts and kelts passing downstream at hydro projects. Information and data describing project design and operation, biological parameters, and study approach and results were reviewed for applicability to the analysis of survival at the Penobscot River projects. Available literature was also reviewed for developing estimates of indirect survival. The successful completion of Phase 2 resulted in total passage survival estimates for smolts and kelts encountering the 15 Penobscot River projects of interest over the range of average monthly flows expected to occur at each site based on historical USGS gage data. The results of Phase 1 and 2 are presented in this report, as well as the methods and data used to generate flow probability distributions and corresponding total project survival rates.

2 DEFINITION OF DOWNSTREAM PASSAGE SURVIVAL

The ability of migratory life stages to pass safely downstream at hydroelectric projects has been a major issue in the management of diadromous fish populations on the West and East coasts of the U.S. Fish passing downstream at hydropower dams are exposed to several sources of potential injury, migratory delays, direct and indirect mortality, and cumulative mortality from multiple dam passage. Direct mortality results from lethal injuries suffered during passage through turbines, over spillways, or through fish bypass systems. These injuries lead to the loss of fish during passage or shortly thereafter (e.g., turbine blade strike). Indirect mortality results from sub-lethal injuries, increased stress, or disorientation (Cada 2001), all of which can lead to increased susceptibility to disease and/or predation or reduced fitness that decreases the probability of successful migration to a river's estuary. Extensive research of direct mortality sources for fish passing downstream at hydropower projects has been conducted during the past 60 years, with most studies focusing on anadromous salmonids. Indirect mortality has been more difficult to assess and characterize, but also has been the subject of considerable research. A third type of mortality that has been the subject of recent studies is cumulative mortality (also referred to as delayed mortality) that occurs in the estuary or marine environment and is directly related to hydropower system experience (i.e., multiple dam passages).

For the purposes of determining downstream passage survival rates for Atlantic salmon smolts and kelts at Penobscot River projects, we define direct mortality as any fish that dies during or immediately following passage through turbines, over a spillway, or through a fish bypass system. Turbine survival was calculated using an established blade strike probability and mortality model. Other injury mechanisms associated with turbine passage (e.g., damaging pressure regimes, shear, and turbulence) are expected to result in little or no direct or indirect mortality to fish passing through turbines at Penobscot River projects due their relatively low heads (14 projects have heads less than 30 ft and one project has a head of 39 ft). Based on analysis of available turbine passage data, Franke et al. (1997) concluded that the primary source of injury and mortality of fish passing through turbines at projects with less than 100 ft of head was blade strike. Consequently, mortality from injury mechanisms other than blade strike is considered to be inconsequential for the Penobscot projects and may not be detectable within the variability of the data.

Indirect (or delayed) mortality will be defined as fish that successfully pass a project but are lost during the migration at some point downstream due to sub-lethal injuries, increased stress, or passage delay. Loss of fish through indirect mortality may result from infections and disease associated with sub-lethal injuries (including excessive scale loss) and increased stress or higher predation risk due to injury and/or disorientation following dam passage (Cada 2001). Migratory delays at one or more dams may also reduce fitness, increase physiological stress, and result in mortality during the migration through downstream river reaches, in the estuary, or after fish begin their ocean migrations. Estimates of indirect mortality of Atlantic salmon smolts and kelts will be derived using data and information from previous studies, including those conducted with Pacific salmonids and other anadromous species, if such studies are shown to be relevant and add to the robustness of our analysis. Indirect mortality rates will be applicable to all fish that survive downstream passage at a given dam and continue their migration towards the next dam. This will result in reach specific (i.e., dam to dam) indirect mortality rates based on data developed for the dam that fish just passed without suffering immediate mortality. Cumulative effects of passage through multiple dams will be considered when determining indirect mortality rates, but may be difficult to determine and include in the survival analysis in an accurate, precise, and reliable manner.

Based on the above definitions and descriptions of passage survival (and mortality), if a known number of fish approach a project, a certain proportion will survive downstream passage (i.e., 1 – direct mortality), of which a certain proportion will survive to reach the next dam (1 – direct mortality – indirect mortality), or the estuary in the case of the lowermost dam. Survival distributions developed for each project will encompass a range of river discharges expected to occur for each month based on historical flow records. The percent of fish expected to pass via each available downstream route will vary with river discharge, thus overall downstream passage survival will vary with the proportion of fish using each passage route based on route specific survival rates established by the analysis conducted by Alden during Phase 2 of this project.

3 SURVIVAL ESTIMATION METHODS`

3.1 Survival Based on Direct Mortality

The survival of fish passing downstream at hydropower projects is dependent on a variety of factors associated with available passage routes. Typically, there are three primary routes for fish passage: over spillways and associated structures (e.g., spill or crest gates), through bypasses (which may be designed and installed specifically for fish passage or may be existing ice or debris sluice gates), and through turbines. The proportion of migrating fish passing through each of these routes will depend on project configuration and operation and the resulting hydraulic conditions experienced by fish as they approach a project. For the Penobscot River projects, it is important to note that not all of the sites have all three types of passage routes available at all river discharges. Also, some of the projects do not currently have dedicated downstream fish bypasses. Insufficient flow depth over spillways is assumed to prohibit passage (< 6 inches for smolts and < 12 inches for kelts) via this route and low river flows may prevent the operation of one or more turbines. Certain levels of injury and mortality are expected to occur for fish passing through each available route, and survival of fish passing over spillways and bypasses is typically expected to be higher than for fish passing through turbines (Muir et al. 2001). Downstream passage survival at each project will depend on direct mortality resulting from lethal injuries, indirect mortality associated with increased predation and disease/infection from sub-lethal injuries, and cumulative effects of stress and injury associated with multiple dam passages. This section describes the methods used for estimating direct turbine passage survival and the development of literature-based direct survival rates for fish passing downstream via spillways and bypasses. The estimation of indirect mortality is described in Section 2.2. and, although not incorporated into estimates of total project survival, cumulative mortality associated with multiple dam passages is addressed in Section 2.3.

3.1.1 Methodology for Estimating Turbine Passage Survival

For fish passing through turbines at low head hydroelectric facilities (< 100 ft), such as those on the Penobscot River, it is assumed that the primary injury mechanism leading to mortality will be blade strike (Franke et al. 1997). Consequently, a theoretical model was used to predict blade strike probability and mortality (and, inversely, survival) for the expected operational range of turbines and for a range of fish lengths. Length range and frequency data for Atlantic salmon smolts and kelts in the Penobscot River salmon were provided by NMFS. A detailed description of the development and application of turbine survival model is provided below.

3.1.1.1 Probability of Blade Strike

Based on the probability of strike being equal to the distance the blade leading edges move as compared to the total distance between two leading edges, in the time it takes a fish to be carried past the arc of leading edge motion (Figure 3-1), the probability of strike is given by equation (1) (Ploskey and Carlson 2004):

$$P = \frac{nNL\cos\theta}{60V_{ax}} \quad (1)$$

Where:

P	=	probability of strike (non-dimensional)
n	=	runner rpm
N	=	number of leading edges (blades)
L	=	fish length (ft)
θ	=	angle between absolute and axial (or radial) velocity vectors (degrees)
V_{ax} (or V_{rad})	=	axial (or radial) velocity (ft/s)

Note that $\cos\theta = \sin\alpha$, where α is the angle between the absolute inflow velocity and a tangent line to the runner circumference (Figure 3-1). The parameter $L\cos\theta$ (or $L\sin\alpha$) is the projected fish length in the axial (or radial) direction. Throughout this report, the wicket gate angle (Francis turbines) and flow angle (Kaplan/propeller turbines) are defined as the angle between the absolute velocity and tangential velocity, α.

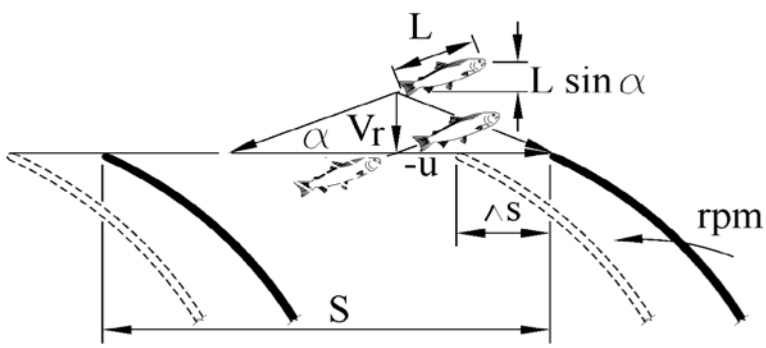

Figure 3-1. Schematic of absolute inflow, axial velocity (or radial for Francis turbines), and relative velocity of flow (and fish) to a blade leading edge. Drawing depicts vertical section of a Kaplan or propeller unit, or plan view for Francis turbines. The parameter Δs is the incremental blade motion in the time fish move through the leading edge circumference.

For the purposes of this analysis, it was assumed that fish orient along the absolute inflow direction. This has typically been the assumption of most strike probability models and there is some evidence supporting this assumption based on video observations of fish approaching the Alden turbine runner during pilot-scale testing.

The relative water (fish) to blade velocity was used with the selected fish length to blade thickness ratio (*L/t*) to determine the mortality coefficient, *K*, based on data from blade strike tests conducted at Alden with rainbow trout and white sturgeon (Hecker et al. 2007; Amaral et al. 2008; EPRI 2008, 2011). Since *K* represents the probability that fish struck by a turbine blade will be killed, Equation (1) (blade strike probability) is multiplied by *K* to estimate turbine passage survival:

$$S_T = 1 - (K)(P) \tag{2}$$

Other sources of mortality associated with turbine passage (e.g., damaging pressure changes, shear, and turbulence) likely do not affect fish passing through turbines at Penobscot River projects because of their relatively low head (< 40 ft) (Franke et al. 1997). More detailed information on the development of *K* for use in turbine passage survival estimation is provided in Section 2.1.1.5.

As a turbine blade approaches a fish, the mechanics of impact vary somewhat with the shape and thickness of the leading edge. For blades with semi-circular profiles, fish bodies will not bend completely about the smallest radius of a leading edge, rather they will deflect to the larger shape of a blade (Figure 3-2) (EPRI 2008).

Although the general profile of the leading edge for most blades may be elliptical rather than semicircular, the most upstream portion of the leading edge can be approximated by a circle of an appropriate radius. This allows the blades of different turbines to be related to strike survival tests that utilized a semicircular shape (EPRI 2008, 2011a). To correlate fish strike testing data to a real world turbine blade, a semicircular shape is fitted to the actual leading edge profile. If the sharpest point of the leading edge is small compared to the fish deflection curvature, the fitted semicircle is pulled back and enlarged to better represent the general shape to which the fish body will deflect (Figure 3-3). Even with this adjustment, a blade typically increases in width downstream of the fitted circle, in effect providing a larger radius for the fish.

Depending on a blade's profile, there is potential for a semicircle fitting to the most upstream portion of the leading edge to be unrealistically small compared to the shape to which a fish body may deflect. As such, professional judgment may be used to slightly move the circular fit back from the leading edge to provide a more reasonable equivalent shape and leading edge thickness for correlation to the strike test survival data. Blade strike testing that produced the data for estimating *K* used the same methodology for determining leading edge blade thickness (EPRI 2008, 2011a).

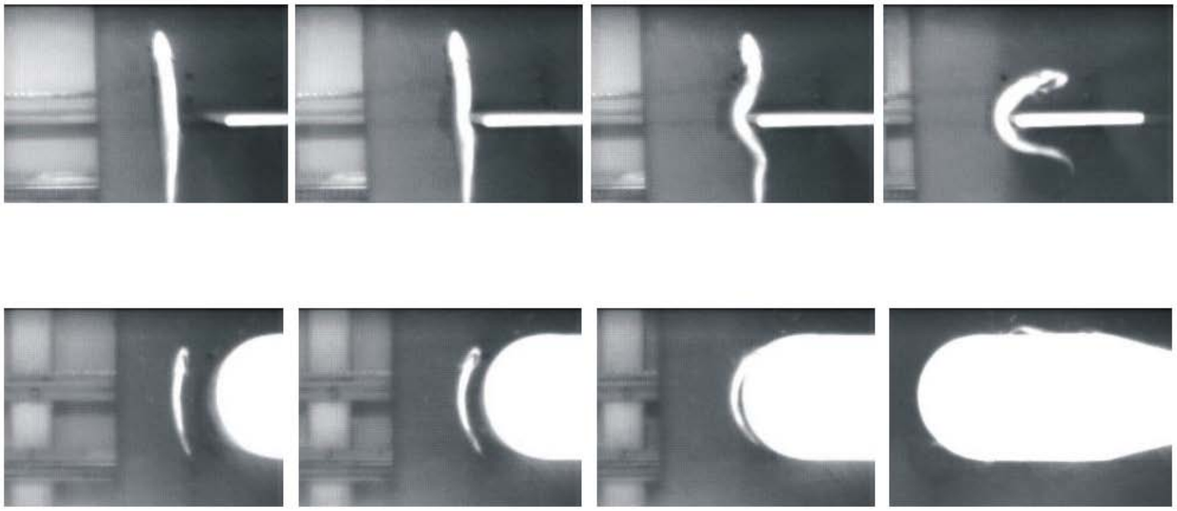

Figure 3-2. Images of fish strike for an L/t ratio of 25 (top photos; fish length is about 250 mm, blade thickness is 9.5 mm) and L/t =1 (bottom photos; fish length is about 150 mm, blade thickness is 154 mm), both with a strike velocity of about 24 ft/s (EPRI 2008).

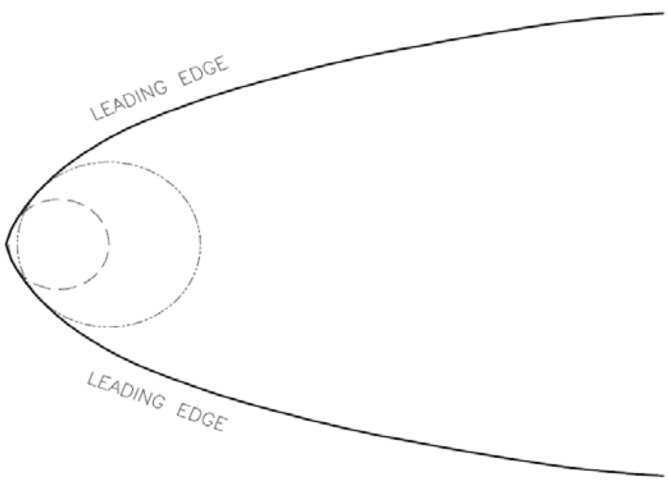

Figure 3-3. Turbine blade profile with two sizes of semicircles fit into the leading edge.

Site-specific turbine characteristics which were utilized to estimate the strike and mortality probabilities for each of the turbines evaluated are presented in Section 3. Additionally, Section 3 provides the results of the survival predictions for each individual type of turbine at each site. Many of the fifteen Penobscot River projects that were evaluated have multiple turbines of varying types. If a site had multiple turbines with identical characteristics, a single prediction was completed. Length ranges that were analyzed for smolts and kelts were provided by NMFS based on available data for Atlantic salmon in the Penobscot River (Table 3-1).

Although the physics of blade strike are the same for both radial and axial type turbine runners, the actual methods for calculating the probability of strike varies due to the geometric differences. Flow entering and making contact with the Francis turbine is in a radial direction, whereas flow entering a Kaplan or propeller turbine approaches the wicket gates in a radial direction before making a downward turn toward the runner in the axial direction (Figure 3-4). Consequently, the methodology used for calculating the various parameters of Equation (1) is presented individually for Francis and Kaplan/propeller units.

Table 3-1. Fish length ranges and intervals used for the estimation of turbine passage survival for Atlantic salmon smolts and kelts.

Life Stage	Minimum Length (mm)	Maximum Length (mm)	Evaluation Interval (mm)
smolt	130	210	10
kelt	650	800	25

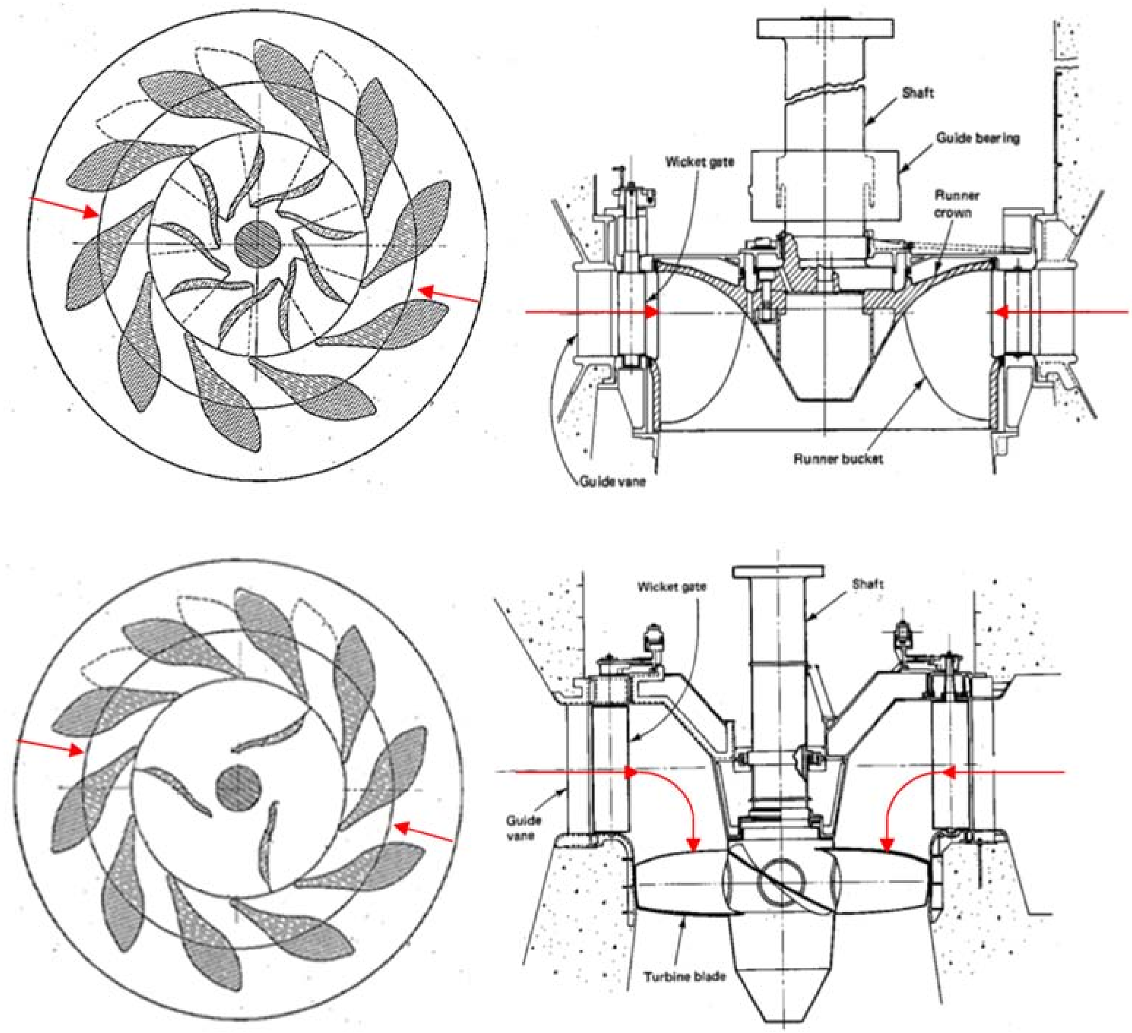

Figure 3-4. Schematic showing radial flow path for Francis turbines (top) and axial path for Kaplan/propeller (bottom).

3.1.1.2 Velocity Calculations for Francis Turbine

To calculate the radial velocity, which is that entering through the wicket gates along the line tangential to the turbine shaft, the flow area at the entrance to the wicket gates and the turbine flow rate are required. For Francis turbines, the radial flow area is measured between the top and bottom ring of the turbine gate case and is assumed to be continuous around the circumference of the turbine diameter. That is:

$$V_{RAD} = \frac{Q}{\pi * D * H_{W.G.}} \tag{3}$$

where:

Q = turbine flow (cfs)

D = turbine runner diameter (ft)

$H_{W.G.}$ = height of wicket gate (or guide vane if no wicket gates) (ft)

It should be noted that the radial velocity calculated above is based on Q=V/A and represents an average radial velocity approaching the turbine runner. The actual velocity of the flow approaching the turbine runner radially may vary slightly from the average value calculated using Equation (3).

To calculate the relative (strike) velocity, the blade tip speed and wicket gate angle are required. The blade tip speed is a function of the turbine diameter as well as the rotational speed:

$$U = \frac{\pi D n}{60} \tag{4}$$

where:

U = Blade Tip Speed (f/s)

D = turbine runner diameter (ft)

n = turbine rotational speed (rpm)

To calculate the mortality coefficient K, the relative water (and fish) to blade velocity is required. This is calculated with the following equation:

$$V_{REL} = \sqrt{(V_{RAD})^2 + \left(U - \frac{V_{RAD}}{\tan(WGA)}\right)^2} \quad (5)$$

where:

WGA = angle between wicket gate cord and a line perpendicular to the radial direction (degree)

U = blade tip speed (f/s)

3.1.1.3 Velocity Calculations for Kaplan/Propeller Turbines

For Kaplan/propeller turbines, to calculate θ (angle between V_{abs} and V_{ax}), the absolute velocity is determined from the following equation:

$$V_{abs} = \left(V_{ax}^2 + V_t^2\right)^{0.5} \quad (6)$$

where:

V_{abs} = absolute velocity at the leading edge (f/s)

V_{ax} = axial velocity in the annular space approaching the blades (f/s)

V_t = tangential velocity at the leading edge (f/s)

The axial velocity is reasonably constant along the leading edge length and is equal to the turbine flow divided by the flow area. For Kaplan/propeller type turbines, the axial (annular) flow area is measured between the hub and the discharge ring at the leading edge. That is:

$$V_{ax} = \frac{Q}{\pi(r_{tip}^2 - r_{hub}^2)} \quad (7)$$

where:

Q = turbine flow (cfs)

r_{tip} = blade tip radius (ft)

r_{hub} = hub radius (ft)

Similar to the radial velocity, the axial velocity calculated above is based on Q = V/A and represents an average axial velocity approaching the turbine runner. The actual velocity of the water entering a turbine runner in an axial direction may vary from the average value calculated using Equation (7).

The tangential velocity needed in Equation (3) varies along the leading edge in accordance with conservation of angular momentum; to calculate average conditions a mean position along the leading edge is selected. The magnitude of the angular momentum is controlled by the wicket gate setting (angle). The tangential velocity leaving the wicket gates is calculated from the gate setting and the radial velocity leaving the gates (Equation (6)). The tangential velocity is then prorated to the point of interest on the blade leading edge by the change in radius from the trailing edge of the gate to a point on the blade. The prorating assumes the tangential velocity is constant, which is true for constant angular momentum:

$$V_{t-wg} = \frac{V_{rad-wg}}{\tan WGA} \tag{8}$$

where:

$V_{\text{t-wg}}$ = tangential velocity (component) leaving wicket gate (f/s)

$V_{\text{rad-wg}}$ = radial velocity (component) leaving wicket gate (f/s)

WGA = angle between wicket gate cord and a line tangential to the runner (degree)

From the turbine flow and the cylindrical area at the gate tail:

$$V_{rad-wg} = \frac{Q}{(2\pi r_{wg} h_{wg})} \tag{9}$$

where:

r_{wg} = radius at trailing edge of wicket gates (ft)

h_{wg} = height of wicket gate (ft)

Based on conservation of angular momentum, the tangential velocity at the blade leading edge may now be determined as follows:

$$V_t = V_{t-wg} \frac{r_{wg}}{r} \quad (10)$$

where:

r = radius of interest at blade leading edge (ft)

To determine the average fish survival (assuming a random distribution of fish along the leading edge), r is selected to be halfway between the hub and tip, or:

$$r = \frac{r_{hub} + r_{tip}}{2} \quad (11)$$

To calculate the mortality coefficient K, the relative water to blade velocity is required. This can be determined with the following equation:

$$V_{REL} = \sqrt{(V_{ax})^2 + (U - V_t)^2} \quad (12)$$

where:

U = blade speed (ft/s) (see equation (4))

3.1.1.4 Estimation of Unknown Turbine Design and Operational Parameters

As discussed previously, specific turbine information is required to complete strike and mortality predictions (Table 3-2). Of the 15 sites included in this study, there are a total of 33 individual turbines for which turbine passage survival calculations are required (as well as 3 new turbine designs that have been or will be installed at three of the projects). Attempts were made to retrieve the required turbine information from project owners and available literature and data sources. Site visits to some projects were also conducted by Alden and NMFS staff to obtain turbine specifications. Ultimately, not all data was available and, therefore, methods for estimating missing information were developed. To complete estimates of missing turbine information, known data and professional judgment were utilized to estimate the relationship between various parameters. Table 3-3 and Table 3-4 summarize the derived data relationships for Francis and Kaplan/propeller turbines.

Table 3-2. Information required to calculate blade strike probability and mortality for fish passing through hydro turbines.

Francis Turbines	Kaplan/propeller Turbines
Turbine rotational speed	Turbine rotational speed
Runner diameter	Blade tip diameter
Wicket gate (or guide vane) Height	Hub diameter
Number of blades/buckets	Number of blades/buckets
Angle wicket gate (or guide vane)	Angle wicket gate (or guide vane)
Flow rate	Flow rate
Leading edge blade thickness	Leading edge blade thickness
	Wicket gate tail radius

Table 3-3. Francis turbine parameter relationships.

Independent Variable (x)	Dependent Variable (y)	Relationship
Head	Radial velocity	y = 1.5965(X) - 11.59
Turbine diameter	Leading edge thickness	y = 0.2794(X)+9.4864
Blade tip speed	Ratio of blade speed tip components	y = 0.0425(X)-0.3541

Table 3-4. Kaplan/propeller turbine parameter relationships.

Independent Variable (x)	Dependent Variable (y)	Relationship
Turbine diameter	Hub diameter	y=0.3653(x)+.0079
Turbine diameter	WG trailing edge diameter	y=1.1552(x)-1.0172
Head	Axial velocity	y = 0.3013(x) + 16.894
Turbine diameter	Leading edge thickness	y=1.6649(x)+5.5927
Blade tip speed	Ratio of blade speed tip Components	y= (-1)(0.0299)(x)+2.8394

The turbine design and operational parameters that were selected for developing predictive relationships were carefully chosen based on a series of iterations as well as professional judgment. Appendix A contains plots of the data comparisons and resulting regression models used to predict unknown parameters. Some relationships, such as that between the turbine diameter and the leading edge blade thickness, are direct in nature. As a turbine becomes larger in diameter, a greater amount of material is required to resist the flow induced forces on the blades. The analysis of available data indicated a direct linear relationship between these two parameters. Other parameters, however, required some alternative approaches to predict missing information. For example, the radial and axial velocity components, which were estimated for Francis and Kaplan/propeller turbines from known data, were used to estimate unknown turbine diameters. Due to geometric differences, the radial and axial velocities for each type of turbine were utilized in different manners to predict the turbine diameter as a function of flow rate (Equation (3) and (7)). Therefore, the turbine diameter can be back calculated as follows for a Francis turbine:

$$D_{turbineFRANCIS} = \frac{Q}{\pi H V_{RAD}} \quad (13)$$

The same diameter estimation can be completed for a Kaplan/propeller turbine, however, it is slightly more complex. To solve for the turbine diameter, a radius must be chosen which satisfies Equation (14) and, as 2r = D, the diameter can be calculated from the estimated radius:

$$\frac{Q_{MAX}}{V_{AX}} = \pi (r_{tip KAP/PROP})^2 - \pi \left(\frac{0.3653 * r_{tip KAP/PROP} * 2 + 0.0079}{2} \right)^2 \quad (14)$$

A second more complex estimation method is used to approximate the velocity components at the blade leading edge. This involves the ratio of the tangential velocity components which make up the blade tip speed to estimate the relative velocity of the flow to the blade. The relative (strike) velocity is used to calculate *K*, in addition to L/t. Typically, relative velocity is calculated through the use of the wicket gate angle; however, this was not available for many of the turbines being evaluated. Additionally, the angle of the wicket gates is not a parameter that is closely related any other turbine components, making direct estimation difficult. However, sufficient data was available for most of the turbines to calculate the blade tip speed. From calculations completed on turbines which had known gate and flow angles (Appendix A, Figures A-2 and A-7), a series of velocity ratios were computed for Francis and Kaplan/propeller turbines.

Following the estimation of missing data, a review of all turbine information (including information that was provided by project owners, obtained from public sources, determined from site visits, and estimated using the methods described above) was completed to establish if there were any aberrations or inconsistencies that would require modifications or adjustments to design and operational parameters based on professional judgment and expertise. In general, data modifications were limited to the wicket gate/flow angle.

The wicket gate angle (α), measured between the absolute and tangential velocities, for a Francis unit is specific to an individual turbine. However, this angle is typically between 15° to 35° (Warnick 1985). Although many of the turbines at Penobscot River projects have wicket gate angles that fall within this range, some of the estimated angles were greater than 35°. Wicket gate angles were confirmed or determined based on the following considerations: (1) a large angle is physically possible but likely creates inefficient flow patterns (radial flow does not produce the moment of momentum needed to generate power); (2) if an angle could not be directly estimated or reliable information was not provided or obtained, components of the velocity vector triangles were estimated such that sufficient information was available to solve for the wicket gate angle; and (3) the wicket gate angle must satisfy the overall solution to the velocity vector analysis. The first consideration indicates that although a typical range of wicket gate angles is 15° to 35°, this range is based more on turbine performance (efficiency) and less so on physical constraints, indicating that an inefficient turbine could have a higher wicket gate angle. The second and third considerations are related. To complete an estimation of wicket gate angle, the data to compute the blade tip speed and radial velocity must be known and then the appropriate relationship between blade tip speed and the tip components is used to estimate the ratio of the two blade tip speed components (Table 3-3 and Table 3-4). All of these components are utilized to back calculate the wicket gate angle and solve the remaining components of the velocity triangles.

If a calculated wicket gate angle was outside of the 15° to 35° range, the angle was modified and all calculations were recomputed moving forward through the velocity triangles. Often, the estimated wicket gate angle was found to be high compared with the range; therefore, the initial modification to the wicket gate angle was a reduction to 35°, the high end of the published range (Warnick 1985). When 35° was used to calculate the velocity triangle along with the known radial/axial velocity and the blade tip speed, it was found in some cases the geometry and trigonometry did not solve properly. Specifically, the use of 35° sometimes resulted in one component of the blade tip speed being larger than the entire blade tip speed. As shown in Figure 3-5, the two components of the blade tip speed; θ_V and θ_W cannot sum to a value greater than the blade tip speed itself for the vector geometry to remain valid. In these cases where the geometry did not remain valid, the wicket gate angle was increased in 5° increments to such a point that the velocity components maintained validity (i.e., both θ_V and θ_W remain positive values and the sum of their values equals the blade tip speed). No modifications were made to wicket gate angles that were provided by project owners or were estimated within the typical range.

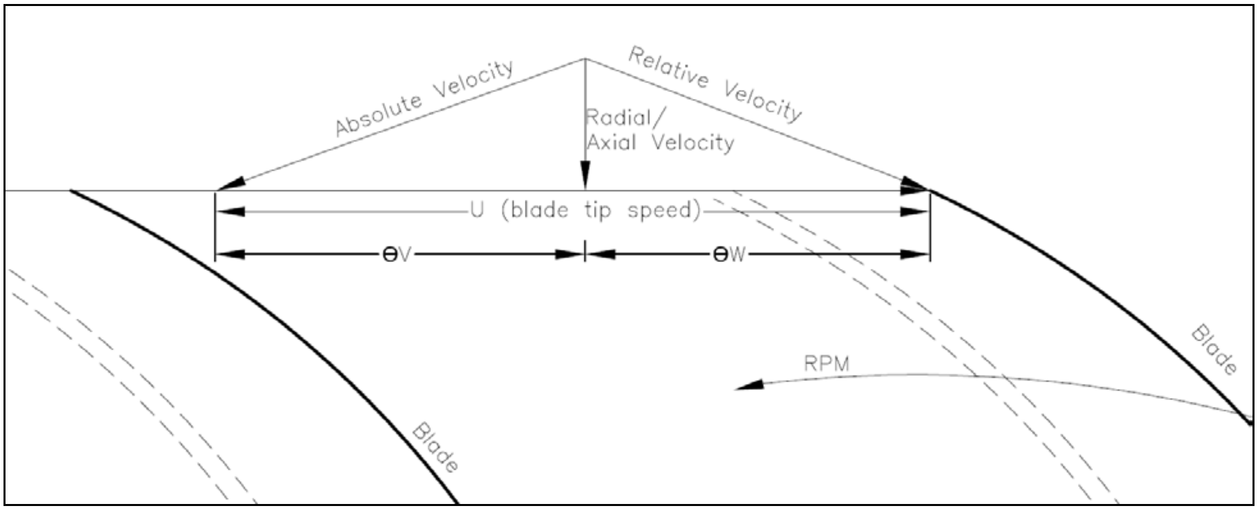

Figure 3-5. Schematic of blade tip speed components; θ_V and θ_W.

For Kaplan/propeller type turbines, two different velocity vector analyses are required to understand the velocities at the turbine blades. The wicket gate angle was used to compute the vector analysis at the wicket gates and information from this analysis was used to compute the velocity vector analysis at the blade leading edges. If the wicket gate angle was unknown, it was not possible to transfer the missing analysis to the blades. Therefore, the velocity components that make up the blade tip speed were estimated to determine the angle of flow directed toward the turbine blade (Appendix A, Figure A2 and A7)

The flow angle at the leading edge of a Kaplan/propeller turbine is not necessarily in the same range as the flow angle for a Francis turbine. For a Francis turbine the inflow angle is dictated by the gate angle (see Figure 3-4). For a Kaplan/propeller turbine, the flow angle at the leading edge (below the gates) is modified by the overall turbine geometry and conservation of angular momentum. Therefore, the Kaplan/propeller flow angle will not necessarily fall within the 15° to 35° range.

3.1.1.5 Turbine Operation Evaluation Points

Based on known and estimated turbine data, each individual turbine located at the fifteen projects was evaluated to estimate the percentage of fish that will survive passing through a given turbine. This analysis was completed at a gate setting of 100% assumed to correlate with the peak (100%) turbine operating flow (referred to as 100-100 condition). Survival estimates were also completed for a second evaluation point at a lower gate setting correlating to 50% gate/50% peak flow (referred to as 50-50 condition). The 50-50 condition is applicable to wicket gates only and does not apply to guide vane units (turbines without wicket gates). Insufficient data were available to use site-specific information to estimate the 50-50 survival condition. However, based on pilot-scale testing completed during the development of the Alden fish-friendly turbine (EPRI 2011b), it was found that when the gate setting is reduced by 50% from fully open, the flow rate is approximately 50% of the peak rate. Therefore, for the 100-100 condition, known and estimated turbine parameters were utilized in developing the survival predictions. For the 50-50 condition, the 100-100 prediction was utilized with the gate angle and flow rate reduced by 50%.

For units that do not have wicket gates, guide vanes are typically present. Because guide vanes are mechanically fixed and have no means of moving, the second evaluation point calculated for these units was 100-50. This represents a gate angle which is the same as the 100% setting while the flow has been reduced to 50% of its peak value representing the survival at 50% turbine load.

Total project survival estimates need to be estimated for a range of flow rates which occur during the specified migration periods for each life stage. Based on river discharge, bypass flow requirements, and the number of turbines, each turbine is allotted a flow rate for a given river discharge. Based on the allotted flow rate, as well as the peak flow rate of the turbine, the percent turbine flow can be estimated assuming an approximate linear distribution. For the purposes of this study, and without turbine-specific information, it was assumed that the percent that the wicket gates were open was approximately equivalent to the percent of peak turbine flow available. Depending on the turbine, the relationship between percent wicket gate opening and percent peak flow rate may not be completely linear. However, because survival was calculated at two points, thereby creating two “bins” for all gate settings, it was deemed sufficiently accurate. For any particular turbine, the survival due to strike was either categorized as greater than or equal to 75% gate or less than 75% gate. Turbine settings which are equal to or greater than 75% were assumed to use the 100% gate bin; settings less than 75% were assumed to fall into the 50% bin. This divide between bins at the 75% gate setting was chosen as the midpoint between the 100% evaluation point and the 50% evaluation point. Figure 3-6 provides an overview of the survival points estimated and the allocation of bins.

For the 50-50 condition, the reduction in gate angle will increase the effective length of a fish exposed to approaching turbine blades, thereby increasing the probability of strike. Also, a reduction in gate angle in conjunction with a reduction in flow rate reduces the axial velocity and corresponding relative (strike) velocity, which will result in a higher blade strike survival rate. Generally, it was found that for a given turbine, the estimated survival at the 50-50 condition was higher than the survival at the 100-100 condition. This indicates that, for these conditions, the change in strike velocity has a greater effect on strike mortality than the change in effective fish length has on strike probability (i.e., despite higher strike probability, the turbine survival increases due to lower strike mortality).

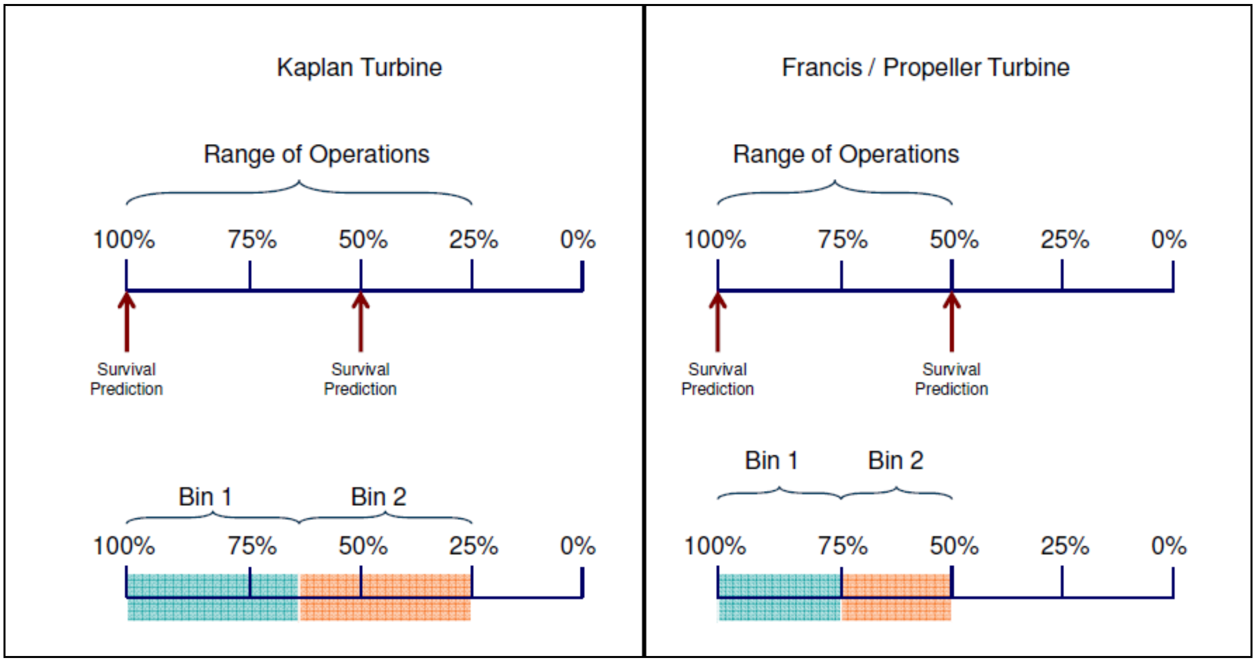

Figure 3-6. Depiction of turbine survival evaluation points and bins.

For the analysis of survival relative to wicket gate setting, some assumptions were made with respect to the operating range of the turbines. First, turbines cannot operate below a certain wicket gate setting (i.e., referred to as a percentage of fully open). Kaplan turbines, which use adjustable blades to operate over a wider flow range, were assumed to operate down to a 25% gate opening. Francis and propeller turbines, which have fixed blades, were assumed to be capable of operating down to a 50% gate opening. These limitations on operations were used as maximum and minimum operating points, but do not necessarily define the exact flow rate and gate position at any given time. Rather, the exact flow rate and gate position of any individual turbine is a function of many factors including the total river flow (see Section 3.4.2 for a discussion of flow allocations among turbines, spillways, and bypasses). In addition to operational limitations of the turbines, physical limitations (e.g., narrow wicket gate spacings) as compared with the size of entrained fish were considered and are discussed below.

3.1.1.6 Physical Limitations

Wicket Gates and Guide Vanes

The minimum clear spacing between wicket gates has the potential to influence the survival of fish passing through turbines. If the opening between wicket gates is smaller than the width of a fish, it will most likely lead to mortality. Conversely, at some ratio of fish width to wicket gate (or guide vane) spacing greater than one, injury and mortality will not occur. Consequently, a means of estimating the minimum clear spacing for a range of wicket gate settings as a function of the turbine diameter was developed. To determine this relationship, manufacturer gate case figures of four turbines showing the rotation of gates were used (Figure 3-7).

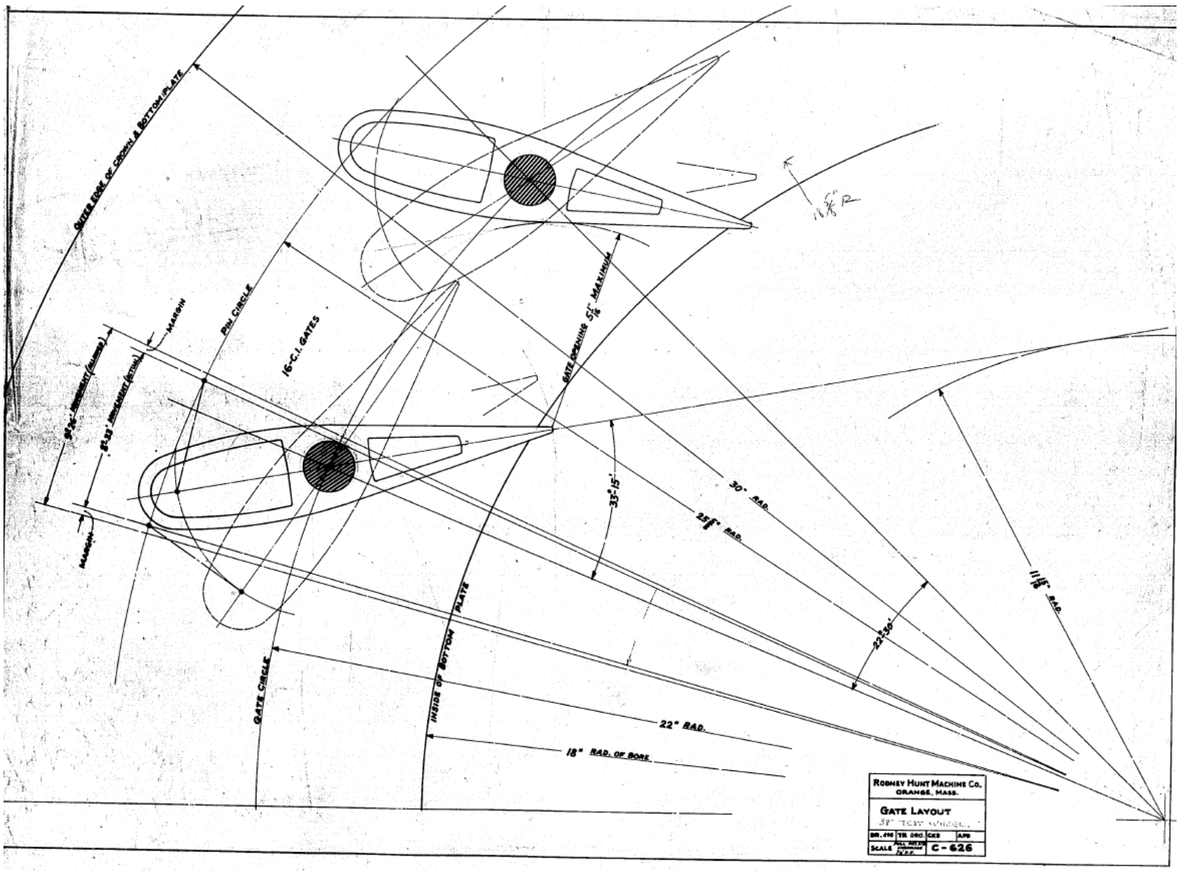

Figure 3-7. Manufacturer drawing depicting wicket gate relationship.

Using several diagrams similar to that shown in Figure 3-7, an evaluation of wicket gate openings was completed such that openings could be estimated for turbines without manufacturer drawings. The gap opening at varying gate settings was estimated using a linear interpolation between closed and fully open positions. These data were plotted for four turbines designs to produce figures for each turbine like those shown on Figure 3-8.

The sets of data summarizing the clear spacing at varying gate settings were plotted as a function of turbine diameter (Figure 3-9). The number of wicket gates associated with these data varies between 16 and 24. Additionally, the data set is associated with several manufacturers. Based on the strong correlation between diameter and minimum wicket gate gap, it is likely that similar optimization goal was used among manufacturers when designing the gate case structures (including wicket gates). Based on the linear correlations (Figure 3-9), the minimum wicket gate clearances for all of the turbines at the Penobscot River projects were estimated. The clearances were estimated for 100%, 75%, 50%, and 25% for Kaplan turbines (adjustable-blade units), and for 100%, 75% and 50% for propeller and Francis turbines (fixed-blade units). For turbines with only guide vanes, it was assumed they are installed close to 100% gate. As such, guide vane units were assumed to consistently have a minimum clearance associated with the 100% gate setting.

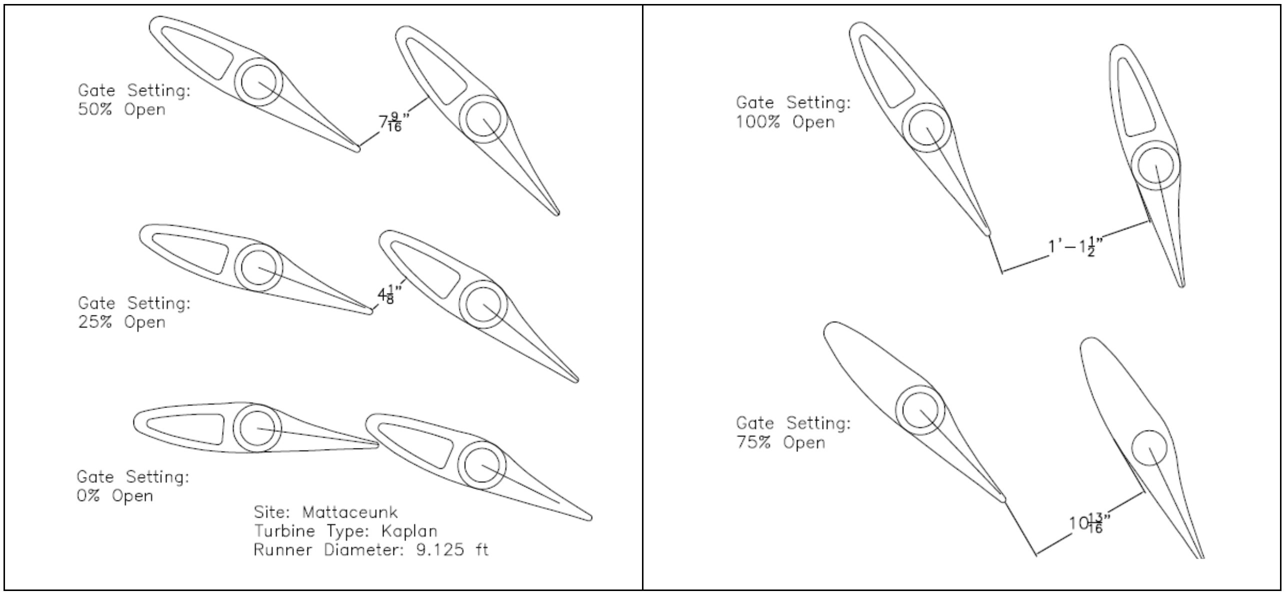

Figure 3-8. Evaluation of minimum clear spacing of wicket gates at varying settings.

To incorporate this potential physical limitation into the turbine survival model, fish widths for the ranges of lengths being analyzed for smolts and kelts were estimated and compared to the estimated physical clearance between wicket gates to form a gate clearance to fish width ratio. If this ratio was greater than two, it was assumed that the physical interaction was minimal and there was no change in turbine survival estimates. If the ratio was less than 2 but greater than 1.5, it was assumed that there would be some impact on survival and the initial strike survival value was reduced by 50%. Finally, if the ratio of fish width to gate clearance was less than 1.5, it was assumed that there would be significant physical interaction and that survival was zero. The following is a summary of the rules developed to estimate the survival associated with physical interactions with wicket gates:

1. gate opening/fish width > 2: no effect on baseline turbine survival
2. gate opening/fish width > 1.5 and < 2: baseline turbine survival reduced by 50%
3. gate opening/fish width ≤ 1.5: 100% mortality

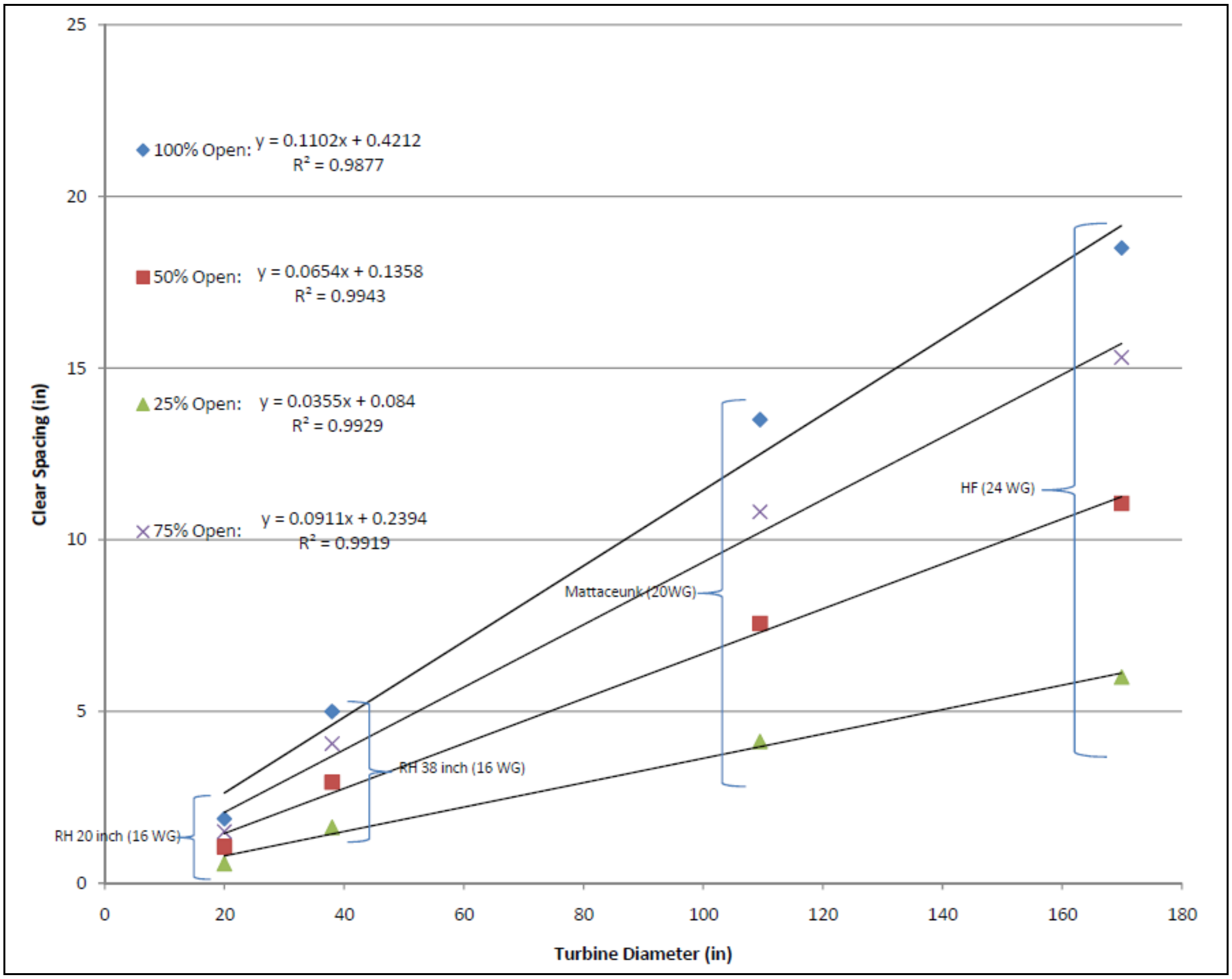

Figure 3-9. Plot of relationship between wicket gate clear spacing and diameter.

Blade Spacing

Similar to the effect of narrow guide vane and wicket gate clearances, there is potential for fish injuries and mortality due to narrow blade spacings relative to fish width (i.e., in addition to the probability of blade strike). Due to design differences between Kaplan/propeller and Francis turbines, different methods were used to estimate the effective spacing between blades of the two designs. The leading edges (in a plan view) of Kaplan/propeller turbines are offset in the direction of rotation more than they are with Francis turbines due to the relatively small number of blades typical of Kaplan/propeller turbines (4 to 6) in comparison to Francis units (14 to 18). A fish hit by one leading edge may have room to fold onto the blade before the next leading edge interacts with the fish. For Kaplan/propeller turbines, the ratio of fish length to actual blade spacing (i.e., $\pi d/N$) was used as a guideline for comparison. In a Francis turbine, the leading edges at a given radius are not offset in the direction of rotation to the extent that they are in the Kaplan turbine. As such, it is more likely that a fish approaching nearly perpendicular to the Francis blades will not have room to fold onto the first blade and, therefore, will also be struck by the next blade. Although fish are oriented approximately the same as the inflow, they move toward a blade (or a blade moves toward a fish) in the direction of the relative velocity. For Francis turbines, the perpendicular blade spacing (i.e., distance between blades along a line perpendicular to the leading edge orientation) is used rather than along the circumference of the runner (i.e., [πd/N]*[sin(90-WGA)]).

For the blade spacing analysis of Kaplan/propeller turbines, fish length was compared to the spacing calculated between blades where the fish length is the total fish length (fish length/blade spacing) rather than any directional component. If a fish's length is less than the blade spacing, the fish will only interact with one blade leading edge and the baseline turbine survival prediction is assumed to be valid. If fish length is greater than the spacing between blades, there is a potential that a fish will be struck by two blades. However, due to the configuration of Kaplan/propeller blades, two consecutive blades will not hit a fish at the same time. Therefore, it is likely that the first blade strike will re-orient the fish more parallel to the blade surface (as seen in blade strike tests; EPRI 2008, 2011a) and may slip between the blades. Under these conditions, the probability of strike is 100% and the survival will be dependent upon the calculated value of the strike mortality coefficient (*K*). This approach is used at ratios equal or greater than 1 but less than 1.5. The certainty of this mechanism decreases as the ratio increases; therefore, ratios equal to or greater than 1.5 but less than 2 are assigned the lesser mortality of either 100% strike with the calculated *K* or the 50% survival bin value. Finally, if the ratio is greater than 2, a fish's length will be spanning across at least two blades leading edges and there is a potential for strike by a third blade. Therefore, it is assumed that survival will be zero. The following is a summary of the rules used to determine mortality due to small ratios of fish length to blade spacing for Kaplan/propeller turbines:

1. fish length/blade spacing < 1: no effect on baseline turbine survival
2. fish length/blade spacing > 1 and < 1.5: strike is assumed to be 100% and *K* is used to estimate strike mortality for the calculation of turbine survival
3. fish length/blade spacing ≥ 1.5 and < 2: survival is lesser of (1) strike assumed to be 100% and *K* is used to determine turbine survival and (2) 50% of baseline survival
4. fish length/blade spacing ≥ 2; 100% mortality

For Francis turbines, fish length was compared to the perpendicular spacing between adjacent blades (fish length/perpendicular blade spacing). If fish length is somewhat less than the perpendicular blade spacing, a fish is expected to only interact with one blade leading edge and the baseline turbine survival prediction is considered valid without any adjustments. For ratios of fish length to blade spacing less than 0.75, it is assumed that the blade spacing will have no effect on survival and baseline calculations of survival are assumed to be correct. As fish length increases relative to perpendicular blade spacing, the probability of interaction with at least one blade increases. As a fish moves between blades (following the direction of the relative velocity), it likely will be struck by at least one blade so the probability of strike is set at 100%. Consequently, for ratios equal or greater than 0.75 and less than 1.25, strike is assumed to be

100% and the survival will be dependent upon the calculated value of *K*. When a fish is of sufficient length to span across at least two blade leading edges, the "single fish/single blade" basis for the prediction of strike probability does not apply. For fish length to blade spacing ratios equal to or greater than 1.25, it is assumed that survival will be zero. The following is a summary of the rules used to account for blade spacing effects associated with fish passing through Francis turbines:

1. fish length/perpendicular blade spacing < 0.75: no effect on baseline turbine survival

2. fish length/perpendicular blade spacing ≥ 0.75 and < 1.25: strike probability is assumed to be 100% and *K* is used for strike mortality to estimate baseline turbine survival

3. fish length/perpendicular blade spacing ≥ 1.25: 100% mortality

3.1.1.7 Calculation of the Blade Strike Mortality Coefficient (K)

The probability of direct mortality for fish struck by a turbine blade depends on a number of factors, such as strike speed (i.e., the relative velocity of a fish to a blade), fish length and orientation, leading edge blade shape and thickness, and location of strike on the fish body. The probability of strike mortality is defined as a mortality coefficient (*K*) and, as discussed previously, is incorporated into the strike probability model to estimate turbine passage survival. For selected fish lengths (*L*) and a given turbine design (such that the rpm, *n*, the number of blades, *N*, and the radial or axial inflow velocity, V_r are known), *K* can be determined from data collected during laboratory studies that evaluated blade strike survival for a range of fish lengths, leading edge blade thicknesses, and strike velocities (EPRI 2008, 2011a). These studies provide estimates for direct immediate and total (96-hr) survival for fish struck by simulated turbine blades and the data are considered sufficient for estimating direct turbine survival at projects for which injury resulting from other mechanisms (pressure, shear, turbulence) is expected to be negligible. Indirect mortality (e.g., increased risk to disease, predation, and reduced fitness when entering salt water) resulting from turbine passage (and blade strike) was not addressed by the blade strike studies. For the purposes of the Penobscot River analysis, indirect mortality estimates were developed from available data reported in the literature and are discussed in Section 3.2

Horizontal blade motion in a closed flume with no flow was used to strike anesthetized rainbow trout at various impact speeds (Hecker et al. 2007; Amaral et al. 2008, 2011; EPRI 2008, 2011a). The fish were suspended vertically with fine lines held loosely in foam clamps that provided negligible friction. Based on CFD simulations of alternative leading edge shapes, a semi-circular profile was selected for tank testing because it provided more differential forces to deflect fish away from the leading edge prior to impact. Any blade can accurately be modeled in a semi-circular shape depending on the scale at which the semi-circle is fit. The approach allows the available strike test results to be applied to a wide variety of turbine blades. For additional information on estimating the semi-circle diameter associated with the leading edge See Section 3.1. Leading edge thicknesses of 9.5 to 154.0 mm were selected for testing to cover the range of actual leading edge geometries that may be considered for practical application. Mean fish lengths of test groups ranged from about 110 to 265 mm and all fish were examined for injury and immediate mortality after being struck and live fish were held for 96 hours to assess latent mortality. Survival estimates for each set of test conditions (fish length and angle, blade thickness, and strike velocity) were adjusted for control mortality and the proportion of fish which were struck at each specified body region (head, mid-section, and caudal). A primary parameter of interest for which the survival data were analyzed was the ratio of fish length to blade thickness (L/t).

The results of the blade strike tests demonstrate that survival decreases (i.e., *K* increases) with strike velocity, but that survival is relatively high (i.e., *K* is relatively low) for small L/t ratios, even at relatively high strike velocities (Figure 3-10). In particular, when fish length is similar to the blade thickness (L/t ratio of about 1), survival is generally greater than about 80% at strike velocities of 20 to 40 ft/s (6 to 12 m/s). It is also apparent that the maximum strike velocity at which the survival will be 100% (V100) changes with L/t, and that the slope of the decrease in survival (increase in mortality) with strike velocity changes with L/t. Therefore, when the strike velocity, V_{rel}, is greater than V100 for a particular L/t ratio, the decrease in survival (i.e., mortality proportion), referred to as *K*, is given by:

$$K = m(V_{rel} - V100) \qquad (15)$$

where m is the slope of survival versus strike velocity for a given L/t. If V_{rel} is less than V100 for a given L/t ratio, then there will be no mortality from blade strike, resulting in 100% strike survival (K = 0).

To allow interpolation of the slope m between the tested values of L/t, a logistic regression model was used to derive the following equation for estimating the slope of survival versus strike velocity for any L/t ratio:

$$m = -6.06 \ln(L/t) - 3.36 \qquad (16)$$

Therefore, knowledge of the leading edge blade thickness and the relative water (fish) to blade velocity (i.e., strike velocity, V_{rel}), allows *K* to be determined using above equations and the blade strike data from lab tests (Figure 3-10).

For a given fish length, blade thickness, and strike velocity, the resulting *K* is incorporated into Equation (1) (strike probability model) to estimate turbine passage mortality (or, inversely, turbine survival) for turbines at low head projects, such as those on the Penobscot River (for which pressure, shear, and turbulence are not expected lead to injury and mortality).

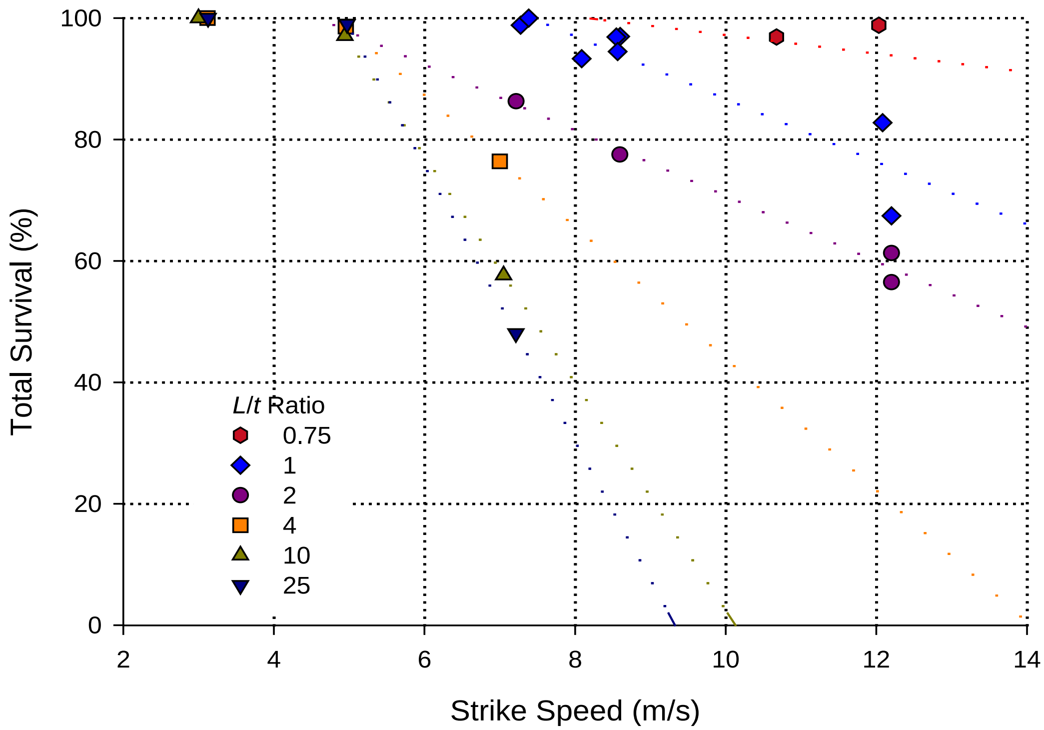

Figure 3-10. Fish survival after a direct (90 degree) blade strike as a function of strike speed and the ratio of fish length to leading edge thickness (L/t).

The methods described above for calculating *K* and turbine passage survival were applied to the pilot-scale Alden turbine and the results were compared to survival estimates calculated from empirical data collected during lab testing of the turbine. Estimates of *K* and turbine passage survival were calculated for the species, fish lengths, and turbine design and operating conditions that were evaluated in the lab. For each set of test conditions, fish lengths and all of the necessary turbine design and operational parameters are known. The exact shape of the rounded turbine blade leading edges could not been determined, but the thickness was known to be 9 mm. The total mortality estimated from the pilot-scale test data was then compared to the mortality predictions generated with the strike probability model and estimates of *K* from the blade strike data.

The results of this comparison showed that the actual pilot-scale turbine mortality was lower by an average of about 0.65 than the predicted mortality derived from the strike probability and mortality model (Figure 3-11). The probable reason for this difference in actual and predicted mortality is likely related to the angle at which fish were struck by leading edges during blade strike testing and during testing with the Alden turbine. In the blade strike experiments (i.e., tank testing with suspended fish), fish were oriented vertical and the blade moved horizontally, resulting in a 90 degree impact angle. From testing with the pilot-scale turbine, video observations of the fish entering the runner and the estimated angle of the inflow indicated that fish were oriented at about 45 degrees to approaching blades. Also, fish passing through the pilot-scale turbine were not held in place and, not being anesthetized, could have exhibited behaviors affecting their orientation as the passed by the blades. To account for the differences in mortality between the two different data sources (i.e., blade strike tank testing and pilot-scale turbine evaluation), estimates of *K* developed from the blade strike data can be multiplied by 0.65 in the following manner:

$$K = 0.65m(V_{rel} - V100) \tag{17}$$

Using the adjusted *K*, the measured mortality from the pilot-scale tests was compared to the revised predicted mortality (Figure 3-12). There is a strong correlation between the measured and predicted fish mortality, indicating that most of the mortality in the pilot-scale Alden turbine is strike induced and that the adjusted predictive method works well. This also implies that, on average, fish are likely oriented with the absolute inflow velocity, since that is part of the predictive formulation. For the higher mortalities, above about 10%, the predictive method gives higher values of mortality than measured, a conservative feature. Also, four of the five survival estimates for the higher head tested during the pilot-scale evaluation (80 ft), indicate a predicted mortality greater than measured (Figure 3-12). However, given the range of results for each head tested, there were insufficient data points to derive a separate and reliable adjustment for each head.

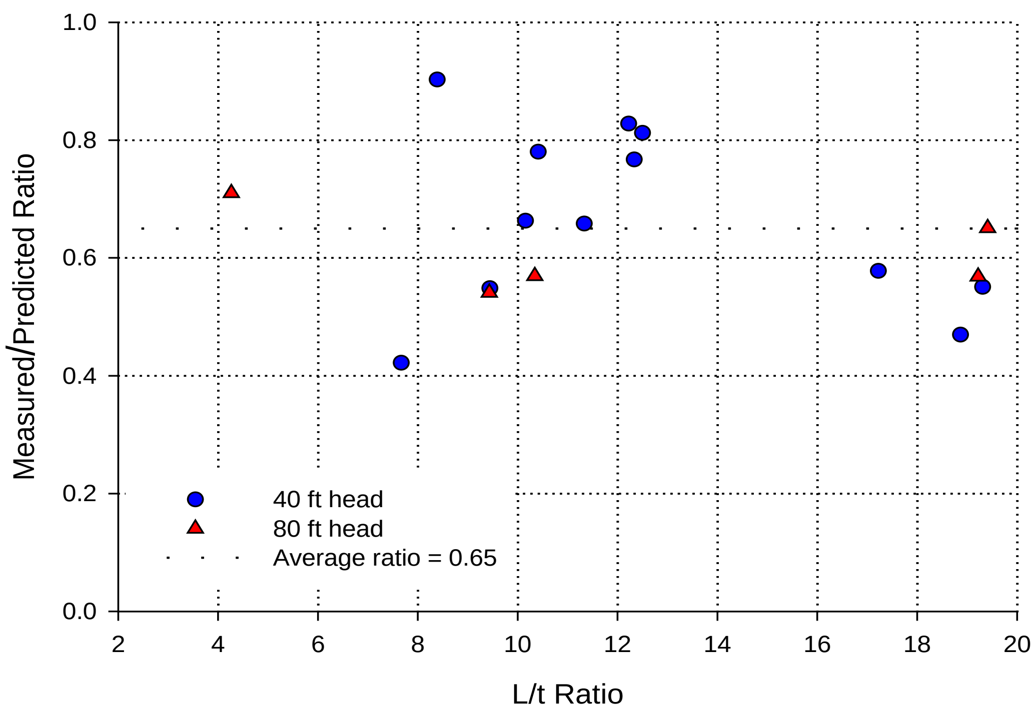

Figure 3-11. Ratio of measured to predicted survival versus L/t ratio for the pilot-scale Alden turbine.

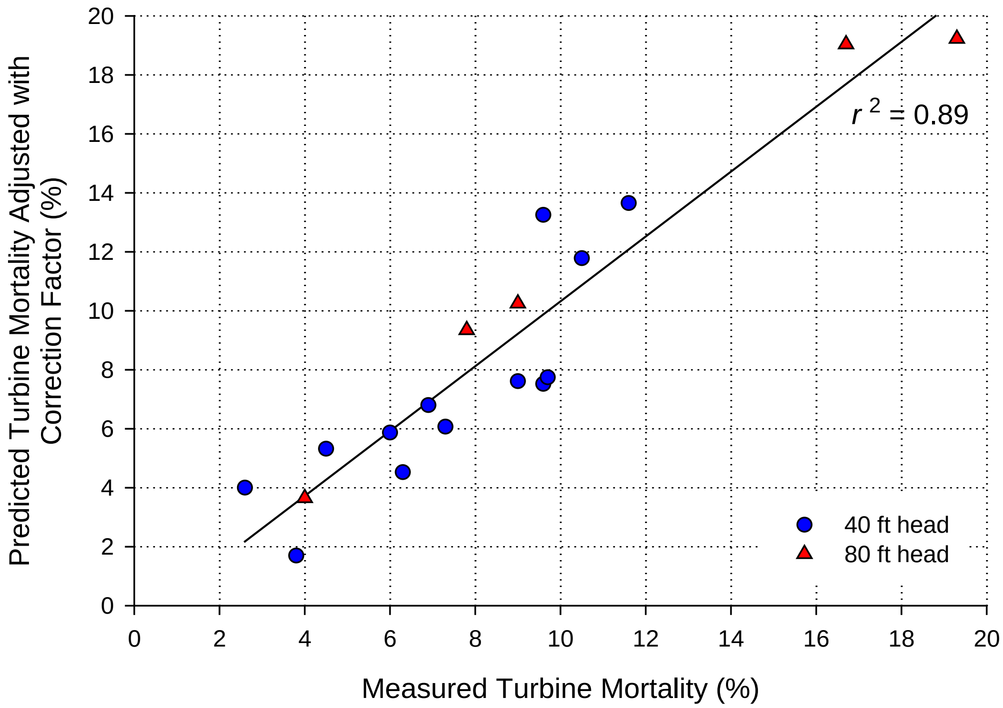

Figure 3-12. Relationship between predicted mortality adjusted with the correction factor and measured mortality for the test conditions evaluated with the pilot-scale Alden turbine.

Greater insight as to which test conditions produce higher or lower predicted values compared to that measured in the pilot-scale is gained by plotting the measured and the adjusted predicted survival rates versus fish length (Figure 3-13). For the lower head (40 ft), the survival predictions of fish larger than about 120 mm are somewhat less than the measured survival rates, with the opposite occurring for fish smaller than 120 mm. Since small fish have high survival in general, this difference is judged to be acceptable. For larger fish, the lower predicted than measured survival is conservative in making predictions for actual turbine installations. For the higher head (80 ft), the predictions of fish survival are somewhat lower than measured over most of the range of fish lengths tested during the pilot-scale study. The lower predicted survival rates provide for more conservative estimates when making predictions for actual turbines. This conservatism is favorable since higher turbine heads typically produce lower fish survival. Although a more complex adjustment of *K* as a function of fish length and head may eventually be developed, this does not appear to be warranted at this time given general agreement in the available data.

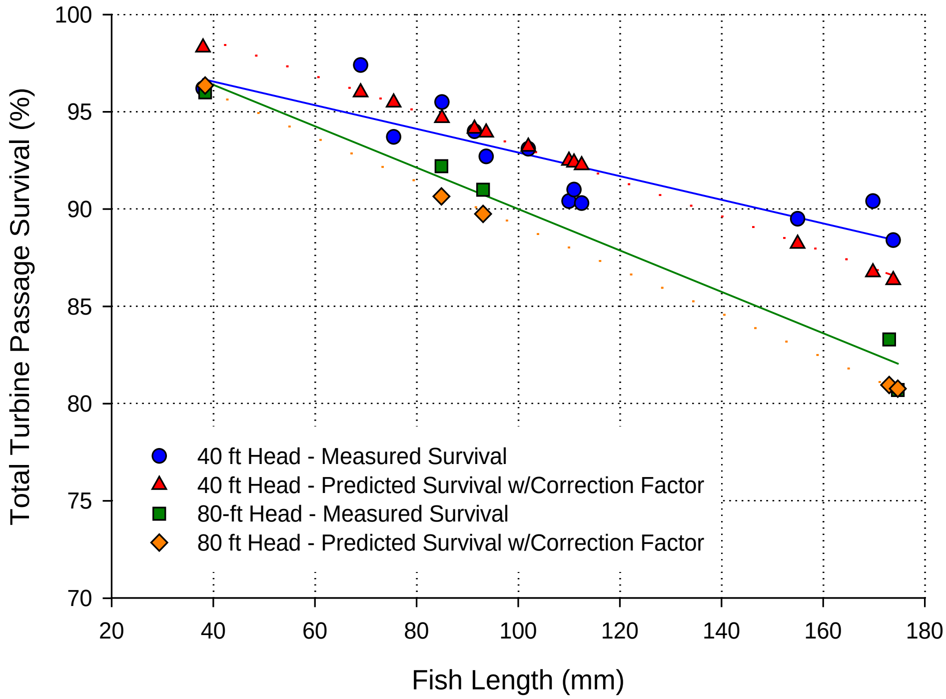

Figure 3-13. Measured and predicted survival versus fish length for the pilot-scale Alden turbine using the adjusted mortality coefficient (0.65K) for the prediction estimates.

3.1.1.8 Comparison of Alden's Approach for Estimating Strike Probability and Survival to Methods Described by Franke et al. (1997)

The probability of fish being struck by a blade during passage through a hydro turbine was formulated in a basic expression initially published by Von Raben (1957). This probability expression, which continues to be used by other researchers (Bell 1991; Turnpenny 2000; Ploskey and Carlson 2004; Hecker and Allen 2005), often includes a coefficient to account for the observation that not all fish that are struck by a turbine blade (in accordance with this probability expression) suffer lethal injuries leading to direct mortality.

The mortality coefficient, which has also been referred to as a mutilation ratio (Turnpenny et al. 2000), has included values derived from comparisons of turbine survival rates estimated form field data to that of survival rates estimated with the strike probability equation with mortality based on separate blade strike tests (Von Raben 1957; Turnpenny 2000). Von Raben (1957) estimated the coefficient to have a value of 0.43 for existing Kaplan turbines based on a comparison of theoretical mortality predictions to field test data. Turnpenny et al. (2000) derived a best fit equation for the coefficient (dependent only on fish length) based on blade strike experiments conducted in a laboratory setting. This best fit equation gives coefficient values of 0.47 for fish 200 mm in length and 0.36 for 100-mm fish (Turnpenny et al. 2000). The biological evaluation of the pilot-scale Alden turbine showed that the test data could be matched well with an expression (for the mortality coefficient) that varied both with fish length and the relative (strike) velocity. For fish about 100 mm in length, the mortality coefficient (also referred to as *K*) for those pilot-scale turbine tests was about 0.6 (Hecker and Allen 2005).

More recently, it was determined from blade strike tests conducted in a laboratory setting that, for semi-circular leading blade edges with a thickness similar to the fish length, the mortality coefficient could have a much lower value (EPRI 2008). Values higher than those stated above occurred for leading edges that were thin relative to the fish length and for relatively high strike velocities. These tests clearly demonstrated the dependence of the coefficient (*K*) value on those variables.

It is important to note that a significant portion of fish passing through a hydro turbine may not be struck by a blade, so the overall turbine passage survival may still be quite high (in spite of a high mortality coefficient) if the probability of strike is low. Turbine survival is usually taken to be 100% minus the strike mortality for turbines with heads of about 100 ft or less since other sources of fish mortality are not considered significant for lower head projects (Franke et al. 1997).

The following information is intended to help understand the role of the correlation coefficient used by Franke et al. (1997) and other researchers and how this coefficient relates to the formulation for the probability of strike-induced mortality.

Basic Formulation of Strike Probability

The probability of strike has been developed from one of three approaches (Von Raben 1957):

1. The ratio of incremental blade motion (in the time it takes fish to pass through the arc of leading edge motion) compared to the total distance between leading edges;
2. The time for fish to pass through the arc of leading edge motion compared to the blade pass time; or
3. The length of fish compared to the length of a streamline that can pass between successive blades.

All of these approaches lead to the same final expression of strike probability that was provided previously (Equation (1)). Consistent units must be used for the variables so that the probability is dimensionless. To obtain the proportion of fish that die from blade strike, Equation (1) is multiplied by a coefficient, referred to as λ by Franke et al (1997) and *K* by Alden, that is usually less than unity to account for the observation that not all struck fish are lethally injured. Blade strike mortality coefficients account for direct mortality only (i.e., lethal injuries suffered from contact with a blade). Indirect mortality may also occur due to sub-lethal injuries that can lead to greater susceptibility to predation and disease/infection or reduced fitness.

Franke's Formulation of Strike Probability

Franke et al. (1997) used the second approach listed above to estimate strike probability for fish passing through turbines. The time for fish to pass through the leading edge blade arc is the radial component of the fish length divided by the radial velocity component, namely:

$$t_{fish} = (L \sin \alpha)/V_r \qquad (18)$$

and the time for a blade pass is the distance between blades divided by the blade tip speed, namely:

$$t_{tunner} = S/u = (\pi D/N)/(\pi Dn/60) = 60/Nn \qquad (19)$$

where S = blade spacing

u = blade tip speed

D = runner tip diameter

Therefore, the ratio of fish transit time to blade passing time is calculated as follows:

$$t_{fish} / t_{runner} = [(L\sin\alpha)/ V_r] / (60/Nn) = n (L\sin\alpha) N/ (60 V_r) \qquad (20)$$

which is identical to Equation (1). By converting the runner rotation rate (n) from rpm to radians per second (ω) as follows:

$\omega = 2\pi n/60$

or $n = 60 \omega /2\pi$

and by substitution, Equation (20) is written by Franke et al. (1997) as:

$$P_S = t_{fish} / t_{runner} = \omega (L\sin\alpha) N / 2\pi V_r \qquad (21)$$

At this point, Franke et al (1997) introduces a new and additional approach to strike probability, namely that the ratio of the tangential component of the fish length to the blade spacing must also be included. This approach is based on the concern that the tangential component of the fish length must fit easily between the blade (leading edge) spacing to avoid strike and that the tangential fish length component relative to the blade spacing indicates something about the strike probability. This new factor is called the tangential strike probability and is expressed as:

$$P_{tangential} = (L\cos\alpha)/(\pi D/N) = (L\cos\alpha)\, N/(\pi D) \qquad (22)$$

This term is simply added to the strike probability expressed by Equation (21) rather than being used as a limit or a guide on how to best describe strike probability. Presumably, there may be cases where this new term is controlling and cases where it is not a factor, such that one term may increase while the other term decreases. However, the new term is always fully added in all cases and final strike probability is, therefore, the addition of two probabilities, one based on relative time and the other based on relative lengths. By adding Equation (22) to Equation (21), Franke et al. (1997) obtains:

$$P_S = \omega\, (L\sin\alpha)\, N / 2\pi\, V_r + (L\cos\alpha)\, N/(\pi D) \qquad (23)$$

This second added term includes the grouping NL/D, which is proportional to the ratio of fish length to blade spacing. This added term is claimed later in the formulation to be the controlling parameter in predicting strike probability. By factoring out NL/D, Franke et al. 1997 obtains:

$$P_S = NL/D\ \{[\omega\, D(\sin\alpha)] / [2\pi\, V_r] + \cos\alpha/\pi\} \qquad (24)$$

Franke et al. (1997) illustrates that for a five bladed Kaplan with fish lengths that are only 1% of the turbine diameter, Equation (24) produces strike probabilities that are about 36% higher (at mid point on the blade) than does Equation (21).

To determine the absolute in-flow angle α, Franke et al. (1997) does not make use of the wicket gate position. Instead, they use conservation of angular momentum (the Euler equation) and the head and discharge of the turbine. The latter are expressed by the non-dimensional head and flow coefficients used in turbine performance testing and these head and flow coefficients include the turbine diameter and runner rotation rate ω. As usual, the radial or axial velocity is determined from the flow and available area. The resulting alternative form of Equation (24) includes the non-dimensional head and flow coefficients but does not change the nature or magnitude of the strike probability given by Equation (24). The use of these head and flow coefficients, however convenient, masks the role of the runner rotation rate and ignores the influence of the wicket gate setting on the inflow angle. Gate position probably does not have a significant influence on inflow direction for turbine operation near the best efficiency point (BEP) but would influence the inflow angle when operating off the BEP. For the purpose of this review, Equation (24) will be retained as written above but it should be noted that predictions of turbine mortality reported by Franke et al. (1997) include the mentioned (non-dimensional) substitutions to obtain the flow angle and velocity.

Franke's Correlation Coefficient λ

As indicated previously, not all fish that make contact with the leading edge are lethally injured. Whether contact is lethal or not depends on factors such as the orientation of the fish relative to the blade, the blade-to-fish impact velocity (i.e., strike velocity; this is different from the peripheral speed of the blade), the shape and thickness of the leading edge, fish length, the region of the fish body that makes contact (the head is more sensitive than the tail), and any behavioral responses of the fish just prior to impact. At the time of the Franke et al. (1997) publication, the results of blade strike tests conducted by Alden that explored most of these factors were not yet available (EPRI 2008). These tests clearly indicated that there is not one value for the correlation (mortality) coefficient (K or λ), but that the value varies considerably with the parameters of a particular case. For example, test data show that the primary physical factors influencing the mortality coefficient are the ratio of the fish length to the leading edge blade thickness and the strike velocity (EPRI 2008).

Not having access to these data, Franke et al. (1997) compared the predicted mortality from blade strike using Equation (24) to observed turbine mortality from field tests. The ratio of these results indicated an average value of a correlation coefficient, called lambda (λ), which by incorporation into Equation (24) would allow that equation to better match field test mortality data. That is:

$$P_S = \lambda\ NL/D\ \{[\omega\ D(\sin\alpha)] / [2\pi\ V_r] + \cos\alpha / \pi\} \qquad (25)$$

Where λ = a coefficient accounting for less observed mortality than predicted by the strike probability of Equation (24).

Figure 3-14 shows turbine mortality measured in field tests divided by the predicted strike probability, and this was used by Franke et al. (1997) to determine that the value of lambda should be 0.2 for Kaplan turbines. That implies that 20% of the struck fish are lethally injured during passage through Kaplan turbines on average. Although it may be an average value of the plotted ratio to account for the lower observed mortality than the predicted blade strike (an expected result), it may be seen that the value of lambda varied significantly from one turbine test to another, generally from 0.0 to 1.0. Based on field tests at Wanapum, Franke et al. (1997) stated that lambda was estimated to have a value of about 0.1 for those results.

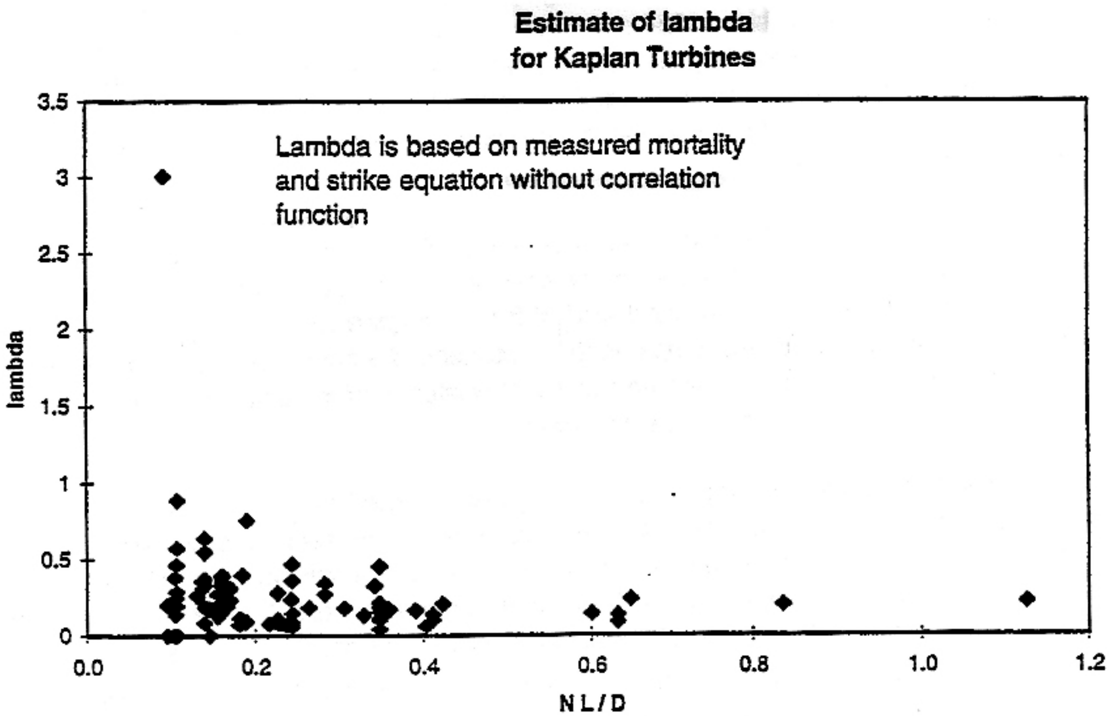

Figure 3-14. Field data for mortality of fish passing through Kaplan turbines divided by blade strike predictions using Equation (24). Source: Franke et al. (1997).

Use of lambda in the range of 0.1 to 0.2 for Kaplan turbines indicates the mortality predictions based on strike are high by a factor of 10 to 5. Some of this seemingly large difference may be accounted for by the second term that was added to the Franke et al. (1997) probability formulation, increasing the probability of strike and, therefore, mortality. However, not understanding the reasons why this large reduction in predicted mortality from strike is necessary undermines the validity of this approach.

A similar graph from Franke et al. (1997) of the measured mortality divided by the predicted strike probability for Francis turbines is shown in Figure 3-15. This graph shows even greater scatter among the data derived from turbine passage survival tests conducted with Francis turbine, leading to greater uncertainty as to what value of lambda should be used for a given Francis turbine.

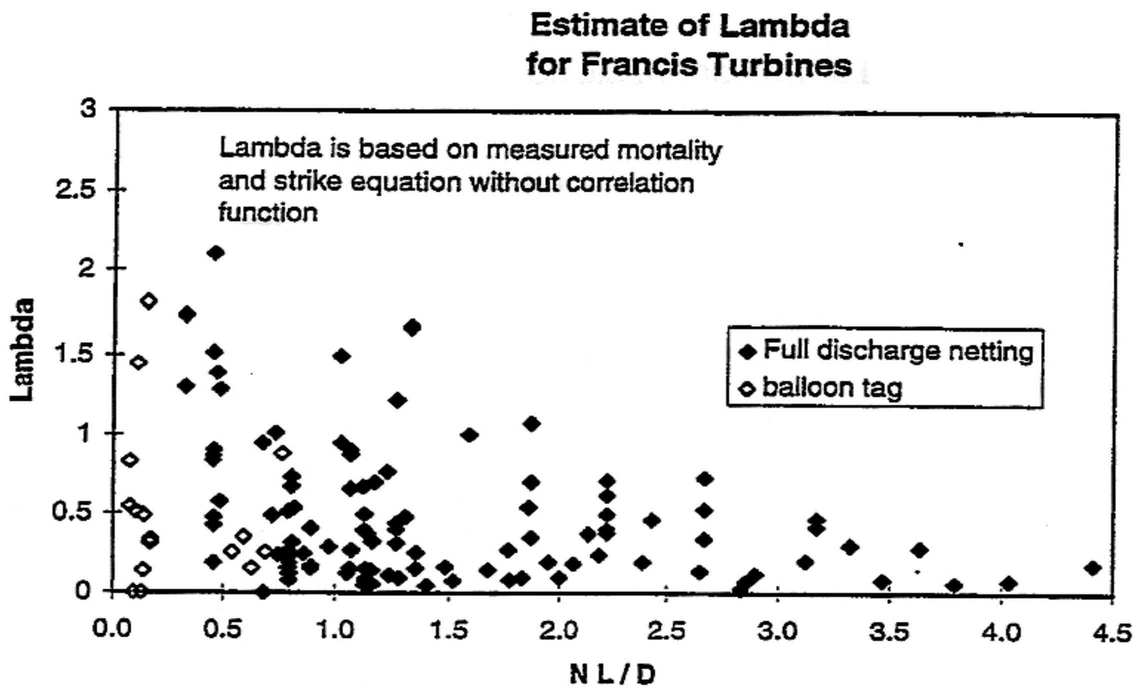

Figure 3-15. Field data for mortality of fish passing through Francis turbines divided by blade strike predictions using Equation (24). Source: Franke et al. (1997).

The following is a summary of the assessment of the Franke et al. (1997) approach to estimating strike probability and mortality and the comparison to Alden's approach:

1. Franke et al. (1997) follows the usual formulation of strike probability except that the authors:

   a. Add a second term to account for the tangential component of fish length relative to blade spacing, thus increasing the probability of strike; and

   b. Use non-dimensional coefficients for head and flow, together with the conservation of angular momentum, to determine the inflow angle.

2. To account for the observation that field test mortality is less than predicted from the strike formulation, Franke develops a correlation coefficient λ that has an average value of between 0.1 and 0.2 for Kaplan turbines. These lower than typical values (for existing turbines) may be the result of the increased probability for strike produced by the added term in the probability formulation. It is not evident if the same value is applicable to Francis turbines, nor if a constant value is appropriate for all turbines of a given type.

3. The data set developed by Alden showing how λ (or *K* as named by others) varies with relative (strike) velocity and the ratio of fish length to blade thickness was not used because those data became available only after the work by Franke was completed.

Those Alden data show that the correlation coefficient *K* may vary from 0.0 (no fish die) to 1.0 (all struck fish die), depending on the mentioned variables.

3.1.2 Spillway Passage Survival

Spillways and associated discharge structures (rubber dams and spill, crest, and sluice gates) are common passage routes utilized by downstream migrating fish that encounter hydro power projects. Spill occurs when river discharge exceeds powerhouse capacity, but is often maintained at lower river flows specifically for downstream fish passage or to meet minimum flow bypass requirements. Spillways and dam gates are typically considered a safe route of egress that can reduce the number of outmigrants passing through turbines, where the potential for injury and mortality is expected to be greater. The FERC generally has considered spillways as acceptable passage routes if dam materials are not excessively coarse, plunge pools have adequate depth, and there are no sharp or protruding rocks or walls that fish can strike (FERC 2000a, 2000b). The FWS also considers spillways to be an acceptable passage route when spill is sufficient and the hydraulic and physical characteristics of spillways and stilling basins do not lead to considerable potential for fish injury and mortality (Amaral 2001). However, fish passing over spillways or through dam gates may be subjected to physical damage as well (Bell and DeLacy 1972; Ferguson 1992; Heisey et al. 1996), both direct and indirect (disorientation or sub-lethal injuries leading to increased predation or reduced fitness). Many studies have been conducted to quantify injury and mortality associated with spillway passage, mainly for juvenile salmon passing downstream at Columbia and Snake River projects (Whitney et al. 1997; Muir et al. 2001; Ferguson et al. 2005). Fewer spillway survival studies have been conducted with Atlantic salmon smolts and, similar to steelhead trout on the west coast, very little information is available on the survival of kelts passing downstream via this route.

Bell and DeLacy (1972) reviewed spillway and gate passage studies conducted prior to 1970 and examined the potential effects of several design features (spillway/gate type, bucket/stilling basin design, vertical drop, water velocity, and discharge) on fish injury and mortality. The primary factors identified as affecting fish injury and mortality were discharge volume, spillway design (or shape), stilling basin design, pressure changes, rapid deceleration, impact with hard surfaces, abrasion, and shearing. Discharge volume and spillway and stilling basin design influence water velocities and back roll characteristics, which in turn influence fish injury and mortality associated with striking hard surfaces, abrasion, and shearing. It was concluded that spillway passage survival could be maximized if turbulence, back rolls, and rapid energy dissipation are minimized.

Based on a review of several studies that evaluated the survival and injury of fish free-falling into water or passing over spillways and gates, Bell and DeLacy (1972) drew the following conclusions regarding spillway survival [as summarized by Amaral (2001)]:

- Survival of fish entering a pool from free-fall was between 98 and 100 percent at velocities up to 15 m/s (49 ft/s).

- Survival rates of fish entering a pool in a column of water decelerating with the jet and without mechanical deflection were similar to rates under free-fall conditions.
- Survival rates of fish entering a pool in a column of water decelerating with the jet and deflected by a baffle was about 93 percent.
- Survival rates of fish passing through a hydraulic jump or stilling basin were between 93 and 98 percent.
- Survival of fish striking a fixed object (e.g., baffle or rock) was near zero.

More recent studies examining fish passage over spillways and gates have supported these observations. Heisey et al. (1996) summarized results from studies that examined turbine and spillway/gate passage survival and reported that spillway/gate survival rates of anadromous outmigrants (Chinook salmon, Atlantic salmon, blueback herring, and American shad) were between 93 and 100%. Dam heights from these studies ranged from about 13 to 69 ft and discharges ranged from 40 to 12,000 cfs, which encompasses the range of conditions experienced by smolts and kelts passing over spillways and gates at most of the Penobscot River projects. Heisey et al. (1996) reported direct survival rates of 93 to 100% for Atlantic salmon smolts passing over sluice gates at three projects on the Connecticut River with dam heights of 27 to 59 ft (these data are also considered in the determination of bypass survival rates discussed in the Section 3.1.3 below). Heisey et al. (1996) cited shear forces, turbulence, rapid deceleration, terminal velocity, impact against the base of a spillbay, scraping rough surfaces, and rapid pressure changes as injury mechanisms for fish passing over spillways and through gates.

In a study that included an investigation of spillway passage with and without spill deflectors, Muir et al (2001) estimated survival rates for yearling Chinook salmon and steelhead at Snake River dams. The estimated relative survival for fish passing over spill bays without flow deflectors was 98.4–100%; with flow deflectors spillway passage survival was 92.7–100%. Because fish were tracked through multiple river reaches as they moved downstream past several dams, these estimates include both direct and indirect mortality. The authors also reported bypass system survival rates of 95.3–99.4% and turbine passage survival rates of 86.5–93.4% (both of which also include direct and indirect mortality). NAI et al. (1996) estimated spillway survival at Bonneville Dam for juvenile Chinook salmon to be 100% with and without spillway deflectors. Unlike the previous study (Muir et al. 2001), the NAI et al. (1996) results only represent direct mortality for the passage routes evaluated (i.e., fish were released at the Bonneville spillway and recaptured immediately downstream). In another study of spill passage survival on the Columbia River, NAI (1996a) reported survival rates of 95.5% to 99.3% for juvenile Chinook salmon passing three different spill bays at the Dalles Dam with varying flow rates. Dawley et al. (2000) also examined spillway survival for juvenile salmonids (Chinook and coho salmon) at the Dalles Dam. Relative survival rates (includes direct and indirect mortality) from this study ranged from 86 to 98%, with the lowest point estimates occurring for fish released at the higher of two spill flow rates and for fish that passed downstream during the day.

Based on the available information, for most spillway designs, the primary factors affecting fish survival will be discharge, velocity of spill, location and angle of spill striking dam face, dam material coarseness, presence of rocks or walls, turbulence in stilling basin or plunge pool, and the distribution of flow across the downstream face of the dam. However, detailed information describing these parameters is not readily available for Penobscot River hydro projects. Larinier (2000) indicated that spillways are considered the safest downstream passage route for dams with heights of about 30 ft (10 m) and less, as long as water depth at the base of the dam is sufficient and no rocks, baffles, or other structures are present in the flow path. With the exception of Mattaceunk, which has a hydraulic head of 39 ft, all of the hydro dams on the Penobscot River are about 30 ft in height or less (from head pond elevation to tailwater elevation) and generally would meet the criteria for safe passage.

A summary of data from 136 tests conducted at Columbia River projects produced a mean spillway passage survival rate of 97.1 for juvenile salmonids, with a range of 76.2 to 100.0% (Table 3-5). Also, sluice gate passage survival rates reported for Atlantic salmon smolts at six projects in the Northeast averaged 97.9% for immediate survival (1-hr) and 96.8 for total survival (48-hr) (see Table 3-8 in following section discussing bypass survival rates). The Penobscot River projects have lower heads and typically experience less spillway discharge than many of the sites where spillway and sluice gate studies have been conducted, suggesting that passage conditions would be less injurious on the Penobscot River. In general, lower head projects are expected to provide safe passage over spillways due to lower velocities leading to less damaging impact with water surfaces and solid structures, as well as less severe shear and turbulence levels. However, unlike on the Columbia River where spill is often concentrated through one or more spill or crest gates, the spill over the Penobscot projects typically has less control and there is insufficient information to determine what the physical and hydraulic conditions are at each site and how they may affect injury and survival rates over a range of spillway flows.

Therefore, without site-specific data or more detailed information on the hydraulic and physical conditions experienced by fish passing over spillways and gates at Penobscot River projects, using a spillway survival rate approximately equivalent to the average of rates reported from past studies is considered a prudent and reasonable approach. Consequently, a direct spillway survival rate of 97% was used in the calculations of total survival for smolts and kelts passing downstream at each of the Penobscot River projects.

Table 3-5. Summary of spillway survival data from studies conducted with juvenile salmonids (primarily Chinook salmon) at Columbia River projects (see Appendix B for a more detailed summary of the data from these studies).

		Head (ft)		Spill/Gate Flow (cfs)				
Project	Tests	Min	Max	Min	Max	Average Survival (%)	Min Survival (%)	Max Survival (%)
Bonneville	10	50	65	4,100	12,000	97.1 (88.6-100.0)	88.6	100.0
Ice Harbor	23	92	100	3,400	13,600	97.6 (90.1-100.0)	90.1	100.0
Little Goose	18	94	98	1,800	12,800	98.8 (95.3-100.0)	95.3	100.0
Lower Granite	4	97	101	3,400	7,000	98.3 (97.5-100.0)	97.5	100.0
Lower Monumental	4	97	97	8,500	8,500	97.7 (94.9-100.0)	94.9	100.0
North Fork (OR)	8	135	135	700	2,000	87.0 (76.2-99.9)	76.2	99.9
Rock Island	8	39	49	1,900	10,000	98.7 (95.1-100.0)	95.1	100.0
The Dalles	44	74	84	4,500	21,000	97.5 (85.1-100.0)	85.1	100.0
Wanapum	17	71	82	2,000	12,500	97.5 (92.0-100.0)	92.0	100.0
All Projects	**136**	**39**	**135**	**700**	**21,000**	**97.1 (76.2-100.0)**	**76.2**	**100.0**

3.1.3 Downstream Bypass Efficiency and Survival

Downstream bypasses are installed at hydro projects specifically to provide fish with an alternative passage route that is safer than passage through turbines. Bypass efficiencies represent the proportion of fish passing a project that will use a downstream bypass, and survival estimates represent any losses of fish that may occur during passage through a bypass. Bypass efficiency is defined as the percent of outmigrants that approach a powerhouse intake that are diverted and passed through a bypass. Fish that pass over a project's spillway typically are not included in the estimate of bypass efficiency. For example, if 100 fish approach a project and 40 pass over the spillway, 30 through the bypass, and 30 through the turbines, then bypass efficiency is 50% (number of fish bypassed divided by total number bypassed and entrained through turbines).

Downstream passage studies have been conducted at five of the fifteen Penobscot River projects being evaluated for smolt and kelt survival (FERC 2004; USASAC 2005; Fay et al. 2006), but only studies at two of these sites (Mattaceunk and Orono) had sufficient data to provide site-specific estimates of bypass efficiency for smolts, and only data from Mattaceunk was sufficient for kelts. To estimate bypass efficiency at the thirteen projects where studies have not been conducted or data were insufficient, data from studies conducted at Mattaceunk and Orono and from studies conducted primarily with Atlantic smolts and/or kelts at other hydro projects in the U.S. and France were compiled and evaluated (see Appendix C for a summary of this information).

Bypass effectiveness data were compiled from studies conducted at 40 hydro projects (28 in the U.S. and 12 in France). Similar to Penobscot River projects, most of the study sites are low head (< 50 ft) and all but one of the U.S. projects are located in the Northeast (including Orono and Mattaceunk on the Penobscot River). Many of the studies investigated multiple downstream passage conditions over one or more years in attempts to optimize the performance bypass systems. Test conditions often included different bypass flows, various configurations of rack porous or solid overlays to reduce spacing or block surface flow, and/or different types of floating booms or configurations of flow inducers to guide fish away from turbine intakes and towards a bypass. Most of the tests were conducted at sites with clear bar rack spacing of 1.5 inches or less (Table 3-6). Only four sites had bar spacings either less than 1 inch or greater than 1.5 inches, including the Lockwood Project on the Kennebec River which had 2.0-inch spacing on the intake racks of six generating units and 3.5-inch spacing for one unit. Consequently, the data were limited for bar spacings outside the 1.0 to 1.5 inch range and are considered insufficient to draw any reasonable conclusions on a broader scale (i.e., with respect to other projects with similar bar spacings where studies have not been conducted). The data from tests with 1-inch bar spacing produced an average bypass efficiency of about 51% with a range of 17 to 100% (Table 3-6).

Table 3-6. Summary of bypass effectiveness data from studies conducted with Atlantic salmon smolts and juvenile trout at low head hydro projects in the U.S. and France (see Appendix C for more detailed information).

Bar Rack Spacing (in)	Number of Tests	Bypass Efficiency (%)		
		Mean	Min	Max
0.50	1	81.5	81.5	81.5
1.00	20	51.3	17.0	100.0
1.25	7	66.6	32.0	92.5
1.50	7	52.2	17.0	73.0
2.00	1	7.0	7.0	7.0
5.00	7	56.7	24.0	88.0
2.00/3.50	1	18.0	18.0	18.0
Unknown	35	57.0	6.0	100.0
Totals	79	55.1	6.0	100.0

Table 3-7. Intake rack spacing and estimated bypass efficiencies for Atlantic salmon smolts and kelts passing downstream at Penobscot River hydro projects.

Project	Bar Rack Clear Spacing (in) (upper/lower)	Upper Rack Depth (ft)	Kelt Entrainment	Smolt Bypass Efficiency (%)	Kelt Bypass Efficiency (%)
Veazie	1.00/2.25	15	no	40	70
Great Works	1.13	--	no	50	100
Milford	3.50	--	yes	10	25
W.Enfield	1.00/3.00	2	yes	25	70
Mattaceunk	1.00/2.63	16	yes	38	70
Orono	1.00/2.38	14	no	42	100
Stillwater	1.00/2.38	14	no	40	100
Medway	2.25	--	no	--	100
Howland	1.00	--	no	50	100
Brown's Mill	1.00	--	no	50	100
Lowell Tannery	2.00	--	no	25	100
Moosehead	1.50	--	no	--	--
Milo	2.00	--	no	--	--
Sebec	2.50	--	no	25	100
Frankfort	3.25	--	yes	10	25

Bypass survival data have only been collected at one of the fifteen Penobscot River projects. These data were collected during a downstream passage study conducted at the Mattaceunk Project and indicated that immediate survival of smolts passing through the bypass system was 99.8% (GNP 1999). Several other bypass survival studies have been conducted with Atlantic salmon smolts at hydro projects on other river systems in New England (Table 3-8). Bypass survival estimates from these studies ranged from 91 to 100.0% with a mean of about 97% (Table 3-8). Most of these studies were conducted at projects with head differentials greater than 40 ft, whereas the Penobscot River projects have operating heads less than 30 ft, with the only exception being Mattaceunk (39 ft). Bypass survival rates are expected to be higher for lower head projects due to slower discharge velocities. Also it is evident from the available data that survival may be at or near 100% at higher head projects which have bypass designs and discharge conditions that will minimize injury to fish. Given the high bypass survival observed at Mattaceunk, which is the highest head project in the Penobscot River basin, and the lower heads of the other 14 projects, bypass survival of Atlantic salmon smolts and kelts was assumed to be 99% for the purposes of the total project survival analysis.

Table 3-8. Summary of bypass survival data from studies conducted with Atlantic salmon smolts.

Project	Mean Fish Length (mm)	Project Head (ft)	Bypass Flow (cfs)	Immediate Survival (%)	Total Survival (%)	Delayed Mortality Holding Period (hr)	Reference
Amoskeag	208	46	149	100.0	100.0	48	NAI 2006
Bellows Falls	252	59	308	96.0	96.0	48	RMC 1991
Garvin Falls	190	30	80	100.0	100.0	48	NAI 2005
Lower Saranac	245	76	36	--	100.0	72	NAI 1994, 1997
Vernon	156	27	40	93.3	93.3	48	NAI 1996b
Wilder	212	52	300	99.0	91.1	48	RMC 1992
Wilder	212	52	200	99.0	97.0	48	RMC 1992
Wilder	212	52	500	98.0	97.0	48	RMC 1992

3.2 Estimation of Indirect Survival Rates

In addition to direct mortality, which represents smolt and kelt losses resulting from lethal injuries suffered during passage over spillways and through bypasses and turbines, indirect mortality may occur due to sub-lethal injuries, increased stress, predation, and/or disorientation. Also, cumulative indirect mortality may occur from delays and passage conditions experienced at multiple dams. That is, the number of hydro projects encountered by a fish during a downstream migration may influence migration success, with mortality increasing with the number of dams passed. Indirect mortality associated with individual projects is reviewed in this section and an estimate of this parameter for smolts and kelts passing downstream at Penobscot River dams is provided. The following section (3.3) discusses cumulative effects of multiple dam passage and the likely decrease in survival of smolt and kelt that may occur based on available research. Because the focus of the analysis presented in this report is the development of site-specific data, only indirect survival rates were incorporated into the calculations of total project survival for each dam. Cumulative mortality is being incorporated by NMFS in their population model for Penobscot River salmon.

Unlike direct mortality, indirect mortality resulting from passage at hydro projects is difficult to isolate and estimate because it typically occurs over longer time frames and greater distances. A large portion of indirect mortality may involve predation on disoriented fish exiting turbines, bypasses, or spillways (Mesa 1994; Ward et al. 1995; Ferguson et al. 2006), whereas other fish suffering sub-lethal injuries during dam passage may experience mortality much further downstream due to secondary effects related to disease, infection, and overall reduced-fitness. Indirect mortality and the effects of multiple dam passage have been examined in depth on the Columbia River, primarily for salmon smolts and juveniles. Fewer studies of indirect mortality suffered by juvenile salmonids have been conducted on smaller river basins similar in size to the

Penobscot, but some studies have reported heavy predation by birds and/or piscivorous fishes on Atlantic salmon smolts that may be linked to passage through hydropower impoundments and tailraces (Blackwell and Juanes 1998; Jepsen et al. 1998; Aarestrup 1999; Koed et al. 2002).

For the purposes of the survival analysis conducted for Penobscot River projects, indirect mortality is considered for each individual dam with respect to predation in the impoundment and tailrace (or bypass reach below spillways) and sub-lethal injuries that likely lead to mortality before fish reach the next downstream dam or, in the case of Veazie and Frankfort, the estuary. Increased predation in impoundments typically results from migration delays (i.e., more exposure to predators that inhabit impoundments), whereas predation in tailraces is probably primarily related to sub-lethal injuries and disorientation following turbine, bypass, or spillway passage.

Čada (2001) cited predation immediately downstream of hydro projects as a prevalent source of indirect mortality for fish passed through turbines and over spillways. Increased susceptibility to predation was attributed to sub-lethal injuries and disorientation or loss of equilibrium. Large-scale turbulence associated with tailrace discharges and dam spill may be leading causes of disorientation. Susceptibility of fish to predation has been shown to increase following exposure to non-injurious levels of shear and turbulence (Neitzel et al. 2000). Čada (2001) also suggested that, despite better hydraulics that may lead to less injury and disorientation, predation at bypass outfalls could be prevalent. Consequently, because sub-lethal injuries and disorientation can occur with any passage route, it is important to account for indirect mortality when considering overall project impacts on downstream migrants. Additionally, although spillway survival has generally been shown to be higher than turbine passage survival, indirect effects may lead to less difference in total survival rates between these two passage routes (Čada 2001).

Indirect mortality of fish passing downstream at hydro projects that can be directly attributed to sub-lethal injuries (excluding predation) is likely low, but probably increases as fish pass additional dams (i.e., cumulative indirect mortality). Such injuries are unlikely to occur in impoundments, where migration delays will have a greater impact on survival through increased susceptibility to predation and reduced fitness throughout a migration period. The occurrence and effects of sub-lethal injuries will be greatest during and immediately after passage through turbines, over spillways, and through bypasses, and may include scale loss, lacerations and bruising, eye and fin damage, and internal hemorrhaging. High direct and indirect survival rates reported for juvenile salmonids passing over spillways and through bypasses indicate the portion of indirect mortality not associated with predation is probably negligible for these passage routes at most projects. There is also evidence that injury rates (including scale loss) are low for fish that survive passage through turbines. However, even a small loss of scales can lead to mortality of smolts entering the salt water (Beck and Smith 1979; Zydleweski et al. 2011)

From an analysis of 33 survival studies conducted at Columbia River projects, Bickford and Skalski (2000) reported an average direct turbine survival rate of 0.933 and an average total survival rate of 0.873. These estimates lead to an estimated indirect survival rate of 0.936 (0.873/0.933) for the data evaluated. Muir et al. (1996) examined balloon tag (direct survival) and PIT tag (total survival) data from studies conducted with chinook salmon that were released at the same location in a turbine intake at Lower Granite Dam. They reported direct and total survival rates of 0.940 and 0.927, respectively, indicating that the indirect survival rate for turbine-passed fish at this site was 0.986 (or 0.014 indirect mortality). Ferguson et al. (2006) also found evidence of delayed mortality when comparing relative survival rates of PIT and radio-tagged juvenile salmon to direct survival rates of balloon-tagged fish released into turbine intakes at McNary Dam and recovered in the tailrace. Based on their analysis, Ferguson et al. (2006) concluded that delayed (indirect) mortality accounted for about 45 to 70% of total mortality for fish that traveled 9.3 to 28.6 miles (15 to 46 km) downstream of the dam. Total relative survival estimates reported in this study ranged from 0.814 to 0.871 and direct survival rates ranged from 0.930 to 0.946. When matched to the turbine flow tested with each tagged fish release, the resulting range of indirect survival rates for this study ranged from 0.860 (0.814/0.946) to 0.937 (0.871/0.930). Combining the results of these three studies produces an average indirect (delayed) survival rate of 0.930 (Table 3-9).

The smaller impoundments and lower heads of Penobscot River projects compared to those on the Columbia River are expected to result in less indirect mortality of smolts and kelts that can be attributed to passage at a single dam. Predation in impoundments and tailraces and below spillways and bypass outfalls is expected to be the primary source of indirect mortality at each project, with the effect of sub-lethal injuries, scale loss, and stress having more influence on cumulative indirect survival rates associated with multiple dam passages. Although information from studies conducted on the Columbia River indicate that indirect mortality may be less for fish passing over spillways and through bypass systems (Bickford and Skalski 2000; Muir et al. 2001), it is not clear if this would also be the case for Atlantic salmon smolts and kelts at Penobscot River projects. Based on the available information discussed in this section, it was assumed for the calculation of total project survival that indirect mortality for a single dam passage by smolts and kelts is 0.95 for each available passage route (spillway, bypass, and turbines) at each of the 15 projects.

Table 3-9. Total and direct survival rates reported for turbine-passed fish evaluated at dam on the Columbia River and indirect survival rates calculated for set of data (i.e., total survival divided by direct survival).

Study	Total Survival	Direct Survival	Indirect Survival
Bickford and Skalski (2000)	0.873	0.933	0.936
Muir et al. (1996)	0.927	0.940	0.986
Ferguson et al. (2006)	0.814	0.946	0.860
Ferguson et al. (2006)	0.871	0.930	0.937
Average	**0.871**	**0.947**	**0.930**

3.3 Latent Mortality Associated with Multiple Dam Passages (Cumulative Effect)

In addition to estimating total, indirect, and direct survival for juvenile salmonids passing downstream at individual projects, some studies have also investigated what is referred to as latent or delayed mortality, which occurs in the estuary or ocean environment and is associated with passage through one or more hydro projects (Budy et al. 2002; ISAB 2007; Schaller and Petrosky 2007; Haeseker et al. 2012). The concept describing this type of latent mortality from the cumulative effects of multiple dam passage is known as the hydrosystem-related, delayed-mortality hypothesis (Budy et al. 2002; Schaller and Petrosky 2007; Haeseker et al. 2012). This type of mortality is difficult to quantify and was not specifically addressed in the estimation of total project survival for smolts and kelts passing downstream at each of the 15 Penobscot River hydro projects of interest.

For the purposes of the Penobscot River analysis, latent mortality is defined as that which can be attributed to the cumulative effects of multiple dam passages and which occurs after migrating fish pass downstream of the last dam on the river (including in the estuary and marine environment). However, some latent mortality may occur within a hydropower system (Budy et al. 2002), but it is difficult to separate cumulative in-river effects from direct and indirect mortality that occurs at or near individual dams. Therefore, the assessment of latent mortality presented in this section applies to smolts and kelts that successfully negotiate all dams they encounter before reaching the lower river and estuary. Budy et al. (2002) took a similar approach when they included latent mortality occurring in the hydrosystem with direct mortality estimates and not in their definition of delayed hydrosystem mortality.

Budy et al. (2002) examined the influence of hydropower experience on estuarine and early ocean survival rates of juvenile salmonids migrating from the Snake River to test the hypothesis that some of the mortality that occurs after downstream migrants leave a river system may be due to cumulative effects of stress and injury associated with multiple dam passages. The primary factors leading to hydrosystem stress (and subsequent latent mortality) cited by Budy et al. (2002) were dam passage (turbines, spillways, bypass systems), migration conditions (e.g., flow, temperature), and collection and transport around dams, all of which could lead to increased predation, greater vulnerability to disease, and general reduced fitness associated with compromised energetic and physiological condition. In addition to linking hydrosystem experience to latent mortality, Budy et al. (2002) cited evidence from mark-recapture studies that demonstrated differences in latent mortality among passage routes (i.e., turbines, spillways, bypass and transport systems).

More recent studies have corroborated the indirect evidence for hydrosystem latent mortality presented by Budy et al. (2002) and provided data on the effects of in-river and marine environmental conditions (Schaller and Petrosky 2007; Haeseker et al. 2012). Based on an evaluation of historical tagging data describing spatial and temporal mortality patterns of downstream migrants, Schaller and Petrosky (2007) concluded that latent mortality of Snake River Chinook salmon was evident and that it did not diminish with more favorable oceanic and climatic conditions. Estimates of latent mortality reported in this study ranged from 0.75 to 0.95

(mean = 0.81) for the study years of 1991-1998 and 0.06 to 0.98 (mean = 0.64) for the period of 1975-1990. These were the only estimates of latent mortality that were found in the literature. Haeseker et al. (2012) assessed the effects of environmental conditions experienced in freshwater and the marine environment on latent mortality of Snake River Chinook salmon and steelhead trout. This study examined seasonal and life-stage-specific survival rates of both species and analyzed the influence of environmental factors (freshwater: river flow spilled and water transit time; marine: spring upwelling, Pacific Decadal Oscillation, sea surface temperatures). Haeseker et al. (2012) found that both the percentage of river flow spilled and water transit time influenced in-river and estuarine/marine survival rates, whereas the Pacific Decadal Oscillation index was the most important factor influencing variation in marine and cumulative smolt-to-adult survival of both species. Also, freshwater and marine survival rates were shown to be correlated, demonstrating the effects of hydrosystem experience on estuarine and marine survival. The studies described above have clearly demonstrated that hydrosystem experience results in latent mortality after salmon smolts leave a freshwater system. However, only one of the studies was able to (or tried to) quantify latnet mortality and the estimates varied considerably. These estimates were reported by Schaller and Petrosky (2011) for Snake River Chinook salmon and ranged from 0.06 to 0.98 (mean = 0.64) for brood years 1975-1990 and 0.75 to 0.90 (mean = 0.81) for brood years 1991-1998.

Although latent mortality following passage through a hydrosystem has been demonstrated by the studies discussed above, effectively quantifying such losses has not been possible, mainly because of practical limitations in directly measuring mortality after fish have left a river system (i.e., during time spent in estuaries and the marine environment). Evaluations of latent mortality have generally produced indirect evidence to support the link between hydrosystem experience and estuary and marine survival rates (and smolt-to-adult returns). In fact, in a review of latent mortality experienced by Columbia River salmon, ISAB (2007) recommended that attempts should not be made to provide direct estimates of absolute latent mortality, concluding that measuring such mortality relative to a damless reference was not possible. Alternatively, it was suggested that the focus should be on estimating total mortality of in-river fish, which was considered more critical to the recovery of listed salmonids. Consequently, it is difficult to draw absolute or quantifiable inferences from the Columbia River studies to other river systems beyond the simple conclusion that latent mortality likely occurs for most anadromous salmonid populations. Additionally, although there is evidence of differential mortality between upper and lower river smolts in the Columbia River basin (Schaller and Petrosky 2007), data are not available for estimating a cumulative mortality rate based on the number of dams passed by downstream migrants.

3.4 Flow and Fish Distributions Assigned to Available Passage Routes

Total passage survival of smolts and kelts moving downstream at each Penobscot River project is dependent on the proportion of fish passing through each available route (spillways, bypasses, and turbines) and the corresponding survival rates for these routes. The flow and fish distributions are a function of total river flow. Route-specific survival rates developed from the literature do not change with flow through spillways and bypasses and are the same for all projects, whereas turbine survival rates vary among the different turbine designs and with discharge through any given unit (i.e., generation load). As long as crest depth is sufficient to allow passage, the number of fish passing over spillways and approaching a powerhouse is assumed to be proportional to discharge (i.e., if 50% of the total river flow is passing over a spillway, then 50% of downstream migrants approaching a project are assumed to pass over the spillway). For fish approaching a powerhouse, turbine entrainment is based on trash rack bar spacing and the estimated effectiveness of available bypasses. In addition, generating flows (and fish) must be distributed among the individual turbines as turbine survival rates will vary among units of different designs and at different generating loads. More detailed discussions of the distribution of flow to each discharge location and a discussion of the distribution of flow to each individual turbine in a powerhouse are provided below. These sections are followed by a discussion of the methods developed for estimating the proportion of smolts and kelts that will pass through each of the available routes (and individual turbines) over the range of river discharges expected to occur at each project.

3.4.1 River Flow Distributions

For any given river flow (Q_{total}), the distribution of flow among available discharge locations is assigned based on the following set of rules:

1. River flow is assigned in the following sequence: (1) bypass flow (fixed flow rate based on requirement for downstream passage); (2) powerhouse flow (based on operation of one or more units at partial or full load); (3) spillway flow (flow depth of spillway crests must exceed 6 inches for smolts passage to occur and 12 inches for kelts to pass).

2. $Q_{total} \leq Q_{bypass}$; all flow discharge through bypass.

3. $Q_{bypass} < Q_{total} \leq Q_{minoperate}$; bypass flow requirement met, remaining flow not sufficient for turbine operation, additional flow assigned to spillway.

4. $Q_{bypass} + Q_{minoperate} < Q_{total} \leq Q_{maxoperate}$; bypass requirement met, all remaining flow assigned to turbines, no spillway flow (unless there is excess flow that is insufficient to start another unit, then it is assigned to the spillway).

5. $Q_{total} > Q_{bypass} + Q_{maxoperate}$; bypass requirement met, all turbines operating at full load, any additional flow is passed over spillway.

where:

Q_{bypass} = bypass flow requirement for downstream fish passage

$Q_{minoperate}$ = minimum flow needed to operate at least one turbine

$Q_{maxoperate}$ = combined maximum flow of all turbines operating at full load

3.4.2 Flow Distribution to Turbines

The distribution of flow to individual turbines is typically designed to maximize energy generation and is usually a function of several factors such as system control devices, operator actions, and turbine performance. In the absence of detailed information on how each of the Penobscot River projects are operated with respect to turbine sequencing and operating loads, it was assumed energy generation would be maximized by eliminating any unnecessary spillway flows. To eliminate unnecessary spillway flow, there are times when the flow to one unit must be reduced to allow another to operate. Efforts were maintained to operate turbines in a range which would likely have a higher efficiency.

An example flow distribution is shown in Figure 3-16. The figure represents the flow distributions to three identical turbines. It can be seen that flows are distributed such that spillway flow occurs only at low flows (below the minimum operating range of the turbines) or at river flows exceeding the total hydraulic capacity of the turbines.

Generally, flow is assigned to units by type and then by size. Flow is distributed to Kaplan units first as they have the ability to operate over a wider flow range than propeller or Francis units. Following the distribution of flows to the Kaplan units, flow is distributed to propeller and then Francis units, respectively. Next, flow is distributed to larger units first followed by smaller units. Depending on the actual turbine capacities and available river flow, some minor modifications to these rules may be required to eliminate unnecessary spillway discharge.

As every site is different with varying combinations of turbine size and type, the distribution rules were evaluated on an individual project basis but always aimed to maintain efficient energy generation at any given time. It should be noted that there was one case in which minor spillway spill could not be eliminated during turbine operations due to the significant difference in unit capacity.

3.4.3 Fish Distribution Among Available Passage Routes

The proportion of fish passing through each discharge location (spillway, bypass, turbines) is determined primarily by the proportion of flow passed over the spillway and approaching the powerhouse. The number of fish passing over the spillway is assumed to be proportional to flow (i.e., if 50% of river discharge is being spilled, then 50% of downstream migrating fish are assumed to pass over the spillway). The number of fish approaching the powerhouse is also proportional to flow (bypass and turbine discharge combined), but other factors determine what proportion of these fish are either bypassed or entrained through a project's turbines. Specifically, as discussed in Section 2.1.3, bypass efficiency was set for each project based on available data from field studies conducted with Atlantic salmon smolts and kelts at Penobscot River projects and bar rack spacing (i.e., ability to physically and behaviorally exclude fish from turbine entrainment).

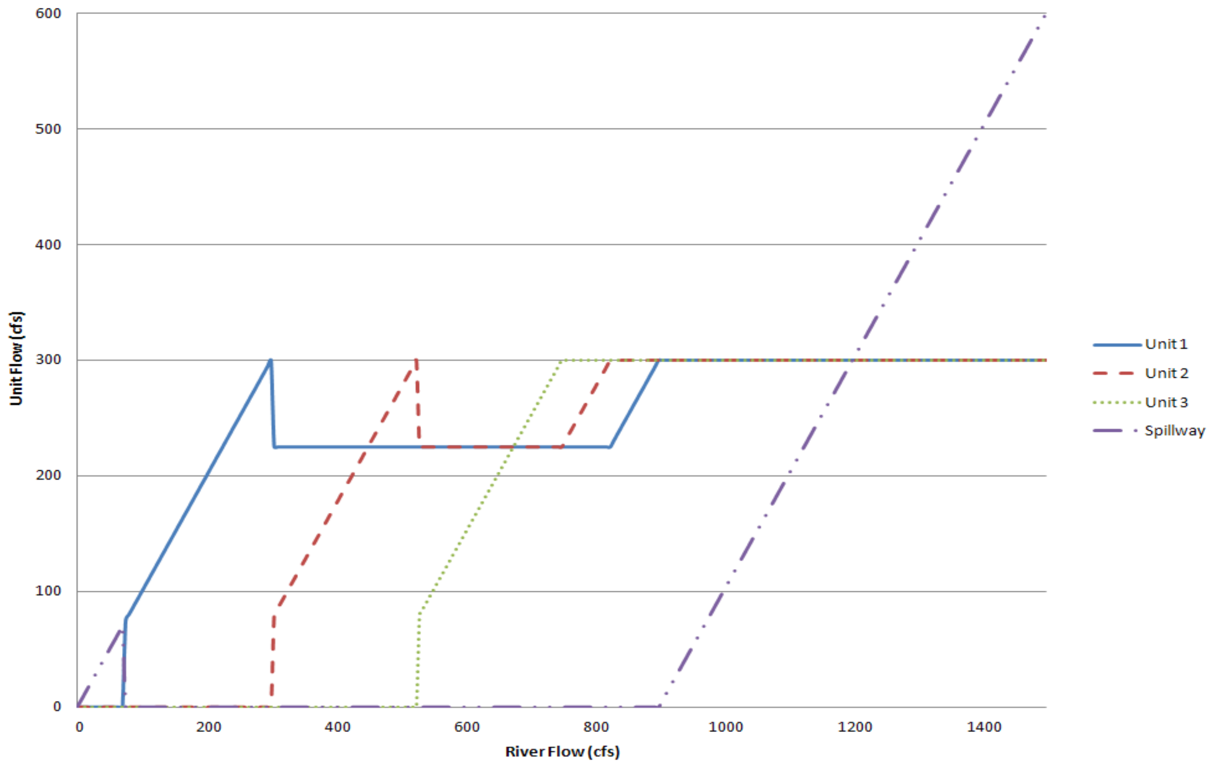

Figure 3-16. Example distribution of flows to three identical turbines.

With respect to spillway passage, it was assumed that a minimum depth of flow over a spillway is required to allow fish to pass. Based on current requirements often cited by the US Fish & Wildlife Services, at least 6 inches of flow depth was considered necessary for smolts to pass over a spillway and a minimum of 12 inches was the requirement for kelts. For flow conditions that result in spillway discharges with insufficient depth for passage, the proportion of smolts and kelts passing over the spillway was assumed to be zero. For flow conditions that produced sufficient spillway depth, the proportion of fish passing over the spillway was equal to the proportion of river discharge passing being spilled. The broad-crested weir equation was used to estimate the required flow rate needed at each project to produce greater than 6 inches of depth for smolts and 12 inches of depth for kelts.

Fish approaching a powerhouse that are not bypassed are assumed to be entrained through powerhouse turbines (i.e., entrainment = 1- bypass efficiency). However, for projects with bar rack spacings less than 2.5 inches, it was assumed that all kelts would be large enough to be physically excluded from turbine entrainment, resulting in a bypass efficiency of 100%. The distribution of entrained fish passed through individual turbines was assumed to be proportional to the amount of the total generating flow passed through each unit. Turbine flow and subsequent proportions of total generating flow through each operating unit will vary as a function of the total river flow, but will be constant when the flow capacity of all turbines is reached.

Three of the Penobscot River projects (Moosehead, Milo, and Medway) do not operate downstream bypasses for Atlantic salmon smolts and kelts and have bar racks with spacing less than 2.5 inches. Consequently, at river flows that result in spill with less than 12 inches of depth over the dam crests at each project, there is no available downstream passage route for kelts (i.e., no bypass, complete exclusion from turbine entrainment due to narrow bar spacing, and insufficient spill depth for passage). In these situations, it was assumed that kelt survival was 0%. Lack of a downstream passage route for kelts has the potential to occur during the spring and fall migration periods at Moosehead and Milo, but only in the spring at Medway due to the operation of a downstream bypass for American eel in the fall which can be used by kelts.

3.5 Flow Probabilities

Turbine passage survival and total project survival are dependent on the total river flow and its distribution among discharge locations at a given project (spillway, bypass, and turbines). In order to estimate survival probabilities for each project, the probability of occurrence for average monthly flows must be known. That is, the probability that any given survival rate will occur is equivalent to the probability of the corresponding flow to occur. To estimate how the probability of occurrence for average monthly flow rates, and therefore how often a particular survival rate would be likely to occur, flow probability distributions were developed, as described in the following sections, for each project using historical USGS flow data.

3.5.1 Migration Periods Evaluated for Downstream Passsage Survival

To identify an appropriate smolt migration window for the downstream passage survival analysis, NMFS analyzed smolt in-river trapping data available from Penobscot River sampling sites. These data were evaluated to determine the 30 day period that maximized the actual smolt run coverage. To simplify the flow distribution analysis using historical USGS gage data, the preference was to use a 30-day smolt window defined by calendar month, rather than a period of similar duration that overlapped two months. Initially, it was determined that using the month of May (Julian days 121-151) as the smolt migration period did not provide maximum coverage of wild smolts moving through upriver sites in the drainage. Therefore, at the request of NMFS, Alden also evaluated downstream passage survival for a 30-day window that started one week earlier than May (April 24 – May 24, or Julian days 114-144).

To determine if the calendar month of May would be acceptable to use as the migration period for smolts in the analysis of total project survival, flow duration curves were developed for each project for the two alternative migration periods (May and Julian days 114-144). These curves provide the expected range and duration of flows during each time period. Survival estimates were calculated using mean flow and 25 and 75% duration flows. Frequency and probability distributions were also calculated for flow rates based on the historical data, and survival rates were generated for these distributions (as explained in Section 3.6). Based on this analysis, it was determined that the differences in total project survival rates of smolts was negligible between the two time periods (May and Julian days 114 – 144) for the three flow rates examined (Table 3-10). Therefore, May was used as the migration period for smolts in the analysis of smolt survival at each of the fifteen projects. A similar analysis could not be calculated for kelts due to a lack of migration timing data. Consequently, survival rates for kelts were calculated for migration periods delineated by the calendar months of April, May, and November.

3.5.2 Flow Data

Flow duration curves as well as mean monthly flow data were estimated based on available United States Geological Survey (USGS) river gaging stations (Table 3-11). Most Projects were located on a gaged River system; however, the Frankfort Project is not. Frankfort was estimated based on a similar sized gauged basin in the area. Additionally, the period of record of some gages was too limited and insufficient for use. In this case, another area gage was utilized to develop the flow data and was compared with the limited period of record. None of the projects had stream gauges located directly at the project. As such, all flow data was adjusted by a drainage basin ratio to estimate from the gauge what flows would be at the Project.

The Stillwater Branch of the Penobscor River diverges from the mainstem in Old Town, flows southerly through Old Town, and rejoins the Penobscot River approximately 12 miles downstream in the Town of Orono. The flow to the Stillwater Branch is controlled by the Milford Project located at the head of the Stillwater Branch. Historic flow allocation to the two branches is based on a 1911 decree while the future allocations are based on a settlement agreement.

In the historic condition, a percentage of the river flow is diverted to the Stillwater branch as a function of the total river flow. This percentage ranges from about 2% when the total river flow is at 1,500 cfs to 30% at a total river flow of 17,500 cfs. For all conditions in which the total river flow exceeds 17,500 cfs, 30% of the river flow will be diverted to the Stillwater branch while the remaining 70% continues on the mainstem. These flow variations affect the Milford, Orono, Stillwater, and Great Works projects.

As per the settlement agreement, flow allocations for the future conditions will follow the following rules. Note that this regime will affect the Milford, Orono, and Stillwater projects.

- Inflows below 3,800 – Comply with minimum flow requirements. At 3,800 cfs, 3,268 cfs in mainstem (86%) and 532 cfs in Stillwater Branch (14%). Incrementally decreasing to 9% in Stillwater Branch (216 cfs) at an inflow of 2,400 cfs.
- Inflows between 3,800 cfs and 5,446 cfs – Maintain the 1911 decree between May 1 and October 31, and from November 1 to April 30 will be allowed to divert up to 40% of total river flow into Stillwater branch.
- Flows greater than 5,446 cfs up to 15,000 cfs – 60% of flow to Penobscot River and 40% of flow to Stillwater Branch
- Flows greater than 15,000 – 70% of flow to the Penobscot River and 30% of flow to Stillwater Branch.

Table 3-10. Comparison of total project survival estimates for smolt migration periods encompassed by the month of May and Julian days 114 to 144 (31 day period beginning about one week earlier than the May period) for three river discharges (mean and 25 and 75% duration curve flows).

Project	Evaluation Period	Total Project Survival for Smolts at Three River Discharges			Difference in Survival Between Time Periods		
		Mean	=<25%	=<75%	Mean	=<25%	=<75%
Sebec	May	0.875	0.892	0.853	0.010	0.006	0.003
	Julian 114-144	0.885	0.898	0.856			
Frankfort	May	0.944	0.908	0.944	0.036	-0.003	0.000
	Julian 114-144	0.908	0.911	0.944			
Great Works	May	0.843	0.867	0.777	-0.013	-0.010	-0.032
	Julian 114-144	0.856	0.877	0.809			
Howland	May	0.915	0.918	0.907	0.000	0.000	0.000
	Julian 114-144	0.915	0.918	0.907			
Medway	May	0.896	0.897	0.884	0.000	0.000	0.000
	Julian 114-144	0.896	0.897	0.884			
Milford	May	0.916	0.918	0.911	-0.001	-0.001	-0.002
	Julian 114-144	0.917	0.919	0.913			
Orno	May	0.899	0.906	0.882	-0.004	-0.003	-0.008
	Julian 114-144	0.903	0.909	0.889			
Stillwater	May	0.919	0.920	0.916	-0.001	0.000	-0.001
	Julian 114-144	0.919	0.920	0.917			
Veazie	May	0.764	0.764	0.764	0.000	0.000	0.000
	Julian 114-144	0.764	0.764	0.764			
West Enfield	May	0.924	0.924	0.930	0.000	0.000	0.005
	Julian 114-144	0.924	0.924	0.925			
Mattaceunk	May	0.804	0.835	0.772	-0.011	-0.007	0.000
	Julian 114-144	0.815	0.842	0.772			
Upper Dover	May	0.888	0.899	0.847	0.000	0.000	0.000
	Julian 114-144	0.888	0.899	0.847			
Brown's Mill	May	0.852	0.874	0.747	-0.018	-0.013	0.000
	Julian 114-144	0.870	0.887	0.747			
Lowell Tannery	May	0.861	0.877	0.847	-0.008	-0.006	0.000
	Julian 114-144	0.869	0.882	0.847			
Milo	May	0.878	0.894	0.869	-0.009	-0.006	0.017
	Julian 114-144	0.887	0.900	0.852			

Table 3-11. USGS gauges and drainage areas used to estimate average monthly flows at the Penobscot River projects.

Project	USGS Gauge No.	Gauge Drainage Area (square miles)	Site Drainage Area (square miles)	Ratio
Veazie	01034500	6,671	7,764	1.16
Great Works	01034500	6,671	5,068	0.76
Milford	01034500	6,671	5,068	0.76
West Enfield	01034500	6,671	5,218	0.78
Mattaceunk	01030000	3,356	3,308	0.98
Orono	01034500	6,671	2,534	0.38
Stillwater	01034500	6,671	2,534	0.38
Medway	01028000	2,115	2,120	1.00
Howland	01034000	1,162	1500	1.29
Browns Mills	01031500	298	336	1.13
Lowell Tannery	01035000	297	301	1.01
Milo	01033000	326	407	1.25
Sebec	01033000	326	327	1.00
Frankfort	01036500	176	166	0.94
Moosehead	01031500	298	295	0.99

3.5.3 Development of Flow Probability Distributions

Flow probability distributions were developed to allow total project survival rates to be estimated for a range of average monthly flows that may occur at each project based on historical flow data. The estimation of flow probabilities required that an appropriate distribution be identified and applied to the data for each site. Daily flow values are typically quite skewed to the right and are approximated by a log-normal distribution. The central limit theorem states that regardless of the sampling distribution, the distribution of the sample mean approaches a normal distribution as sample size approaches infinity (Bickel and Doksum 1977). Thus for an intermediate sample size mean, such as a monthly mean, the distribution is likely to be intermediate to the log-normal and the normal distributions.

A power transformation was proposed by Box and Cox (1964) that covers a continuous family of distributions between the normal and the log normal and yields an approximately normal random variable. The form of the Box-Cox power transformation is:

$$y_i^*(\lambda) = \begin{cases} (y_i^{\lambda} - 1)/\lambda & \lambda \neq 0 \\ \log_e(y_i) & \lambda = 0 \end{cases}$$

where:

y_i is the original untransformed data

λ is the transformation power

$y_i^*(\lambda)$ is the transformed variate given λ

Using this approach, maximum likelihood methods are used to identify the optimal value of λ. In this application, these optimal values were obtained using the BOXCOX function of the R-statistical programming language (R Development Core Team 2011). Using this family of transformations, the algorithm for estimating flow probabilities for each project is as follows:

1. Use available historical data for each project and month (Table 3-12) and identify the value of λ that yields a nearly normal distribution (Table 3-13, Column 3).

2. Apply the Box-Cox transformation to the observed data and obtain the mean and standard deviation (Table 3-13, columns 4 and 5).

3. Take a range of flow values between designated minimum and maximum values as partition this range into flow intervals of equal increments. For example monthly mean flow may extend from 500 cfs to 20000 cfs in increments of 5 cfs. The minimum and maximum were chosen so that there is only a small probability, typically less than 0.005, of flow occurring above the maximum or below the minimum.

4. Use the transformation identified in the first step to transform the endpoints of each interval to scale which follows a normal distribution.

5. Use the mean and standard deviation identified in the second step with a normal probability function to compute the probability of flow falling in each interval.

An example of results from this process is provided in Table 3-14.

Table 3-12. Number of observations of average monthly flow available from relevant USGS gauges.

Location	All Months	April	May	November
Sebec	201	67	67	67
Frankfort	114	38	38	38
Veazie	324	108	108	108
Great Works	324	108	108	108
West Enfield	324	108	108	108
Medway	194	65	65	64
Howland	237	79	79	79
Milford	324	108	108	108
Orono	324	108	108	108
Stillwater	324	108	108	108
Mattaceunk	153	51	51	51
Moosehead	324	108	108	108
Browns Mills	324	108	108	108
Milo	201	67	67	67
Lowell Tannery	192	64	64	64

It should be noted that the approach outlined above is focused on the marginal distribution of flow for each hydro station. That is, this method estimating average monthly flow probabilities is adequate for assessing the likelihood of events at the individual stations, but it does not take into account the strong correlation of flow among sites within a watershed and, consequently, it is not appropriate for assessing a basin-wide likelihood of events. To make basin-wide assessments it would be more appropriate to estimate the flow distribution of the hydro plants as a multivariate normal distribution with correlation among stations that reflects the fact that flow across the watershed tends to be driven by the same weather systems. That is, within any given year all plants will tend to have uniformly high or low flows depending on meteorology. In order to accurately assign probabilities to extreme events, a probability model that reflects this high probability of co-occurrence would need to be implemented.

Table 3-13. Box-Cox transformation Statistics for each Project and Month

Project	Month	Lambda	Mean	Standard Deviation	Shapiro-Wilkes statistic	Shapiro-Wilkes *p*-value
Sebec	4	0.8687	738.263	221.9821	0.9869	0.7061
Sebec	5	0.1970	15.153	2.0216	0.9706	0.1135
Sebec	11	0.3030	18.091	5.6649	0.9871	0.7196
Frankfort	4	0.0909	9.770	0.6746	0.9762	0.5838
Frankfort	5	0.1263	8.806	1.1789	0.9365	0.0323
Frankfort	11	0.3737	19.763	7.3131	0.9741	0.5129
Veazie	4	0.2323	44.142	3.3202	0.9877	0.4296
Veazie	5	0.2323	41.161	4.6521	0.9607	0.0028
Veazie	11	0.0909	14.929	1.2985	0.9842	0.2299
Great Works	4	0.2323	39.575	3.0070	0.9877	0.4296
Great Works	5	0.2323	36.871	4.2132	0.9607	0.0028
Great Works	11	0.0909	13.943	1.2491	0.9842	0.2300
West Enfield	4	0.2323	39.870	3.0274	0.9877	0.4296
West Enfield	5	0.2323	37.151	4.2419	0.9607	0.0028
West Enfield	11	0.0909	14.009	1.2524	0.9842	0.2301
Medway	4	-0.1566	4.669	0.0731	0.9758	0.2316
Medway	5	-0.8636	1.157	0.0003	0.9502	0.0108
Medway	11	-1.5000	0.667	0.0000	0.9660	0.0751
Howland	4	0.5505	273.953	49.2857	0.9922	0.9176
Howland	5	0.3030	41.493	6.7292	0.9861	0.5517
Howland	11	0.1970	19.478	3.4377	0.9752	0.1261
Milford	4	0.2323	39.572	3.0070	0.9877	0.4296
Milford	5	0.2323	36.871	4.2132	0.9607	0.0028
Milford	11	0.0909	13.943	1.2491	0.9842	0.2300
Orono	4	0.2323	33.046	2.5597	0.9877	0.4297
Orono	5	0.2323	30.747	3.5865	0.9607	0.0028
Orono	11	0.0909	12.419	1.1728	0.9842	0.2297
Stillwater	4	0.2323	33.046	2.5597	0.9877	0.4297
Stillwater	5	0.2323	30.747	3.5865	0.9607	0.0028
Stillwater	11	0.0909	12.419	1.1728	0.9842	0.2297
Mattaceunk	4	-0.3687	2.618	0.0114	0.9788	0.4885
Mattaceunk	5	-0.3333	2.856	0.0216	0.9486	0.0276
Mattaceunk	11	-1.0404	0.961	0.0000	0.9533	0.0432
Upper Dover	4	0.5505	118.309	20.5343	0.9951	0.9708
Upper Dover	5	0.3030	24.2619	4.5741	0.9797	0.0984
Upper Dover	11	0.3384	22.488	6.9201	0.9851	0.2748
Browns Mills	4	0.5505	127.231	22.0574	0.9951	0.9705
Browns Mills	5	0.3030	25.371	4.7575	0.9797	0.0981
Browns Mills	11	0.3384	23.637	7.2312	0.9852	0.2796
Milo	4	0.8687	893.090	268.4577	0.9869	0.7055
Milo	5	0.1970	16.044	2.1109	0.9707	0.1140
Milo	11	0.3030	19.557	6.0527	0.9871	0.7173
Lowell Tannery	4	0.2323	18.186	1.6178	0.9734	0.1807
Lowell Tannery	5	0.2323	17.267	1.8125	0.9856	0.6618
Lowell Tannery	11	0.0556	7.087	0.8169	0.9852	0.6389

Table 3-14. Example of flow probability calculations using a portion of the distribution for the average May flow at the Sebec Project.

Project	Month	Flow Lower Bound	Flow Upper Bound	Flow Midpoint	Probability
Sebec	5	0.0	212.5	210	0.00263
	5	212.5	217.5	215	0.00028
	5	217.5	222.5	220	0.00030
	5	222.5	227.5	225	0.00033
	5	227.5	232.5	230	0.00034
	5	232.5	237.5	235	0.00037
	5	237.5	242.5	240	0.00039
	5	242.5	247.5	245	0.00042
	5	247.5	252.5	250	0.00045
	5	252.5	257.5	255	0.00047
	5	257.5	262.5	260	0.00050

The flow data for the individual projects that are used for this estimation procedure are not measured flow at each project. These are estimated flows based on projections from the nearest USGS gauge. Typically, the algorithm for projecting flow is estimated with the flow for a given project based on flow at the gauge multiplied by the ratio of project watershed area to gauge watershed area. This may result in the flow at multiple projects being estimated from a single gauge, which can lead to a lack of independence among projects. As long as the focus is on the stations individually, this is not an important issue. However, this is another issue that would need to be resolved before making basin-wide assessments. As noted above, a multivariate probability model with appropriate correlation structure could be implemented.

While most flow projections were based on simple watershed area ratios, the Medway station is a special case. For the Medway project, which is near the bottom of the watershed of the west branch of the Penobscot, only data from 1917-1939 were available. Although this number of observations is fewer than desired for estimating a flow distribution, they are sufficient to show that the flow distribution of the west branch was very different from the flow distribution of the east branch, which has the next nearest gauge. To increase the sample size of observations for Medway, the best additional estimates were obtained by computing the difference between the Mattawamkeag gauge near the bottom of the east branch watershed and the Grindstone gauge located below the confluence of the east and west branches. The differences between these two gauges seem to adequately represent the flow for the west branch.

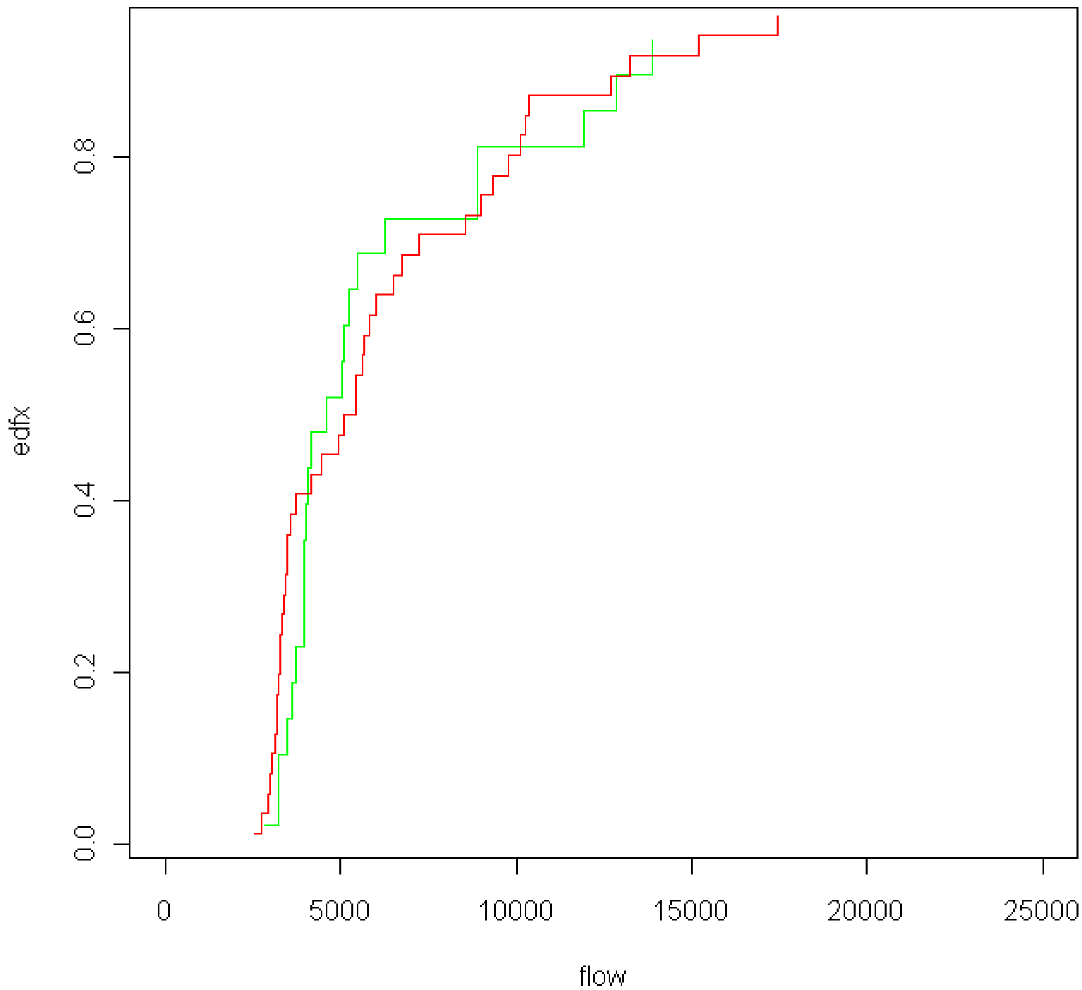

Figure 3-17. Comparison of Flow distribution curves for Medway for the years 1917-1939 (green) and Mattawamkeag-Grindstone for the years 1941-1982 (red).

3.6 Estimation of Total Project Survival

The final step of the analysis of smolt and kelt downstream passage at Penobscot River hydro projects is the estimation of total project survival at each site. This parameter is the product of direct survival estimates for turbine, spillway, and bypass passage and a common estimate of indirect survival applied to all three passage routes. Total project survival is calculated for the flow probability distributions developed for each site based on the methods described in Section 2.5. As river flow changes, the number of fish passing through each available route also changes. At lower flows when there is no spill, the operation of turbines has the greatest influence on total survival rates because entrainment will increase as more units come on line and turbine survival rates will fluctuate with partial and full load operation. As flow increases and spill begins to occur, total survival rates typically will gradually increase as a greater proportion of fish will avoid turbine entrainment and pass over spillways, for which survival is typically greater.

Based on the methods described previously for estimating route-specific survival rates and determining the proportion of fish passing through each route based on river flow and turbine operations, the calculation of total project survival (S_{TP}) can be summarized for a given fish length as follows:

$$S_{TP} = [(P_{SW} \text{ x } S_{SW}) \text{ x } (P_{BYP} \text{ x } S_{BYP}) \text{ x } (P_T \text{ x } S_T)] \text{ x } S_I \quad (26)$$

where:

P_{SW} = proportion of fish passing over the spillway;

S_{SW} = literature-based estimate of direct survival for fish passing over the spillway (0.97 for all projects);

P_{BYP} = proportion of fish passing through the bypass (assigned value based on life stage, bar rack spacing, and site-specific studies or literature-based data; Table 3-7);

S_{BYP} = literature-based estimate of survival for fish passing through the bypass (0.99 for all projects);

P_T = proportion of fish passing through operating turbines;

S_T = estimated survival rate of fish passing through operating turbines;

S_I = literature-based estimate of indirect (delayed) survival (0.95) assigned to all passage routes.

Turbine passage survival rates (S_T) were estimated for specified length intervals covering the expected size ranges provided by NMFS for smolts and kelts in the Penobscot River (see Table 3-1). Frequency probabilities provided by NMFS for each length interval were multiplied by corresponding project survival rates (Equation 26) and summed across intervals to provide a total passage survival rate for all lengths combined. Although turbine survival is length-specific, it was assumed that direct survival over spillways and through bypasses does not vary with length or life stage. Direct spillway and bypass survival rates were set at 97 and 99%, respectively, as discussed in Sections 3.1.2 and 3.1.3. Indirect mortality for all passage routes was assumed to be the same (5%; Section 3.2) and also does not vary with fish size or life stage.

The flow probability distributions developed for each site basically determine the probability that any given total project survival rate will occur. With respect to turbine entrainment and survival, and as described previously, some assumptions have been made with regard to turbine operation, including the order of unit operation, the distribution of flows to individual turbines, and operating ranges. Therefore, turbine entrainment and survival will both fluctuate with flow and the operation of available units. The influence of turbine survival on total project survival will be greatest when there is no spill and will decrease with increasing river flow after sufficient spill becomes available for fish to pass over a spillway.

4 DOWNSTREAM PASSAGE SURVIVAL ESTIMATES FOR PENOBSCOT RIVER PROJECTS

This section presents turbine passage survival and total project survival estimates for the 15 Penobscot River hydro projects of interest. Turbine passage survival rates were calculated for all turbines at each project, and for three of the sites at which new units have been or will be installed in the future. To account for potential uncertainty and/or variability associated with two of the theoretical model inputs used to estimate turbine survival (fish approach angle and K), turbine passage survival estimates for each turbine were calculated for a range of these input parameters. The angle at which a fish passes through a turbine's blade sweep may be a sensitive factor in strike probability estimation because it is typically assumed that fish are oriented with the flow and approach the blades at the same angle. This assumption does not account for the possibility that fish behavior could result in different approach angles. Due to the biological uncertainty of this assumption, survival predictions have been calculated assuming the angles of fish approach varies by ± 10° from the turbine inflow. Similarly, a second set of predictions were calculated to evaluate the effect of potential uncertainty in the strike mortality coefficient, K. These predictions vary the estimated K value by ± 20%. As both the angle of fish approach and K are being varied individually the result is essentially a sensitivity analysis of each variable. The variations in the angle of fish approach and K were also compounded to provide an overall range in survival that accounts for potential combination of uncertainty in both of these parameters. The resulting survival estimates provided for each turbine at the 15 projects include the baseline estimates, a set of estimates with the fish angle modified by ± 10^{o}, a set of estimates with K modified by ± 20%, and a final set of estimates which compound the angle modification and K modification.

The pertinent turbine design and operational data used for the estimation of turbine passage survival were acquired from one or more sources, including project operator responses to information requests, data obtained during site visits, publically available information (e.g., through the FERC online library or other internet sources), and parameter estimations when information was unavailable (see Section 3.1.1.4 for the methods used to estimate unknown parameters).

4.1 Veazie (FERC No. P-2403)

The Veazie Hydroelectric Project is the first dam on the Penobscot River and is located at approximately river mile 6 in the town of Veazie. An aerial view of the project is provided in Figure 4-1. About 90% of the Penobscot River drainage area contributes to the flow passing the Veazie Project. At the time that the NMFS salmon survival study was initiated in September 2010, Veazie was owned by PPL. However, in December 2010, the project ownership was transferred to the PRRT, which plans to remove the dam as part of the Penobscot River Restoration Project. Information describing the project design and operation was provided by BBHP in response to the survey that was sent by Alden to each project owner. Additional sources of information were obtained from the FERC online library, including the most recent relicensing application.

Figure 4-1. Aerial view of the Veazie Hydroelectric Project.

The Veazie Project is a run-of-river facility (ROR) with mean monthly flows from 7,610 (August) to 36,600 (April) cfs (Table 4-1).

4.1.1 Power Generating Facilities

The Veazie Project spillway consists of a 64-foot long gravity concrete segment near its left abutment and the main 487-foot long concrete buttress segment with a maximum height of 32 ft. Some of the other structural features include a 230-foot long masonry forebay wall, fishway, and 65-foot long radial gate structure. The site has two powerhouse buildings; Station A, which is the original powerhouse, is a wood and masonry structure. The Station A powerhouse measures 239 ft long by 113 ft wide and the bar racks have 2.25-inch clear spacing over the full depth of the intake structure. Station A contains 15 turbine-generator vertical Francis units with a total installed generating capacity of 5.4 MW and a hydraulic capacity of 5,105 cfs. The Station B powerhouse is constructed of brick and concrete and is located immediately south of Station A. The Station B powerhouse is 60 feet long by 76 ft wide and the bar racks have 1-inch clear spacing to a depth of 15 ft, below which the spacing is 2.25 inches. The station Station B has 2 turbine-generators (fixed-blade) with a total installed generating capacity of 3.0 MW and a hydraulic capacity of 2,420 cfs. The typical head at the Veazie Project for all units is 19.

Table 4-1. Average monthly river discharge at the Veazie Hydroelectric Project.

Month	Average Flow (cfs)
January	10,000
February	10,100
March	13,300
April	36,600
May	23,000
June	13,400
July	8,670
August	7,610
September	7,880
October	11,200
November	15,400
December	13,800

4.1.2 Downstream Passage Facilities and Evaluations

An existing gate with a bottom opening leading to an ice sluice is used for downstream passage at the Veazie Project. Use of the sluice gate by adult salmon has been documented and smolt use has been observed frequently. USASAC (2005) reported studies were conducted during a three year period (1988-1990) with smolts and kelts. The results of these studies indicated that turbine passage for smolts was 29% and spillway and sluice gate passage combined was 71%. Passage efficiencies for kelts were not provided.

4.1.3 Upstream Passage Facilities

The Veazie Dam has a vertical slot fishway installed near the middle of the spillway.

4.1.4 Turbine Design and Operation Parameters

The two Veazie powerhouses contain a total of 17 turbine/generating units which can be categorized into 6 different types. Table 4-2 through Table 4-7 summarize the pertinent design and operational data utilized in the estimation of survival for fish passing through the Veazie turbines.

Design parameters estimated for Veazie Units 16 and 17 include the hub diameter, flow angle approaching the blade, and the leading edge blade thickness (Table 4-2). The hub diameter and the leading edge blade thickness were estimated directly from the relationship to the turbine diameter while the flow angle was estimated based upon a relationship between the blade tip speed components (Table 3-4). Based on a review of the operator/literature data, as well as the estimated data, modifications and adjustments were not judged necessary for any of the turbine data for these units.

Design parameters estimated for Veazie Unit 1 include the wicket gate angle and the leading edge blade thickness (Table 4-3). The leading edge blade thickness was estimated directly from the relationship to the turbine diameter while the wicket gate angle was estimated based upon a relationship between the blade tip speed components (Table 3-3). Based on a review of the operator/literature data it was judged that the wicket gate angle was compared to literature and other available data. To refine the wicket gate angle, Alden found the angle closest to 35° (typical max) for which the flow vector relationship remained similar to other Francis turbines which was 45°.

Design parameters estimated for Veazie Units 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, and 14 include the wicket gate angle and the leading edge blade thickness (Table 4-4). The leading edge blade thickness was estimated directly from the relationship to the turbine diameter while the wicket gate angle was estimated based upon a relationship between the blade tip speed components (Table 3-3). Based on a review of the operator/literature data it was judged that the wicket gate angle was high compared to literature and other available data. To refine the wicket gate angle, Alden found the angle closest to 35° (typical max) for which the flow vector relationship remained similar to other Francis turbines which was 40°.

Design parameters estimated for Veazie Unit 6 include the wicket gate angle and the leading edge blade thickness (Table 4-5). The leading edge blade thickness was estimated directly from the relationship to the turbine diameter while the wicket gate angle was estimated based upon a relationship between the blade tip speed components (Table 3-3). Based on a review of the operator/literature data it was judged that the wicket gate angle was high compared to literature and other available data. To refine the wicket gate angle, Alden found the angle closest to 35° (typical max) for which the flow vector relationship remained similar to other Francis turbines was 45°.

Table 4-2. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Veazie Units 16 and 17.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Fixed-blade Propeller	--
Flow (cfs)	1,210	--
Runner Diameter (ft)	9.1	--
Hub Diameter (ft)	3.3[1]	--
Turbine speed (rpm)	128.5	--
Number Blades	4	--
Flow Angle, α (deg)	40[1]	--
Leading Edge Blade Thickness (mm)	20.7[1]	--

[1] Parameter was estimated.

Table 4-3. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Veazie Unit 1.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	585	--
Runner Diameter (ft)	4.3	--
Wicket Gate Height (ft)	1.8	--
Turbine speed (rpm)	128.5	--
Number Blades	16	--
Wicket Gate Angle (deg)	61[1]	45
Leading Edge Blade Thickness (mm)	10.7[1]	--

[1] Parameter was estimated.

Table 4-4. Pertinent design and operational parameters used to estimate turbine passage

survival of smolts and kelts passing through Veazie Units 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, and 14.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	295	--
Runner Diameter (ft)	3.4	--
Wicket Gate Height (ft)	1.5	--
Turbine speed (rpm)	150	--
Number Blades	14	--
Wicket Gate Angle (deg)	58[1]	40
Leading Edge Blade Thickness (mm)	10.4[1]	--

[1] Parameter was estimated.

Table 4-5. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Veazie Unit 6.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	365	--
Runner Diameter (ft)	3.2	--
Wicket Gate Height (ft)	1.5	--
Turbine speed (rpm)	150	--
Number Blades	14	--
Wicket Gate Angle (deg)	67[1]	45
Leading Edge Blade Thickness (mm)	10.4[1]	--

[1] Parameter was estimated.

Design parameters estimated for Veazie Unit 7 include the wicket gate angle and the leading edge blade thickness (Table 4-6). The leading edge blade thickness was estimated directly from the relationship to the turbine diameter while the wicket gate angle was estimated based upon a relationship between the blade tip speed components (Table 3-3). Based on a review of the Owner/operator/literature data it was judged that the wicket gate angle was high compared to literature and other available data. To refine the wicket gate angle, Alden found the angle closest to 35° (typical max) for which the flow vector relationship remained similar to other Francis turbines which was 45°.

Design parameters estimated for Veazie Unit 15 include the wicket gate angle and the leading edge blade thickness (Table 4-7). The leading edge blade thickness was estimated directly from the relationship to the turbine diameter while the wicket gate angle was estimated based upon a relationship between the blade tip speed components (Table 3-3). Based on a review of the operator/literature data it was judged that the wicket gate angle was high compared to literature and other available data. To refine the wicket gate angle, Alden found the angle closest to 35° (typical max) for which the flow vector relationship remained similar to other Francis turbines which was 40°.

Table 4-6. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Veazie Unit 7.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	365	--
Runner Diameter (ft)	3.3	--
Wicket Gate Height (ft)	1.5	--
Turbine speed (rpm)	150	--
Number Blades	14	--
Wicket Gate Angle (deg):	66[1]	45
Leading Edge Blade Thickness (mm)	10.4[1]	--

[1] Parameter was estimated.

Table 4-7. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Veazie Unit 15.

Design/Operational Parameters	Data	Modified/Adjusted

	Acquired/Estimated	
Turbine Type	Francis	--
Flow (cfs)	545	--
Runner Diameter (ft)	5.0	--
Wicket Gate Height (ft)	1.7	--
Turbine speed (rpm)	90	--
Number Blades	16	--
Wicket Gate Angle (deg)	66[1]	45
Leading Edge Blade Thickness (mm)	10.9[1]	--

[1] Parameter was estimated.

4.1.5 Turbine Passage Survival

Strike probabilities and turbine survival estimates for Atlantic salmon passing through each turbine at Veazie are presented in Table 4-8 through Table 4-13 for smolts and Table 4-14 through Table 4-19 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

For smolts, the effects of varying radial fish length and K individually were relatively minor. As expected, a greater effect was apparent when the radial fish length and K were varied together to estimate survival for worst and best case scenarios associated with the variability in these parameters. Also, the differences between the modified estimates and the baseline increased with smolt length and were greater for the Francis units than they were for the propeller turbines.

Modifying the radial fish length for kelts did not change survival rates from the baseline for any of the fifteen Francis turbines because strike probability remained at 100% for the three fish angles evaluated (baseline and ± 10^{o}) and mortality from strike (K) did not change across the length range. For the two propeller turbines, the magnitude of differences in survival between the modified and the baseline estimates increased with kelt length and consequently, these differences were also greater than were observed for smolts. This was also true for the changes in kelt survival for the fifteen Francis turbines that resulted from varying K by ± 20%. Also, the range of kelt survival estimates for each length interval associated with changes to K were greater for the Francis turbines than they were for the propeller units.

Table 4-8. Turbine survival estimates for smolts passing through Veazie Units 16 and 17 (fixed-blade propeller turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.109	0.965	0.130	0.958	0.085	0.973	0.958	0.971	0.950	0.977
140	0.117	0.961	0.140	0.953	0.091	0.970	0.953	0.967	0.944	0.975
150	0.126	0.957	0.150	0.949	0.098	0.967	0.948	0.964	0.938	0.972
160	0.134	0.953	0.160	0.944	0.104	0.963	0.944	0.961	0.933	0.969
170	0.143	0.949	0.170	0.939	0.111	0.960	0.939	0.957	0.927	0.967
180	0.151	0.945	0.180	0.934	0.118	0.957	0.934	0.954	0.921	0.964
190	0.159	0.940	0.190	0.929	0.124	0.954	0.929	0.950	0.915	0.961
200	0.168	0.936	0.200	0.924	0.131	0.950	0.923	0.947	0.909	0.959
210	0.176	0.932	0.210	0.919	0.137	0.947	0.918	0.943	0.902	0.956

[1]Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-9. Turbine survival estimates for smolts passing through Veazie Unit 1 (Francis turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.425	0.859	0.492	0.837	0.344	0.886	0.831	0.883	0.805	0.905
140	0.457	0.845	0.530	0.820	0.371	0.874	0.814	0.871	0.784	0.895
150	0.490	0.830	0.568	0.803	0.397	0.862	0.796	0.859	0.764	0.885
160	0.523	0.815	0.605	0.786	0.424	0.850	0.778	0.846	0.743	0.875
170	0.555	0.800	0.643	0.768	0.450	0.838	0.760	0.833	0.722	0.865
180	0.588	0.785	0.681	0.751	0.477	0.825	0.742	0.821	0.701	0.854
190	0.621	0.769	0.719	0.732	0.503	0.813	0.723	0.808	0.679	0.844
200	0.653	0.753	0.757	0.714	0.530	0.800	0.704	0.794	0.657	0.833
210	0.686	0.737	0.795	0.696	0.556	0.787	0.685	0.781	0.635	0.822

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-10. Turbine survival estimates for smolts passing through Veazie 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, and 14 (Francis turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.517	0.935	0.617	0.923	0.402	0.950	0.922	0.946	0.908	0.958
140	0.557	0.929	0.664	0.915	0.433	0.945	0.914	0.941	0.898	0.954
150	0.597	0.922	0.711	0.907	0.464	0.939	0.906	0.935	0.888	0.949
160	0.637	0.915	0.759	0.899	0.495	0.934	0.898	0.929	0.879	0.945
170	0.676	0.908	0.806	0.891	0.526	0.929	0.890	0.923	0.869	0.940
180	0.716	0.901	0.854	0.882	0.557	0.923	0.881	0.918	0.859	0.936
190	0.756	0.894	0.901	0.874	0.588	0.917	0.873	0.912	0.848	0.931
200	0.796	0.887	0.948	0.865	0.619	0.912	0.864	0.906	0.838	0.927
210	0.836	0.879	0.996	0.856	0.650	0.906	0.855	0.899	0.827	0.922

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-11. Turbine survival estimates for smolts passing through Veazie Unit 6 (Francis turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.436	0.862	0.505	0.840	0.354	0.888	0.835	0.885	0.808	0.907
140	0.470	0.848	0.544	0.824	0.381	0.877	0.818	0.873	0.789	0.897
150	0.503	0.834	0.583	0.807	0.408	0.865	0.800	0.861	0.769	0.888
160	0.537	0.819	0.622	0.790	0.435	0.853	0.783	0.849	0.748	0.878
170	0.570	0.804	0.661	0.773	0.463	0.841	0.765	0.837	0.728	0.868
180	0.604	0.789	0.700	0.756	0.490	0.829	0.747	0.824	0.707	0.857
190	0.637	0.774	0.738	0.738	0.517	0.817	0.729	0.811	0.686	0.847
200	0.671	0.758	0.777	0.720	0.544	0.804	0.710	0.799	0.664	0.837
210	0.704	0.743	0.816	0.702	0.571	0.791	0.691	0.786	0.642	0.826

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-12. Turbine survival estimates for smolts passing through Veazie Unit 7 (Francis turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.443	0.866	0.513	0.844	0.359	0.891	0.839	0.888	0.813	0.909
140	0.477	0.852	0.553	0.828	0.387	0.880	0.822	0.876	0.794	0.900
150	0.511	0.838	0.592	0.812	0.415	0.868	0.805	0.865	0.774	0.890
160	0.545	0.823	0.631	0.795	0.442	0.857	0.788	0.853	0.754	0.881
170	0.579	0.809	0.671	0.779	0.470	0.845	0.771	0.841	0.734	0.871
180	0.613	0.794	0.710	0.761	0.497	0.833	0.753	0.828	0.714	0.861
190	0.647	0.779	0.750	0.744	0.525	0.821	0.735	0.816	0.693	0.851
200	0.681	0.764	0.789	0.727	0.553	0.809	0.717	0.803	0.672	0.841
210	0.715	0.749	0.829	0.709	0.580	0.796	0.699	0.791	0.651	0.830

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-13. Turbine survival estimates for smolts passing through Veazie Unit 15 (Francis turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.348	0.933	0.404	0.922	0.283	0.946	0.920	0.944	0.907	0.955
140	0.375	0.926	0.435	0.914	0.304	0.940	0.911	0.938	0.897	0.950
150	0.402	0.919	0.466	0.906	0.326	0.934	0.903	0.933	0.887	0.945
160	0.429	0.912	0.497	0.898	0.348	0.929	0.894	0.927	0.877	0.940
170	0.456	0.905	0.528	0.890	0.370	0.923	0.886	0.921	0.867	0.936
180	0.482	0.897	0.559	0.881	0.391	0.917	0.877	0.914	0.857	0.931
190	0.509	0.890	0.590	0.872	0.413	0.911	0.868	0.908	0.847	0.926
200	0.536	0.882	0.621	0.864	0.435	0.904	0.859	0.902	0.836	0.920
210	0.563	0.875	0.652	0.855	0.457	0.898	0.850	0.896	0.826	0.915

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-14. Turbine survival estimates for kelts passing through Veazie Units 16 and 17 (fixed-blade propeller).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	0.545	0.706	0.650	0.649	0.424	0.771	0.647	0.755	0.579	0.809
675	0.566	0.691	0.675	0.632	0.441	0.760	0.630	0.743	0.559	0.800
700	0.587	0.677	0.700	0.615	0.457	0.749	0.613	0.731	0.539	0.791
725	0.608	0.663	0.725	0.598	0.473	0.738	0.595	0.719	0.518	0.781
750	0.629	0.648	0.750	0.581	0.490	0.726	0.578	0.707	0.497	0.772
775	0.650	0.634	0.775	0.564	0.506	0.715	0.560	0.695	0.476	0.762
800	0.671	0.619	0.800	0.546	0.522	0.703	0.543	0.682	0.455	0.753

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-15. Turbine survival estimates for kelts passing through Veazie Unit 1 (Francis turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.495	1.000	0.495	1.000	0.495	0.393	0.579	0.393	0.579
675	1.000	0.490	1.000	0.490	1.000	0.490	0.389	0.575	0.389	0.575
700	1.000	0.486	1.000	0.486	1.000	0.486	0.384	0.572	0.384	0.572
725	1.000	0.483	1.000	0.483	1.000	0.483	0.379	0.569	0.379	0.569
750	1.000	0.479	1.000	0.479	1.000	0.479	0.375	0.566	0.375	0.566
775	1.000	0.475	1.000	0.475	1.000	0.475	0.371	0.563	0.371	0.563
800	1.000	0.472	1.000	0.472	1.000	0.472	0.366	0.560	0.366	0.560

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-16. Turbine survival estimates for kelts passing through Veazie Units 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, and 14 (Francis turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.810	1.000	0.810	1.000	0.810	0.772	0.841	0.772	0.841
675	1.000	0.808	1.000	0.808	1.000	0.808	0.770	0.840	0.770	0.840
700	1.000	0.807	1.000	0.807	1.000	0.807	0.768	0.839	0.768	0.839
725	1.000	0.805	1.000	0.805	1.000	0.805	0.766	0.838	0.766	0.838
750	1.000	0.804	1.000	0.804	1.000	0.804	0.765	0.837	0.765	0.837
775	1.000	0.803	1.000	0.803	1.000	0.803	0.763	0.836	0.763	0.836
800	1.000	0.801	1.000	0.801	1.000	0.801	0.762	0.834	0.762	0.834

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-17. Turbine survival estimates for kelts passing through Veazie Unit 6 (Francis turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.519	1.000	0.519	1.000	0.519	0.423	0.599	0.423	0.599
675	1.000	0.515	1.000	0.515	1.000	0.515	0.418	0.596	0.418	0.596
700	1.000	0.511	1.000	0.511	1.000	0.511	0.414	0.593	0.414	0.593
725	1.000	0.508	1.000	0.508	1.000	0.508	0.409	0.590	0.409	0.590
750	1.000	0.504	1.000	0.504	1.000	0.504	0.405	0.587	0.405	0.587
775	1.000	0.501	1.000	0.501	1.000	0.501	0.401	0.584	0.401	0.584
800	1.000	0.498	1.000	0.498	1.000	0.498	0.397	0.581	0.397	0.581

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-18. Turbine survival estimates for kelts passing through Veazie Unit 7 (Francis turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.538	1.000	0.538	1.000	0.538	0.445	0.615	0.445	0.615
675	1.000	0.534	1.000	0.534	1.000	0.534	0.441	0.612	0.441	0.612
700	1.000	0.530	1.000	0.530	1.000	0.530	0.436	0.609	0.436	0.609
725	1.000	0.527	1.000	0.527	1.000	0.527	0.432	0.606	0.432	0.606
750	1.000	0.524	1.000	0.524	1.000	0.524	0.428	0.603	0.428	0.603
775	1.000	0.520	1.000	0.520	1.000	0.520	0.424	0.600	0.424	0.600
800	1.000	0.517	1.000	0.517	1.000	0.517	0.421	0.598	0.421	0.598

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-19. Turbine survival estimates for kelts passing through Veazie Unit 15 (Francis turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.706	1.000	0.706	1.000	0.706	0.647	0.755	0.647	0.755
675	1.000	0.703	1.000	0.703	1.000	0.703	0.644	0.753	0.644	0.753
700	1.000	0.701	1.000	0.701	1.000	0.701	0.641	0.751	0.641	0.751
725	1.000	0.699	1.000	0.699	1.000	0.699	0.638	0.749	0.638	0.749
750	1.000	0.697	1.000	0.697	1.000	0.697	0.636	0.747	0.636	0.747
775	1.000	0.694	1.000	0.694	1.000	0.694	0.633	0.745	0.633	0.745
800	1.000	0.692	1.000	0.692	1.000	0.692	0.631	0.744	0.631	0.744

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.1.6 Bypass Efficiency and Survival

Downstream passage studies were conducted at Veazie with smolts from 1988 to 1990. The results of these studies indicated that 29% of smolts passed through the project turbines and 71% passed downstream either via the spillway or a sluice gate (as reported by USASAC 2005). The bar racks on the intake of Powerhouse A have 2.25-inch clear spacing and the racks have on Powerhouse B have 1-inch spacing over the upper 15 ft of the intake and 2.25 inches over the lower portion. Because both Veazie powerhouses have relatively wide spacing over all or a portion of the intake structures and the bypass efficiency of the sluice gate could not be delineated from spillway passage, it was assumed that bypass efficiency was 25% for smolts. The maximum spacing of the racks (2.25 inches) is sufficient to prevent entrainment of kelts, resulting in 100% bypass efficieny for this life stage. Bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.1.7 Spillway Passage Survival

Direct spillway passage survival for smolts and kelts passing downstream at the Veazie Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Section 3.1.2.

4.1.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Veazie Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Section 3.2.

4.1.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 82.7 to 91.3% (with a mean of 89.7%) across the range of average monthly flows likely to occur at Veazie during the specified migration period (Table 4-20; Figure 4-2). Predicted smolt survival rates fluctuate at lower river flows as turbines come on line and alternate between partial and full load. After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival gradually increases to a peak at the highest discharge (Figure 4-2). Mean total project survival for kelts was did not vary considerably within and among the three months examined, ranging from 92.9 to 94.1% for the range of expected monthly average flows (Table 4-20; Figure 4-3). The high and narrow range of kelt survival rates was mainly due to the complete exclusion of this life stage from turbine passage by the existing bar rack spacing (< 2.5 inches), resulting in spillway and the bypass passage being the only sources of direct and indirect mortality.

Table 4-20. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Veazie Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolt Survival			Kelt Survival		
		Mean	Min	Max	Mean	Min	Max
April	13370 - 71500	--	--	--	0.932	0.926	0.932
May	5940 - 75620	0.897	0.827	0.913	0.932	0.927	0.941
November	2360 - 53045	--	--	--	0.929	0.924	0.941

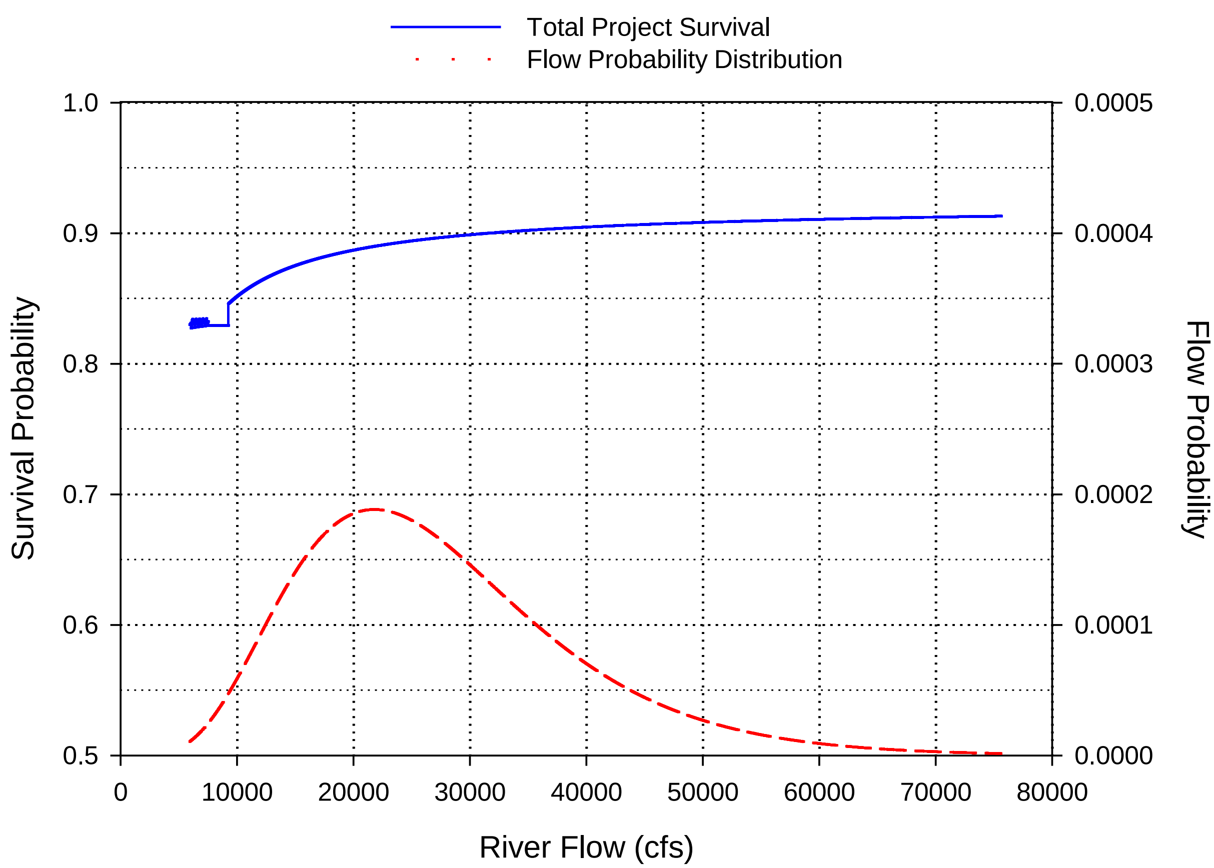

Figure 4-2. Total project survival for smolts and the flow probability distribution for May at the Veazie Project. Flow probabilities were estimated and plotted in 5 cfs increments.

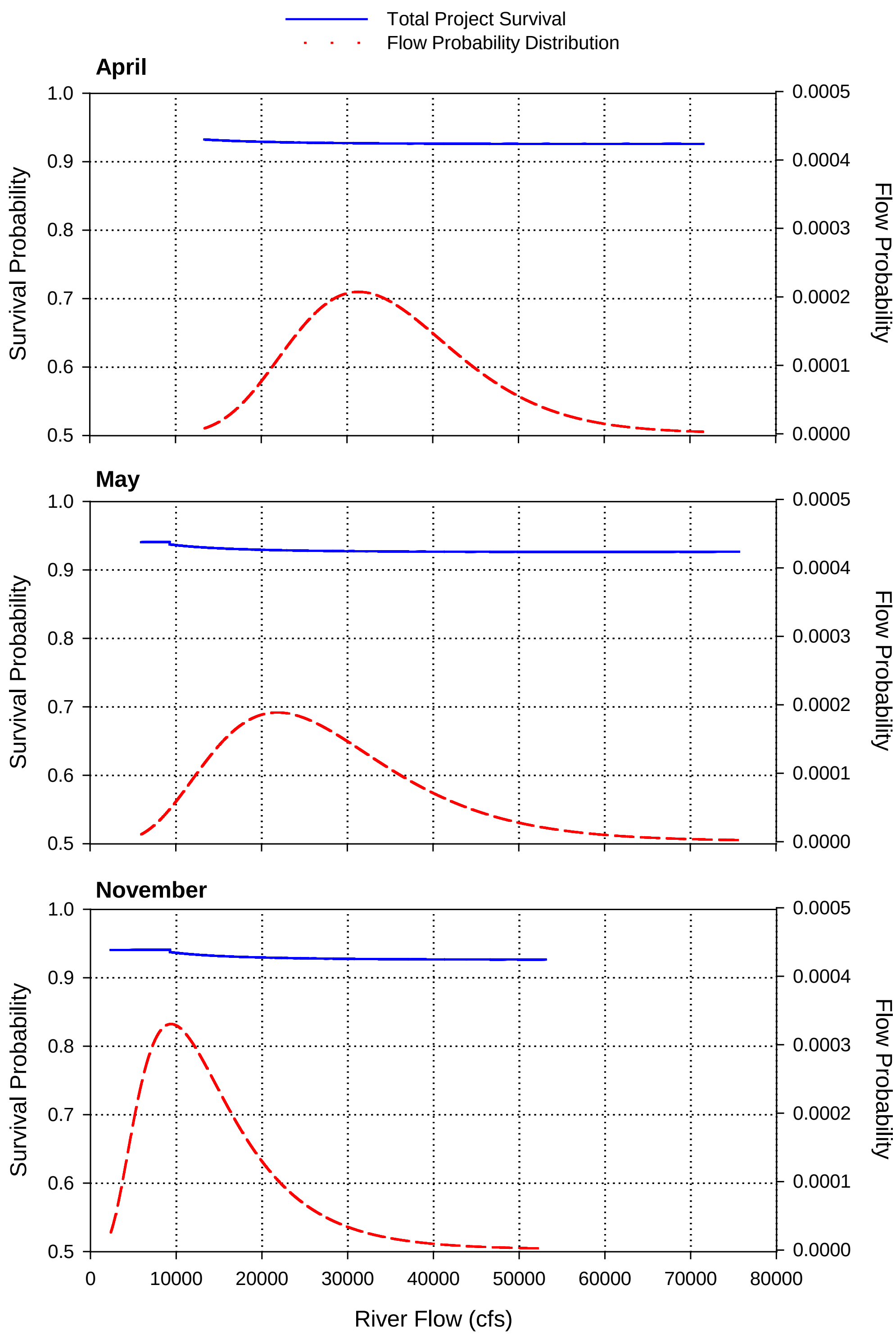

Figure 4-3. Total project survival for kelts and flow probability distributions for April, May, and November at the Veazie Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.2 Great Works (FERC No. P-2312)

The Great Works Hydroelectric Project is located at river mile 10.7 on the mainstem of the Penobscot River in Old Town. An aerial view of the project is provided in Figure 4-4. About 90% of the Penobscot River drainage area contributes to the flow passing the Great Works Project. The Veazie Hydroelectric project is located about 7 miles downstream form Great Works, and the Milford Project is about 2 miles upstream. At the time that the NMFS salmon survival study was initiated in September 2010, Great Works was owned and operated by BBHP. However, in December 2010, the project ownership was transferred to the PRRT, which plans to remove the dam as part of the Penobscot River Restoration Project. Information describing the project design and operation was provided by BBHP in response to the survey that was distributed by Alden to the project owners. Additional sources of information were obtained from the FERC online library, including the most recent relicensing application.

The Great Works Project is operated in a ROR mode with an estimated mean monthly flow ranging from 6,549 cfs in August to 29,795 in April (Table 4-21).

Figure 4-4. Aerial view of the Great Works Hydroelectric Project.

Table 4-21. Average monthly river discharge at the Great Works Hydroelectric Project.

Month	Average Flow (cfs)
January	7100
February	6500
March	9200
April	23700
May	18800
June	9600
July	6700
August	5800
September	5800
October	7500
November	10100
December	9100

4.2.1 Power Generating Facilities

According to the most recent relicensing application, the Great Works Project consists of a powerhouse with eleven turbines, a non-overflow dam section with two fish ladders and three gated outlets (one 6 ft square and two 9-ft in diameter), and spillway with flashboards. The impoundment is about 128 acres at a normal head pond elevation of 81.73 ft. Great Works has a total generating and hydraulic capacity of 7.65 MW and 8,640 cfs, respectively. The project dam comprises a concrete gravity non-overflow section, an un-gated spillway and a sheet-pile and earthen abutment on the east bank (the powerhouse is on the west bank). The total length of the dam and powerhouse is 1,353 ft. The non-overflow is located between the un-gated spillway to the powerhouse. This section has the three gated outlets which are used to increase discharge capacity under flood conditions or to draw down the impoundment. The un-gated spillway is about 955 ft long with five concrete and rock-filled timber crib sections, including a 178-ft long forebay section that is oriented parallel to the river flow. The powerhouse has 11 turbines, eight horizontal paired Francis units (Leffel and S. Morgan Companies) in bays 4 through 11and three horizontal Kaplan turbines (Voith) in bays 1 through 3. The typical head at Great Works Project for all units is 17.5 ft. The clear spacing of the bar racks is 1.13 inches over the entire intake structure.

4.2.2 Downstream Passage Facilities and Evaluations

Information provided by BBHP indicated there were no downstream passage facilities at the Great Works Project. However, the 2000 relicensing application prepared by PP&L Great Works stated that downstream passage for diadromous species was provided through a 6-ft diameter pipe located at the northwest corner of the powerhouse that discharged 500 cfs into the tailrace immediately downstream of the powerhouse. The relicensing application also indicated that the intake trash rack bar spacing ranged from 1.125 to 1.250 inches (assumed to be clear spacing). Proposed modifications to the downstream passage facilities described in the relicensing application included the use of current inducers, backlighting of the bypass pipe entrance, and a new flow control gate. No information was obtained either from the BBHP or FERC documents that suggested any of these modifications have been implemented. Additionally, no information was obtained indicating that downstream passage effectiveness or survival studies have been conducted at the Great Works Project.

4.2.3 Upstream Passage Facilities

The Great Works Project has two Denil ladders for passing anadromous species upstream. One ladder is located at the downstream end of the forebay spillway section and provides passage for fish moving upstream through the bypass reach below the spillway. The other is adjacent to the powerhouse for fish moving upstream through the powerhouse tailrace.

4.2.4 Turbine Design and Operation Parameters

The Great Works powerhouse has eleven turbine/generating units which can be categorized into four different individual types. Table 4-22 through Table 4-25 provide summaries of the pertinent design and operational data used in the estimation of turbine passage survival rates for each turbine.

Design parameters estimated for Great Works Units 4 through 11 (all with three double Francis runners; six runners per turbine with one shaft and generator) include runner diameter, the number of blades, the wicket gate angle, and the leading edge blade thickness (Table 4-22). The Owner indicated that the runner diameter for each of the Great Works units was approximately 36 inches to 40 inches. It was assumed that Units 4, 5, 9, 10, and 11, which utilize 674 cfs, have 36-inch runners, and Units 6, 7, and 8, which have higher flow capacities, are 40-inch runners. The wicket gate angle was indirectly estimated based on the estimated blade tip speed components (Table 3-3). The radial velocity, which was estimated from the known head, was used in conjunction with the flow rate and the wicket gate height to solve for the runner diameter. The wicket gate angle was estimated based on an estimated ratio of the blade tip speed components. The number of turbine blades on a Francis runner typically is 16 to 18. As the number of blades for all of the Francis units was unknown, a value of 18 was conservatively assumed. The leading edge blade thickness was estimated directly from the relationship to the turbine diameter (Table 3-3).

Table 4-22. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Great Works Units 4, 5, 9, 10, and 11. These units each have three double runners (six runners per unit with one shaft and generator).

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	674	--
Runner Diameter (ft)	3.0	--
Wicket Gate Height (ft)	1.5	--
Turbine speed (rpm)	164	--
Number Blades	18[1]	--
Wicket Gate Angle (deg)	36[1]	--
Leading Edge Blade Thickness (mm)	10.3[1]	15.5

[1] Parameter was estimated.

Table 4-23. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Great Works Unit 6. These units each have three double runners (six runners per unit with one shaft and generator).

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	844	--
Runner Diameter (ft)	3.3	--
Wicket Gate Height (ft)	1.7	--
Turbine speed (rpm)	240	--
Number Blades	18[1]	--
Wicket Gate Angle (deg)	18[1]	--
Leading Edge Blade Thickness (mm)	10.4[1]	--

[1] Parameter was estimated.

Table 4-24. Pertinent design and operational parameters used to estimate turbine passage

survival of smolts and kelts passing through Great Works Units 7 and 8. These units each have three double runners (six runners per unit with one shaft and generator).

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	863	--
Runner Diameter (ft)	3.3	--
Wicket Gate Height (ft)	1.7	--
Turbine speed (rpm)	164	--
Number Blades	18[1]	--
Wicket Gate Angle (deg)	32[1]	--
Leading Edge Blade Thickness (mm)	10.4[1]	--

[1] Parameter was estimated.

Table 4-25. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Great Works Units 1, 2, and 3.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Propeller (S-turbine)	--
Flow (cfs)	895	--
Runner Diameter (ft)	7.7[1]	--
Hub Diameter (ft)	2.8[1]	--
Turbine speed (rpm)	163.6	--
Number Blades	4	--
Flow Angle (deg)	39[1]	--
Leading Edge Blade Thickness (mm)	18.4[1]	--

[1] Parameter was estimated.

Design parameters estimated for Great Works Units 1, 2, and 3 (propeller S-turbines) include runner diameter, hub diameter, flow angle approaching the turbine blade, and leading edge blade thickness (Table 4-25). The runner diameter and the flow angle were indirectly calculated based on the estimated axial velocity and blade tip speed components, respectively (Table 3-4). The radial velocity, which was estimated from the known head, was used in conjunction with the flow rate and hub diameter to solve for the runner diameter. The hub diameter was directly estimated from the runner diameter (Table 3-4). However, since both the runner diameter and the hub diameter are unknown, it creates a circular reference when solving. Therefore, all equations were put in terms of the runner radius with the runner diameter solved through an iterative process. The flow angle was estimated based on an estimated ratio of the blade tip speed components. The leading edge blade thickness was estimated directly from the relationship to the turbine diameter (Table 3-4). Based on a review of available data, it was judged that no data modifications were warranted.

4.2.5 Turbine Passage Survival

Strike probabilities and turbine survival estimates for Atlantic salmon passing through each turbine at Great Works are presented in Table 4-26 through Table 4-29 for smolts and Table 4-30 through Table 4-33 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

With the exception of Unit 6, survival estimates for smolts and kelts passing through the Great Works turbines did not vary considerably with the changes in fish radial length and K that were evaluated. For the Francis turbines, this was mainly due to strike probabilities and survival rates that did not change from the baseline for fish greater than 140 mm in length when approach angles were increased by 10^{o}; for kelts, strike probabilities and survival rates also remained the same when the fish approach angle was increased by 10^{o}. For the S-turbines, survival rates of larger fish of both life stages were more sensitive to changes in the fish approach angle and K, and the ranges of the modified estimates were relatively small for smolts but large for all kelt size intervals.

4.2.6 Bypass Efficiency and Survival

Downstream passage studies have not been conducted for smolts or kelts at Great Works. Therefore, bypass efficiency for smolts was assumed to be 50% based on available data from other projects and because the intake racks at Great Works have narrow bar spacing (about 1.13 inches). The narrow bar spacing is considered sufficient to prevent kelt passage through the turbines, resulting in 100% bypass efficiency for this life stage. Direct bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.2.7 Spillway Passage Survival

Direct spillway passage survival for smolts and kelts passing downstream at the Great Works Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Section 3.1.2.

4.2.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Great Works Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Section 3.2.

4.2.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 77.7 to 89.3% across the range of average monthly flows likely to occur at Great Works (Table 4-34; Figure 4-5), with a mean of 85.7%. Smolt survival was lowest with all turbines at full load and no spillway flow, and began to increase with river flow when sufficient spill occurred to allow passage (river flows greater than about 10,000 cfs). Total project survival for kelts did not vary considerably within and among the three migration months, with the highest average survival occurring in May (93.2%) and lowest in April (92.8%) for the range of expected monthly average flows (Table 4-34; Figure 4-6). The high and narrow range of kelt survival rates was mainly due to the complete exclusion of this life stage from turbine passage by the existing bar rack spacing (< 2.5 inches), resulting in spillway and bypass passage being the only sources of direct and indirect mortality.

Table 4-26. Turbine survival estimates for smolts passing through Great Works Units 4, 5, 9, 10, and 11 (Francis turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	1.000	0.959	1.000	0.964	1.000	0.964	0.957	0.970	0.957	0.970
140	1.000	0.958	1.000	0.963	1.000	0.963	0.956	0.969	0.956	0.969
150	1.000	0.957	1.000	0.962	1.000	0.962	0.955	0.968	0.955	0.968
160	1.000	0.956	1.000	0.961	1.000	0.961	0.954	0.968	0.954	0.968
170	1.000	0.955	1.000	0.961	1.000	0.961	0.953	0.967	0.953	0.967
180	1.000	0.954	1.000	0.960	1.000	0.960	0.952	0.966	0.952	0.966
190	1.000	0.954	1.000	0.959	1.000	0.959	0.951	0.966	0.951	0.966
200	1.000	0.953	1.000	0.958	1.000	0.958	0.950	0.965	0.950	0.965
210	1.000	0.952	1.000	0.958	1.000	0.958	0.949	0.965	0.949	0.965

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-27. Turbine survival estimates for smolts passing through Great Works Unit 6 (Francis turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	1.000	0.876	1.000	0.876	0.537	0.933	0.851	0.896	0.851	0.944
140	1.000	0.873	1.000	0.873	0.579	0.926	0.847	0.894	0.847	0.939
150	1.000	0.870	1.000	0.870	0.620	0.919	0.844	0.892	0.844	0.933
160	1.000	0.867	1.000	0.867	0.661	0.912	0.841	0.889	0.841	0.927
170	1.000	0.865	1.000	0.865	0.703	0.905	0.838	0.887	0.838	0.921
180	1.000	0.863	1.000	0.863	0.744	0.898	0.835	0.885	0.835	0.915
190	1.000	0.860	1.000	0.860	0.785	0.890	0.832	0.884	0.832	0.909
200	1.000	0.858	1.000	0.858	0.827	0.883	0.830	0.882	0.830	0.902
210	1.000	0.856	1.000	0.856	0.868	0.875	0.828	0.880	0.828	0.896

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-28. Turbine survival estimates for smolts passing through Great Works Units 7 and 8 (Francis turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	1.000	0.935	1.000	0.935	0.948	0.939	0.922	0.946	0.922	0.949
140	1.000	0.934	1.000	0.934	1.000	0.934	0.921	0.945	0.921	0.945
150	1.000	0.932	1.000	0.932	1.000	0.932	0.919	0.944	0.919	0.944
160	1.000	0.931	1.000	0.931	1.000	0.931	0.917	0.942	0.917	0.942
170	1.000	0.930	1.000	0.930	1.000	0.930	0.916	0.941	0.916	0.941
180	1.000	0.929	1.000	0.929	1.000	0.929	0.914	0.940	0.914	0.940
190	1.000	0.927	1.000	0.927	1.000	0.927	0.913	0.939	0.913	0.939
200	1.000	0.926	1.000	0.926	1.000	0.926	0.912	0.939	0.912	0.939
210	1.000	0.925	1.000	0.925	1.000	0.925	0.910	0.938	0.910	0.938

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-29. Turbine survival estimates for smolts passing through Great Works Units 1, 2, and 3 (propeller S-turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.133	0.948	0.159	0.938	0.103	0.960	0.938	0.957	0.925	0.967
140	0.143	0.942	0.171	0.931	0.111	0.955	0.931	0.952	0.917	0.963
150	0.154	0.937	0.184	0.924	0.119	0.951	0.924	0.947	0.909	0.959
160	0.164	0.931	0.196	0.917	0.127	0.946	0.917	0.942	0.901	0.955
170	0.174	0.925	0.208	0.910	0.135	0.942	0.910	0.937	0.892	0.952
180	0.184	0.919	0.220	0.903	0.143	0.937	0.903	0.932	0.883	0.948
190	0.195	0.913	0.233	0.896	0.151	0.932	0.895	0.927	0.875	0.944
200	0.205	0.906	0.245	0.888	0.158	0.928	0.888	0.922	0.866	0.940
210	0.215	0.900	0.257	0.881	0.166	0.923	0.880	0.917	0.857	0.936

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-30. Turbine survival estimates for kelts passing through Great Works Units 4, 5, 9, 10, and 11 (Francis turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.937	1.000	0.943	1.000	0.943	0.931	0.952	0.931	0.952
675	1.000	0.937	1.000	0.942	1.000	0.942	0.930	0.952	0.930	0.952
700	1.000	0.936	1.000	0.942	1.000	0.942	0.930	0.951	0.930	0.951
725	1.000	0.936	1.000	0.941	1.000	0.941	0.929	0.951	0.929	0.951
750	1.000	0.935	1.000	0.941	1.000	0.941	0.929	0.951	0.929	0.951
775	1.000	0.935	1.000	0.940	1.000	0.940	0.928	0.950	0.928	0.950
800	1.000	0.934	1.000	0.940	1.000	0.940	0.928	0.950	0.928	0.950

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-31. Turbine survival estimates for kelts passing through Great Works Unit 6 (Francis turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.811	1.000	0.811	1.000	0.811	0.773	0.842	0.773	0.842
675	1.000	0.809	1.000	0.809	1.000	0.809	0.771	0.841	0.771	0.841
700	1.000	0.808	1.000	0.808	1.000	0.808	0.769	0.840	0.769	0.840
725	1.000	0.806	1.000	0.806	1.000	0.806	0.767	0.839	0.767	0.839
750	1.000	0.805	1.000	0.805	1.000	0.805	0.766	0.837	0.766	0.837
775	1.000	0.804	1.000	0.804	1.000	0.804	0.764	0.836	0.764	0.836
800	1.000	0.802	1.000	0.802	1.000	0.802	0.763	0.835	0.763	0.835

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-32. Turbine survival estimates for kelts passing through Great Works Units 7 and 8 (Francis turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.902	1.000	0.902	1.000	0.902	0.882	0.918	0.882	0.918
675	1.000	0.901	1.000	0.901	1.000	0.901	0.881	0.917	0.881	0.917
700	1.000	0.900	1.000	0.900	1.000	0.900	0.880	0.917	0.880	0.917
725	1.000	0.899	1.000	0.899	1.000	0.899	0.879	0.916	0.879	0.916
750	1.000	0.899	1.000	0.899	1.000	0.899	0.878	0.915	0.878	0.915
775	1.000	0.898	1.000	0.898	1.000	0.898	0.877	0.915	0.877	0.915
800	1.000	0.897	1.000	0.897	1.000	0.897	0.877	0.914	0.877	0.914

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-33. Turbine survival estimates for kelts passing through Great Works Units 1, 2, and 3 (propeller S-turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; - 10° Fish Approach Angle
650	0.666	0.574	0.796	0.490	0.515	0.670	0.489	0.645	0.388	0.725
675	0.691	0.553	0.827	0.466	0.535	0.654	0.464	0.628	0.359	0.712
700	0.717	0.534	0.857	0.443	0.555	0.639	0.441	0.612	0.331	0.700
725	0.743	0.517	0.888	0.423	0.575	0.627	0.421	0.598	0.307	0.689
750	0.768	0.501	0.919	0.403	0.594	0.614	0.401	0.584	0.284	0.678
775	0.794	0.484	0.949	0.383	0.614	0.601	0.381	0.570	0.260	0.667
800	0.819	0.467	0.980	0.363	0.634	0.588	0.361	0.556	0.236	0.657

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-34. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Great Works Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	8725 - 46670	--	--	--	0.928	0.926	0.932
May	3880 - 49360	0.857	0.777	0.893	0.932	0.927	0.941
November	1540 - 34625	--	--	--	0.929	0.924	0.941

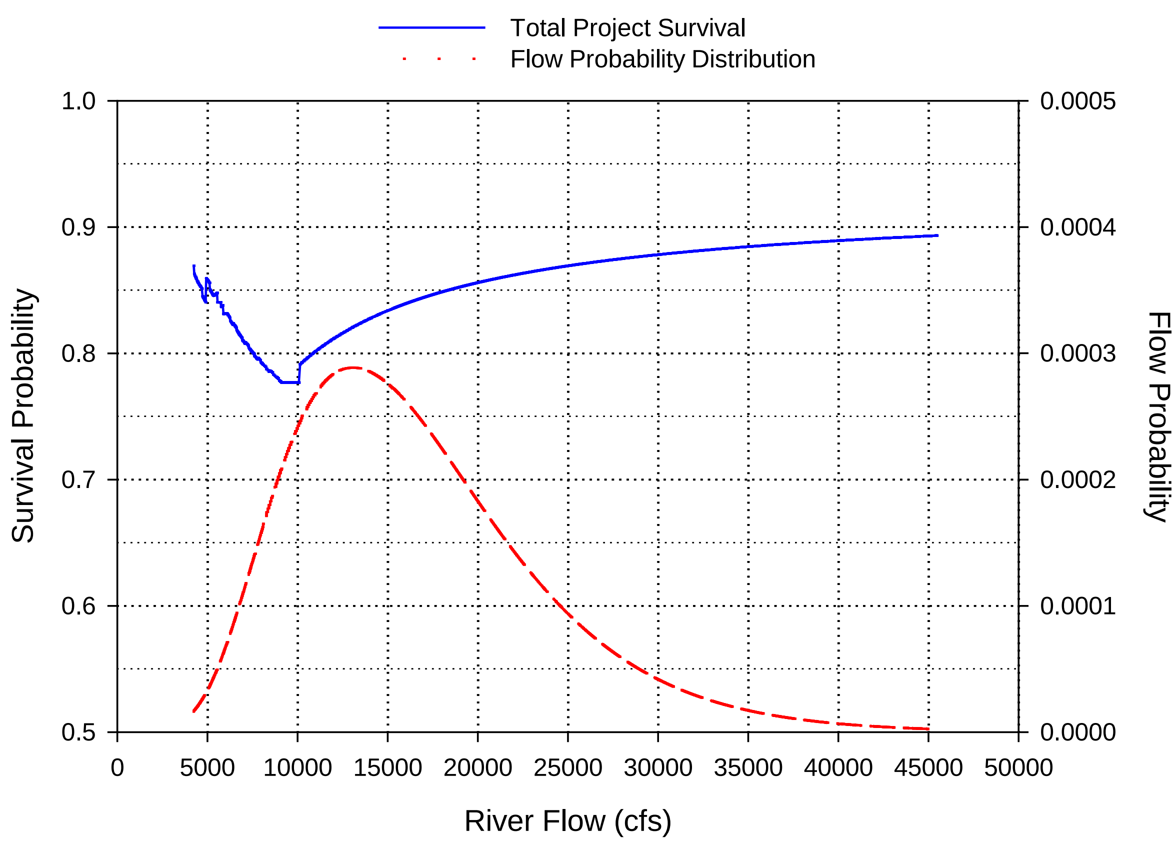

Figure 4-5. Total project survival for smolts and the flow probability distribution for May at the Great Works Project. Flow probabilities were estimated and plotted in 5 cfs increments.

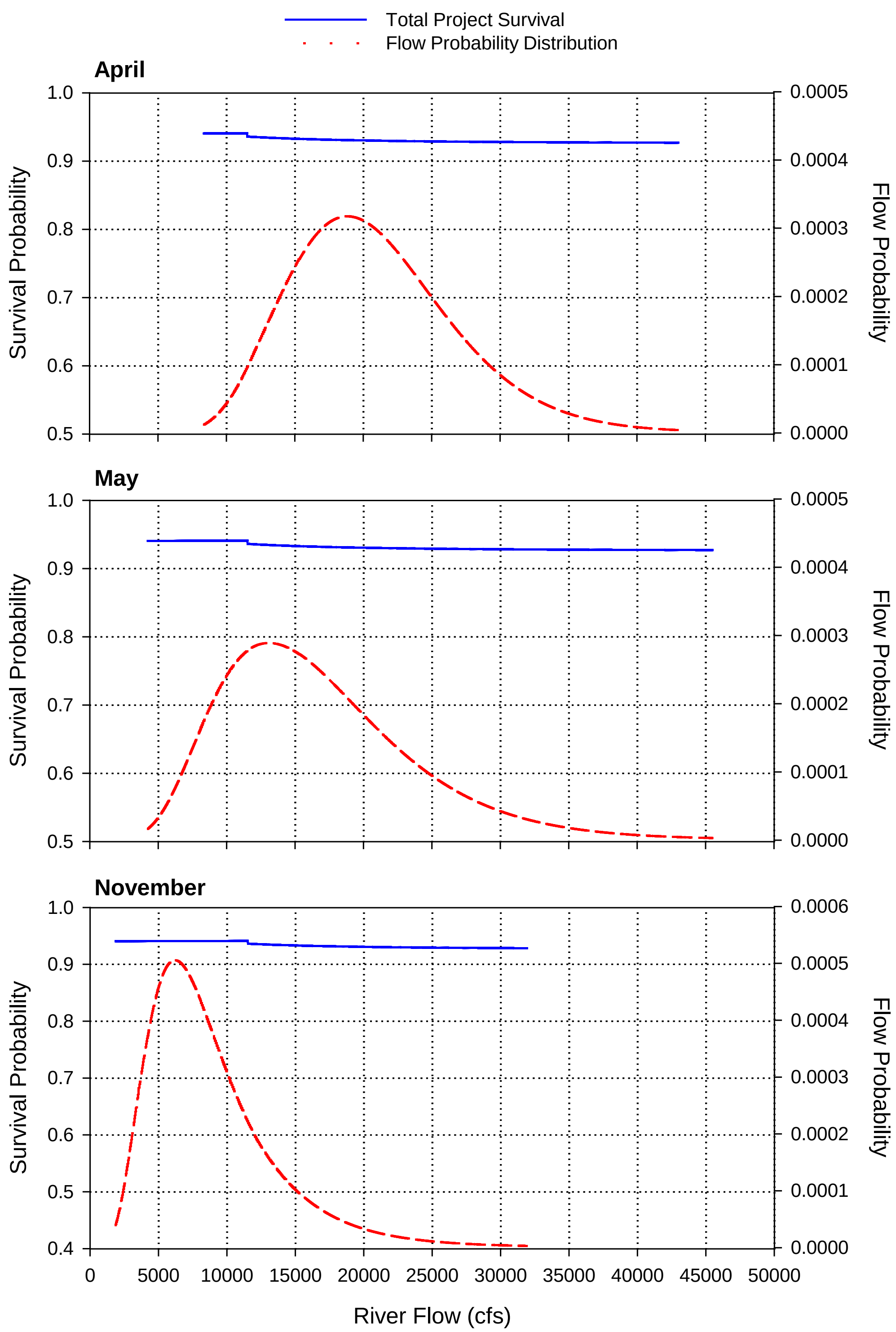

Figure 4-6. Total project survival for kelts and flow probability distributions for April, May, and November at the Great Works Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.3 Milford (FERC No. P-2534) - Original Turbine Configuration (pre-2011)

The Milford Hydroelectric Project is located approximately at river mile 20 on the Penobscot River in Milford. An aerial view of the project is provided in Figure 4-7. The Milford Project is located about 2 miles upstream from the Great Works Project and about 15 miles downstream from West Enfield. Approximately 90% of the Penobscot River drainage passes through the project. As part of the Penobscort River Restoratoin Project (and following the initiation of this survival study), BBHP has upgraded Milford with new turbines to increase power generation. This section presents a survival analysis prior to the turbine updrades (i.e., original turbine configuration), whereas the following section (4.4) provides survival data for the post-upgrade conditions.

Milford is operated as a ROR facility with an estimated mean monthly flow ranging from 7,449 cfs in August to 35,827 cfs in April (Table 4-35).

4.3.1 Power Generating Facilities

The Milford Project consists of a powerhouse, a 1,159-ft long concrete gravity spillway with 4.5-ft flashboards, and a 25-ft wide gate and sluiceway. The powerhouse has four generating units with a combined generating capacity of 6.4 MW. There are three Kaplan turbines and one fixed-blade turbine with a combined hydraulic capacity of 5,630 cubic feet per second (CFS). An additional turbine generator has been proposed that will bring the project capacity to 8.0 MW. All four turbines have a rated head of about 19 ft, a wicket gate height of 45 inches, four blades, and a rotational speed of 120 rpm. No additional information on turbine design was provided by the owner or located in available project documents and reports. The clear spacing of the intake bar racks is 3.5 inches over the entire intake structure.

4.3.2 Downstream Passage Facilities and Evaluations

An existing 10-ft wide gate is used as a downstream bypass at the Milford Project. The gate flow is set at 113 cfs during the established migration periods. USASAC (2005) also indicated that an empty turbine pit is used to pass fish downstream.

There was no indication from project reports and documents that downstream passage effectiveness or survival studies have been conducted at the Milford Project. However, USASAC (2005) indicated that downstream passage studies were conducted with smolts in 1989 and 1990 and with kelts in 1988 and 1989. Turbine and spillway passage for smolts was reported to be 41 and 59%, respectively, and that all kelts passed over the spillway in the spring. There was no dedicated downstream bypass system in operation at the time these studies were conducted.

Figure 4-7. Aerial view of the Milford Hydroelectric Project.

Table 4-35. Average monthly river discharge at the Milford Hydroelectric Project.

Month	Average Flow (cfs)
January	7100
February	6500
March	9200
April	23700
May	18800
June	9600
July	6700
August	5800
September	5800
October	7500
November	10100
December	9100

4.3.3 Upstream Passage Facilities

The Milford Project has a Denil fish ladder. A new upstream fishlift will likely be installed at the project in the next several years.

4.3.4 Turbine Design and Operation Parameters

The Milford powerhouse contains a four turbine/generating units which can be categorized into two different individual types. Table 4-36 and Table 4-37 summarize the pertinent design and operational data used in the estimation of turbine passage survival rates for each turbine.

Design parameters estimated for Milford Unit 3 include the hub diameter, flow angle approaching the blade, and the leading edge blade thickness (Table 4-36). The hub diameter and the leading edge blade thickness were estimated directly from relationships with the turbine diameter (Table 3-4). The flow angle was estimated based on the relationship between the blade tip speed components (Table 3-4). It was concluded that the design and operational data acquired and estimated for Unit 3 were reasonable and, therefore, modifications or adjustments to any of the data were not considered necessary.

As part of an ongoing restoration program in the Penobscot Basin, the Milford Project will be undergoing an upgrade which will include the installation of an additional two turbine/generating units. Section 4.3 focuses on an evaluation of the Orono Project in its existing condition. See Section 4.4 for an evaluation of the Orono Project in its proposed condition.

Design parameters estimated for Milford units 4, 5, and 6 include the hub diameter, flow angle approaching the blade, and the leading edge blade thickness (Table 4-37). The hub diameter and the leading edge blade thickness were estimated directly from relationships with turbine diameter (Table 3-4). Flow angle was estimated based on the relationship between the blade tip speed components (Table 3-4). It was concluded that the design and operational data acquired and estimated for units 4, 5, and 6 were reasonable and, therefore, modifications or adjustments to any of the data were not considered necessary.

Table 4-36. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Milford Unit 3.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	fixed-blade propeller	--
Flow (cfs)	1,370	--
Runner Diameter (ft)	9.1	--
Hub Diameter (ft)	3.3[1]	--
Turbine speed (rpm)	120	--
Number Blades	4	--
Flow Angle (deg)	45[1]	--
Leading Edge Blade Thickness (mm)	20.7[1]	--

[1] Parameter was estimated.

Table 4-37. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Milford units 4, 5, and 6.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Kaplan	--
Flow (cfs)	1,420	--
Runner Diameter (ft)	9.1	--
Hub Diameter (ft)	3.3[1]	--
Turbine speed (rpm)	120	--
Number Blades	4	--
Flow Angle (deg)	46[1]	--
Leading Edge Blade Thickness (mm)	20.7[1]	--

[1] Parameter was estimated.

4.3.5 Turbine Passage Survival

Strike probabilities and turbine survival estimates for Atlantic salmon passing through each turbine at Milford are presented in Table 4-38 and Table 4-39 for smolts and Table 4-40 and Table 4-41 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and survival estimates for smolts did not vary considerably with changes in fish radial length and K for any of the four Milford units. Conversely, strike and survival probabilities for kelts were relatively sensitive to the modified parameters, exhibiting large ranges across the length intervals evaluated for this life stage.

4.3.6 Bypass Efficiency and Survival

There was no indication from available reports and documents that downstream passage effectiveness or survival studies have been conducted at the Milford Project. However, USASAC (2005) indicated that turbine and spillway passage for smolts was 41% and 59%, respectively, and that all kelts passed over the spillway in the spring at Milford. Due to a lack of more detailed information on passage route selection, bypass efficiency for smolts was assumed to be 10% based on available data from studies at other projects and because the intake racks at Milford have a wide bar spacing (3.5-inch clear). Due to the wide bar spacing, the potential for kelt entrainment is high, therefore, bypass efficiency for this life stage was assumed to be 25%. Direct bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.3.7 Spillway Passage Survival

Direct spillway passage survival for smolts and kelts passing downstream at the Milford Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Section 3.1.2.

4.3.8 Indirect Survival

Indirect for smolts and kelts passing downstream at the Milford Project survival was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Section 3.2.

Table 4-38. Turbine survival estimates for smolts passing through Milford Unit 3 (fixed-blade propeller turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.099	0.964	0.114	0.958	0.080	0.971	0.957	0.970	0.950	0.976
140	0.106	0.960	0.123	0.953	0.086	0.967	0.952	0.966	0.944	0.973
150	0.114	0.956	0.132	0.949	0.093	0.964	0.947	0.963	0.938	0.970
160	0.122	0.952	0.141	0.944	0.099	0.961	0.942	0.960	0.933	0.967
170	0.129	0.947	0.150	0.939	0.105	0.957	0.937	0.956	0.927	0.964
180	0.137	0.943	0.158	0.934	0.111	0.954	0.932	0.953	0.921	0.961
190	0.144	0.939	0.167	0.929	0.117	0.950	0.926	0.949	0.915	0.959
200	0.152	0.934	0.176	0.924	0.123	0.947	0.921	0.945	0.909	0.956
210	0.160	0.930	0.185	0.919	0.130	0.943	0.916	0.941	0.902	0.953

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-39. Turbine survival estimates for smolts passing through Milford units 4, 5, and 6 (Kaplan turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.097	0.962	0.112	0.957	0.079	0.969	0.955	0.969	0.948	0.974
140	0.104	0.958	0.120	0.952	0.085	0.966	0.950	0.965	0.942	0.971
150	0.112	0.954	0.129	0.947	0.092	0.962	0.945	0.962	0.936	0.969
160	0.119	0.950	0.138	0.942	0.098	0.959	0.939	0.958	0.930	0.966
170	0.127	0.945	0.146	0.937	0.104	0.955	0.934	0.954	0.924	0.963
180	0.134	0.941	0.155	0.932	0.110	0.952	0.929	0.951	0.918	0.960
190	0.142	0.936	0.163	0.926	0.116	0.948	0.923	0.947	0.912	0.956
200	0.149	0.932	0.172	0.921	0.122	0.944	0.918	0.943	0.905	0.953
210	0.157	0.927	0.181	0.916	0.128	0.940	0.912	0.939	0.899	0.950

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-40. Turbine survival estimates for kelts passing through Milford Unit 3 (fixed-blade propeller turbine).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	0.494	0.697	0.572	0.649	0.401	0.754	0.636	0.748	0.579	0.795
675	0.513	0.682	0.594	0.632	0.416	0.742	0.619	0.735	0.559	0.785
700	0.532	0.668	0.616	0.615	0.432	0.730	0.601	0.723	0.538	0.775
725	0.551	0.653	0.638	0.598	0.447	0.718	0.583	0.711	0.517	0.765
750	0.570	0.638	0.660	0.581	0.463	0.706	0.565	0.698	0.497	0.755
775	0.589	0.623	0.682	0.563	0.478	0.694	0.547	0.686	0.476	0.745
800	0.608	0.608	0.704	0.546	0.493	0.682	0.529	0.673	0.455	0.735

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-41. Turbine survival estimates for kelts passing through Milford units 4, 5, and 6 (Kaplan turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	0.485	0.685	0.559	0.637	0.397	0.742	0.622	0.737	0.564	0.785
675	0.504	0.673	0.580	0.623	0.412	0.732	0.607	0.727	0.547	0.777
700	0.522	0.660	0.602	0.609	0.427	0.722	0.592	0.717	0.530	0.769
725	0.541	0.648	0.623	0.595	0.442	0.712	0.578	0.707	0.514	0.760
750	0.560	0.636	0.645	0.581	0.458	0.703	0.563	0.697	0.497	0.752
775	0.578	0.624	0.666	0.567	0.473	0.693	0.549	0.687	0.480	0.744
800	0.597	0.612	0.688	0.553	0.488	0.683	0.534	0.677	0.463	0.736

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.3.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 90.3 to 92.0% (with a mean of 91.6%) across the range of average monthly flows likely to occur at Milford during the specified migration period (Table 4-42; Figure 4-8). Kelt survival at Milford was similar for all three of the specified migration months, but with relatively wide ranges (differences of at least 20% between the minimum and maximum survival rates for each month; Table 4-42). Mean total project survival for kelts was highest in April (86.2%) and lowest in November (81.8%) for the range of expected monthly average flows (Table 4-42; Figure 4-9). After sufficient flow occurred to allow kelt passage over the spillway, survival of this life stage during each month increased by about 10% as river flow increased to maximum levels (Figure 4-9). As expected, Kelt survival was lowest when all turbines were operating at full load and there was insufficient flow for spillway passage.

Table 4-42. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Milford Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	8725 - 46670	--	--	--	0.862	0.693	0.893
May	3880 - 49360	0.917	0.903	0.920	0.847	0.693	0.895
November	1540 - 34625	--	--	--	0.818	0.646	0.884

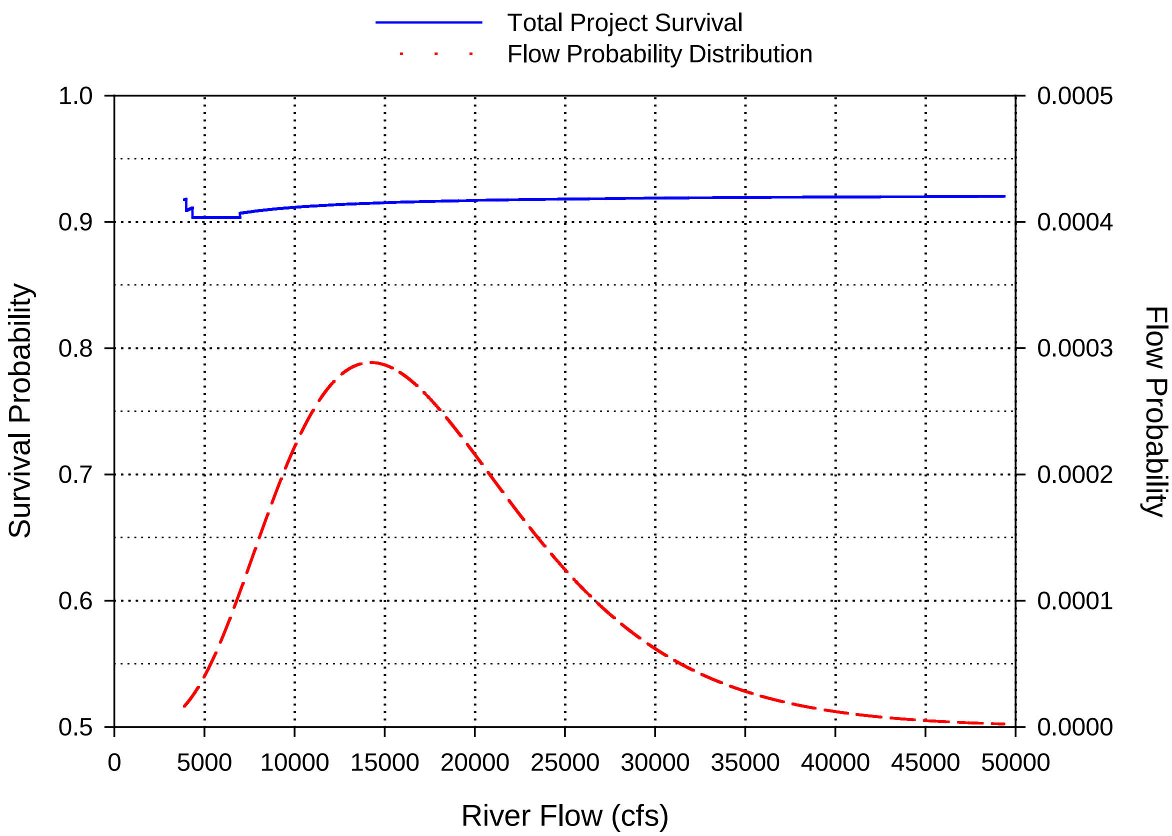

Figure 4-8. Total project survival for smolts and the flow probability distribution for May at the Milford Project. Flow probabilities were estimated and plotted in 5 cfs increments.

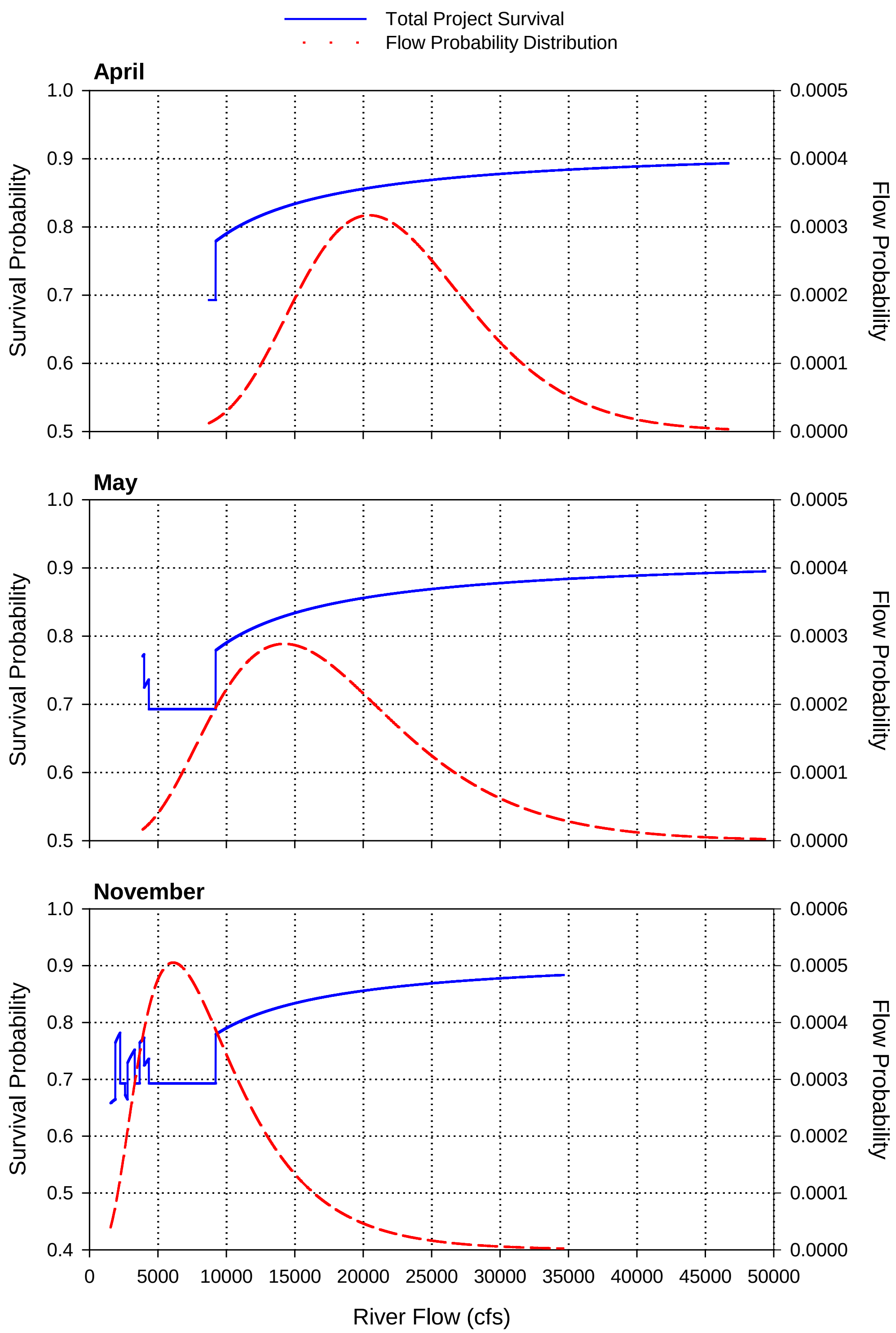

Figure 4-9. Total project survival for kelts and flow probability distributions for April, May, and November at the Milford Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.4 Milford (FERC No. P-2534) - Upgraded Turbine Configuration (post-2011)

As part of the agreement that established the Penobscot Rive Restoration Program, the Milford Project has been upgraded with the installation of two additional turbines (Units 7 and 8). Section 4.3 provides data for the survival of smolts and kelts passing downstream at Milford under the original turbine configuration (Units 1 through 6) prior to the addition of the two new units. This section presents the analysis of downstream passage survival with the new turbines installed, including design information and turbine passage survival rates for the these units. Section 4.3 should be referenced for general information describing the Milford Project and for turbine survival rates associated with fish entrainment through the original turbines (Units 1 through 6). The total passage survival rates estimated for smolts and kelts with the new turbine configuration also account for the installation of full depth 1-inch spaced bar racks at the powerhouse intake.

4.4.1 Turbine Design and Operation Parameters

Due to sufficient information provided by the project owner and manufacturer, design parameter estimation was not required for the new units. Based on a review of the design parameters (Table 4-43), no modifications or adjustments to any of the data were considered necessary.

Table 4-43. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Milford units 7 and 8.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Kaplan	--
Flow (cfs)	544	--
Runner Diameter (ft)	5.6	--
Hub Diameter (ft)	2.2	--
Turbine speed (rpm)	257	--
Number Blades	4	--
Flow Angle (deg)	60	--
Leading Edge Blade Thickness (mm)	11.2	--

4.4.2 Turbine Passage Survival

Strike probabilities and turbine survival estimates for Atlantic salmon passing through the new turbines are presented in Table 4-44 for smolts and Table 4-45 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and survival estimates for smolts did not vary considerably with changes in fish radial length and K for both of the new turbines when these parameters were modified individually (Table 4-44). However, when the modifications were combined, the range in survival was greater and increased with fish size. For kelts, changes in radial fish length did not affect turbine survival because strike probability remained at 100% (Table 4-45). Modifications to K resulted in relatively large changes to kelt turbine survival (greater than 10%) for the new turbines, but survival did not change with fish length.

4.4.3 Bypass Efficiency and Survival

The installation of full depth 1-inch spaced bar racks is part of the new turbine configuration at Milford. Therefore, bypass efficiencies were estimated to be 50% for smolts and 100% for kelts, with direct bypass survival for both life stages set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.4.4 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Milford Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Section 3.1.2.

4.4.5 Indirect Survival

Indirect for smolts and kelts passing downstream at the Milford Project survival was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Section 3.2.

Table 4-44. Turbine survival estimates for smolts passing through Milford units 7 and 8 (Kaplan turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.238	0.845	0.259	0.832	0.211	0.863	0.814	0.871	0.798	0.886
140	0.257	0.833	0.279	0.819	0.227	0.852	0.800	0.861	0.783	0.877
150	0.275	0.821	0.298	0.806	0.243	0.842	0.785	0.851	0.767	0.868
160	0.294	0.809	0.318	0.793	0.260	0.831	0.771	0.841	0.752	0.859
170	0.312	0.797	0.338	0.780	0.276	0.821	0.757	0.831	0.736	0.851
180	0.330	0.785	0.358	0.767	0.292	0.810	0.743	0.821	0.721	0.842
190	0.349	0.773	0.378	0.754	0.308	0.800	0.728	0.811	0.705	0.833
200	0.367	0.762	0.398	0.741	0.324	0.789	0.714	0.801	0.690	0.824
210	0.385	0.750	0.418	0.728	0.341	0.779	0.700	0.791	0.674	0.815

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-45. Turbine survival estimates for kelts passing through Milford units 7 and 8 (Kaplan turbines).

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
675	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
700	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
725	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
750	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
775	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
800	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.4.6 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts with the new turbines installed is expected to range from 90.6 to 92.5% (with a mean of 91.8%) across the range of average monthly flows likely to occur at Milford (Table 4-46; Figure 4-10). After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival gradually increases with river discharge (Figure 4-10). Despite lower turbine survival rates for the new turbines compared to the existing units, total passage survival rates for the upgraded turbine conditions at Milford increased slightly from the existing conditions. The slight increases in smolt survival were mainly due to the narrower bar spacing for the upgraded conditions which reduced turbine entrainment considerably for this life stage. Mean, min, and max total project survival rates for kelts did not vary among months with the upgraded turbine conditions, with a range of 92.4 to 94.1% for all three months (Table 4-46; Figure 4-11). Kelt survival rates were higher with the new turbine configuration due to the addition of 1-inch spaced bar racks, which completely prevents turbine entrainment of this life stage.

Table 4-46. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Milford Project (upgraded turbine configuration) over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	9165 - 49005	--	--	--	0.927	0.924	0.941
May	2445 - 49210	0.918	0.906	0.928	0.929	0.924	0.941
November	1980 - 58155	--	--	--	0.928	0.924	0.941

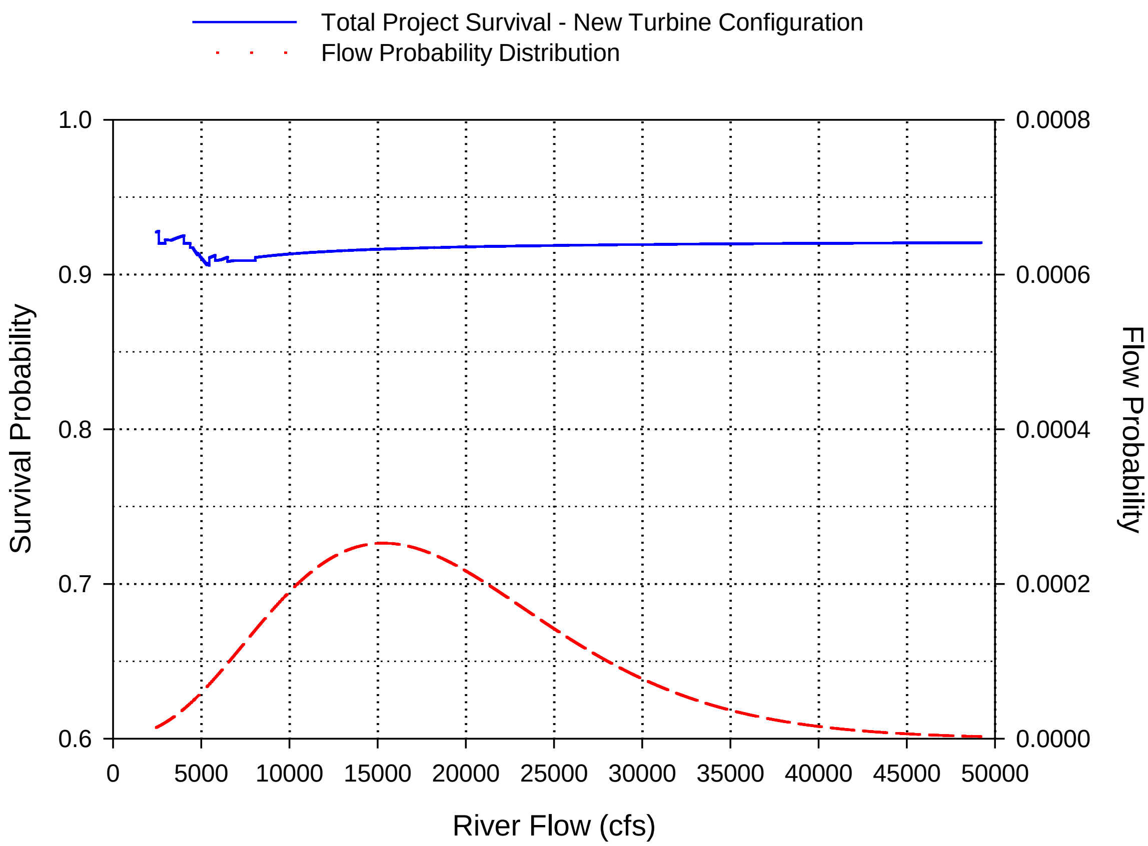

Figure 4-10. Total project survival for smolts and the flow probability distribution for May at the Milford Project with the new turbines installed. Flow probabilities were estimated and plotted in 5 cfs increments.

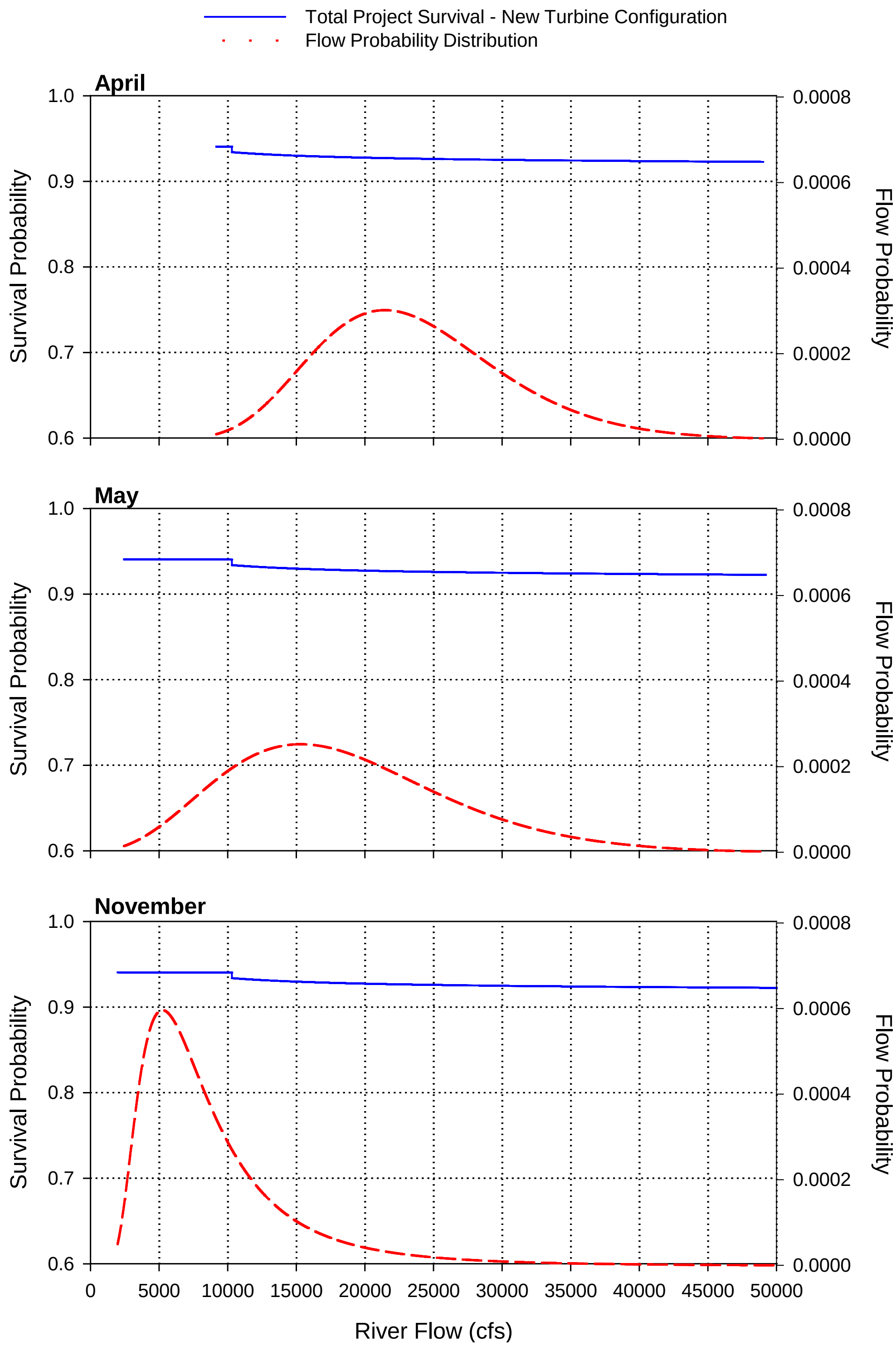

Figure 4-11. Total project survival for kelts and flow probability distributions for April, May, and November at the Milford Project with the new turbines installed. Flow probabilities were estimated and plotted in 5 cfs increments.

4.5 West Enfield (FERC No. P-2600)

The West Enfield Hydroelectric Project is located approximately at river mile 30 on the Penobscot River in Enfield. An aerial view of the project is provided in Figure 4-12. West Enfield dam is located about 15 miles upstream from the Milford dam. Approximately 64% of the Penobscot River drainage passes through the project.

West Enfield is operated as a ROR facility with an estimated mean monthly flow ranging from 5,123 cfs in August to 23,309 cfs in April (Table 4-47).

4.5.1 Power Generating Facilities

The West Enfield Project consists of a powerhouse a 363-ft long ogee spillway (with 6-ft flashboards), a 45-ft non-overflow section, and a 107-ft long gated section. The powerhouse has two turbine-generator units with a combined generating capacity of 13 MW and a hydraulic capacity of 9,000 cfs. The turbines are horizontal Kaplan (pit-type) units, each with four blades, a diameter of 16.7 ft, a rated head of 26 ft, and a rotational speed of 86 rpm. No additional information on wicket gate or turbine blade designs was provided by the owner or obtained from other documents with project descriptions. The clear spacing of the bar racks is 1 inch to a depth of 2 ft, below which the spacing is 3 inches.

Figure 4-12. Aerial view of the West Enfield Hydroelectric Project.

Table 4-47. Average monthly river discharge at the West Enfield Hydroelectric Project.

Month	Average Flow (cfs)
January	6,430
February	5,882
March	8,604
April	23,309
May	18,538
June	9,152
July	6,101
August	5,123
September	5,170
October	6,868
November	9,543
December	8,604

4.5.2 Downstream Passage Facilities and Evaluations

Five surface bypasses are located across the top of the turbine intake at the West Enfield Project. A series of downstream passage effectiveness studies were conducted from 1990 through 1994 with radio-tagged. The results of these studies indicated bypass efficiency ranged from about 2 to 36% for smolts and was 4% for kelts. The effectiveness of the bypass system following operational changes based on the results of a CFD evaluation indicated some improvement in passage rates. Also, low level lighting was shown to increase the effectiveness to some degree.

An evaluation of turbine passage survival was conducted in 1992 and 1993 at the West Enfield Project to determine immediate and delayed survival of smolts passing through the turbines (Shepard 1993a) after previous studies showed that a greater percentage of turbine-passed fish were reaching the estuary compared to fish that used a downstream passage facility (Shepard 1991, 1993b). Turbine-passed fish were collected at West Enfield using a partial-flow tailrace net located in the draft tube discharge of one of the project's four turbines. In addition to smolts collected after turbine passage, control fish were released directly into the collection net live car and at the net mouth to determine injury and mortality associated with sampling and handling methods. Modifications were made to the net prior to sampling in 1993 in attempts to reduce collection-related injury and scale loss. During the two year study, 406 whole smolts and 9.5 half (severed) smolts were collected following turbine passage. About 94% of these fish were collected during the 1992 sampling effort. The lower number of smolts collected in 1993 was attributed to sample timing (after peak migration in 1993), less fish passing through the unit sampled in 1993 (Unit 1 in 1993 versus Unit 2 in 1992), and less fish stocked in 1993. The author estimated acute (or immediate) turbine passage mortality to be 2.3%. Delayed turbine passage mortality (72 hr) was not estimated because delayed control mortality was high (> 20% during both years). Ruggles (1993) concluded that control mortality rates greater than 10% can make turbine passage survival estimates unreliable. The high delayed mortality observed during the West Enfield study was attributed to significant descaling of fish passing through the collection net. Based on the results of other turbine passage studies, the author concluded that total mortality for smolts passing through the turbines at West Enfield likely was about 3 to 6%.

4.5.3 Upstream Passage Facilities

West Enfield has a vertical slot fish ladder located on the east bank adjacent to the powerhouse.

4.5.4 Turbine Design and Operation Parameters

The West Enfield powerhouse has two turbine/generating units which can be categorized as single individual turbine type. Table 4-48 provides a summary of the pertinent design and operational data used in the estimation of turbine passage survival rates for the two units.

Design parameters estimated for the two West Enfield turbines include the hub diameter, flow angle approaching the blade, and the leading edge blade thickness (Table 4-48). The hub diameter and the leading edge blade thickness were estimated directly from the relationship to the turbine diameter (Table 3-4) and the flow angle was estimated from the relationship between the blade tip speed components (Table 3-4).

4.5.5 Turbine Passage Survival

Strike probabilities and turbine survival estimates for Atlantic salmon passing through the West Enfield turbines are presented Table 4-49 for smolts and Table 4-50 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and survival estimates for smolts did not vary considerably with changes in fish radial length (approach angle) and K when these parameters were examined separately. However, when the changes in the two parameters were combined, the differences between the baseline estimates and the modified survival rates were larger and this sensitivity increased with fish length. For larger smolts, this indicates there is some sensitivity of the survival rates to potential variability in fish approach angle and K. For kelts, strike probability was 100% for all three of the fish approach angles evaluated and the corresponding survival rates were equivalent. Kelts survival rates were relatively sensitive to changes in K, but did not vary much across the range of fish lengths examined.

Table 4-48. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through West Enfield units 1 and 2.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Kaplan (pit-type)	--
Flow (cfs)	6,730	--
Runner Diameter (ft)	16.7	--
Hub Diameter (ft)	6.1[1]	--
Turbine speed (rpm)	86	--
Number Blades	4	--
Flow Angle (deg)	51[1]	--
Leading Edge Blade Thickness (mm)	33.4[1]	--

[1] Parameter was estimated.

4.5.6 Bypass Efficiency and Survival

Studies conducted at West Enfield indicated bypass efficiencies were 2 to 36% for smolts and 4% for kelts. Following operational modifications, the effectiveness of the bypass system appeared to improve. However, more detailed information on these improvements and subsequent effectiveness could not be found in the available literature for this site. Consequently, bypass efficiency for smolts was assumed to be 25% based on available data from studies conducted at other projects and because the intake racks at West Enfield have narrow bar spacing (1-inch clear) only on the upper 2 ft of the racks. Bypass efficiency of kelts was assumed to be 70% based on the studies conducted at Mattaceunk with this life stage. Direct bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.5.7 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the West Enfield Project was assumed to be 97%. More detailed information on the estimation of spillway survival rate is provided in Section 3.1.2.

Table 4-49. Turbine survival estimates for smolts passing through West Enfield units 1 and 2.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.040	0.976	0.049	0.971	0.029	0.982	0.971	0.980	0.965	0.985
140	0.043	0.973	0.052	0.967	0.031	0.980	0.968	0.978	0.961	0.984
150	0.046	0.970	0.056	0.964	0.034	0.978	0.965	0.975	0.956	0.982
160	0.049	0.968	0.060	0.961	0.036	0.977	0.962	0.974	0.953	0.981
170	0.052	0.966	0.064	0.959	0.038	0.975	0.960	0.972	0.950	0.979
180	0.055	0.964	0.067	0.956	0.040	0.974	0.957	0.970	0.947	0.978
190	0.058	0.962	0.071	0.954	0.043	0.972	0.955	0.969	0.944	0.977
200	0.061	0.960	0.075	0.951	0.045	0.971	0.953	0.967	0.942	0.976
210	0.064	0.958	0.079	0.949	0.047	0.969	0.950	0.965	0.939	0.975

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-50. Turbine survival estimates for kelts passing through West Enfield units 1 and 2.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	0.198	0.871	0.244	0.842	0.146	0.905	0.846	0.893	0.810	0.921
675	0.205	0.867	0.253	0.835	0.151	0.902	0.840	0.889	0.803	0.918
700	0.213	0.862	0.262	0.829	0.157	0.898	0.834	0.885	0.795	0.915
725	0.221	0.857	0.272	0.823	0.162	0.894	0.828	0.881	0.788	0.912
750	0.228	0.852	0.281	0.817	0.168	0.891	0.822	0.876	0.781	0.909
775	0.236	0.847	0.291	0.811	0.174	0.887	0.816	0.872	0.773	0.906
800	0.243	0.842	0.300	0.805	0.179	0.883	0.810	0.868	0.766	0.903

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.5.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the West Enfield Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Section 3.2.

4.5.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 92.3 to 93.6% across the range of average monthly flows likely to occur at West Enfield (Table 4-51; Figure 4-13), with a mean of 92.5%. Mean, min, and max total project survival rates for kelts did not vary considerably between the three months evaluated (Table 4-51; Figure 4-14), with a range of 90.8 to 94.1%.

Table 4-51. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the West Enfield Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	8985 - 48050	--	--	--	0.910	0.902	0.916
May	3995 - 50820	0.925	0.923	0.936	0.910	0.902	0.916
November	1585 - 35650	--	--	--	0.908	0.902	0.941

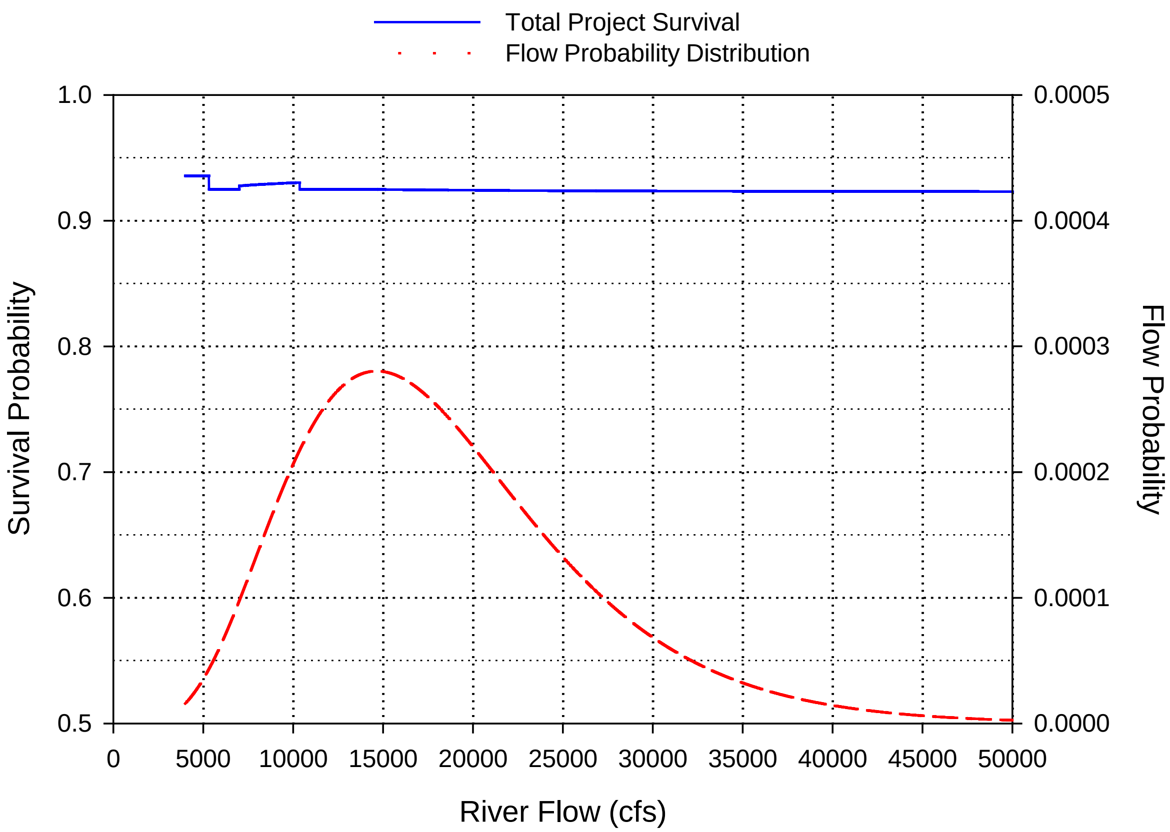

Figure 4-13. Total project survival for smolts and the flow probability distribution for May at the West Enfield Project. Flow probabilities were estimated and plotted in 5 cfs increments.

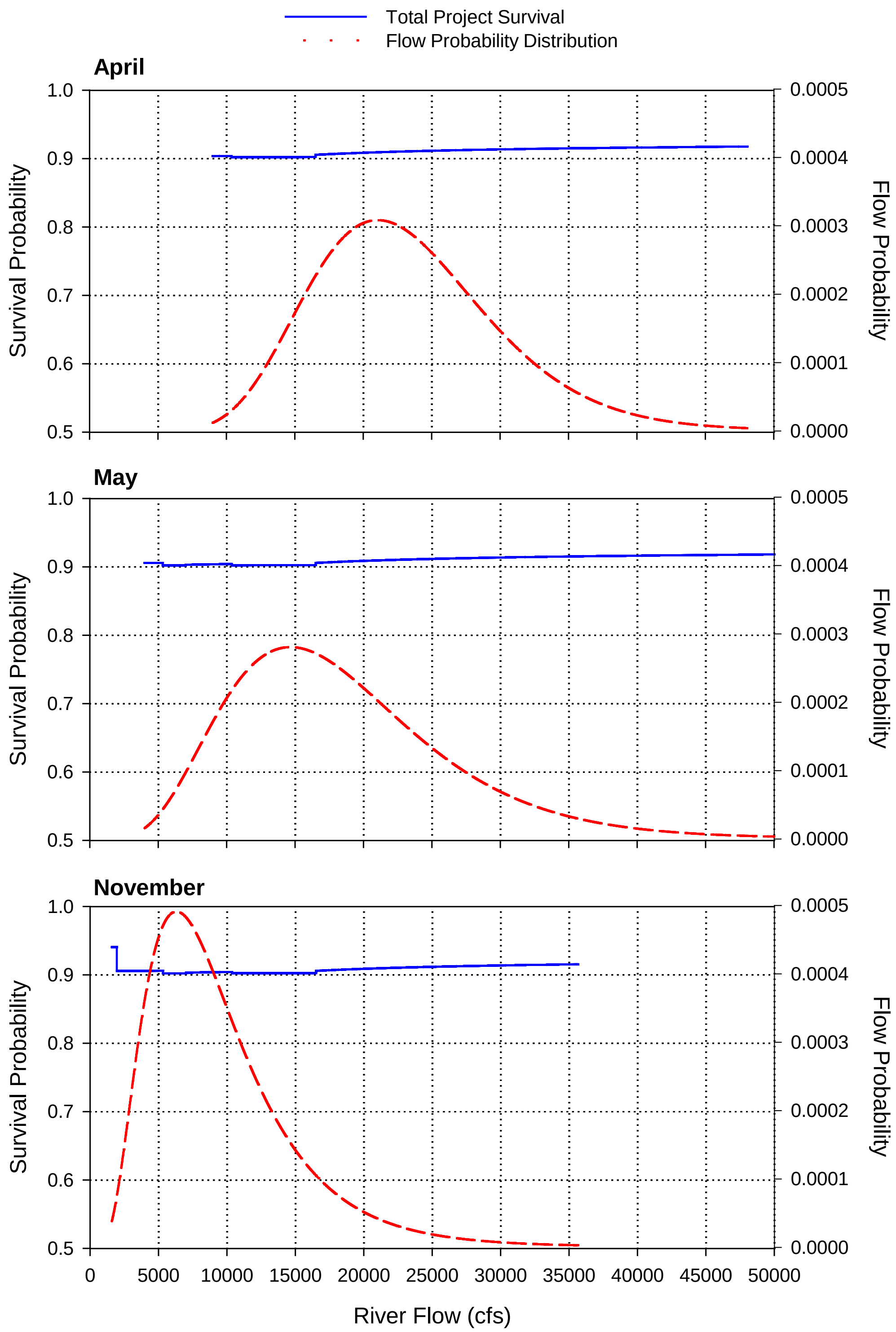

Figure 4-14. Total project survival for kelts and flow probability distributions for April, May, and November at the West Enfield Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.6 Mattaceunk (FERC No. P-2520)

The Mattaceunk Hydroelectric Project (also referred to as Weldon Dam) is owned and operated by Brookfield Power New England LLC. An aerial view of the Mattaceunk Project is provided in Figure 4-15. The project is located on the Penobscot River in the towns of Mattawamkeag and Woodville. Some information describing the project design and operation was provided by Brookfield in response to the information survey that was sent by Alden to each project owner. Additional information was also obtained from various documents identified during a search of the FERC online library and Maine DEP and DMR databases and reports.

Mattaceunk is operated as a ROR facility with an estimated mean monthly flow ranging from 4,258 cfs in August to 10,448 cfs in May (Table 4-52).

4.6.1 Power Generating Facilities

The Mattaceunk Project consists of a spillway, a roller gate, and a powerhouse with four turbines. The ogee-type gravity spillway is about 750 ft long with a height of about 45 ft. A roller gate is located in the spillway on the end near the powerhouse and is 90 ft wide by 19 ft high. Normal head pond elevation is 240 ft. There is a fish ladder and a debris sluice located between the roller gate and the powerhouse. The powerhouse has two Kaplan and two fixed-propeller turbines, all manufactured by IP Morris and with a rated head of 39 ft. The Kaplan units each have five blades with generating and flow capacities of 5.48 MW and 1,883 cfs, respectively. The fixed-propeller units also have five blades and are rated for 5.33 MW and 1,836 cfs. All four turbines have a runner diameter of 9.125 ft and a rotational speed of 189.5 rpm. The wicket gate height of all units is 46.5 ft. No additional information on wicket gate or turbine blade designs was provided by the owner or obtained from other documents with project descriptions. The clear spacing of the bar racks is 1-inch to a depth of 16 ft, below which the spacing is 2.63 inches.

4.6.2 Downstream Passage Facilities and Evaluations

Downstream passage facilities at the Mattaceunk Project include narrow-spaced bar rack overlays (1-inch clear to a depth of 16 ft) and a bypass system with two surface entrances, one located above the Unit 3 intake and the other above Unit 4. From 1995 to 1999, strobe lights were incorporated into the downstream passage design in attempts to repel fish from the turbine intakes, but their effectiveness was mixed and they currently are not being used. Total bypass flow is 140 cfs and each bypass entrance is 4.5 ft wide by 6.5 ft high. The bypass gate setting elevation is 236.5 ft and the sill elevation is 234 ft. The surface inlets discharge into rectangular chambers that transition to a 42-inch diameter pipe. The gravity-fed bypass pipe discharges below the powerhouse into a monitoring facility, from which fish can be collected or released directly into the tailrace.

Figure 4-15. Aerial view of the Mattaceunk Hydroelectric Project.

Table 4-52. Average monthly river discharge at the Mattaceunk Hydroelectric Project.

Month	Average Flow (cfs)
January	4,485
February	4,574
March	5,145
April	9,768
May	10,448
June	5,963
July	4,347
August	4,258
September	4,376
October	4,692
November	5,461
December	5,076

A series of downstream passage effectiveness studies were conducted from 1987 to 1999. Attempts were made to conduct evaluations during several years after 1999, but high flows limited the owner's ability to effectively perform additional field testing. No studies appear to have been conducted since the 1999 evaluation. Effectiveness testing with smolts was conducted with various configurations of strobe lights installed on the powerhouse intakes as a means to reduce entrainment and improve the ability of downstream migrants to locate the surface inlets. Mercury lights were also used over the surface inlets as an attractant. Bypass efficiency (percent of radio-tagged smolts released that passed downstream through the bypass system) ranged from about 17 to 59% during seven years of study form 1993 to 1999. The variation in bypass efficiency during tests with the strobe lights was attributed, in part, to differences in strobe light configuration, turbine operation, and bypass flow. In general, it was concluded that the strobe light system was capable of reducing entrainment into units 1 and 2, which had a full array of strobe lights, but bypass efficiency did not improve, even when strobe lights were placed over the lower half of units 3 and 4 (i.e., the upper halves of units 3 and 4 where the bypass entrances are located were the only sections of the powerhouse intake that were not illuminated with strobe light). Some testing has also been conducted with kelts and, primarily due to the narrow bar spacing of the intake bar racks (1-inch clear), bypass efficiencies were found to be relatively high (60 to 80%).

Downstream passage survival studies have not been conducted at the Mattaceunk Project. However, as part of the downstream passage effectiveness studies, fish condition in the bypass collection facility was monitored during some of the study years and the results indicated that bypass survival rates are likely greater than 99% for salmon smolts and kelts.

4.6.3 Upstream Passage Facilities

The Mattaceunk Project has a fish ladder installed between the powerhouse and spillway.

4.6.4 Turbine Design and Operation Perameters

The Mattaceunk Project has four turbine/generating units which can be categorized into two different individual types. Table 4-53 and Table 4-54 summarize the pertinent design and operational data used in the estimation of turbine passage survival for each turbine. Design parameters estimated for all of the Mattaceunk turbines include the flow angle approaching the blade and the leading edge blade thickness (Table 4-53 and Table 4-54). The leading edge blade thicknesses were estimated directly from the relationship to the turbine diameter (Table 3-4). The flow angle was estimated based upon the relationship among the blade tip speed components (Table 3-4). It was concluded that the design and operational data acquired and estimated for all of the Mattaceunk units were reasonable and, therefore, modifications or adjustments to any of the data were not considered necessary. Although the flow angle appears to be slightly high, all estimated velocity data were generated directly from drawings provided by the project owner.

Table 4-53. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Mattaceunk units 3 and 4.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Fixed-blade Propeller	--
Flow (cfs)	1,836	--
Runner Diameter (ft)	9.1	--
Hub Diameter (ft)	3.3	--
Turbine Speed (rpm)	189.5	--
Number Blades	5	--
Flow Angle (deg)	66[1]	--
Leading Edge Blade Thickness (mm)	20.8[1]	--

[1] Parameter was estimated.

Table 4-54. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Mattaceunk units 1 and 2.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Kaplan	--
Flow (cfs)	1,883	--
Runner Diameter (ft)	9.1	--
Hub Diameter (ft)	3.3	--
Turbine Speed (rpm)	189.5	--
Number Blades	5	--
Flow Angle (deg)	66[1]	--
Leading Edge Blade Thickness (mm)	20.8[1]	--

[1] Parameter was estimated.

4.6.5 Turbine Passage Survival

Strike probabilities and turbine survival estimates for Atlantic salmon passing through the Mattaceunk turbines are presented in Table 4-55 and Table 4-56 for smolts and Table 4-57 and Table 4-58 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and survival estimates for smolts did not vary considerably with changes in fish radial length for the two turbine designs at Mattaceunk, indicating that the sensitivity of survival rates to variability in fish approach angle is minor. There were greater differences in smolt survival rates associated with changes to K, and these differences increased with smolt length. For kelts, strike probability was 100% for all lengths and fish approach angles evaluated. Turbine survival rates also did not vary with length of fish approach angle. Varying K produced a relatively large range in kelt survival rates and these differences (and the survival estimates) were the same for all fish lengths.

4.6.6 Bypass Efficiency and Survival

Bypass efficiencies ranged from about 17 to 59% during seven years of study conducted at the Mattaceunk Project from 1993 to 1999. Some testing was also conducted with kelts and, primarily due to the narrow clear spacing of the bar racks (1-inch clear) over the upper 16 ft of the intake structure, bypass efficiencies were found to be relatively high (60 to 80%) for this life stage. For the analysis of total project survival, it was concluded that these data provided sufficient estimates of bypass efficiency for smolts and kelts passing downstream at Mattaceunk. Consequently, the approximate average bypass efficiency for each life stage (38% for smolts and 70% for kelts, as reported by USASAC 1995) was used for the total project survival analysis. Bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.6.7 Spillway Passage Survival

Direct spillway passage survival for smolts and kelts passing downstream at the Mattaceunk Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Sections 3.1.2.

4.6.8 Indirect Survival

Indirect survival was assumed to be 95% for fish passing downstream through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Section 3.2.

Table 4-55. Turbine survival estimates for smolts passing through Mattaceunk units 3 and 4.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.352	0.771	0.374	0.757	0.319	0.793	0.726	0.810	0.709	0.827
140	0.379	0.754	0.402	0.738	0.343	0.777	0.705	0.795	0.686	0.814
150	0.406	0.736	0.431	0.720	0.368	0.761	0.684	0.780	0.664	0.801
160	0.433	0.719	0.460	0.701	0.392	0.745	0.663	0.766	0.641	0.787
170	0.460	0.701	0.489	0.682	0.417	0.729	0.641	0.751	0.619	0.774
180	0.487	0.684	0.517	0.664	0.441	0.713	0.620	0.736	0.597	0.761
190	0.514	0.666	0.546	0.645	0.466	0.697	0.599	0.722	0.574	0.748
200	0.541	0.648	0.575	0.626	0.491	0.681	0.578	0.707	0.552	0.734
210	0.568	0.631	0.603	0.608	0.515	0.665	0.557	0.692	0.529	0.721

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-56. Turbine survival estimates for smolts passing through Mattaceunk units 1 and 2.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.351	0.772	0.372	0.758	0.318	0.793	0.727	0.810	0.709	0.828
140	0.377	0.755	0.401	0.739	0.342	0.777	0.706	0.796	0.687	0.815
150	0.404	0.737	0.430	0.721	0.367	0.762	0.685	0.781	0.665	0.801
160	0.431	0.720	0.458	0.702	0.391	0.746	0.664	0.766	0.642	0.788
170	0.458	0.702	0.487	0.683	0.416	0.730	0.642	0.752	0.620	0.775
180	0.485	0.685	0.516	0.665	0.440	0.714	0.621	0.737	0.598	0.762
190	0.512	0.667	0.544	0.646	0.465	0.698	0.600	0.723	0.575	0.748
200	0.539	0.649	0.573	0.628	0.489	0.682	0.579	0.708	0.553	0.735
210	0.566	0.632	0.602	0.609	0.514	0.666	0.558	0.693	0.531	0.722

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-57. Turbine survival estimates for kelts passing through Mattaceunk units 3 and 4.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
675	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
700	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
725	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
750	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
775	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
800	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-58. Turbine survival estimates for kelts passing through Mattaceunk units 1 and 2.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
675	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
700	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
725	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
750	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
775	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
800	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.6.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 77.2 to 89.8% across the range of average monthly flows likely to occur at Mattaceunk (Table 4-59; Figure 4-16), with a mean of 86.0%. Predicted smolt survival rates fluctuate slightly at lower river flows as turbines come on line and alternate between partial and full load. After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival gradually increases to a peak at the highest discharge (Figure 4-16). Total project survival rates (mean, min, and max) for kelts were similar among the three months when migration occurs for this life stage (Table 4-59; Figure 4-17). Similar to smolts, once river flow was high enough to allow spillway passage, kelt survival rates increased gradually as flows increased (Figure 4-17). Fluctuations in survival due to turbine operations are magnified for the smolts as compared to the kelts due to the difference in bypass efficiencies.

Table 4-59. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Mattaceunk Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	4115 - 27780	--	--	--	0.827	0.758	0.877
May	3165 - 46555	0.860	0.772	0.898	0.852	0.758	0.895
November	2595 - 49310	--	--	--	0.853	0.758	0.896

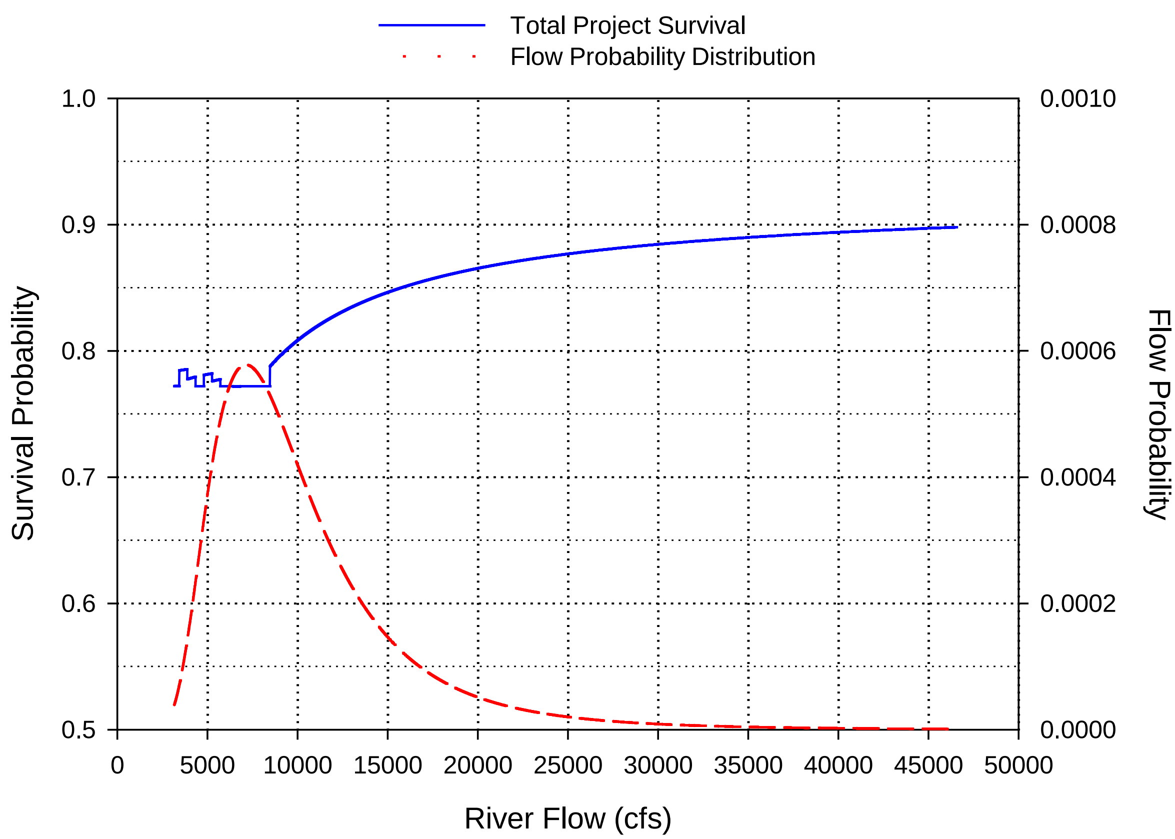

Figure 4-16. Total project survival for smolts and the flow probability distribution for May at the Mattaceunk Project. Flow probabilities were estimated and plotted in 5 cfs increments.

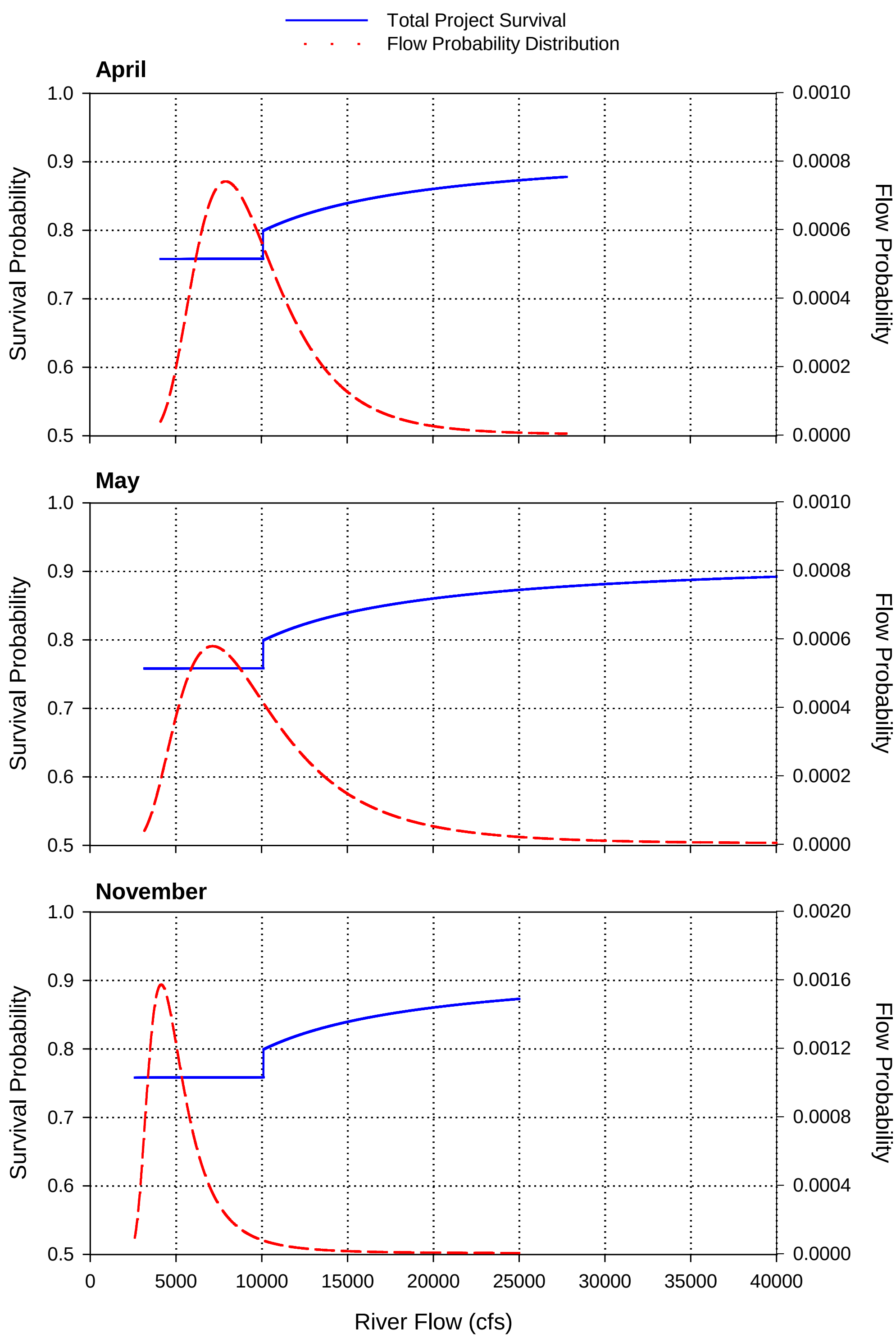

Figure 4-17. Total project survival for kelts and flow probability distributions for April, May, and November at the Mattaceunk Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.7 Orono (FERC No. P-2710) – Existing Turbine Configuration

The Orono Hydroelectric Project is located on the Stillwater Branch of the Penobscot River in Orono. An aerial view of the Orono Project is provided in Figure 4-18. The Veazie Project (mainstem) is located about 5 miles downstream from Orono and the Stillwater Project is the next dam upstream (also on the Stillwater Branch).

The Orono Project is operated as a ROR facility with an estimated mean monthly flow ranging from 7,570 cfs in August to 34,441 cfs in April (Table 4-60).

4.7.1 Power Generating Facilities

The Orono Project consists of 1180-ft long dam and a powerhouse. The dam has two non-overflow sections separated by an intake gate structure and two spillway sections. With flashboards installed on the western spillway section, the normal head pond elevation is 72.4 ft. The eastern most spillway section has a permanent crest elevation at elevation of 73.2 ft does not have flashboards. The gate structure has three 10.6-ft wide by 10.5-ft high steel gates. There are four generating units with a combined generating capacity of 2.78 MW. The turbines are all horizontal paired Francis units with a combined hydraulic capacity of 1,740 cfs at a rated head of 24 ft. A second powerhouse is proposed which that will bring the project generating capacity to 6.5 MW and the hydraulic capacity to 3,822 cfs. Three vertical axial-flow turbines will be installed in the new powerhouse. All four of the existing units have an 18-inch wicket gate height, 0.48 wicket gate tail radius, 14 blades, and a blade leading edge thickness of 0.48 inches. Three of the units have a diameter of 2.75 ft and the fourth is 3.58 ft. Rotational speeds range from 200 to 225 rpm. The clear spacing of the bar racks is 1- inch to a depth of 14 ft, below which it is 2.38 inches.

4.7.2 Downstream Passage Facilities and Evlauations

BBHP recently installed a downstream fish bypass (weir and sluice) adjacent to the powerhouse intake. In addition, 1-inch clear spaced bar racks were installed over the upper 14 ft of the intake structure.

BBHP conducted an evaluation of the new downstream passage facilities in 2010 with PIT and radio-tagged hatchery-reared smolts. With about 71% of river flow passing over the spillway, an estimated 13% of released smolts used the bypass, 69% passed over the spillway, and 18% were entrained through the turbines. Without spill, 42% of the released fish passed through the bypass and 58% through the turbines. The percentage of fish using the spillway was roughly proportional to the amount of river discharge being spilled, which has also been demonstrated for Atlantic salmon smolts at other hydropower projects.

Figure 4-18. Aerial view of the Orono Hydroelectric Project.

Table 4-60. Average monthly river discharge at the Orono Hydroelectric Project.

Month	Average Flow (cfs)
January	2300
February	2100
March	3400
April	10200
May	8000
June	3700
July	2100
August	1600
September	1700
October	2500
November	3900
December	3400

4.7.3 Upstream Passage Facilities

The Orono Project does not have upstream passage facilities for anadromous fish species. A fishway for eels was installed at that project several years ago. The project owner has proposed to install a fish trap for anadromous species.

4.7.4 Turbine Design and Operation Parameters

The Orono powerhouse has a four turbine/generating units which can be categorized into three different individual types. Table 4-61 through Table 4-63 summarizes the pertinent design and operational data used in the estimation of turbine passage survival at Orono. Design parameters estimated for each of the four Orono turbines include the wicket gate angle and the leading edge blade thickness. Wicket gate angles were indirectly calculated based on the estimated blade tip speed components (Table 3-3). The leading edge blade thickness for each turbine type was estimated directly from relationships with turbine diameter (Table 3-3). It was concluded that the design and operational data acquired and estimated for each turbine type were reasonable and, therefore, modifications or adjustments to any of the data were not considered necessary.

As part of an ongoing restoration program in the Penobscot Basin, the Orono Project will be undergoing an upgrade which will include the installation of an additional three turbine/generating units. This section focuses on an evaluation of the Orono Project in its existing condition. An evaluation of the Orono Project for the proposed turbine upgrade condition is presented in Section 4.8.

Table 4-61. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Orono Unit 1.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	123	--
Runner Diameter (ft)	2.8	--
Wicket Gate Height (ft)	1.5	--
Turbine Speed (rpm)	225	--
Number Blades	14	--
Wicket Gate Angle (deg)	30[1]	--
Leading Edge Blade Thickness (mm)	12.2[1]	--

[1] Parameter was estimated.

Table 4-62. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Orono Unit 2.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	123	--
Runner Diameter (ft)	2.8	--
Wicket Gate Height (ft)	1.5	--
Turbine Speed (rpm)	200	--
Number Blades	14	--
Wicket Gate Angle (deg)	35[1]	--
Leading Edge Blade Thickness (mm)	12.2[1]	--

[1] Parameter was estimated.

Table 4-63. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Orono units 3 and 4.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	167	--
Runner Diameter (ft)	3.6	--
Wicket Gate Height (ft)	1.5	--
Turbine speed (rpm)	212	--
Number Blades	14	--
Wicket Gate Angle (deg)	24[1]	--
Leading Edge Blade Thickness (mm)	12.2[1]	--

[1] Parameter was estimated.

4.7.5 Turbine Passage Survival Estimates

Strike Probabilities and turbine survival estimates for Atlantic salmon passing through each turbine at Orono are presented in Table 4-64 through Table 4-66 for smolts and Table 4-67 through Table 4-69 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and survival estimates for smolts did not vary considerably with changes in fish radial length (approach angle) and/or K for any of the four Orono units. This was due, in part, to strike probabilities of 100% for the baseline conditions and for most fish lengths analyzed with modified approach angles. Similar to smolts, strike and survival probabilities for kelts did not vary considerably with changes in the fish approach angle and K for any of the Orono turbines. The probability of strike for kelts was 100% for all of the conditions evaluated.

4.7.6 Bypass Efficiency and Survival

Field evaluatoions conducted by BBHP demonstrated that 13% of released smolts used the bypass, 69% passed over the spillway, and 18% were entrained through the turbines when about 71% of river discharge was passed over the spillway. Without spill, 42% of the released fish passed through the bypass and 58% through the turbines. Interestingly, if the data from tests with spill are evaluated using just the fish that either went through the bypass or the turbines, bypass efficiency is also estimated to be 42% (i.e., number of fish using bypass divided by total number using bypass and passing through turbines combined). Based on these site-specific data, smolt bypass efficiency at Orono was assumed to be 42%. Bypass efficiency of kelts at Orono was set at 100% because the bar spacing is sufficiently small (< 2.4 inches clear) to prevent entrainment of this life stage through the turbines. Direct bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.7.7 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Orono Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Section 3.1.2.

Table 4-64. Turbine survival estimates for smolts passing through Orono Unit 1.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	1.000	0.897	1.000	0.897	0.811	0.916	0.876	0.914	0.876	0.930
140	1.000	0.894	1.000	0.894	0.873	0.907	0.873	0.912	0.873	0.923
150	1.000	0.892	1.000	0.892	0.935	0.899	0.870	0.910	0.870	0.915
160	1.000	0.889	1.000	0.889	0.998	0.890	0.867	0.908	0.867	0.908
170	1.000	0.887	1.000	0.887	1.000	0.887	0.865	0.906	0.865	0.906
180	1.000	0.885	1.000	0.885	1.000	0.885	0.862	0.904	0.862	0.904
190	1.000	0.883	1.000	0.883	1.000	0.883	0.860	0.903	0.860	0.903
200	1.000	0.881	1.000	0.881	1.000	0.881	0.858	0.901	0.858	0.901
210	1.000	0.880	1.000	0.880	1.000	0.880	0.856	0.900	0.856	0.900

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-65. Turbine survival estimates for smolts passing through Orono Unit 2.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	1.000	0.915	1.000	0.915	0.897	0.924	0.898	0.929	0.898	0.937
140	1.000	0.913	1.000	0.913	0.966	0.916	0.895	0.927	0.895	0.930
150	1.000	0.911	1.000	0.911	1.000	0.911	0.893	0.926	0.893	0.926
160	1.000	0.909	1.000	0.909	1.000	0.909	0.891	0.924	0.891	0.924
170	1.000	0.907	1.000	0.907	1.000	0.907	0.889	0.923	0.889	0.923
180	1.000	0.906	1.000	0.906	1.000	0.906	0.887	0.921	0.887	0.921
190	1.000	0.904	1.000	0.904	1.000	0.904	0.885	0.920	0.885	0.920
200	1.000	0.903	1.000	0.903	1.000	0.903	0.883	0.919	0.883	0.919
210	1.000	0.901	1.000	0.901	1.000	0.901	0.881	0.918	0.881	0.918

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-66. Turbine survival estimates for smolts passing through Orono units 3 and 4.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length1				Turbine Passage Survival for Modified K2		Compounded Turbine Passage Survival Estimate3	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.852	0.881	1.000	0.860	0.499	0.930	0.857	0.901	0.832	0.942
140	0.917	0.868	1.000	0.856	0.537	0.923	0.842	0.890	0.828	0.936
150	0.983	0.855	1.000	0.853	0.575	0.915	0.827	0.880	0.824	0.929
160	1.000	0.850	1.000	0.850	0.614	0.908	0.820	0.875	0.820	0.923
170	1.000	0.847	1.000	0.847	0.652	0.900	0.816	0.872	0.816	0.917
180	1.000	0.844	1.000	0.844	0.690	0.892	0.813	0.870	0.813	0.910
190	1.000	0.842	1.000	0.842	0.729	0.885	0.810	0.868	0.810	0.904
200	1.000	0.839	1.000	0.839	0.767	0.877	0.807	0.866	0.807	0.897
210	1.000	0.837	1.000	0.837	0.805	0.869	0.804	0.864	0.804	0.890

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-67. Turbine survival estimates for kelts passing through Orono Unit 1.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.840	1.000	0.840	1.000	0.840	0.808	0.866	0.808	0.866
675	1.000	0.838	1.000	0.838	1.000	0.838	0.806	0.865	0.806	0.865
700	1.000	0.837	1.000	0.837	1.000	0.837	0.804	0.864	0.804	0.864
725	1.000	0.836	1.000	0.836	1.000	0.836	0.803	0.863	0.803	0.863
750	1.000	0.835	1.000	0.835	1.000	0.835	0.801	0.862	0.801	0.862
775	1.000	0.833	1.000	0.833	1.000	0.833	0.800	0.861	0.800	0.861
800	1.000	0.832	1.000	0.832	1.000	0.832	0.799	0.860	0.799	0.860

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-68. Turbine survival estimates for kelts passing through Orono Unit 2.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.868	1.000	0.868	1.000	0.868	0.842	0.890	0.842	0.890
675	1.000	0.867	1.000	0.867	1.000	0.867	0.841	0.889	0.841	0.889
700	1.000	0.866	1.000	0.866	1.000	0.866	0.839	0.888	0.839	0.888
725	1.000	0.865	1.000	0.865	1.000	0.865	0.838	0.888	0.838	0.888
750	1.000	0.864	1.000	0.864	1.000	0.864	0.837	0.887	0.837	0.887
775	1.000	0.863	1.000	0.863	1.000	0.863	0.836	0.886	0.836	0.886
800	1.000	0.862	1.000	0.862	1.000	0.862	0.835	0.885	0.835	0.885

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-69. Turbine survival estimates for kelts passing through Orono units 3 and 4.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.783	1.000	0.783	1.000	0.783	0.739	0.819	0.739	0.819
675	1.000	0.781	1.000	0.781	1.000	0.781	0.737	0.817	0.737	0.817
700	1.000	0.779	1.000	0.779	1.000	0.779	0.735	0.816	0.735	0.816
725	1.000	0.777	1.000	0.777	1.000	0.777	0.733	0.814	0.733	0.814
750	1.000	0.776	1.000	0.776	1.000	0.776	0.731	0.813	0.731	0.813
775	1.000	0.774	1.000	0.774	1.000	0.774	0.729	0.812	0.729	0.812
800	1.000	0.773	1.000	0.773	1.000	0.773	0.727	0.811	0.727	0.811

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.7.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Orono Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Section 3.2.

4.7.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 80.9 to 91.2% across the range of average monthly flows likely to occur at Orono (Table 4-70; Figure 4-19), with a mean of 89.4%. At low river discharges (i.e., no spill), smolt survival fluctuates slightly as turbines come on line and alternate between partial and full load. After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival gradually increases to a peak at the highest discharge (Figure 4-19). Mean, minimum, and maximum total project survival for kelts was similar among months and did not vary considerably with flow (Table 4-70; Figure 4-20). The anrrow range of survival for kelts is mainly due to this life stage being completely excluded from turbine passage at Orono by the bar spacing (< 2.5 inches), leaving spillway and bypass passage as the only sources of mortality.

Table 4-70. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Orono Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

.	River Flow	Smolts			Kelts		
Month	**Range (cfs)**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
April	4365 - 23335	--	--	--	0.925	0.923	0.933
May	1940 - 24680	0.894	0.809	0.912	0.927	0.923	0.941
November	770 - 17310	--	--	--	0.929	0.924	0.941

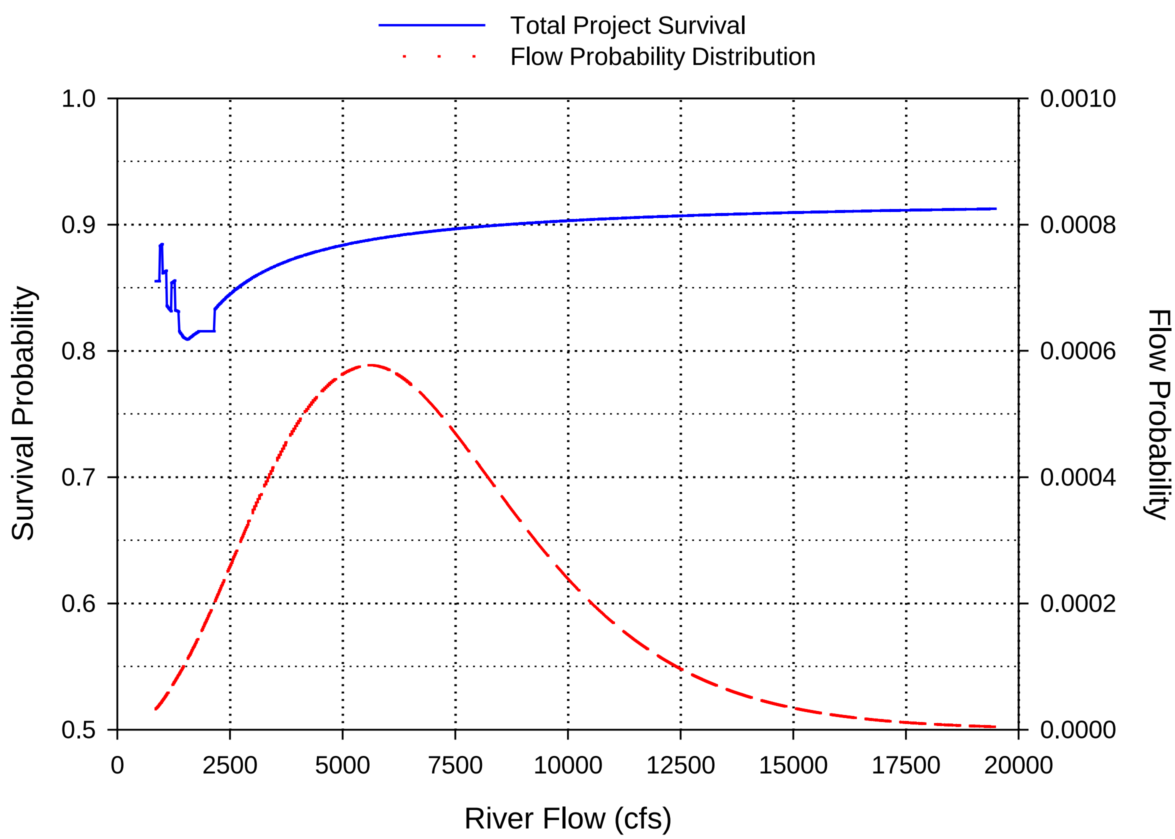

Figure 4-19. Total project survival for smolts and the flow probability distribution for May at the Orono Project. Flow probabilities were estimated and plotted in 5 cfs increments.

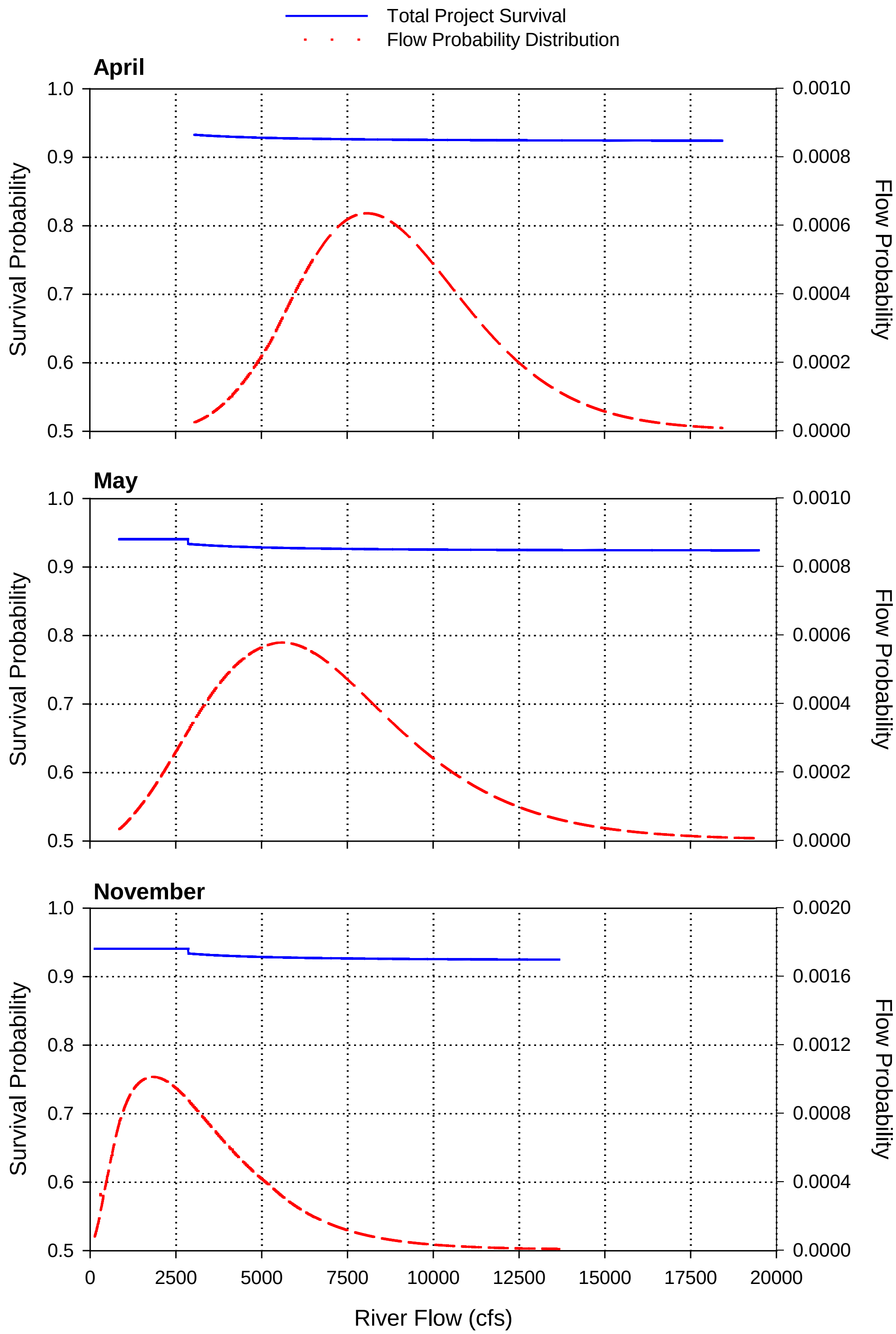

Figure 4-20. Total project survival for kelts and flow probability distributions for April, May, and November at the Orono Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.8 Orono (FERC No. P-2710) – Proposed Turbine Upgrade Configuration

As part of the agreement that established the Penobscot Rive Restoration Program, the Orono Project has been upgraded with the installation of three additional turbines (Units 5, 6 and 7). Section 4.7 provides data for the survival of smolts and kelts passing downstream at Orono under the original turbine configuration (Units 1 through 4) prior to the addition of the three new units. This section presents the analysis of downstream passage survival with the new turbines installed, including design information and turbine passage survival rates for the these units. Section 4.7 should be referenced for general information describing the Orono Project and for turbine survival rates associated with fish entrainment through the original turbines (Units 1 through 4). The total passage survival rates estimated for smolts and kelts with the new turbine configuration also account for the installation of full depth 1-inch spaced bar racks.

Due to sufficient information provided by the project owner and manufacturer, design parameter estimation was not required for Orono Units 5, 6 and 7. Based on a review of the design parameters (Table 4-71), no modifications or adjustments to any of the data were considered necessary.

Table 4-71. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Orono units 5, 6 and 7.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Kaplan	--
Flow (cfs)	694	--
Runner Diameter (ft)	5.6	--
Turbine speed (rpm)	300	--
Number Blades	4	--
Wicket Gate Angle (deg)	60	--
Leading Edge Blade Thickness (mm)	11.2	--

4.8.1 Turbine Passage Survival Estimates

Strike probabilities and turbine survival estimates for Atlantic salmon passing through the new turbines are presented in Table 4-72 for smolts and Table 4-73 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and survival estimates for smolts did not vary considerably with changes in fish radial length (approach angle) and/or K for Orono Units 1, 2, 3, 4, 5, 6, and 7. For Units 1, 2, 3, and 4 this was due, in part, to strike probabilities of 100% for the baseline conditions and for most fish lengths analyzed with modified approach angles. Similar to smolts, strike and survival probabilities for kelts did not vary considerably with changes in the fish approach angle and K for any of the Orono turbines.

4.8.2 Bypass Efficiency and Survival

The installation of full depth 1-inch spaced bar racks is part of the new turbine configuration at Orono. Therefore, bypass efficiencies were estimated to be 50% for smolts and 100% for kelts, with direct bypass survival for both life stages set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.8.3 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Orono Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Section 3.1.2.

Table 4-72. Turbine survival estimates for smolts passing through Orono units 5, 6 and 7.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length1				Turbine Passage Survival for Modified K2		Compounded Turbine Passage Survival Estimate3	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.218	0.858	0.237	0.846	0.193	0.875	0.830	0.882	0.815	0.895
140	0.235	0.847	0.255	0.834	0.208	0.865	0.817	0.873	0.801	0.887
150	0.252	0.836	0.273	0.822	0.223	0.855	0.804	0.864	0.787	0.879
160	0.269	0.825	0.291	0.811	0.237	0.846	0.791	0.855	0.773	0.871
170	0.285	0.815	0.310	0.799	0.252	0.836	0.777	0.845	0.759	0.863
180	0.302	0.804	0.328	0.787	0.267	0.826	0.764	0.836	0.744	0.855
190	0.319	0.793	0.346	0.775	0.282	0.817	0.751	0.827	0.730	0.847
200	0.336	0.782	0.364	0.763	0.297	0.807	0.738	0.818	0.716	0.839
210	0.352	0.771	0.382	0.751	0.312	0.797	0.725	0.809	0.702	0.831

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-73. Turbine survival estimates for kelts passing through Orono units 5, 6 and 7.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.350	1.000	0.350	0.965	0.373	0.220	0.458	0.220	0.477
675	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
700	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
725	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
750	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
775	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
800	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.8.4 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Orono Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Section 3.2.

4.8.5 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts with the new turbines installed is expected to range from 84.7 to 91.0% across the range of average monthly flows likely to occur at Orono (Table 4-74; Figure 4-21), with a mean of 89.3%. Over most of the river flow range, smolt survival rates were slightly lower with the new turbines compared to the original configuration. Differences in smolt survival between the existing and upgraded conditions at Orono are due to less entrainment following the installation of full depth 1-inch bar spacing and changes in how flow is split between the Stillwater and mainstem branches following the generation upgrades. However, similar to the orginal configuration, after all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival with the new turbines gradually increases to a peak at the highest discharge (Figure 4-21). Mean, min, and max total project survival rates for kelts did not vary considerably among the three months evaluated (Table 4-74; Figure 4-22), ranging from 92.4 to 94.1%. Mean and minimum kelt survival rates are slightly higher with the new turbine configuration due to differences in the flow distributions for the existing and upgraded conditions.

Table 4-74. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Orono Project (upgraded turbine configuration) over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

.	River Flow	Smolts			Kelts		
Month	**Range (cfs)**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
April	3930 - 21000	--	--	--	0.929	0.925	0.941
May	2955 - 25220	0.895	0.847	0.911	0.929	0.924	0.941
November	55 - 11535	--	--	--	0.935	0.928	0.941

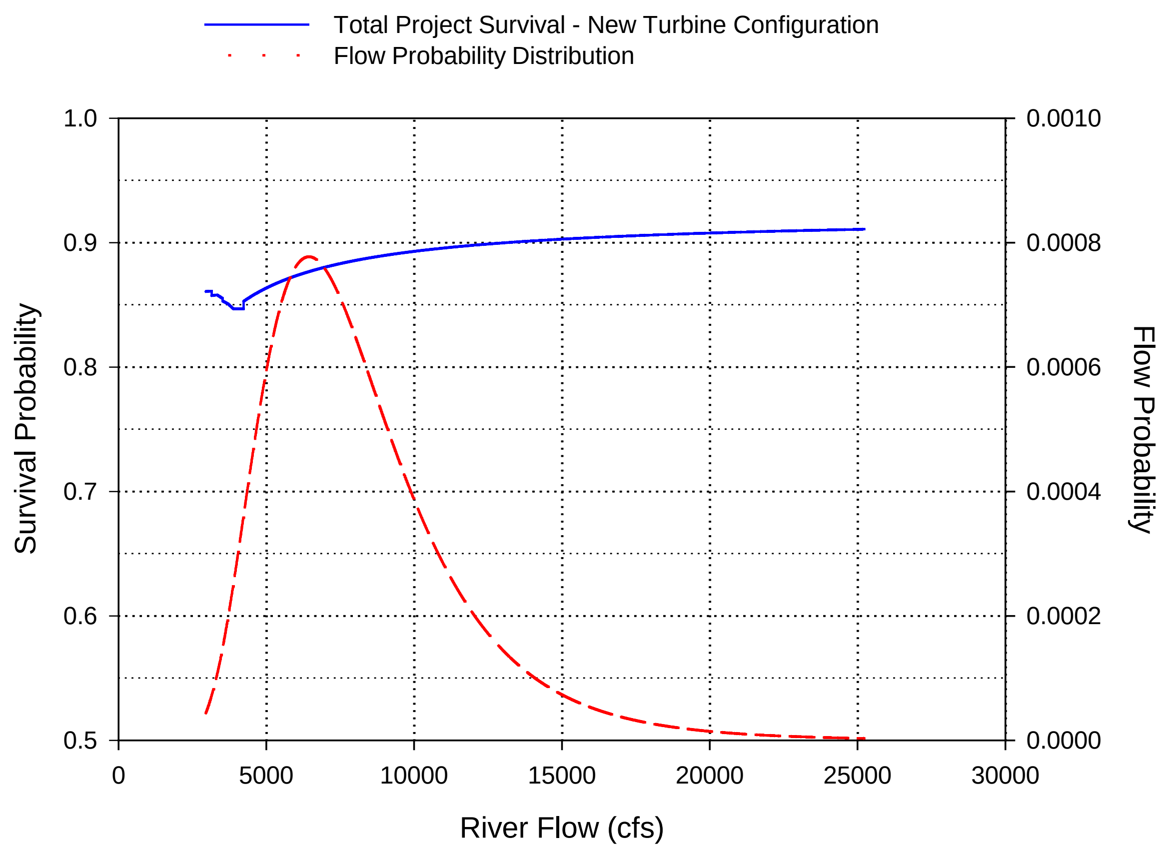

Figure 4-21. Total project survival for smolts and the flow probability distribution for May at the Orono Project with the new turbines installed. Flow probabilities were estimated and plotted in 5 cfs increments.

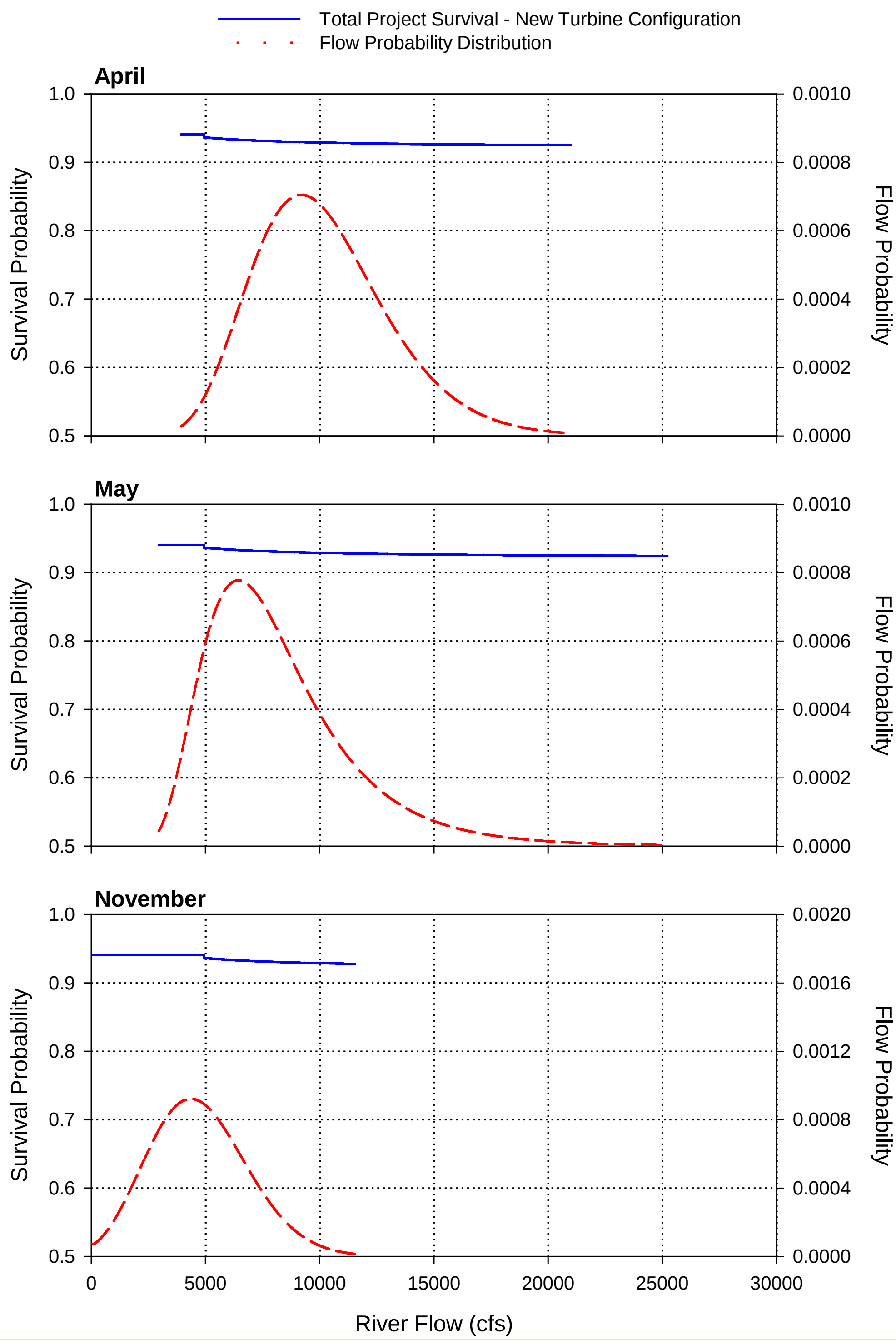

Figure 4-22. Total project survival for kelts and flow probability distributions for April, May, and November at the Orono Project with the new turbines installed. Flow probabilities were estimated and plotted in 5 cfs increments.

4.9 Stillwater (FERC No. P-2712) – Existing Turbine Configuration

The Stillwater Hydroelectric Project, owned and operated by BBHP, is located on the Stillwater Branch of the Penobscot River in the city of Old Town. An aerial view of the Stillwater Project is provided in Figure 4-23. The Veazie Project (mainstem) is located about 5 miles downstream from Stillwater, and the West Enfield Project (mainstem) is about 25 miles upstream.

The Stillwater Project is operated as a ROR facility with an estimated mean monthly flow ranging from 7,464 cfs in August to 33,959 cfs in April (Table 4-75).

Figure 4-23. Aerial view of the Stillwater Hydroelectric Project.

Table 4-75. Average monthly river discharge at the Stillwater Hydroelectric Project.

Month	Average Flow (cfs)
January	2300
February	2100
March	3400
April	10200
May	8000
June	3700
July	2100
August	1600
September	1700
October	2500
November	3900
December	3400

4.9.1 Power Generating Facilities

The Stillwater Project has four generating units with a combined generating capacity of 2.78 MW. The turbines are all horizontal paired Francis units with a combined hydraulic capacity of 1,700 cfs at a rated head of 18 ft. All four units have a wicket gate height of 18 inches, a wicket gate tail radius of 0.48 inches, a runner diameter of 3.5 ft, 14 blades, and a leading edge blade thickness of 0.48 inches. Three of the turbines have a rotational speed of 150 rpm and the fourth has a speed of 180 rpm. BBHP is proposing to increase the totaled installed capacity at the Stillwater Project to approximately 4.2 MW by constructing a second powerhouse and installing three turbine-generator units. The three new units will all be vertical axial-flow machines with a total hydraulic capacity of 586 cfs. The clear spacing of the bar racks is 1- inch to a depth of 14 ft, below which it is 2.38 inches.

4.9.2 Downstream Passage Facilities and Evaluations

The downstream passage facilities at the Stillwater Project include bar racks with 1-inch clear spacing to a depth of 14 ft and a 3-ft by 6.5-ft surface bypass gate. The new powerhouse will have a gated downstream bypass (surface and bottom gates) integral to the dam and 1-inch clear bar spacing over the full depth of the intake racks.

4.9.3 Upstream Passage Facilities

There are no upstream passage facilities at Stillwater. Upstream passage in the Stillwater Branch of the Penobscot River will be provided with the new fish trapping facility proposed for the Orono Project.

4.9.4 Turbine Design and Operations Parameters

The powerhouse contains a total of four turbine/generating units which can be categorized into two different individual types. Table 4-76 and Table 4-77 summarize the pertinent design and operational data used in the estimation of turbine passage survival rates for each turbine. Wicket gate angle was the only design parameter that needed to be estimated for the Stillwater turbines (Table 4-76, Table 4-77). Wicket gate angles for each unit were estimated from the relationship between the blade tip speed components (Table 3-3). Based on values reported in available literature and data sources, it was judged that the estimated wicket gate angle was high and, consequently, it was reduced to 35°.

As part of the ongoing Penobscot River Restoration Program, the Stillwater Project will be undergoing a generation upgrade, which will include the installation of three new turbine/generating units. The survival evaluation presented in this section is for the Stillwater Project in its existing condition. See Section 4.10 for an evaluation of the Stillwater Project in its proposed upgraded configuration.

4.9.5 Turbine Passage Survival

The results of the smolt survival predictions for the four Stillwater turbines are presented in Table 4-78 and Table 4-79 for smolts and Table 4-80 and Table 4-81 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and survival estimates for smolts did not vary considerably with changes in fish radial length and/or K for any of the four Stillwater units, indicating very little sensitivity to potential variability in these parameters. This was also true for kelts, which had strike probabilities of 100% for the baseline conditions and with the modified approach angles. Consequently, kelt survival rates only varied with changes in K, and this variation was relatively minor.

Table 4-76. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Stillwater units 1, 2, and 3.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	190	--
Runner Diameter (ft)	3.5	--
Wicket Gate Height (ft)	1.5	--
Turbine Speed (rpm)	150	--
Number Blades	14	--
Wicket Gate Angle (deg)	43[1]	35
Leading Edge Blade Thickness (mm)	12.2	--

[1] Parameter was estimated.

Table 4-77. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Stillwater unit 4.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	280	--
Runner Diameter (ft)	3.5	--
Wicket Gate Height (ft)	1.5	--
Turbine Speed (rpm)	180	--
Number Blades	14	--
Wicket Gate Angle (deg)	45[1]	35
Leading Edge Blade Thickness (mm)	12.2	--

[1] Parameter was estimated.

Table 4-78. Turbine survival estimates for smolts passing through Stillwater units 1, 2, and 3.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.743	0.993	0.916	0.991	0.548	0.995	0.992	0.994	0.992	0.996
140	0.800	0.992	0.987	0.990	0.590	0.994	0.991	0.993	0.991	0.995
150	0.858	0.991	1.000	0.990	0.632	0.994	0.990	0.993	0.990	0.995
160	0.915	0.991	1.000	0.990	0.674	0.993	0.989	0.992	0.989	0.994
170	0.972	0.990	1.000	0.990	0.716	0.993	0.988	0.992	0.988	0.994
180	1.000	0.989	1.000	0.989	0.758	0.992	0.987	0.991	0.987	0.993
190	1.000	0.989	1.000	0.989	0.800	0.991	0.987	0.991	0.987	0.993
200	1.000	0.989	1.000	0.989	0.843	0.991	0.987	0.991	0.987	0.992
210	1.000	0.989	1.000	0.989	0.885	0.990	0.987	0.991	0.987	0.992

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-79. Turbine survival estimates for smolts passing through Stillwater Unit 4.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.605	0.928	0.746	0.911	0.446	0.947	0.913	0.940	0.893	0.956
140	0.652	0.920	0.804	0.901	0.480	0.941	0.904	0.933	0.882	0.951
150	0.698	0.912	0.861	0.892	0.515	0.935	0.895	0.927	0.870	0.946
160	0.745	0.905	0.918	0.882	0.549	0.930	0.885	0.920	0.859	0.941
170	0.791	0.897	0.976	0.872	0.583	0.924	0.876	0.914	0.847	0.936
180	0.838	0.889	1.000	0.867	0.617	0.918	0.866	0.907	0.840	0.932
190	0.885	0.880	1.000	0.865	0.652	0.912	0.856	0.900	0.838	0.927
200	0.931	0.872	1.000	0.863	0.686	0.906	0.847	0.893	0.835	0.921
210	0.978	0.864	1.000	0.861	0.720	0.900	0.837	0.886	0.833	0.916

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-80. Turbine survival estimates for kelts passing through Stillwater units 1, 2, and 3.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.985	1.000	0.985	1.000	0.985	0.982	0.988	0.982	0.988
675	1.000	0.985	1.000	0.985	1.000	0.985	0.982	0.988	0.982	0.988
700	1.000	0.985	1.000	0.985	1.000	0.985	0.982	0.988	0.982	0.988
725	1.000	0.985	1.000	0.985	1.000	0.985	0.982	0.987	0.982	0.987
750	1.000	0.985	1.000	0.985	1.000	0.985	0.982	0.987	0.982	0.987
775	1.000	0.985	1.000	0.985	1.000	0.985	0.982	0.987	0.982	0.987
800	1.000	0.985	1.000	0.985	1.000	0.985	0.981	0.987	0.981	0.987

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-81. Turbine survival estimates for kelts passing through Stillwater Unit 4.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.814	1.000	0.814	1.000	0.814	0.777	0.845	0.777	0.845
675	1.000	0.813	1.000	0.813	1.000	0.813	0.775	0.844	0.775	0.844
700	1.000	0.811	1.000	0.811	1.000	0.811	0.774	0.843	0.774	0.843
725	1.000	0.810	1.000	0.810	1.000	0.810	0.772	0.842	0.772	0.842
750	1.000	0.809	1.000	0.809	1.000	0.809	0.770	0.840	0.770	0.840
775	1.000	0.807	1.000	0.807	1.000	0.807	0.769	0.839	0.769	0.839
800	1.000	0.806	1.000	0.806	1.000	0.806	0.767	0.838	0.767	0.838

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.9.6 Bypass Efficiency and Survival

Downstream passage studies have not been conducted at the Stillwater Project. Therefore, bypass efficiency for smolts was assumed to be 40% based on available data from studies conducted at Mattaceunk and Orono, which have bar spacing configurations that are the same (Orono) or similar (Mattaceunk) to Stillwater (i.e., 1-inch clear on the upper portion of intake racks). The clear bar spacing (< 2.5 inches) at Stillwater is considered sufficient to prevent kelt entrainment through the turbines, resulting in 100% bypass efficiency for this life stage. Bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.9.7 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Stillwater Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Sections 3.1.2.

4.9.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Stillwater Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Sections 3.2.

4.9.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 88.1 to 92.1% across the range of average monthly flows likely to occur at Stillwater (Table 4-82; Figure 4-24), with a mean of 91.9%. Predicted smolt survival rates fluctuate slightly at lower river flows as turbines come on line and alternate between partial and full load. After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival gradually increases to a peak at the highest discharge (Figure 4-24). Mean, minimum, and maximum total project survival for kelts was similar among months and did not vary considerably with flow (Table 4-82; Figure 4-25). The narrow range of survival for kelts is mainly due to this life stage being completely excluded from turbine passage at Stillwater by the bar spacing (< 2.5 inches), leaving spillway and bypass passage as the only sources of mortality.

Table 4-82. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Stillwater Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	4365 - 23335	--	--	--	0.926	0.923	0.941
May	1940 - 24680	0.918	0.881	0.921	0.927	0.923	0.941
November	770 - 17310	--	--	--	0.930	0.924	0.941

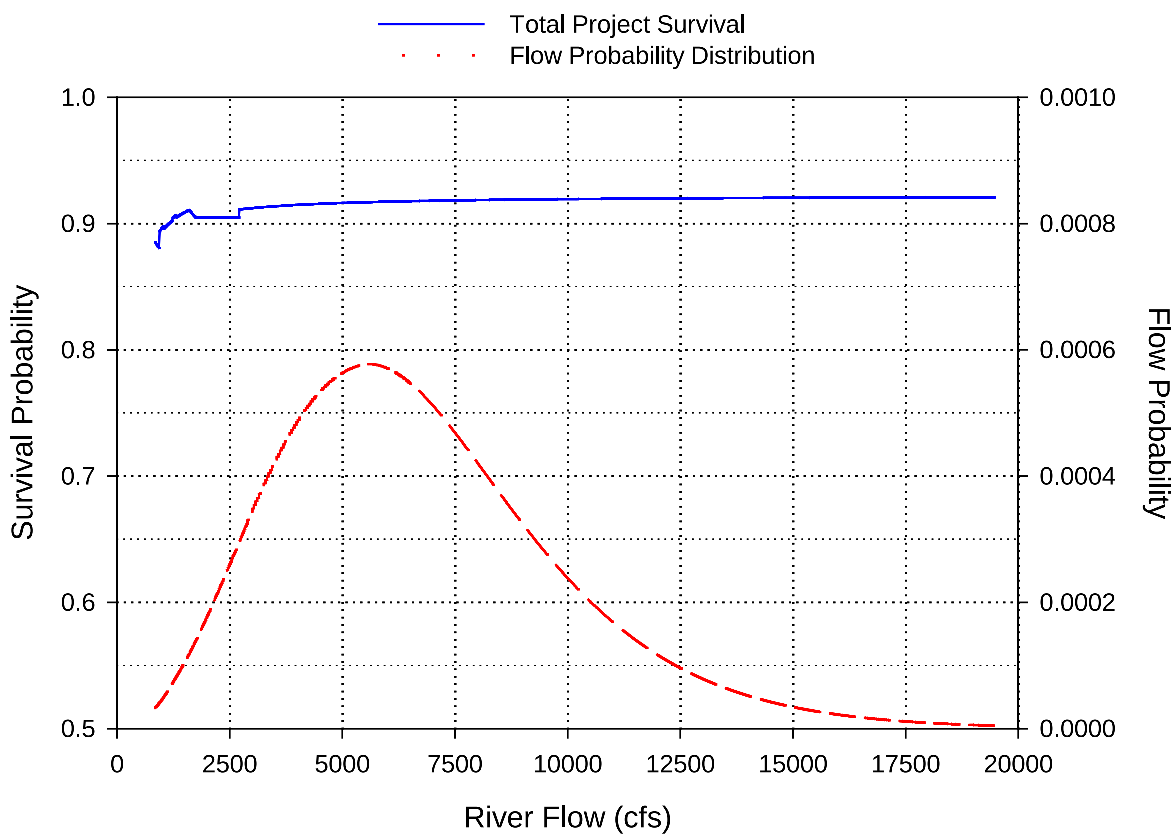

Figure 4-24. Total project survival for smolts and the flow probability distribution for May at the Stillwater Project. Flow probabilities were estimated and plotted in 5 cfs increments.

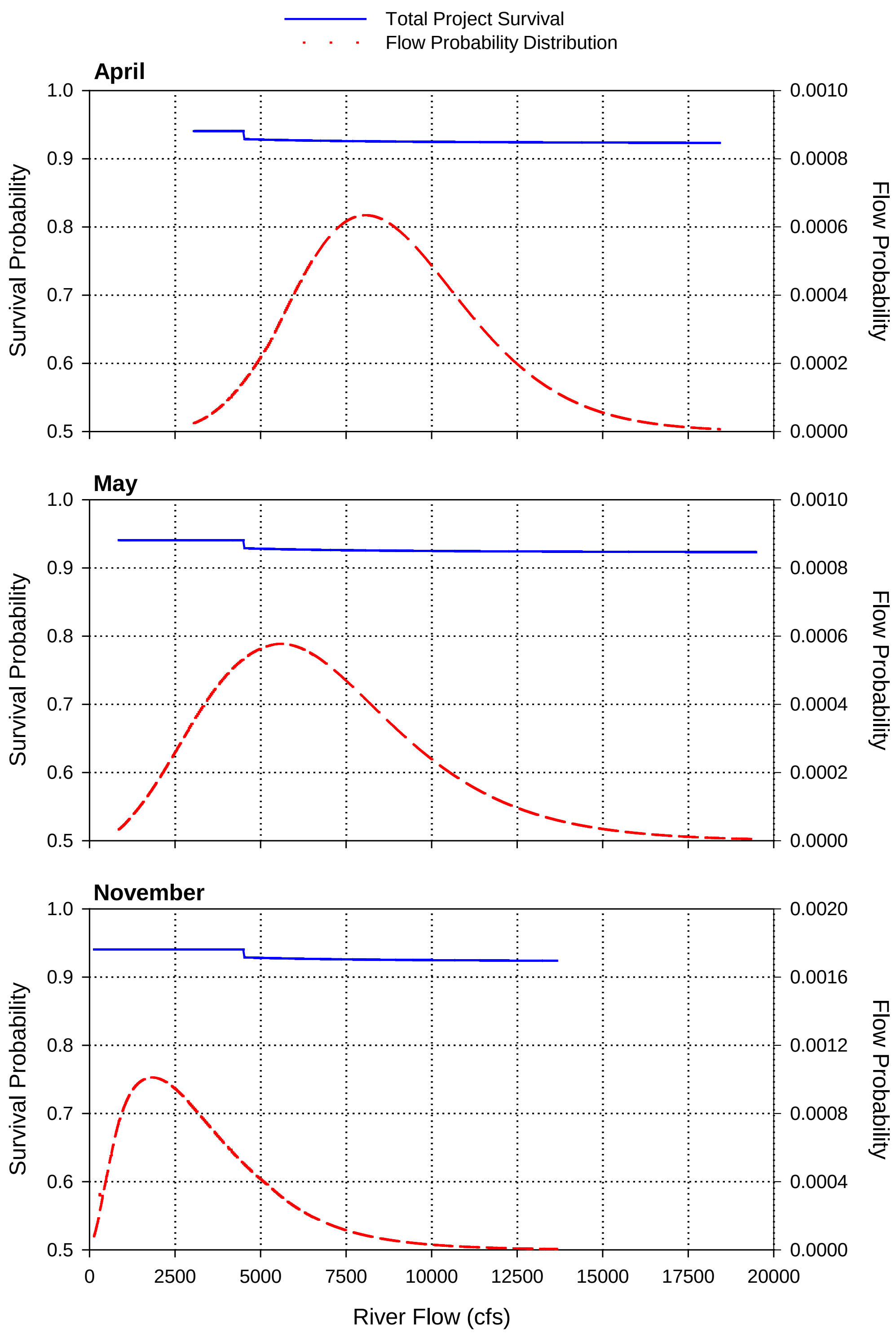

Figure 4-25. Total project survival for kelts and flow probability distributions for April, May, and November at the Stillwater Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.10 Stillwater (FERC No. P-2712) – Proposed Turbine Upgrade Configuration

As part of the agreement that established the Penobscot Rive Restoration Program, the Milford Project has been upgraded with the installation of three additional turbines (Units 5, 6 and 7). Section 4.9 provides data for the survival of smolts and kelts passing downstream at Stillwater under the original turbine configuration (Units 1 through 4) prior to the addition of the three new units. This section presents the analysis of downstream passage survival with the new turbines installed, including design information and turbine passage survival rates for the these units. Section 4.9 should be referenced for general information describing the Stillwater Project and for turbine survival rates associated with fish entrainment through the original turbines (Units 1 through 4). The total passage survival rates estimated for smolts and kelts with the new turbine configuration also account for the installation of full depth 1-inch spaced bar racks.

Due to sufficient information provided by the project owner and manufacturer, design parameter estimation was not required for Stillwater Units 5, 6 and 7. Based on a review of the design parameters (Table 4-83), no modifications or adjustments to any of the data were considered necessary.

Table 4-83. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through proposed Stillwater units 5, 6, and 7.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Kaplan	--
Flow (cfs)	586	--
Runner Diameter (ft)	5.6	--
Turbine Speed (rpm)	257	--
Number Blades	4	--
Wicket Gate Angle (deg)	60	--
Leading Edge Blade Thickness (mm)	11.2	--

4.10.1 Turbine Passage Survival Estimates

Strike probabilities and turbine survival estimates for Atlantic salmon passing through the new turbines are presented in Table 4-84 for smolts and Table 4-85 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and survival estimates for smolts did not vary considerably with changes in fish radial length and/or K for any of the four Stillwater units, indicating very little sensitivity to potential variability in these parameters. This was also true for kelts, which had strike probabilities close to 100% for the majority of the baseline conditions and with the modified approach angles. Consequently, kelt survival rates only varied with changes in K and this variation was relatively minor.

4.10.2 Bypass Efficiency and Survival

The installation of full depth 1-inch spaced bar racks is part of the new turbine configuration at Stillwater. Therefore, bypass efficiencies were estimated to be 50% for smolts and 100% for kelts, with direct bypass survival for both life stages set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.10.3 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Stillwater Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Sections 3.1.2.

4.10.4 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Stillwater Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Section 3.2.

Table 4-84. Turbine survival estimates for smolts passing through Stillwater Units 5, 6, and 7.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.221	0.856	0.240	0.844	0.196	0.873	0.827	0.880	0.813	0.894
140	0.238	0.845	0.259	0.832	0.211	0.863	0.814	0.871	0.798	0.886
150	0.255	0.834	0.277	0.820	0.226	0.853	0.801	0.862	0.784	0.878
160	0.272	0.823	0.296	0.808	0.241	0.843	0.788	0.852	0.769	0.869
170	0.289	0.812	0.314	0.796	0.256	0.834	0.774	0.843	0.755	0.861
180	0.306	0.801	0.333	0.784	0.271	0.824	0.761	0.834	0.741	0.853
190	0.323	0.790	0.351	0.772	0.286	0.814	0.748	0.825	0.726	0.845
200	0.340	0.779	0.369	0.760	0.301	0.804	0.734	0.816	0.712	0.837
210	0.358	0.768	0.388	0.748	0.316	0.794	0.721	0.806	0.697	0.829

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-85. Turbine survival estimates for kelts passing through Stillwater Units 5, 6, and 7.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.350	1.000	0.350	0.979	0.364	0.220	0.458	0.220	0.470
675	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
700	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
725	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
750	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
775	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458
800	1.000	0.350	1.000	0.350	1.000	0.350	0.220	0.458	0.220	0.458

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.10.5 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts with the new turbines installed is expected to range from 87.4 to 91.7% across the range of average monthly flows likely to occur at Stillwater (Table 4-86; Figure 4-26), with a mean of 90.9%. Despite less turbine entrainment with full depth 1-inch clear bar spacing, smolts survival rates were lower with the new turbines installed compared to the original configuration. This is mainly due to less flow being allocated to the Stillwater Branch following the turbine upgrades, which reduces spillway flows and subsequent fish passage via this route (i.e., a greater proportion of smolts are entrained through the turbines with the lower flows). Similar to the original configuration, after all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival with the new turbines gradually increases to a peak at the highest discharge (Figure 4-26). Mean, min, and max total project survival for kelts did not vary considerably among the three months evaluated, ranging from 92.4 to 94.1% (Table 4-86; Figure 4-27). Kelt survival rates are slightly higher with the new turbine configuration, mainly due to less spillway flow with the upgraded conditions. Less spillway flow results in a greater proportion of downstream migrating fish passing through the bypass (where survival is higher) relative to the spillway (the bar rack spacing for both the existing and upgraded conditions is sufficiently narrow to prevent turbine entainment of kelts).

Table 4-86. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Stillwater Project (upgraded turbine configuration) over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	3930 - 21000	--	--	--	0.928	0.925	0.941
May	2955 - 25220	0.909	0.874	0.917	0.928	0.924	0.941
November	55 - 11535	--	--	--	0.934	0.927	0.941

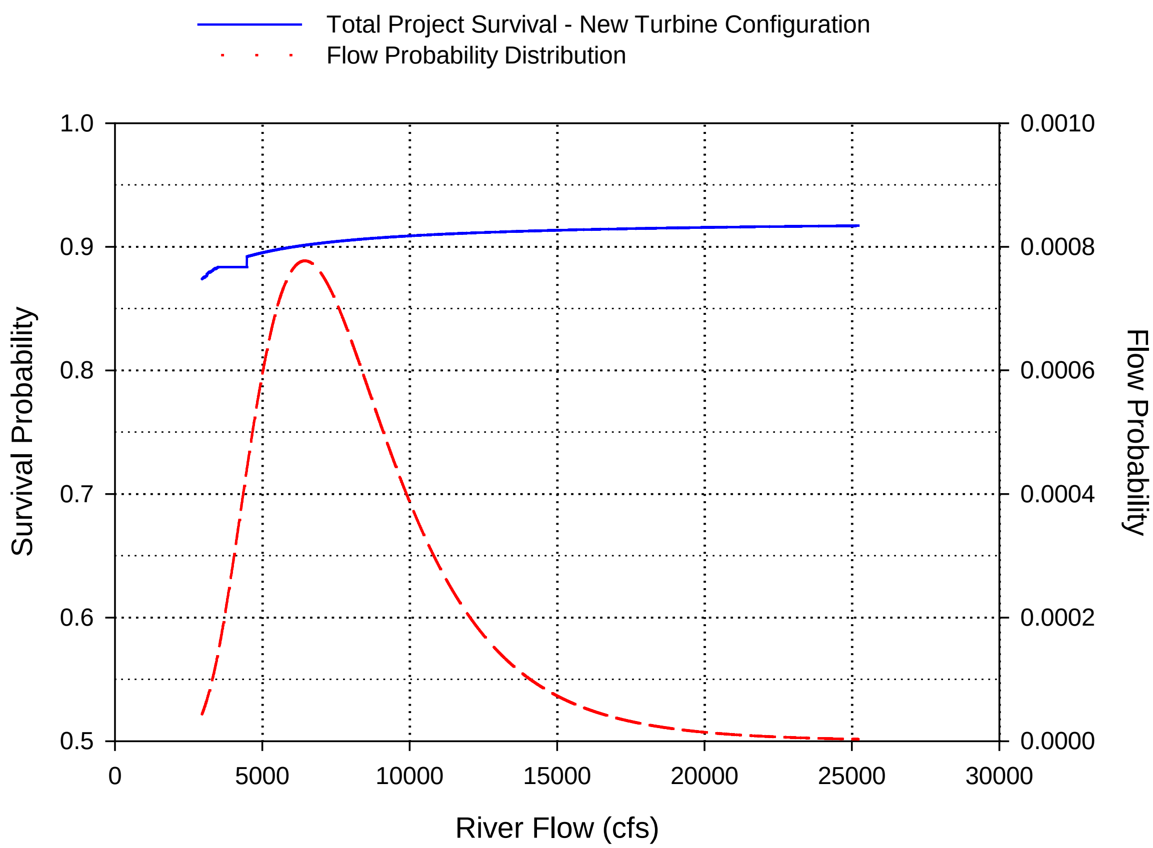

Figure 4-26. Total project survival for smolts and the flow probability distribution for May at the Stillwater Project with the new turbines installed. Flow probabilities were estimated and plotted in 5 cfs increments.

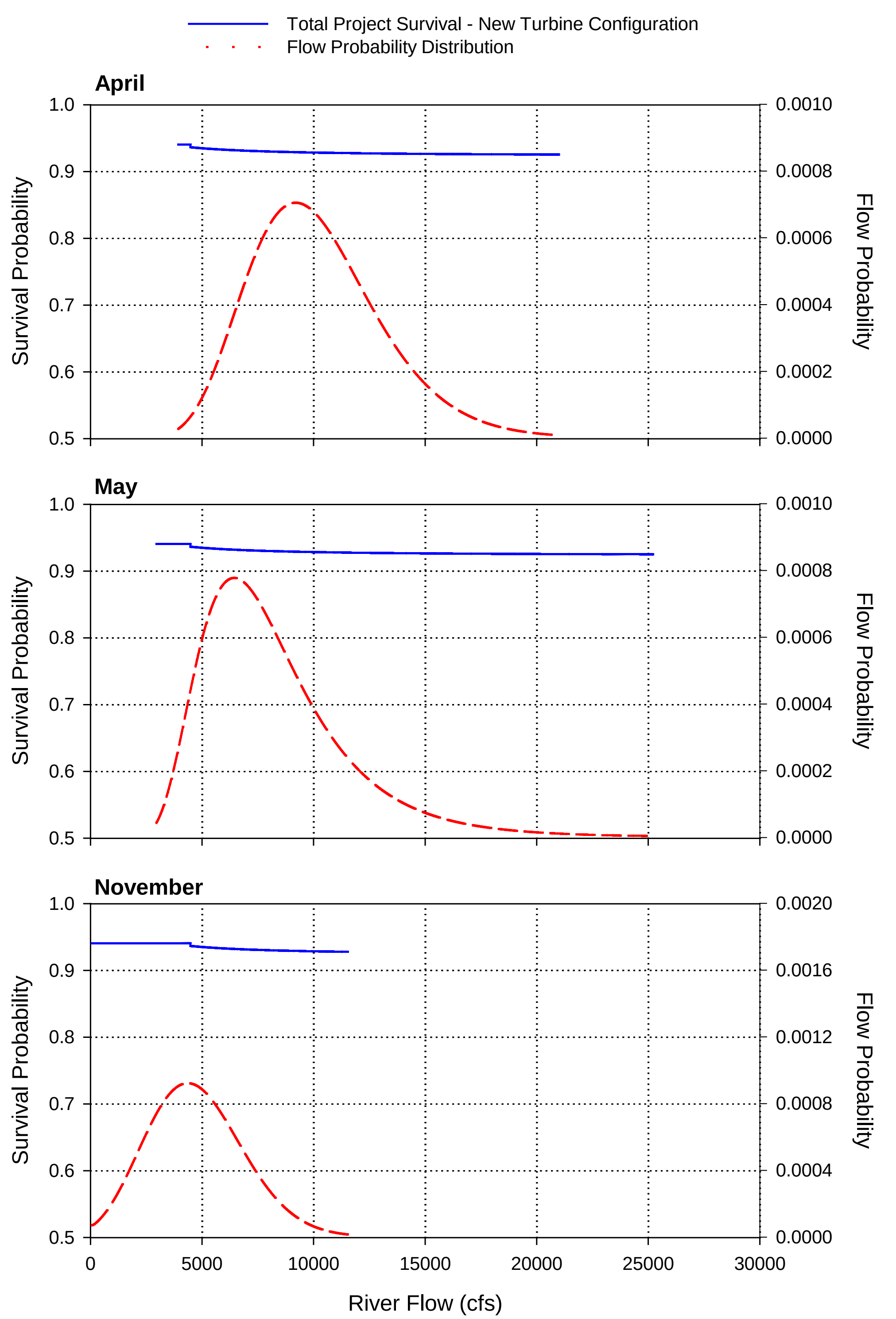

Figure 4-27. Total project survival for kelts and flow probability distributions for April, May, and November at the Orono Project with the new turbines installed. Flow probabilities were estimated and plotted in 5 cfs increments.

4.11 Medway (FERC No. P-2666)

The Medway Hydroelectric Project is located at river mile 0.5 on the West Branch Penobscot River in Medway. An aerial view of the Medway Project is provided in Figure 4-28. The West Branch of the Penobscot River encompasses about 26% of the total Penobscot River basin area.

Medway is a ROR facility with an estimated mean monthly flow ranging from 3,438 cfs in August to 4,190 cfs in April (Table 4-87).

4.11.1 Power Generating Facilities

The Medway Project works consists of a 343-ft gravity dam topped with 5.75-ft flashboards, an impoundment elevation of 260.3 ft with flashboards in place, a 64-ft concrete gravity forebay wall, and a powerhouse containing five turbine generating units. The turbines have a combined generating capacity of 3.44 MW (with an additional 0.7 proposed). The turbines are vertical Francis units with a combined hydraulic capacity of about 3,450 cfs at rated head of 19.6 ft. All five turbines are 8.71 ft in diameter and have a wicket gate height of 39 inches, a wicket gate tail radius of 0.48 inches, 16 blades, a leading edge blade thickness of 0.48 inches, and a rotational speed of 100 rpm. The clear spacing of the intake bar racks at Medway is 2.25 inches.

Figure 4-28. Aerial view of the Medway Hydroelectric Project.

Table 4-87. Average monthly river discharge at the Medway Hydroelectric Project.

Month	Average Flow (cfs)
January	3,388
February	3,288
March	3,388
April	4,190
May	5,764
June	4,430
July	3,518
August	3,438
September	3,298
October	3,338
November	3,568
December	3,428

4.11.2 Downstream Passage Facilities and Evaluations

There currently are no downstream passage facilities for anadromous fish at the Medway Project. However, a downstream bypass is operated for eels during fall months and is available for kelt passage in November. No information was obtained that indicated downstream passage effectiveness studies for smolts or kelts have been conducted at the Medway Project.

4.11.3 Upstream Passage Facilties

Upstream fish passage facilities have not been installed at the Medway Project.

4.11.4 Turbine Dersign and Operation Parameters

The Medway powerhouse has five turbine/generating units which can be categorized into a single turbine type. Table 4-88 summarizes the pertinent design and operational data used in the estimation of turbine passage survival rates for the Medway turbines. The Wicket gate angle was the only design parameter that needed to be estimated for Medway turbines (Table 4-88). The wicket gate angle was estimated from the relationship between the blade tip speed components (Table 3-3). Based on a review of available literature and data, modifications or adjustments to the acquired and estimated parameters were not considered necessary.

4.11.5 Turbine Passage Survival

The results of the survival predictions for the Medway turbines are presented in Table 4-89 (smolts) and Table 4-90 (kelts). In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and survival estimates for smolts did not vary considerably when changes in fish radial length (approach angle) and K were examined separately for the Medway turbines. However, survival estimates were moderately sensitive to changes in these parameters when they were varied together. The range in survival estimates also increased with fish length when the two parameters were varied separately and together. These observations were also evident for estimates of kelt survival.

Table 4-88. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Medway units 1, 2, 3, 4, and 5.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	690	--
Runner Diameter (ft)	8.7	--
Wicket Gate Height (ft)	3.3	--
Turbine Speed (rpm)	100	--
Number Blades	16	--
Wicket Gate Angle (deg)	16[1]	--
Leading Edge Blade Thickness (mm)	12.2	--

[1] Parameter was estimated.

Table 4-89. Turbine survival estimates for smolts passing through Medway units 1, 2, 3, and 4.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.392	0.951	0.631	0.920	0.141	0.982	0.941	0.959	0.904	0.985
140	0.422	0.945	0.680	0.912	0.152	0.980	0.934	0.955	0.894	0.984
150	0.452	0.940	0.728	0.904	0.162	0.979	0.928	0.950	0.884	0.982
160	0.482	0.935	0.777	0.895	0.173	0.977	0.922	0.946	0.874	0.980
170	0.513	0.929	0.826	0.886	0.184	0.975	0.915	0.941	0.864	0.979
180	0.543	0.924	0.874	0.877	0.195	0.973	0.909	0.937	0.853	0.977
190	0.573	0.918	0.923	0.869	0.206	0.971	0.902	0.932	0.842	0.976
200	0.603	0.913	0.971	0.859	0.217	0.969	0.895	0.927	0.831	0.974
210	0.633	0.907	1.000	0.853	0.227	0.967	0.888	0.923	0.824	0.972

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-90. Turbine survival estimates for kelts passing through Medway units 1, 2, 3, and 4.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.804	1.000	0.804	0.704	0.862	0.765	0.837	0.765	0.885
675	1.000	0.803	1.000	0.803	0.731	0.856	0.763	0.836	0.763	0.880
700	1.000	0.801	1.000	0.801	0.758	0.849	0.761	0.834	0.761	0.874
725	1.000	0.800	1.000	0.800	0.785	0.843	0.760	0.833	0.760	0.869
750	1.000	0.798	1.000	0.798	0.812	0.836	0.758	0.832	0.758	0.863
775	1.000	0.797	1.000	0.797	0.839	0.829	0.756	0.831	0.756	0.858
800	1.000	0.795	1.000	0.795	0.866	0.823	0.755	0.830	0.755	0.852

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.11.6 Bypass Efficiency and Survival

Downstream passage facilities for anadromous species have not been installed at the Medway Project. However, a downstream bypass for silver American eels is operated during the fall and is assumed to be suitable for kelt passage in November. Based on the clear spacing of the Medway bar racks (2.25 inches), it was assumed that bypass efficiency was 25% for smolts. For kelts, the bar rack spacing is sufficiently narrow to completely prevent turbine entrainment. Consequently, kelts must pass over the spillway during April and May and over the spillway or through the eel bypass in November. Direct survival for kelts using the eel bypass in November was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.11.7 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Medway Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Sections 3.1.2.

4.11.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Medway Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Sections 3.2.

4.11.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 88.4 to 91.9% across the range of average monthly flows likely to occur at Medway (Table 4-91; Figure 4-29), with a mean of 91.2%. Predicted smolt survival rates fluctuate slightly at lower river flows as turbines come on line and alternate between partial and full load. After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival gradually increases to a peak at the highest discharge (Figure 4-27). Mean total project survival for kelts was highest in November (93.2%) (Table 4-91; Figure 4-27). Because a downsream bypass is not available to kelts in April and May, lack of adequate spill resulted in no viable outlet for kelts for the low river discharges during these months. Consequently, the minimum survival for kelts was set at 0% in April and May for the lower river discharges when there was not available downstream passage route (kelts are excluded by from turbine entrainment at Medwa by the 2.25 inch bar rack spacing). When sufficient flow over the spillway occurred in April and May, total passage survival was 92.2% for kelts (Figure 4-27).

Table 4-91. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Medway Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	2140 - 9895	--	--	--	0.609	0.000	0.922
May	2065 - 39995	0.912	0.884	0.919	0.856	0.000	0.922
November	2245 - 12725	--	--	--	0.932	0.927	0.941

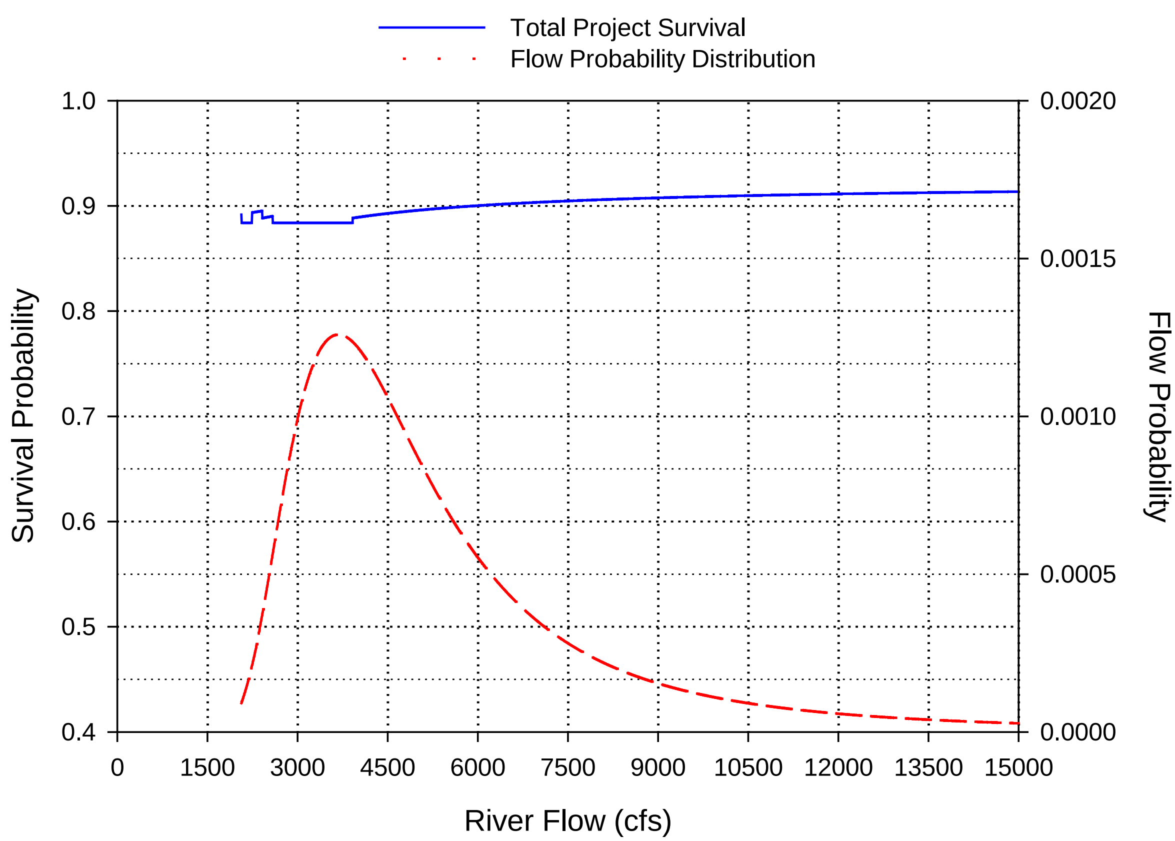

Figure 4-29. Total project survival for smolts and the flow probability distribution for May at the Medway Project. Flow probabilities were estimated and plotted in 5 cfs increments.

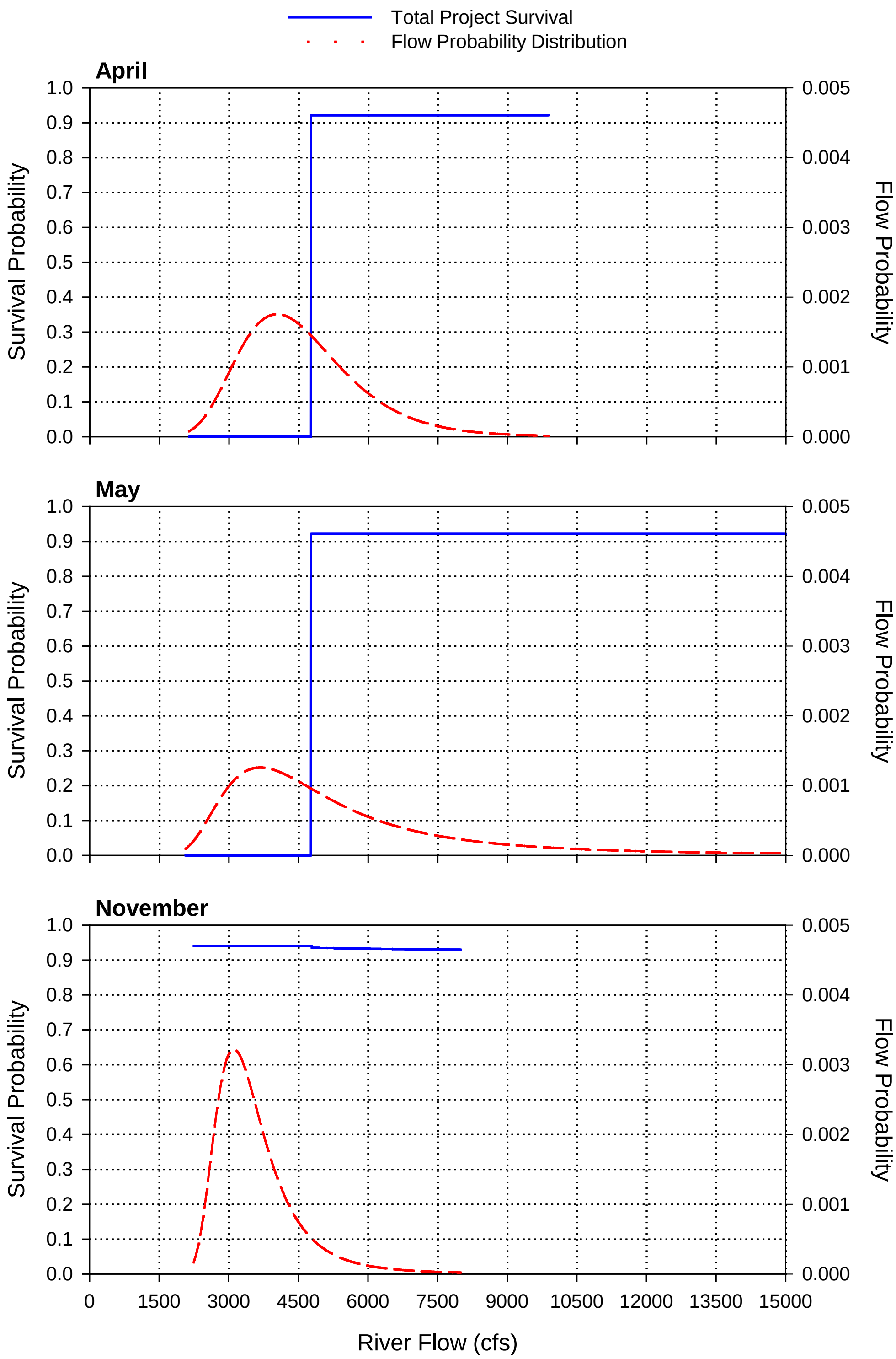

Figure 4-30. Total project survival for kelts and flow probability distributions for April, May, and November at the Medway Project. Flow probabilities were estimated and plotted in 5 cfs increments. A downstream bypass operated for American eels was assumed to be used by kelts in November.

4.12 Howland (FERC NO. 2721)

The Howland Hydroelectric Project is located approximately at river mile 2 on the Piscataquis River in Howland. An aerial view of the project is provided in Figure 4-31. The Piscataquis River Basin contributes about 17% of the Penobscot River flow passing the Howland Project. On the Main Branch of the Penobscot River, the Milford dam is located about 13 miles downstream from Howland, and the West Enfield dam is about 2 miles upstream. Upstream of the Howland Project there are three dams on the Piscataquis River and 2 dams on the Sebec River.

The Howland Project is operated as a ROR facility with an estimated mean monthly flow ranging from 1,181cfs in August to 9,410 cfs in April (Table 4-92).

4.12.1 Power Generating Facilities

The Howland Project consists of a powerhouse, an ogee spillway, and three sluice gates. Normal head pond elevation is 148.17. The powerhouse has three generating units with a combined generating capacity of 1,875 kW. The turbines are all vertical Francis units with a combined hydraulic capacity of 1,710 cfs at a rated head of 19.8 ft. All three turbines are 5.92 ft in diameter and have a wicket gate height of 19 inches, a wicket gate tail radius of 0.48 inches, 14 blades, a leading edge blade thickness of 0.48 inches, and a rotational speed of 120 rpm.

Figure 4-31. Aerial view of the Howland Hydroelectric Project.

Table 4-92. Average monthly river discharge at the Howland Hydroelectric Project.

Month	Average Flow (cfs)
January	1,884
February	1,755
March	2,956
April	9,410
May	5,989
June	2,478
July	1,432
August	1,035
September	1,181
October	2,246
November	3,58
December	3,072

4.12.2 Downstream Passage Facilities and Evaluations

Downstream fish passage was provided through operation of a 5-foot 9-inch wide trash sluice located immediately adjacent to the trash racks. This sluice was enhanced in 1993 by the addition of a 3-foot 6-inch deep bell mouth weir and new trash racks (1994) with 1-inch clear spacing. In addition, a fluorescent light is located downstream of the bell mouth flange to provide attraction. Both improvements were made in consultation with state and federal resource agencies. The facility operates from ice-out to June 30 and in November for kelts and smolts. From July 1 October 31 the facility is operated for alewife when passage above Howland or through the West Enfield fishway is observed.

No formal evaluations of downstream passage effectiveness have been conducted at the Howland Project, but passage of downstream migrating salmon smolts (usually in groups of 15 to 20) has been documented through the use of video.

4.12.3 Upstream Passage Facilities

A Denil fishway is installed at the Howland Project.

4.12.4 Turbine Design and Operation Parameters

The Howland powerhouse has three turbine/generating units which can be categorized into a single turbine type. Table 4-93 summarizes the pertinent design and operational data used in the estimation of turbine passage survival rates for the Howland turbines. The Wicket gate angle was the only design parameter that needed to be estimated for Medway turbines (Table 4-93). The wicket gate angle was estimated from the relationship between the blade tip speed components (Table 3-3). Modifications to the wicket gate angle were made.

4.12.5 Turbine Passage Survival

The results of the survival predictions for the units Howland turbines are presented in Table 4-94 (smolts) and Table 4-95 (kelts). In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and survival estimates for smolts at the lower end of the size range investigated did not vary considerably when changes in fish radial length (approach angle) and K were examined separately for the Howland turbines. However, the survival estimate ranges were considerably greater for larger smolts when the two parameters were varied separately and for all size groups when they were varied together. Kelt survival estimates did not vary with changes in fish approach angle because strike probability was 100% for the baseline and the modified angles. Moderate changes in kelt survival were observed due to modified K values and these changes were generally consistent across the size range evaluated.

4.12.6 Bypass Efficiency and Survival

No formal evaluations of downstream passage effectiveness have been conducted at the Howland Project. Consequently, bypass efficiency for smolts was assumed to be 50% based on available data from studies conducted at other projects and because the intake racks at Howland have narrow bar spacing (1-inch clear). The narrow bar spacing is considered sufficient to prevent kelt passage through the turbines, resulting in 100% bypass efficiency for this life stage. Bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

Table 4-93. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Howland units 1, 2, and 3.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	570	--
Runner Diameter (ft)	5.9	--
Wicket Gate Height (ft)	1.6	--
Turbine Speed (rpm)	120	--
Number Blades	14	--
Wicket Gate Angle (deg)	43[1]	35
Leading Edge Blade Thickness (mm)	12.2	--

[1] Parameter was estimated.

4.12.7 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Howland Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Sections 3.1.2.

4.12.8 Indirect Survival

Indirect survival was assumed to be 95% for fish passing downstream through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Section 3.2.

Table 4-94. Turbine survival estimates for smolts passing through Howland units 1, 2, 3, and 4.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.353	0.927	0.435	0.910	0.260	0.946	0.912	0.939	0.892	0.955
140	0.380	0.919	0.469	0.900	0.280	0.940	0.903	0.933	0.880	0.950
150	0.407	0.911	0.502	0.891	0.300	0.935	0.894	0.926	0.869	0.946
160	0.435	0.903	0.536	0.881	0.320	0.929	0.884	0.920	0.857	0.941
170	0.462	0.895	0.569	0.871	0.340	0.923	0.875	0.913	0.845	0.936
180	0.489	0.887	0.603	0.861	0.360	0.917	0.865	0.906	0.833	0.931
190	0.516	0.879	0.636	0.851	0.380	0.911	0.855	0.899	0.821	0.926
200	0.543	0.871	0.670	0.841	0.400	0.905	0.845	0.892	0.809	0.921
210	0.570	0.862	0.703	0.830	0.420	0.899	0.835	0.885	0.796	0.915

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-95. Turbine survival estimates for kelts passing through Howland units 1, 2, 3, and 4.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.678	1.000	0.678	1.000	0.678	0.614	0.732	0.614	0.732
675	1.000	0.676	1.000	0.676	1.000	0.676	0.611	0.730	0.611	0.730
700	1.000	0.673	1.000	0.673	1.000	0.673	0.608	0.728	0.608	0.728
725	1.000	0.671	1.000	0.671	1.000	0.671	0.605	0.725	0.605	0.725
750	1.000	0.668	1.000	0.668	1.000	0.668	0.602	0.723	0.602	0.723
775	1.000	0.666	1.000	0.666	1.000	0.666	0.599	0.722	0.599	0.722
800	1.000	0.664	1.000	0.664	1.000	0.664	0.596	0.720	0.596	0.720

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.12.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 89.6 to 92.7% across the range of average monthly flows likely to occur at Howland (Table 4-96; Figure 4-32), with a mean of 91.5%. Predicted smolt survival rates fluctuate slighlty at lower river flows as turbines come on line and alternate between partial and full load. After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival gradually increases to a peak at the highest discharge (Figure 4-32). Due to complete exclusion from turbine entrainment by the 1-inch spaced bar racks, kelt total project survival rates did not vary considerably among months or over the expected flow rates, ranging from a minimum of 92.3% to a maximum of 94.1% (Table 4-96; Figure 4-33).

Table 4-96. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Howland Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	2590 - 19190	--	--	--	0.926	0.923	0.941
May	900 - 17460	0.915	0.896	0.927	0.928	0.923	0.941
November	240 - 16070	--	--	--	0.929	0.924	0.941

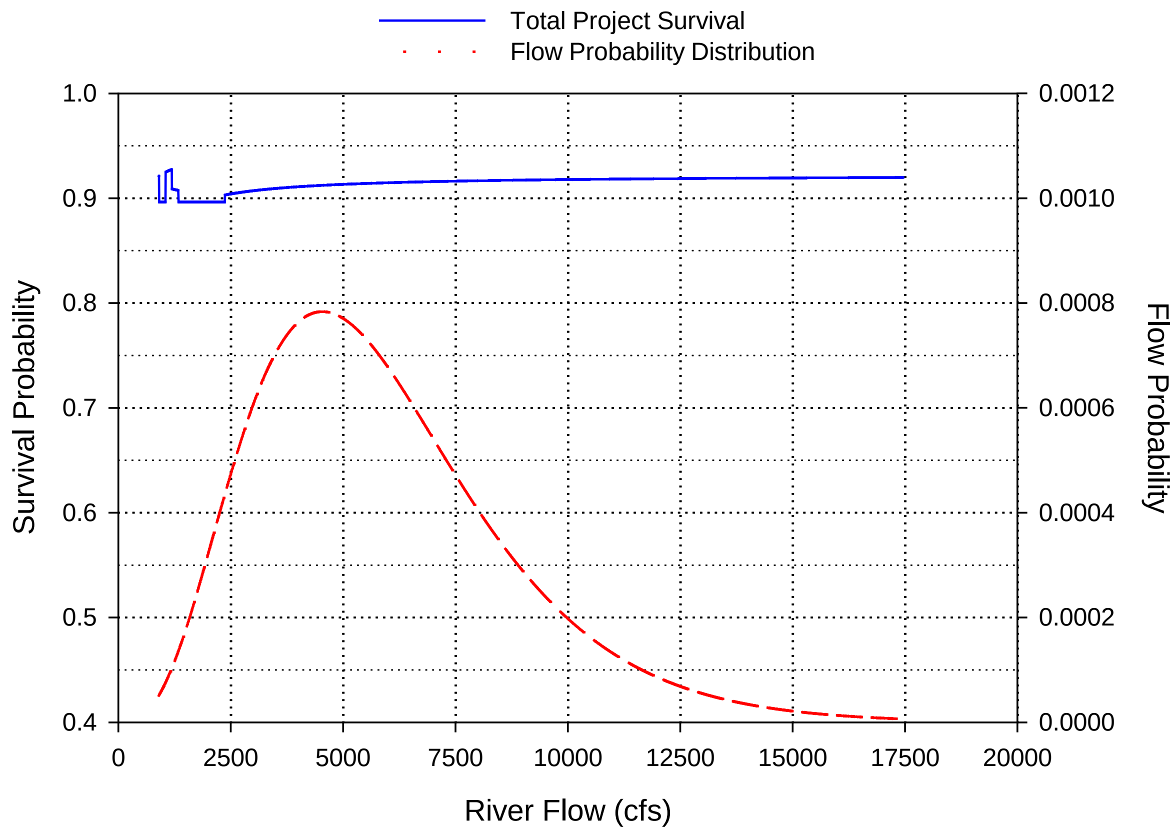

Figure 4-32. Total project survival for smolts and the flow probability distribution for May at the Howland Project. Flow probabilities were estimated and plotted in 5 cfs increments.

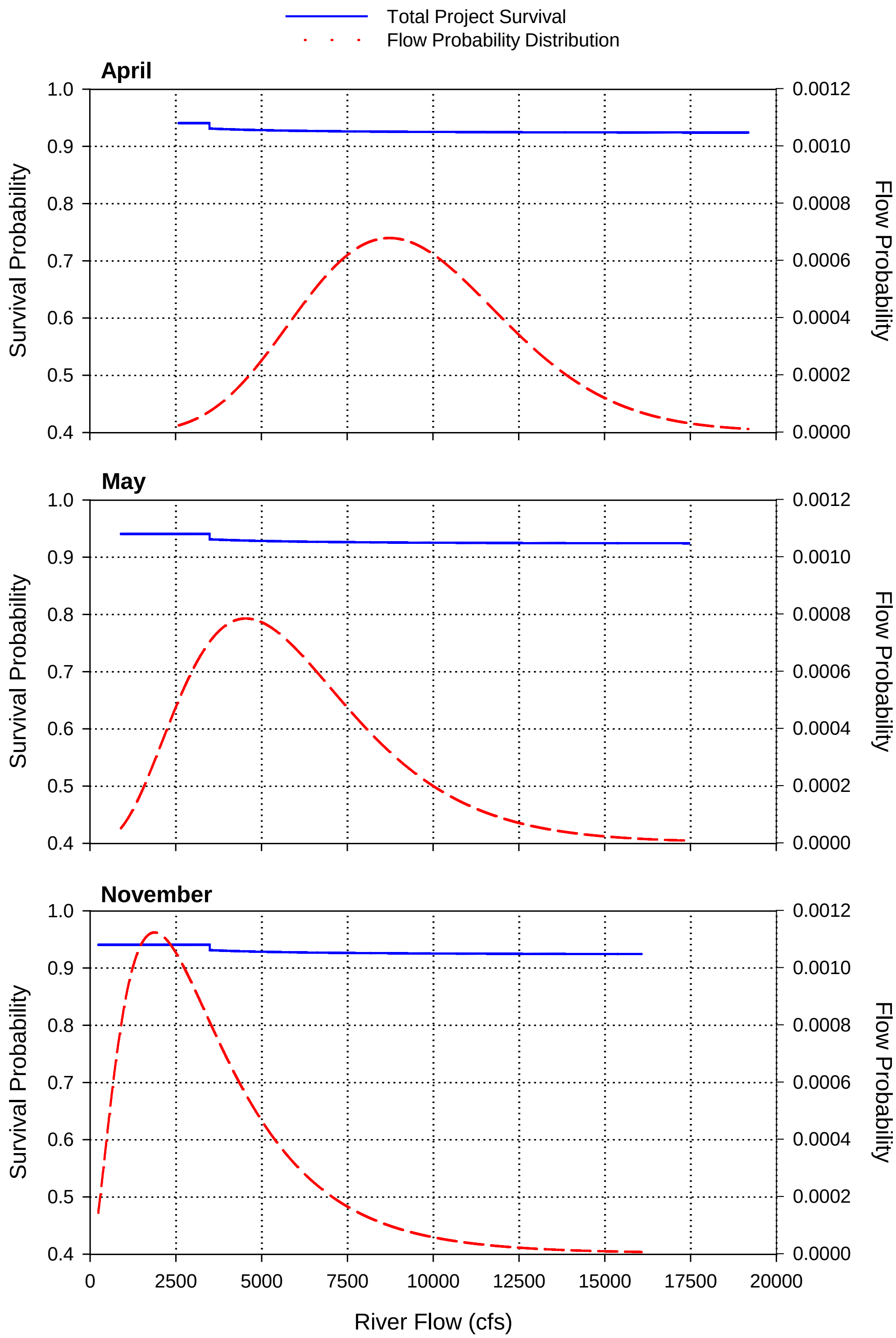

Figure 4-33. Total project survival for kelts and flow probability distributions for April, May, and November at the Howland Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.13 Brown's Mill (FERC No. P-5613)

The Brown's Mill Hydroelectric Project is owned and operated by Kruger Energy, Inc. (KEI) and is located on the Piscataquis River in the town of Dover-Foxcroft. An aerial view of the Brown's Mill Project is provided in Figure 4-34. Brown's Mill has a FERC license exemption. Some information describing the project design and operation was provided by KEI in response to the information survey that was sent by Alden to each project owner. Additional information was obtained from the FERC license exemption issued in 1982.

The Brown's Mill Project has an estimated mean monthly flow ranging from 201 cfs in August to 2,368 cfs in April (Table 4-97). It is believed that the project is operated in a ROR mode, but this could not be confirmed through available publications and documents describing the project facilities and operation.

4.13.1 Power Generating Facilities

The Brown's Mill Project consists of an ogee-type spillway, a debris sluice with a slide gate, and a powerhouse. The concrete and masonry spillway is about 265 ft long and impounds a reservoir of approximately 4 acres with minimal storage. Normal pool elevation is 328 ft. According to the license exemption, flow to the powerhouse passes through a canal that is about 256 ft long and 24 to 40 ft wide. There are three 50-ft long penstocks leading from the canal to the powerhouse. The powerhouse has two Leffel-type Francis turbines, each with a rated head of 24 ft. The larger of the two units has a rated output of 550 kW with a discharge of 360 cfs. The diameter of this turbine is 4 ft and has a rotational speed of 200 rpm. The smaller unit has rated output of 165 kW with a discharge of 115 cfs. Its diameter is 2.2 ft and it has a rotational speed of 200 rpm. The wicket gate tail radius is 1.5 inches. No additional turbine blade or wicket gate design specifications were provided by the project owner for either turbine.

Figure 4-34. Aerial view of the Brown's Mill Hydroelectric Project.

Table 4-97. Average monthly river discharge at the Brown's Mill Hydroelectric Project.

Month	Average Flow (cfs)
January	357
February	309
March	675
April	2,368
May	1,398
June	542
July	284
August	201
September	207
October	484
November	796
December	638

4.13.2 Downstream Passage Facilities and Evaluations

The intake bar racks at the Brown's Mill Project are set at a 45 degree angle to the approaching river flow and have 1-inch clear spacing over the full depth of the intake structure. The downstream bypass is adjacent to the intake racks and transfers fish downstream through an 18-inch diameter pipe that discharges into a plunge pool. The bypass flow is controlled with a knife valve just upstream of the bypass pipe and is opened 18 inches to provide a flow of 20 cfs for smolt and kelt passage. When the river flow exceeds the powerhouse capacity, fish are able to pass with spill over the ogee-style dam and into a splash pool that is located at the toe of the dam. The bypass system is operated for downstream smolt passage from ice-out through June 15. Downstream passage for in the late fall and early winter is provided for kelts from November 1 to ice-in. Fish passage effectiveness studies have not been conducted at the Brown's Mill Project for smolts or kelts.

4.13.3 Upstream Passage Facilities

A Denil ladder has been installed for upstream passage and is operated with 40 cfs of flow from May 15 through November 10.

4.13.4 Turbine Design and Operation Parameters

The Brown's Mill powerhouse has two turbine/generating units which can be categorized into two different individual types. Table 4-98 and Table 4-99 summarize the pertinent design and operational data used in the estimation of turbine passage survival through the Brown's Mill turbines. All turbine design and operational parameters needed for the estimation of strike probability and survival were acquired from public documents and/or the project owner (i.e., estimation was not required for any of the parameters).

4.13.5 Turbine Passage Survival

The results of the survival predictions for Brown's Mill turbines are presented in Table 4-100 and Table 4-101 for smolts and Table 4-102 and Table 4-103 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Table 4-98. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Brown's Mill Unit 2.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	115	--
Runner Diameter (ft)	2.2	--
Wicket Gate Height (ft)	1.2	--
Turbine Speed (rpm)	200	--
Number Blades	14	--
Wicket Gate Angle (deg)	60	--
Leading Edge Blade Thickness (mm)	8.0	--

Table 4-99. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Brown's Mill Unit 1.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	360	--
Runner Diameter (ft)	4.0	--
Wicket Gate Height (ft)	2.0	--
Turbine speed (rpm)	200	--
Number Blades	16	--
Wicket Gate Angle (deg)	30	--
Leading Edge Blade Thickness (mm)	15.9	--

Table 4-100. Turbine survival estimates for smolts passing through Brown's Mill Unit 2.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	1.000	0.811	1.000	0.811	1.000	0.811	0.773	0.842	0.773	0.842
140	1.000	0.807	1.000	0.807	1.000	0.807	0.768	0.839	0.768	0.839
150	1.000	0.803	1.000	0.803	1.000	0.803	0.763	0.836	0.763	0.836
160	1.000	0.799	1.000	0.799	1.000	0.799	0.759	0.833	0.759	0.833
170	1.000	0.796	1.000	0.796	1.000	0.796	0.755	0.830	0.755	0.830
180	1.000	0.792	1.000	0.792	1.000	0.792	0.751	0.827	0.751	0.827
190	1.000	0.789	1.000	0.789	1.000	0.789	0.747	0.824	0.747	0.824
200	1.000	0.786	1.000	0.786	1.000	0.786	0.744	0.822	0.744	0.822
210	1.000	0.784	1.000	0.784	1.000	0.784	0.740	0.820	0.740	0.820

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length

Table 4-101. Turbine survival estimates for smolts passing through Brown's Mill Unit 1.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.794	0.833	1.000	0.789	0.543	0.886	0.799	0.861	0.747	0.905
140	0.855	0.815	1.000	0.783	0.585	0.873	0.778	0.846	0.740	0.894
150	0.916	0.796	1.000	0.778	0.627	0.861	0.756	0.830	0.733	0.884
160	0.977	0.778	1.000	0.773	0.668	0.848	0.733	0.815	0.727	0.873
170	1.000	0.768	1.000	0.768	0.710	0.835	0.722	0.807	0.722	0.863
180	1.000	0.763	1.000	0.763	0.752	0.822	0.716	0.803	0.716	0.852
190	1.000	0.759	1.000	0.759	0.794	0.809	0.711	0.799	0.711	0.841
200	1.000	0.755	1.000	0.755	0.836	0.795	0.706	0.796	0.706	0.829
210	1.000	0.751	1.000	0.751	0.877	0.782	0.701	0.793	0.701	0.818

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length

Table 4-102. Turbine survival estimates for kelts passing through Brown's Mill Unit 2.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.720	1.000	0.720	1.000	0.720	0.664	0.766	0.664	0.766
675	1.000	0.718	1.000	0.718	1.000	0.718	0.661	0.765	0.661	0.765
700	1.000	0.716	1.000	0.716	1.000	0.716	0.659	0.763	0.659	0.763
725	1.000	0.714	1.000	0.714	1.000	0.714	0.656	0.761	0.656	0.761
750	1.000	0.712	1.000	0.712	1.000	0.712	0.654	0.760	0.654	0.760
775	1.000	0.710	1.000	0.710	1.000	0.710	0.652	0.758	0.652	0.758
800	1.000	0.708	1.000	0.708	1.000	0.708	0.650	0.757	0.650	0.757

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length

Table 4-103. Turbine survival estimates for kelts passing through Brown's Mill unit 1.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.662	1.000	0.662	1.000	0.662	0.594	0.718	0.594	0.718
675	1.000	0.659	1.000	0.659	1.000	0.659	0.590	0.715	0.590	0.715
700	1.000	0.656	1.000	0.656	1.000	0.656	0.587	0.713	0.587	0.713
725	1.000	0.653	1.000	0.653	1.000	0.653	0.583	0.711	0.583	0.711
750	1.000	0.650	1.000	0.650	1.000	0.650	0.580	0.708	0.580	0.708
775	1.000	0.648	1.000	0.648	1.000	0.648	0.577	0.706	0.577	0.706
800	1.000	0.645	1.000	0.645	1.000	0.645	0.574	0.704	0.574	0.704

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length

Strike probabilities and survival estimates for smolts did not vary considerably with changes in fish radial length (approach angle) and K for either of the two Brown's Mills turbines. For Unit 2, smolt strike probabilities for all fish lengths evaluated were 100% for the baseline estimate and for the modified fish approach angles. Strike probabilities of 100% were also estimated for smolts greater than 160 mm passing through Unit 1. Consequently, smolt survival rates did not change from the baseline for Unit 2 and for larger fish with Unit 1. For both units, kelt survival estimates did not vary with changes in fish approach angle because strike probability was 100% for the baseline and the modified angles. Moderate changes in kelt survival were observed due to modified K values and these changes were generally consistent across the size range evaluated and slightly higher for fish passing through Unit 1.

4.13.6 Bypass Efficiency and Survival

Fish passage effectiveness studies have not been conducted at the Brown's Mill Project for smolts or kelts. Consequently, bypass efficiency for smolts was assumed to be 50% based on available data from studies conducted at other projects and because the intake racks at Brown's Mill have narrow bar spacing (1-inch clear). The narrow bar spacing is considered sufficient to prevent kelt passage through the turbines, resulting in 100% bypass efficiency for this life stage. Bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.13.7 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Brown's Mill Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Section 3.1.2.

4.13.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Brown's Mill Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Sections 3.2.

4.13.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 61.5 to 91.8% across the range of average monthly flows likely to occur at Brown's Mill (Table 4-104; Figure 4-35), with a mean of 86.5%. Predicted smolt survival rates fluctuate at lower river flows as turbines come on line and alternate between partial and full load. After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival gradually increases to a peak at the highest discharge (Figure 4-35). Due to complete exclusion from turbine entrainment by the 1-inch spaced bar racks, total project survival for kelts did not vary considerably, ranging from a minimum of 92.4% to a maximum of 94.1% over the range of expected monthly average flows (Table 4-104; Figure 4-36).

Table 4-104. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Brown's Mill Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	705 - 4700	--	--	--	0.927	0.924	0.941
May	160 - 4430	0.865	0.615	0.918	0.929	0.924	0.941
November	10 - 3525	--	--	--	0.931	0.924	0.941

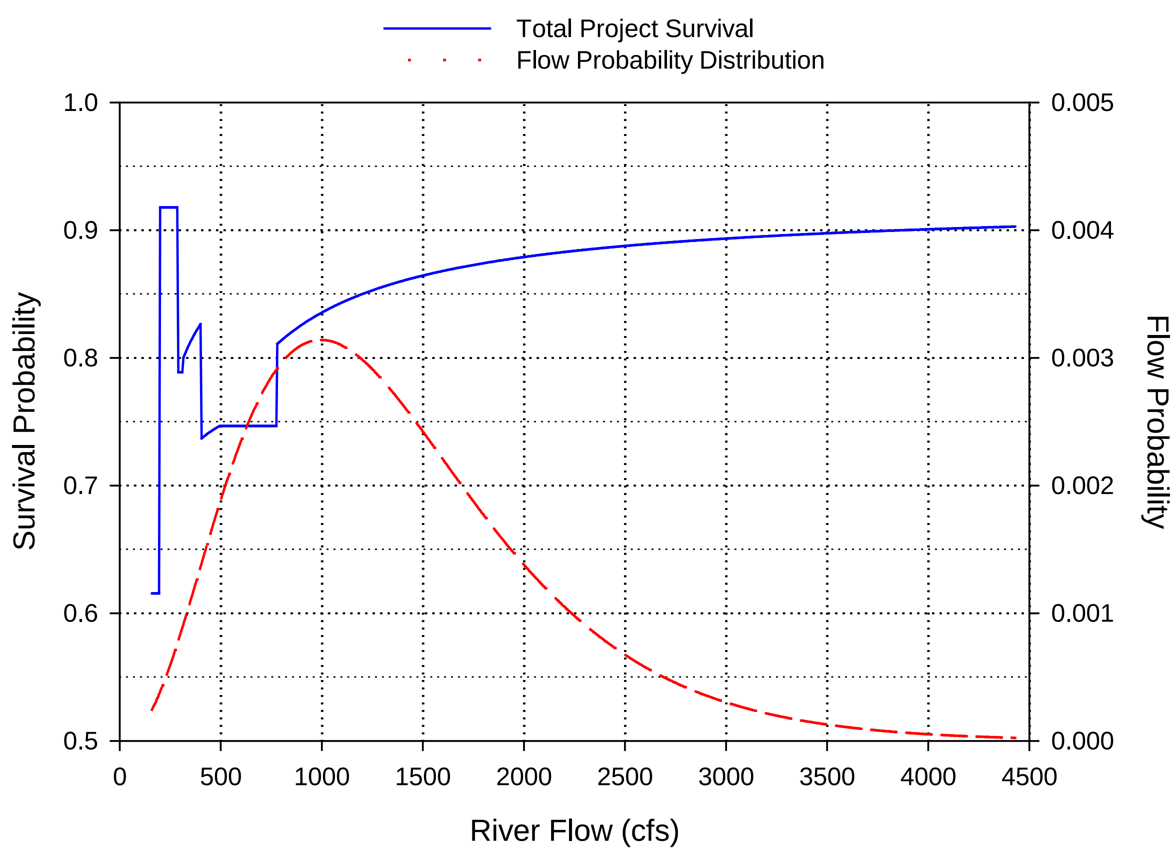

Figure 4-35. Total project survival for smolts and the flow probability distribution for May at the Brown's Mill Project. Flow probabilities were estimated and plotted in 5 cfs increments.

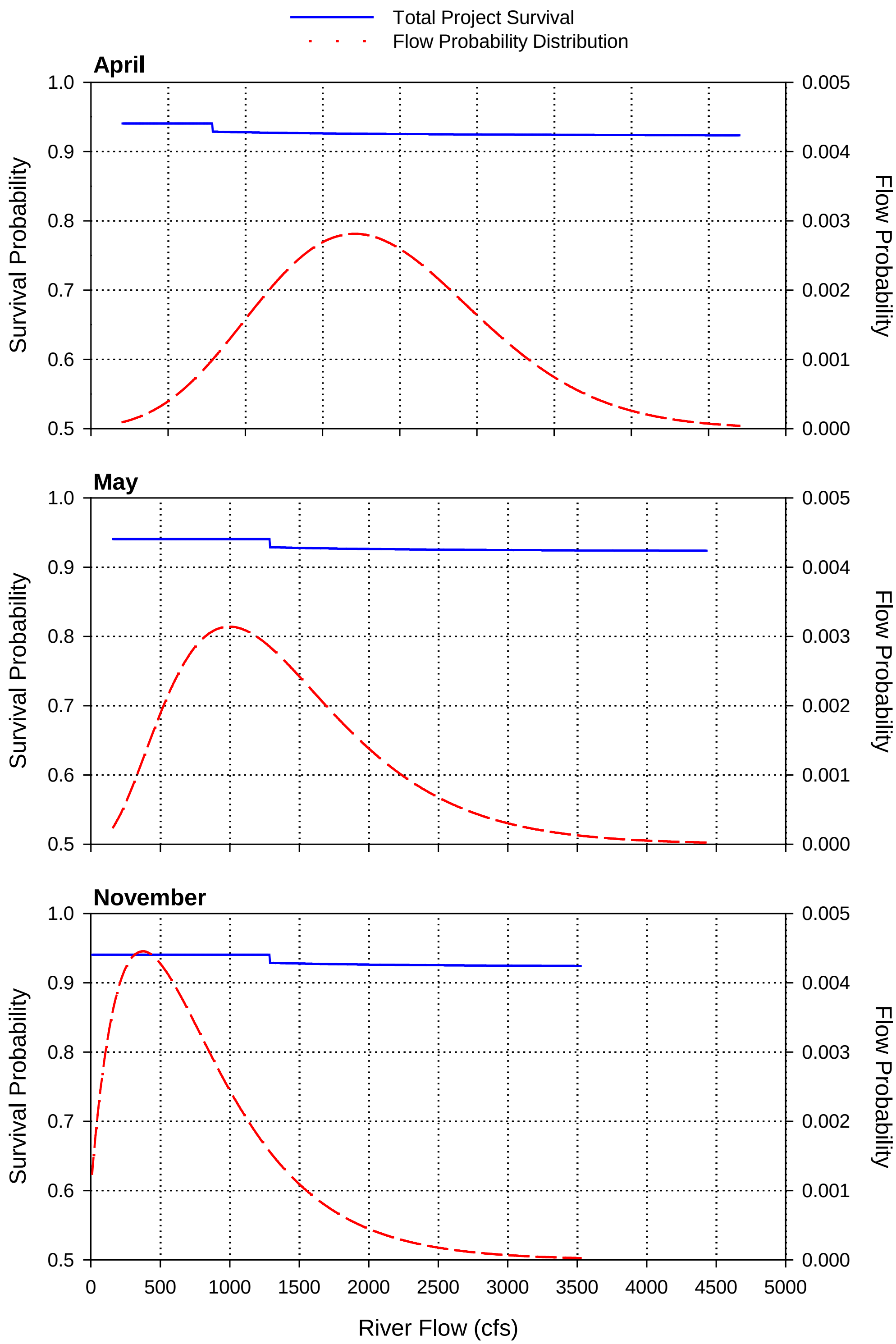

Figure 4-36. Total project survival for kelts and flow probability distributions for April, May, and November at the Brown's Mill Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.14 Lowell Tannery (Pumpkin Hill; FERC NO. 4202)

The Lowell Tannery Hydroelectric Project (also referred to as Pumpkin Hill) is owned and operated by KEI. The project is located in the town of Lowell on the Passadumkeag River. An aerial view of the project is provided in Figure 4-37. Some information describing the project design and operation was provided by KEI in response to the information survey distributed by Alden to the project owners. Additional information was obtained from the project's FERC license issued in 1983.

Lowell Tannery is a ROR project with an estimated mean monthly flow ranging from 211 cfs in August to 1,277 cfs in April (Table 4-105). There is a minimum flow requirement of 150 cfs or inflow into the impoundment, whichever is less.

4.14.1 Power Generating Facilities

The Lowell Tannery Project consists of a spillway (described as a gravity angled type by the project owner) and a powerhouse. According to the FERC license, the dam is 230 ft long with 30 and 80-ft long spillway sections that can be topped with 3.5 ft flashboards. There is also a low-level outlet gate and a log/debris sluice, both of which are located between the two spillway sections. Normal pool elevation is 187.5 ft provides an impoundment size of about 100 acres. The existing powerhouse was rehabilitated following issuance of the license in 1983 and has one Kaplan turbine with a power rating of 1.5 MW at a rated head and flow of 27 ft and 960 cfs, respectively. The turbine has four blades, a diameter of 4.6 ft, and a rotational speed of 189 rpm. No additional information was provided by the project owner for turbine blade and wicket gate specifications. The intake bar racks have a clear spacing of 2 inches.

Figure 4-37. Aerial view of the Lowell Tannery Hydroelectric Project.

Table 4-105. Average monthly river discharge at the Lowell-Tannery Hydroelectric Project.

Month	Average Flow (cfs)
January	362
February	337
March	475
April	1,277
May	1,084
June	614
July	349
August	211
September	214
October	282
November	460
December	495

4.14.2 Downstream Passage Facilities and Evaluations

According to the project owner, the intake bar racks at the Lowell Tannery Project are set at a 45 degree angle to the approaching river flow and have 2-inch clear spacing. A downstream bypass (surface outlet) is adjacent to the east intake racks and transfers fish downstream through an 18-inch bypass pipe discharging into a plunge pool next to the tailrace. Bypass pipe flow is controlled with stop logs at the entrance to a fish collection box. The bypass pipe sill elevation is 182.5 ft. Bypass flow is set at 20 cfs for smolt and kelt passage. When the river flows exceed the powerhouse capacity, fish can pass with spill over the vertical concrete gravity dam into the stream bed below. The bypass system is operated for downstream smolt and kelt passage in the spring from ice-out through June 15. Downstream passage is provided for kelts in the late fall and early winter from November 1 to ice-in. Fish passage effectiveness studies have not been conducted at the Lowell Tannery Project for smolts or kelts.

4.14.3 Upstream Passage Facilities

A Denil ladder has been installed for upstream passage and is operated with 40 cfs of flow from May 15 through November 10.

4.14.4 Turbine Design and Operation Parameters

The Lowell Tannery powerhouse has a single Kaplan unit. Table 4-106 summarizes the pertinent design and operational data of this unit used to estimate turbine survival for smolts and kelts. The only design parameter that was estimated was leading edge blade thickness (Table 4-106), which was calculated directly from the relationship with turbine diameter (Table 3-4). Based on a review of available literature and data, modifications or adjustments to the acquired and estimated parameters were not considered necessary.

4.14.5 Turbine Passage Survival

The turbine survival predictions for the Lowell Tannery Project are presented in Table 4-107 (smolts) and Table 4-108 (kelts). In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and survival estimates for smolts demonstrated moderate to large variations with changes in radial fish length (approach angle) and K when the two parameters were examined separately and together. The range of the modified estimates from the baseline increased with smolt length. For both units, kelt survival estimates did not vary with changes in fish approach angle because strike probability was 100% for the baseline and the modified angles. Relatively large changes in kelt survival were observed due to modified K values and these changes were generally consistent across the size range evaluated and slightly higher for fish passing through Unit 1.

Table 4-106. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Lowell Tannery Unit 1.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Kaplan	--
Flow (cfs)	800	--
Runner Diameter (ft)	7.2	--
Hub Diameter (ft)	1.7	--
Turbine Speed (rpm)	189	--
Number Blades	4	--
Flow Angle (deg)	32	--
Leading Edge Blade Thickness (mm)	17.6[1]	--

[1] Parameter was estimated.

4.14.6 Bypass Efficiency and Survival

Fish passage effectiveness studies have not been conducted at the Lowell Tannery Project for smolts or kelts. Because the Lowell Tannery powerhouse has relatively wide bar spacing (2 inches clear), it was assumed that bypass efficiency was 25% for smolts. However, the bar spacing is narrow enough to completely exclude kelts from turbine entrainment. Therefore, bypass efficiency of kelts is assumed to be 100%. Direct bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.14.7 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Lowell Tannery Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Sections 3.1.2.

Table 4-107. Turbine survival estimates for smolts passing through Lowell Tannery Unit 1.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.399	0.902	0.502	0.876	0.284	0.930	0.882	0.918	0.852	0.942
140	0.430	0.891	0.541	0.863	0.306	0.922	0.869	0.909	0.836	0.935
150	0.461	0.880	0.580	0.849	0.328	0.915	0.856	0.900	0.819	0.929
160	0.492	0.869	0.618	0.836	0.350	0.907	0.843	0.891	0.803	0.922
170	0.522	0.858	0.657	0.821	0.372	0.899	0.830	0.882	0.786	0.916
180	0.553	0.847	0.696	0.807	0.394	0.891	0.816	0.872	0.769	0.909
190	0.584	0.835	0.734	0.793	0.416	0.883	0.802	0.863	0.751	0.902
200	0.615	0.823	0.773	0.778	0.438	0.874	0.788	0.853	0.733	0.895
210	0.645	0.811	0.812	0.763	0.459	0.866	0.774	0.843	0.715	0.888

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length

Table 4-108. Turbine survival estimates for kelts passing through Lowell Tannery Unit 1.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.599	1.000	0.599	1.000	0.599	0.519	0.666	0.519	0.666
675	1.000	0.595	1.000	0.595	1.000	0.595	0.514	0.663	0.514	0.663
700	1.000	0.592	1.000	0.592	1.000	0.592	0.510	0.660	0.510	0.660
725	1.000	0.589	1.000	0.589	1.000	0.589	0.506	0.657	0.506	0.657
750	1.000	0.585	1.000	0.585	1.000	0.585	0.502	0.654	0.502	0.654
775	1.000	0.582	1.000	0.582	1.000	0.582	0.499	0.652	0.499	0.652
800	1.000	0.579	1.000	0.579	1.000	0.579	0.495	0.649	0.495	0.649

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length

4.14.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Lowell Tannery Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Sections 3.2.

4.14.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 84.7 to 94.9% across the range of average monthly flows likely to occur at Lowell Tannery (Table 4-109; Figure 4-38), with a mean of 88.7%. After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival gradually increases with river discharge (Figure 4-38). Due to complete exclusion from turbine entrainment by the 2-inch spaced bar racks, total project survival for kelts did not vary considerably, ranging from a minimum of 92.7% to a maximum of 94.1% over the range of expected monthly average flows (Table 4-109; Figure 4-39).

Table 4-109. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Lowell Tannery Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	470 - 2720	--	--	--	0.933	0.927	0.941
May	325 - 2560	0.887	0.847	0.949	0.934	0.928	0.941
November	75 - 1900	--	--	--	0.937	0.930	0.941

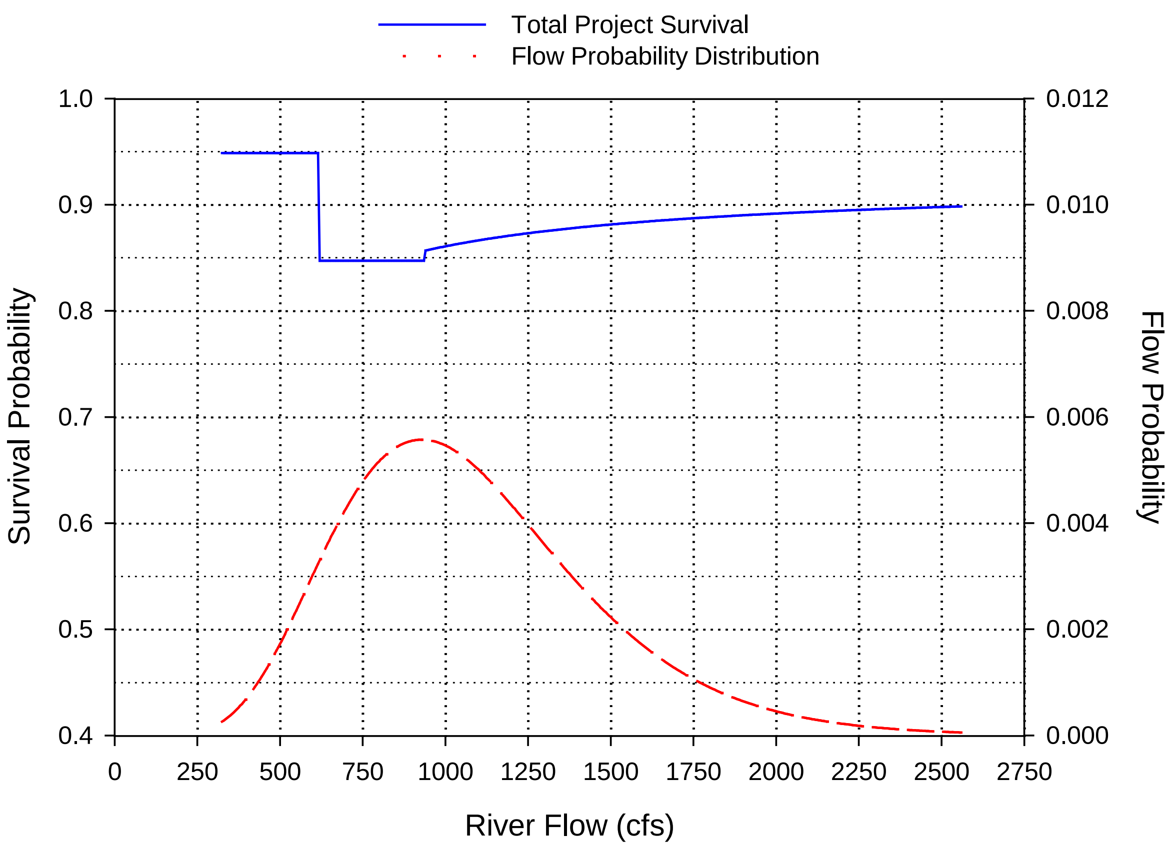

Figure 4-38. Total project survival for smolts and the flow probability distribution for May at the Lowell Tannery Project. Flow probabilities were estimated and plotted in 5 cfs increments.

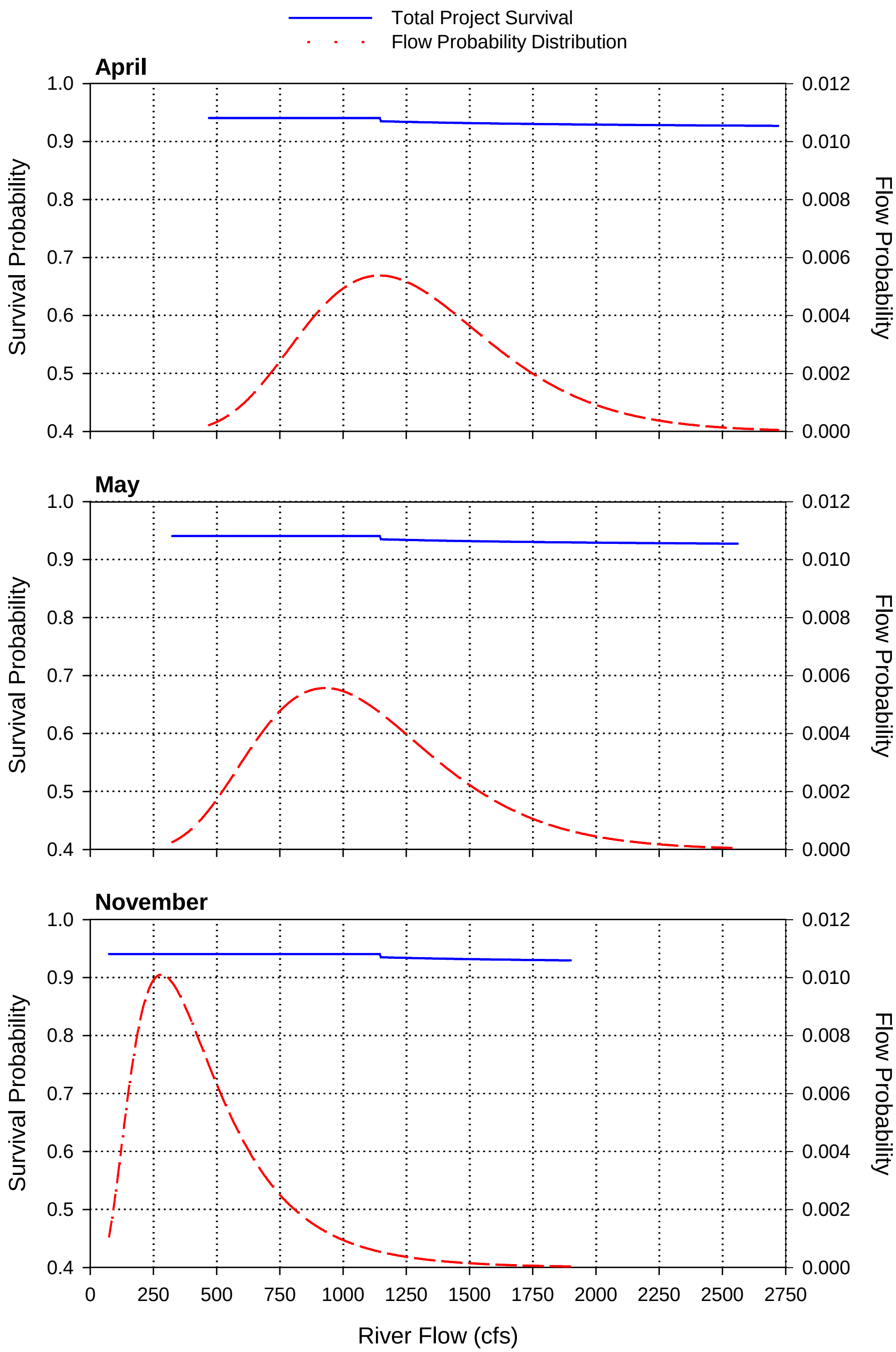

Figure 4-39. Total project survival for kelts and flow probability distributions for April, May, and November at the Lowell Tannery Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.15 Moosehead (Dover Upper Dam; FERC NO. 5912)

The Moosehead Hydroelectric Project (also referred to as Dover Upper Dam) is owned and operated by the Town of Dover-Foxcroft and is located on the Piscataquis River in the town of Dover-Foxcroft. An aerial view of the Moosehead Project is provided in Figure 4-40. Currently the project is not operational, but a town official indicated they were considering makeing repairs and upgrades to bring it online in the near future. Limited information on the project design and operation was obtained during a search for relevant documents in the FERC online library.

The Moosehead Project has an estimated mean monthly flow ranging from 176 cfs in August to cfs in 2,079 April (Table 4-110). It is believed that the project is operated in a ROR mode, but this could not be confirmed through available publications and documents describing the project facilities and operation.

4.15.1 Power Generating Facilities

The Moosehead Project consists of a former manufacturing mill where the generating equipment is located, spillway, and debris sluices on either side of a Denil fish ladder adjacent to the mill. The project is operated in a run-of-the-river mode with an impoundment area of about 30 to 40 acres. No information has been obtained for the generating equipment at this site. The intake bar racks have a clear spacing of 1.5 inches.

Figure 4-40. Aerial view of the Moosehead Hydroelectric Project (Upper Dover Dam).

Table 4-110. Average monthly river discharge at the Moosehead Hydroelectric Project.

Month	Average Flow (cfs)
January	314
February	271
March	593
April	2,079
May	1,228
June	476
July	249
August	176
September	182
October	425
November	699
December	560

4.15.2 Downstream Passage Facilities and Evaluations

Measures for passing fish downstream have not been implemented at the Moosehead Project. Consequently, downstream passage studies have not been conducted at this site. However, the upstream fishway, as described below, was considered a viable downstream passage route for smolts and kelts during the spring migration periods for each life stage.

4.15.3 Upstream Passage Facilities

A Denil ladder has been installed at the project for passing anadromous species upstream. When operational, the minimum flow released through the fish ladder is 40 cfs.

4.15.4 Turbine Design and Operation Parameters

The Moosehead powerhouse has two turbine/generating units which can be categorized into two different individual types. Table 4-111 and Table 4-112 summarize the pertinent design and operational data used in the estimation of survival through the Moosehead turbines. Estimation of design parameters was not required for either of the two Moosehead turbines (i.e., all of the required design and operational information was acquired from available literature, the project owner, and/or field measurements).

Table 4-111. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Moosehead Unit 2.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	150	--
Runner Diameter (ft)	4.3	--
Wicket Gate Height (ft)	2.7	--
Turbine Speed (rpm)	79	--
Number Blades	18	--
Wicket Gate Angle (deg)	39	--
Leading Edge Blade Thickness (mm)	5.1	--

Table 4-112. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Moosehead Unit 1.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Francis	--
Flow (cfs)	90	--
Runner Diameter (ft)	3.3	--
Wicket Gate Height (ft)	2.0	--
Turbine Speed (rpm)	103	--
Number Blades	18	--
Wicket Gate Angle (deg)	42	--
Leading Edge Blade Thickness (mm)	5.1	--

4.15.5 Turbine Passage Survival

The results of the smolt survival predictions for the units located at the Moosehead Hydroelectric station are located in Table 4-113 and Table 4-114 for smolts and Table 4-115 and Table 4-116 for kelts. In addition to the turbine design and operational information provided below, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities for smolts and kelts passing through both Moosehead units were 100% for the baseline estimate and the estimates using the modified fish radial lengths (approach angle). Also, because the estimated strike velocities for each unit were less than the threshold at which injury and mortality begin to occur, turbine passage survival rates for both life stages were 100% for the baseline conditions and the modified approach angles. Survival rates of smolts and kelts were less than 100% only when K was increased by 20%.

4.15.6 Bypass Efficiency and Survival

There are no dedicated downstream fish passage facilities at the Moosehead Project, but an existing Denil fish operated for upstream passage is available for smolts and kelts to use as a downstream bypass during the month of May. Consequently, bypass efficiency for smolts was assumed to be 50% based on available data from studies conducted at other projects and because the intake racks at Moosehead have relatively narrow bar spacing (1.5-inch clear). The narrow bar spacing is considered sufficient to prevent kelt passage through the turbines, resulting in 100% bypass efficiency for this life stage when the upstream fishway is available for use by downstream migrants in May. However, in November, there is no outlet for kelts at river flows below about 600 cfs, whereas spillway flow is sufficient for Kelt passage over the range of expected river discharges in April. For the month of May (smolts and kelts), direct bypass survival for for both life stages was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.15.7 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Moosehead Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Sections 3.1.2.

Table 4-113. Turbine survival estimates for smolts passing through Moosehead Unit 2.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
140	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
150	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
160	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
170	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
180	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
190	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
200	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
210	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-114. Turbine survival estimates for smolts passing through Moosehead Unit 1.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
140	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
150	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
160	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
170	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
180	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
190	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
200	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
210	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-115. Turbine survival estimates for kelts passing through Moosehead Unit 2.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
675	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
700	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
725	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
750	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
775	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
800	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-116. Turbine survival estimates for kelts passing through Moosehead unit 1.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
675	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
700	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
725	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
750	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
775	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000
800	1.000	1.000	1.000	1.000	1.000	1.000	0.922	1.000	0.922	1.000

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.15.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Moosehead Project was assumed to be 95% for fish passing downstream through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Section 3.2.

4.15.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 68.0 to 91.0% across the range of average monthly flows likely to occur at Moosehead (Table 4-117; Figure 4-41), with a mean of 88.0%. After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival initially increases rapidly with average river flow before leveling to a gradual increase and peaking at the highest discharge (Figure 4-41). The only passage route available for kelts in April and November at Moosehead is the spillway because there is no fish bypass and the 1.5-inch spaced bar racks prevent turbine entrainment of this life stage. Average river flow in April is always high enough to allow spillway passage. In November there is insufficient flow for spillway passage at river discharges of about 600 cfs and less, resulting in 0% survival until sufficient spill occurs (Table 4-117; Figure 4-42). The operation of a fish ladder in May for upstream passage is also available for downstream passage and provides kelts with an outlet when river flow is insufficient for spillway passage (Table 4-117). Consequently, total passage survival rates for kelts are similar in Apri and May, ranging from 92.2 to 94.1%. November survival rates range from 0.0 to 92.2% (Table 4-117).

Table 4-117. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Moosehead Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	620 - 4130	--	--	--	0.922	0.922	0.922
May	140 - 3890	0.880	0.686	0.910	0.926	0.923	0.941
November	10 - 3095	--	--	--	0.763	0.000	0.922

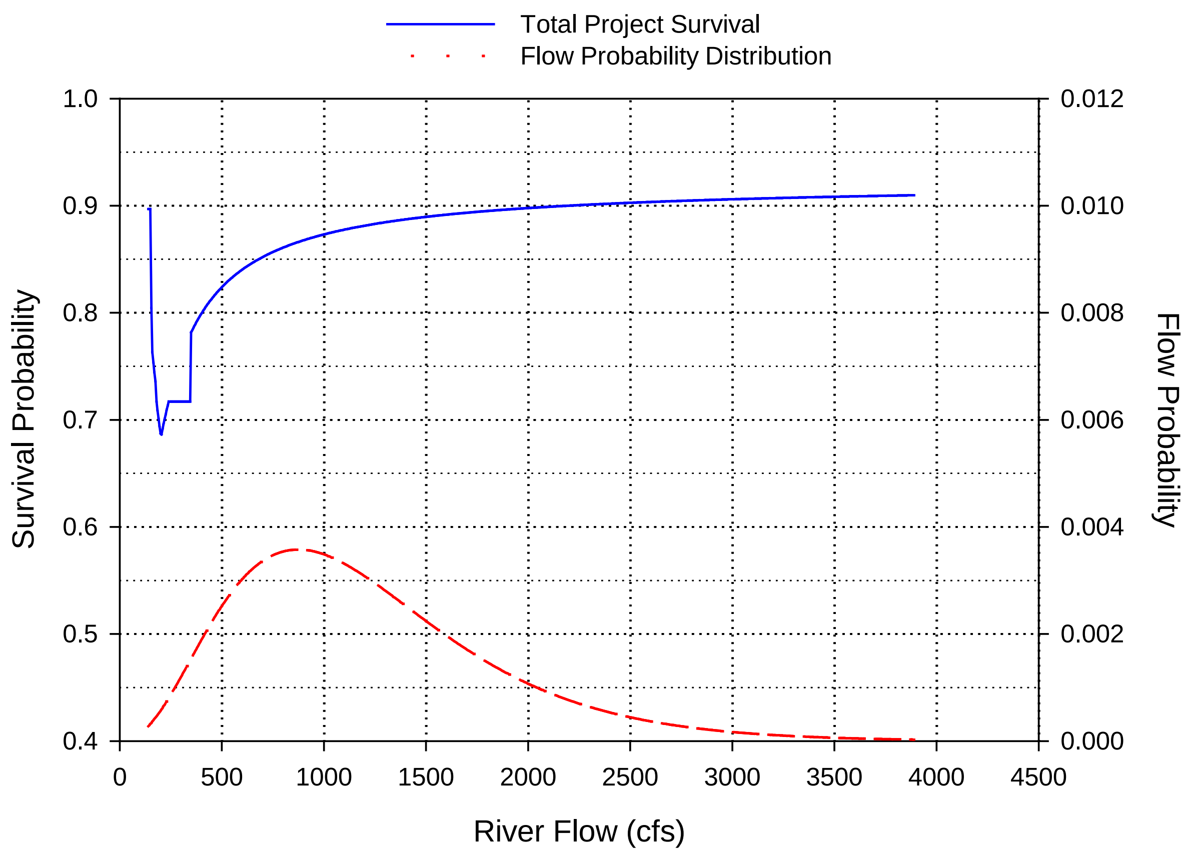

Figure 4-41. Total project survival for smolts and the flow probability distribution for May at the Moosehead Project. Flow probabilities were estimated and plotted in 5 cfs increments.

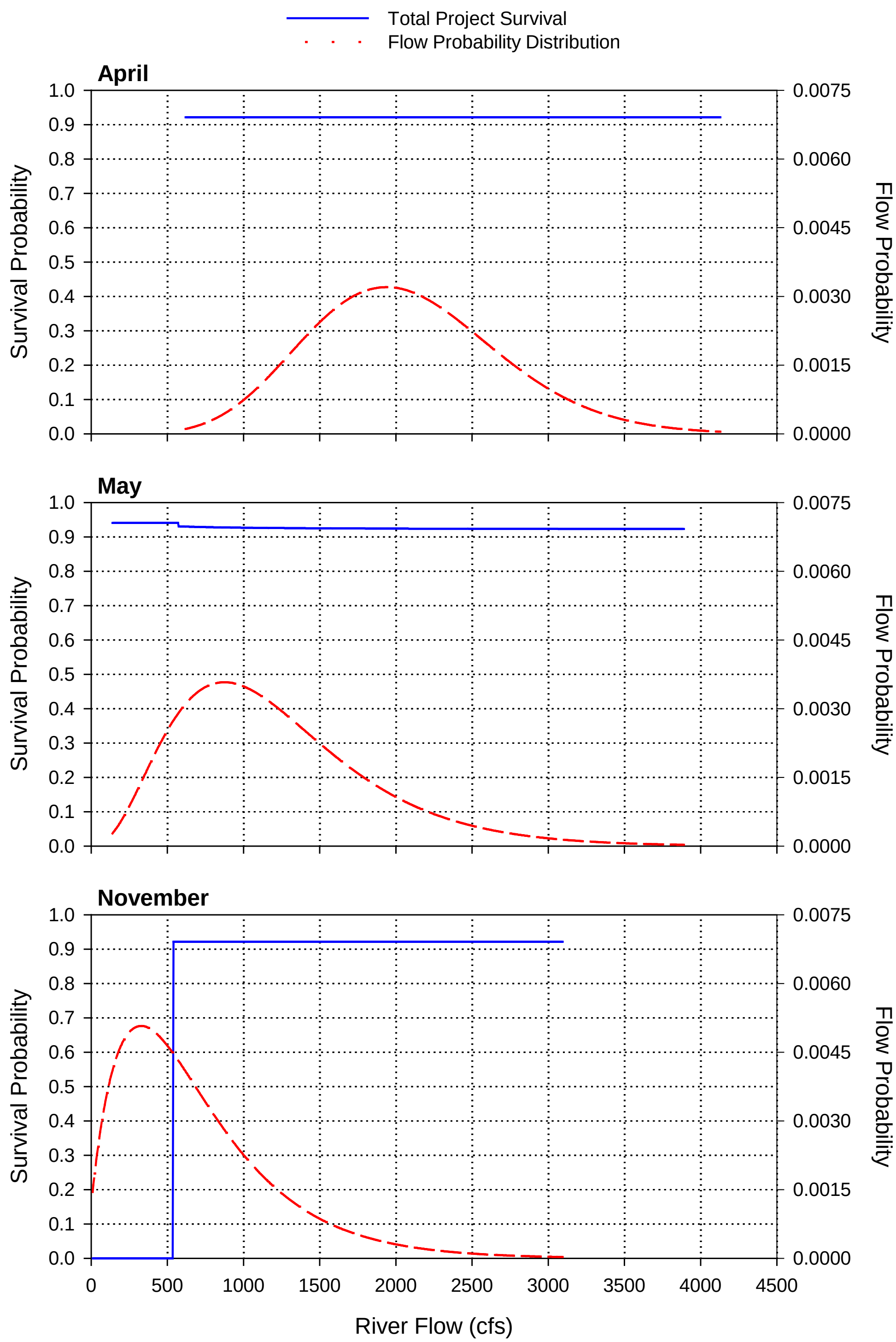

Figure 4-42. Total project survival for kelts and flow probability distributions for April, May, and November at the Moosehead Project. Flow probabilities were estimated and plotted in 5 cfs increments. A fish ladder is available as a downstream bypass for kelts in May, but it is not operated in November resulting in no viable outlet during this month when there is insufficient flow for spillway passage and turbine operation (i.e., river discharges less than about 600 cfs).

4.16 Milo (FERC NO. 5647)

The Milo Hydroelectric Project is owned and operated by KEI and is located on the Sebec River (tributary to the Piscataquis River) in the town of Milo. An aerial view of the Milo Project is provided in Figure 4-43. The Milo Project was issued a FERC license exemption in 1982. Some information describing the project design and operation was provided by KEI in response to the information survey that was distributed by Alden to the project owners. Additional information was obtained from the license exemption.

The Milo Project has an estimated mean monthly flow ranging from 341 cfs in August to 2,147 cfs in April (Table 4-118). It is believed that the project is operated in a ROR mode, but this could not be confirmed through available publications and documents describing the project facilities and operation.

4.16.1 Power Generating Facilities

The Milo Project consists of a powerhouse and a timber crib dam separated by an island. The dam is about 250 ft long with an impoundment of about 50 acres at a normal pool elevation 279 ft. The powerhouse has three identical Kaplan turbines (T15-type Leroy Somer angle drive) each with a rated output of 240 kW at a head of 15 ft and discharge of 300 cfs. Total rated project output and powerhouse discharge are 720 kW and 900 cfs, respectively. Each runner has 4 blades, is 3.9 ft in diameter, and has a rotational speed of 175 rpm. The project owner indicated that the blade tip radius of the three turbines was “flat” with a thickness of about 1 inch. No additional turbine blade or wicket gate design specifications were provided by the project owner for either turbine. The intake bar racks have a clear spacing of 2 inches.

4.16.2 Downstream Passage Facilities and Evaluations

The intake trash racks at the Milo project are oriented perpendicular to the approaching river flow and have 2-inch clear spacing. The project owner indicated that downstream passage is currently not required at Milo and, therefore, no measures have been implemented to reduce turbine entrainment and pass fish downstream through an alternate route. Consequently, downstream fish passage studies have not been conducted at the Milo Project.

4.16.3 Upstream Passage Facilities

Upstream passage facilities have not been installed at the Milo Project.

Figure 4-43. Aerial view of the Milo Hydroelectric Project.

Table 4-118. Average monthly river discharge at the Milo Hydroelectric Project.

Month	Average Flow (cfs)
January	538
February	593
March	755
April	2,147
May	1,536
June	645
July	397
August	341
September	451
October	492
November	750
December	758

4.16.4 Turbine Design and Operation Parameters

The Milo powerhouse contains a total of three identical turbine/generating units. Table 4-119 summarizes the pertinent design and operational data used in the estimation of survival through the Milo turbines. Design parameters estimated for Milo units 1, 2, and 3 include the flow angle approaching the blade and the leading edge blade thickness (Table 4-119). The leading edge blade thickness was estimated directly from the relationship with turbine diameter (Table 3-4) and flow angle was estimated based upon a relationship between the blade tip speed components (Table 3-4). Based on a review of available literature and data, modifications or adjustments to the acquired and estimated parameters were not considered necessary.

4.16.5 Turbine Passage Survival

The results of the survival predictions for Milo turbines are presented in Table 4-120 (smolts) and Table 4-121 (kelts). In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and turbine passage survival rates for smolts did not vary considerably with changes in fish radial length (approach angle). Varying K also resulted in only minor changes in survival, although sensitivity to changes in K increased slightly with smolt length. Kelt strike probabilities and survival rates demonstrated much larger variations with changes in fish approach angle and survival rates were very sensitive to changes in K.

4.16.6 Bypass Efficiency and Survival

The Milo Project does not operate a bypass (gate, weir, or other conveyance) for downstream passage of anadromous fish. Consequently, all outmigrating smolts and kelts must pass over the spillway or through the turbines. At low river discharges when there insufficient flow for spillway passage, all smolts will pass through the project turbines bar rack due to the relatively wide bar spacing (2-inch clear). For kelts, the bar spacing at Milo is narrow enough to prevent turbine entrainment, resulting in no available outlet for this life stage when spillway flow is not sufficient for passage (i.e., 12 inches of depth or greater). More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.16.7 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Milo Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Sections 3.1.2.

Table 4-119. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Milo units 1, 2, and 3.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Kaplan	--
Flow (cfs)	300	--
Runner Diameter (ft)	3.9	--
Hub Diameter (ft)	1.5	--
Turbine Speed (rpm)	175	--
Number Blades	4	--
Flow Angle (deg)	60[1]	--
Leading Edge Blade Thickness (mm)	14.3[1]	--

[1] Parameter was estimated.

4.16.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Milo Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Sections 3.2.

4.16.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 85.2 to 90.9% across the range of average monthly flows likely to occur at Milo (Table 4-122; Figure 4-44), with a mean of 89.0%. Predicted smolt survival rates fluctuate at lower river flows as turbines come on line and alternate between partial and full load. After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival gradually increases to a peak at the highest discharge (Figure 4-44). Mean total project survival for kelts is highest in May (59.1%) and lowest in November (44.7%) for the range of expected monthly average flows (Table 4-122; Figure 4-45). Because there is no downstream bypass at Milo and the bar rack spacing is narrow enough to prevent turbine entrainment, kelt survival is assumed to be 0% at river discharges when there is insufficient flow for spillway passage (i.e., no viable means to pass downstream).

Table 4-120. Turbine survival estimates for smolts passing through Milo units 1, 2, and 3.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.147	0.928	0.159	0.922	0.130	0.936	0.913	0.940	0.906	0.947
140	0.158	0.920	0.171	0.913	0.140	0.929	0.904	0.933	0.896	0.941
150	0.169	0.912	0.183	0.905	0.150	0.922	0.895	0.927	0.886	0.935
160	0.181	0.904	0.196	0.896	0.160	0.915	0.885	0.920	0.876	0.929
170	0.192	0.896	0.208	0.888	0.170	0.908	0.876	0.914	0.865	0.923
180	0.203	0.888	0.220	0.879	0.180	0.901	0.866	0.907	0.855	0.917
190	0.215	0.880	0.232	0.870	0.190	0.894	0.856	0.900	0.844	0.911
200	0.226	0.871	0.245	0.861	0.200	0.886	0.846	0.893	0.833	0.905
210	0.237	0.863	0.257	0.851	0.210	0.879	0.836	0.886	0.822	0.899

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-121. Turbine survival estimates for kelts passing through Milo units 1, 2, and 3.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	0.734	0.523	0.795	0.483	0.650	0.577	0.428	0.603	0.380	0.648
675	0.762	0.505	0.826	0.463	0.675	0.561	0.406	0.587	0.356	0.634
700	0.790	0.486	0.856	0.443	0.700	0.545	0.384	0.572	0.332	0.621
725	0.818	0.468	0.887	0.424	0.725	0.529	0.362	0.557	0.308	0.607
750	0.847	0.450	0.917	0.404	0.750	0.512	0.340	0.541	0.284	0.594
775	0.875	0.431	0.948	0.384	0.775	0.496	0.318	0.526	0.261	0.580
800	0.903	0.413	0.979	0.364	0.800	0.480	0.296	0.511	0.237	0.567

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-122. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Milo Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	255 - 4290	--	--	--	0.542	0.000	0.922
May	265 - 4875	0.890	0.852	0.909	0.591	0.000	0.922
November	10 - 3715	--	--	--	0.447	0.000	0.922

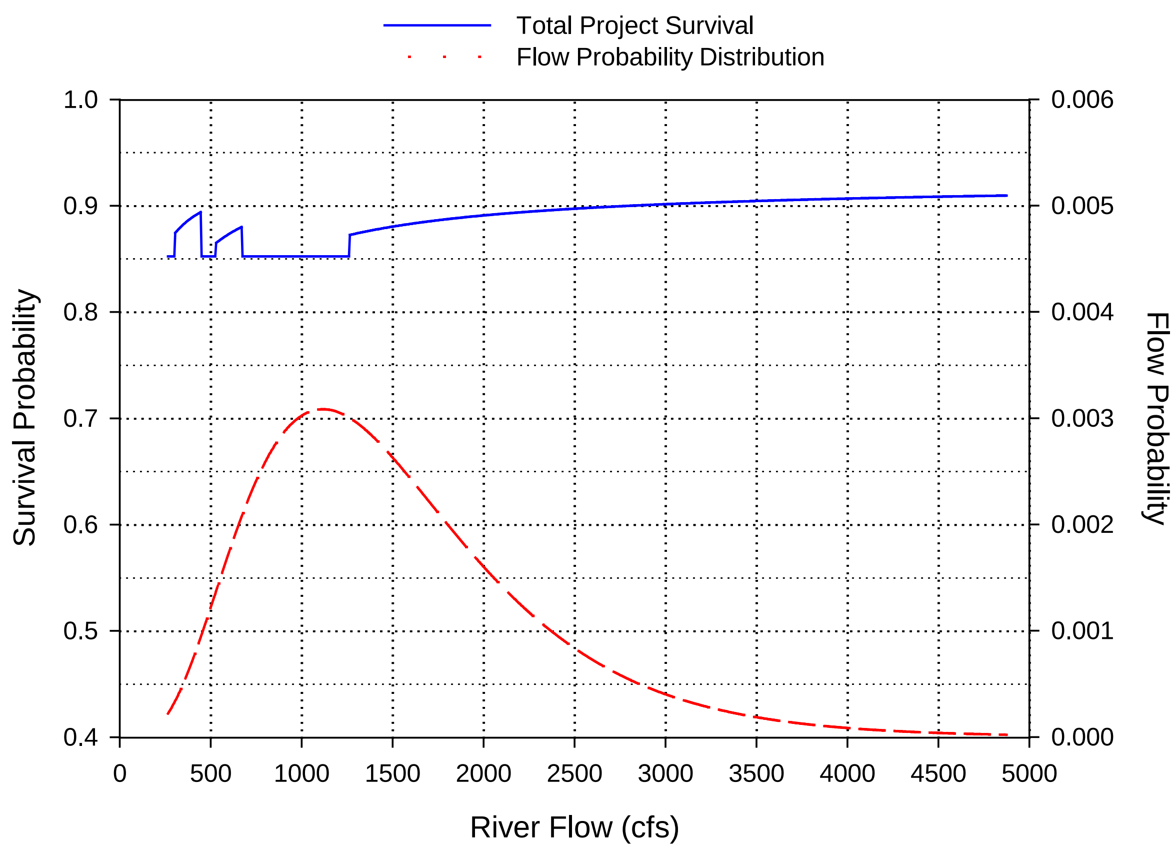

Figure 4-44. Total project survival for smolts and the flow probability distribution for May at the Milo Project. Flow probabilities were estimated and plotted in 5 cfs increments.

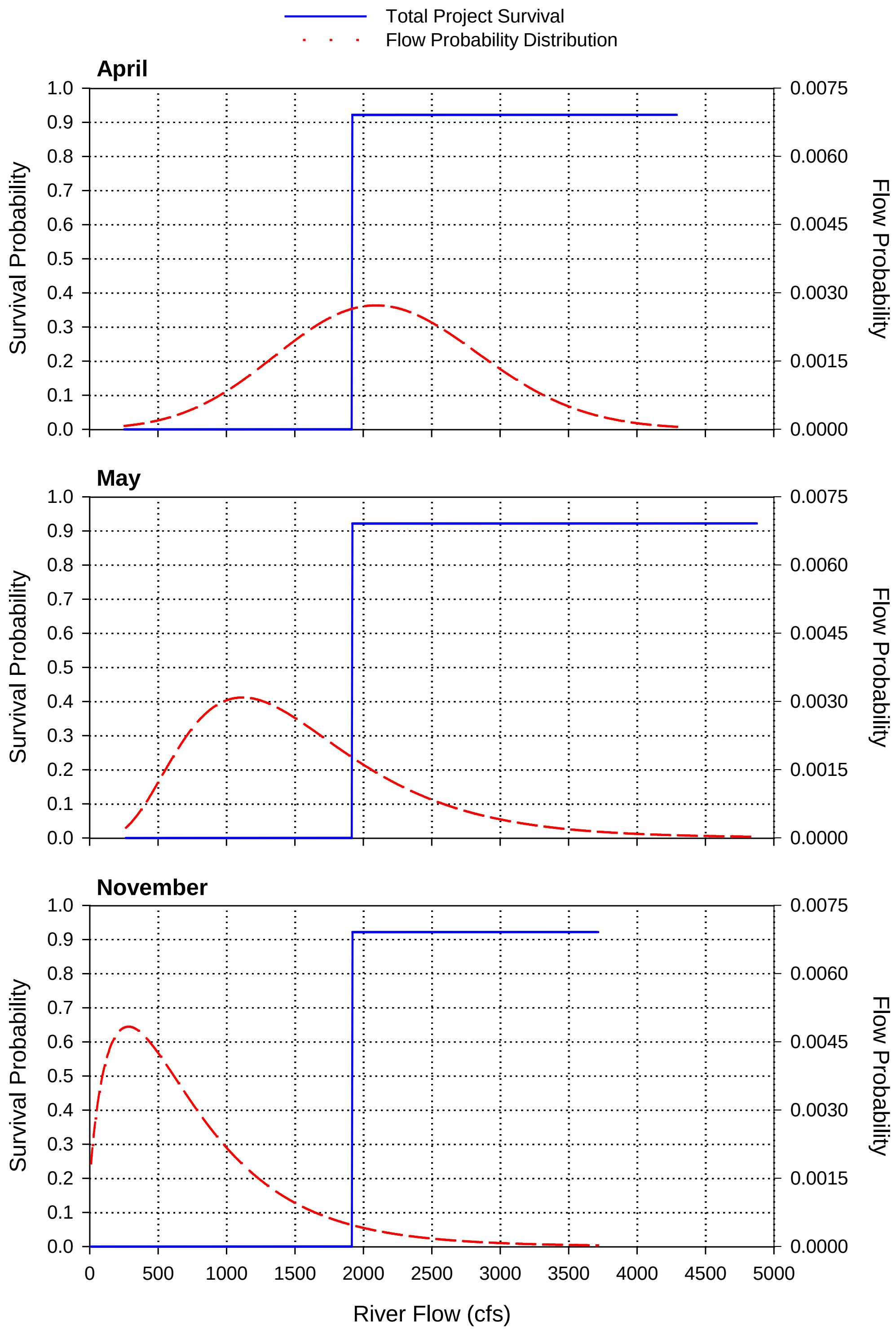

Figure 4-45. Total project survival for kelts and flow probability distributions for April, May, and November at the Milo Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.17 Sebec (FERC NO. 7253)

The Sebec Hydroelectric Project is owned and operated by Ampersand and is located on the Sebec River in the town of Sebec. An aerial view of the Sebec Project is provided in Figure 4-46. The Sebec Project has a FERC license exemption. Information on the project design and operation was obtained from the project owner and from a search for relevant documents in the FERC online library and other internet sites.

The Sebec Project has an estimated mean monthly flow ranging from 273 cfs in August to 1,725 cfs in April (Table 4-123). It is believed that the project is operated in a ROR mode, but this could not be confirmed through available publications and documents describing the project facilities and operation.

4.17.1 Power Generating Facilities

The Sebec Project consists of a timber-crib dam (with gradually sloped and stepped concrete apron) and a powerhouse. The dam and powerhouse were rehabilitated in the mid-1980's. Two ESAC bulb turbines were installed, both with a design head of 17 ft. The smaller of the two units is 4.6 ft in diameter and has a generating capacity of 305 kW, a flow capacity of 297 cfs, and a rotational speed of 260 rpm. The larger turbine is 5.9 ft in diameter and is rated for 562 kW with a flow capacity 494 cfs and a rotational speed of 240 rpm. Both units have 4 blades. The clear spacing of the intake bar racks is 2.5 inches.

4.17.2 Downstream Passage Facility Design and Operation

The Sebec Project powerhouse bar racks are slightly angled to the flow with a sluice gate used as downstream bypass. The project owner indicated there was also a notch in the dam that released 15 cfs for downstream passage. The use of the sluice gate for downstream passage and the presence of a dam notch were obtained from two different information sources and it is not clear if they are separate structures or only one is operated at any given time (i.e., depending on impoundment level and flow conditions). In response to Alden's request for information, the project owner only mentioned the dam notch, whereas the company that rehabilitated the facility had a photo and brief description of the sluice gate on their website (http://www.swiftriverhydro.com/Sebec%20photo%20appendix.htm). No information was obtained indicating that downstream passage effectiveness or survival studies have been conducted at the Sebec Project.

4.17.3 Upstream Passage Facilities

The available information indicated that upstream passage facilities have not been installed at the Sebec Project.

Figure 4-46. Aerial view of the Sebec Hydroelectric Project.

Table 4-123. Average monthly river discharge at the Sebec Hydroelectric Project.

Month	Average Flow (cfs)
January	432
February	476
March	606
April	1,725
May	1,233
June	518
July	318
August	273
September	362
October	395
November	602
December	608

4.17.4 Turbine Design and Operations Parameters

The Sebec Hydroelectric Project is located on the Sebec River in Sebec, Maine. The typical head at the Sebec Project for is 17 ft and the total plant hydraulic capacity is 791 cfs. The powerhouse contains a total of two turbine/generating units which can be categorized into two different individual types. Table 4-124 and Table 4-125 summarize the pertinent design and operational data used in the estimation of survival through the Sebec turbines. Design parameters estimated for the Sebec turbines include the flow angle approaching the blade and the leading edge blade thickness (Table 4-124 and Table 4-125). The leading edge blade thickness was estimated directly from the relationship with turbine diameter (Table 3-4) and the flow angle was estimated based upon a relationship between the blade tip speed components (Table 3-4). Based on a review of available literature and data, modifications or adjustments to the acquired and estimated parameters were not considered necessary.

4.17.5 Turbine Passage Survival Estimates

The results of the survival predictions for the Sebec units are presented in Table 4-126 and Table 4-127 for smolts and Table 4-128 and Table 4-129 for kelts. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and turbine passage survival rates for smolts passing through both Sebec turbines showed low to moderate sensitivity to changes in radial fish length (approach angle) and the range of survival estimates for the modified parameter increased with fish length. Changes to K also resulted in low to moderate differences in smolt survival compared to the baseline for both units, with the same fish length effect. When the changes to both parameters were combined, the range of the smolt survival estimates increased, resulting in greater differences from the baseline estimates. Strike probability for kelts was 100% for the baseline conditions and with a higher fish approach angle ($+10^{o}$), resulting in no change in survival estimates from the baseline. At the lower approach angle, moderate increases in survival were observed for Unit H4 and relatively large increases occurred with Unit H6. Kelt survival was also sensitive to changes in K, with relatively large differences from the baseline for both lower and higher values of K. The sensitivity of kelt survival rates to changes in approach angle and K was greater for Unit H6.

Table 4-124. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Sebec H4 unit.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Kaplan	--
Flow (cfs)	297	--
Runner Diameter (ft)	4.6	--
Hub Diameter (ft)	1.8	--
Turbine Speed (rpm)	260	--
Number Blades	4	--
Flow Angle (deg)	39[1]	--
Leading Edge Blade Thickness (mm)	13.3[1]	--

[1] Parameter was estimated.

Table 4-125. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through Sebec H6 unit.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Kaplan	--
Flow (cfs)	494	--
Runner Diameter (ft)	5.9	--
Hub Diameter (ft)	2.3	--
Turbine Speed (rpm)	240	--
Number Blades	4	--
Flow Angle (deg)	36[1]	--
Leading Edge Blade Thickness (mm)	15.4[1]	--

[1] Parameter was estimated.

Table 4-126. Turbine survival estimates for smolts passing through Sebec H4 unit.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.219	0.914	0.263	0.897	0.168	0.934	0.897	0.928	0.876	0.945
140	0.236	0.905	0.283	0.886	0.181	0.927	0.886	0.921	0.863	0.939
150	0.252	0.896	0.303	0.875	0.194	0.920	0.875	0.913	0.850	0.933
160	0.269	0.887	0.324	0.864	0.207	0.913	0.864	0.905	0.836	0.927
170	0.286	0.877	0.344	0.852	0.220	0.906	0.852	0.898	0.823	0.921
180	0.303	0.867	0.364	0.841	0.233	0.898	0.841	0.890	0.809	0.915
190	0.320	0.858	0.384	0.829	0.245	0.891	0.829	0.881	0.795	0.909
200	0.337	0.848	0.405	0.817	0.258	0.883	0.817	0.873	0.780	0.903
210	0.353	0.838	0.425	0.805	0.271	0.875	0.805	0.865	0.766	0.896

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-127. Turbine survival estimates for smolts passing through Sebec H6 unit.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.189	0.906	0.231	0.886	0.141	0.930	0.888	0.922	0.863	0.942
140	0.203	0.897	0.248	0.874	0.152	0.923	0.876	0.914	0.848	0.935
150	0.218	0.886	0.266	0.861	0.163	0.915	0.864	0.905	0.833	0.929
160	0.232	0.876	0.284	0.849	0.174	0.907	0.851	0.897	0.818	0.923
170	0.247	0.866	0.302	0.836	0.185	0.899	0.839	0.888	0.803	0.916
180	0.261	0.855	0.319	0.823	0.196	0.891	0.826	0.879	0.787	0.910
190	0.276	0.844	0.337	0.809	0.206	0.883	0.813	0.870	0.771	0.903
200	0.290	0.833	0.355	0.796	0.217	0.875	0.800	0.861	0.755	0.896
210	0.305	0.822	0.373	0.783	0.228	0.867	0.786	0.852	0.739	0.889

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-128. Turbine survival estimates for Kelts passing through Sebec H4 unit.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	1.000	0.385	1.000	0.385	0.840	0.483	0.262	0.487	0.262	0.569
675	1.000	0.379	1.000	0.379	0.872	0.459	0.255	0.483	0.255	0.549
700	1.000	0.374	1.000	0.374	0.904	0.434	0.249	0.479	0.249	0.529
725	1.000	0.370	1.000	0.370	0.937	0.410	0.243	0.475	0.243	0.508
750	1.000	0.365	1.000	0.365	0.969	0.385	0.238	0.471	0.238	0.487
775	1.000	0.360	1.000	0.360	1.000	0.360	0.232	0.467	0.232	0.467
800	1.000	0.356	1.000	0.356	1.000	0.356	0.227	0.463	0.227	0.463

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-129. Turbine survival estimates for Kelts passing through Sebec H6 unit.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	0.944	0.386	1.000	0.350	0.706	0.541	0.264	0.489	0.220	0.617
675	0.980	0.363	1.000	0.350	0.733	0.523	0.235	0.469	0.220	0.603
700	1.000	0.350	1.000	0.350	0.761	0.506	0.220	0.458	0.220	0.588
725	1.000	0.350	1.000	0.350	0.788	0.488	0.220	0.458	0.220	0.573
750	1.000	0.350	1.000	0.350	0.815	0.470	0.220	0.458	0.220	0.559
775	1.000	0.350	1.000	0.350	0.842	0.453	0.220	0.458	0.220	0.544
800	1.000	0.350	1.000	0.350	0.869	0.435	0.220	0.458	0.220	0.529

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.17.6 Bypass Efficiency and Survival

Fish passage effectiveness studies have not been conducted at the Sebec Project for smolts or kelts. Because the Sebec powerhouse has relatively wide bar spacing (2.5 inches clear), it was assumed that bypass efficiency was 25% for smolts. However, the bar spacing is sufficiently narrow to prevent turbine entrainment of kelts at Sebec. Direct bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.17.7 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Sebec Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Sections 3.1.2.

4.17.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Sebec Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Sections 3.2.

4.17.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 83.4 to 90.9% across the range of average monthly flows likely to occur at Sebec (Table 4-130; Figure 4-47), with a mean of 88.7%. Predicted smolt survival rates fluctuate at lower river flows as turbines come on line and alternate between partial and full load. After all turbines reach full load and river flow increases to levels sufficient for spillway passage, smolt survival gradually increases to a peak at the highest discharge (Figure 4-47). Due to complete exclusion from turbine entrainment by the 2.5-inch bar spacing, total project survival for kelts did not vary considerably among months or across the expected flow ranges within each month (Table 4-130; Figure 4-48).

Table 4-130. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Sebec Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

Month	River Flow Range (cfs)	Smolts			Kelts		
		Mean	Min	Max	Mean	Min	Max
April	205 - 3445	--	--	--	0.933	0.926	0.941
May	215 - 3920	0.887	0.834	0.909	0.932	0.925	0.941
November	10 - 2985	--	--	--	0.934	0.927	0.941

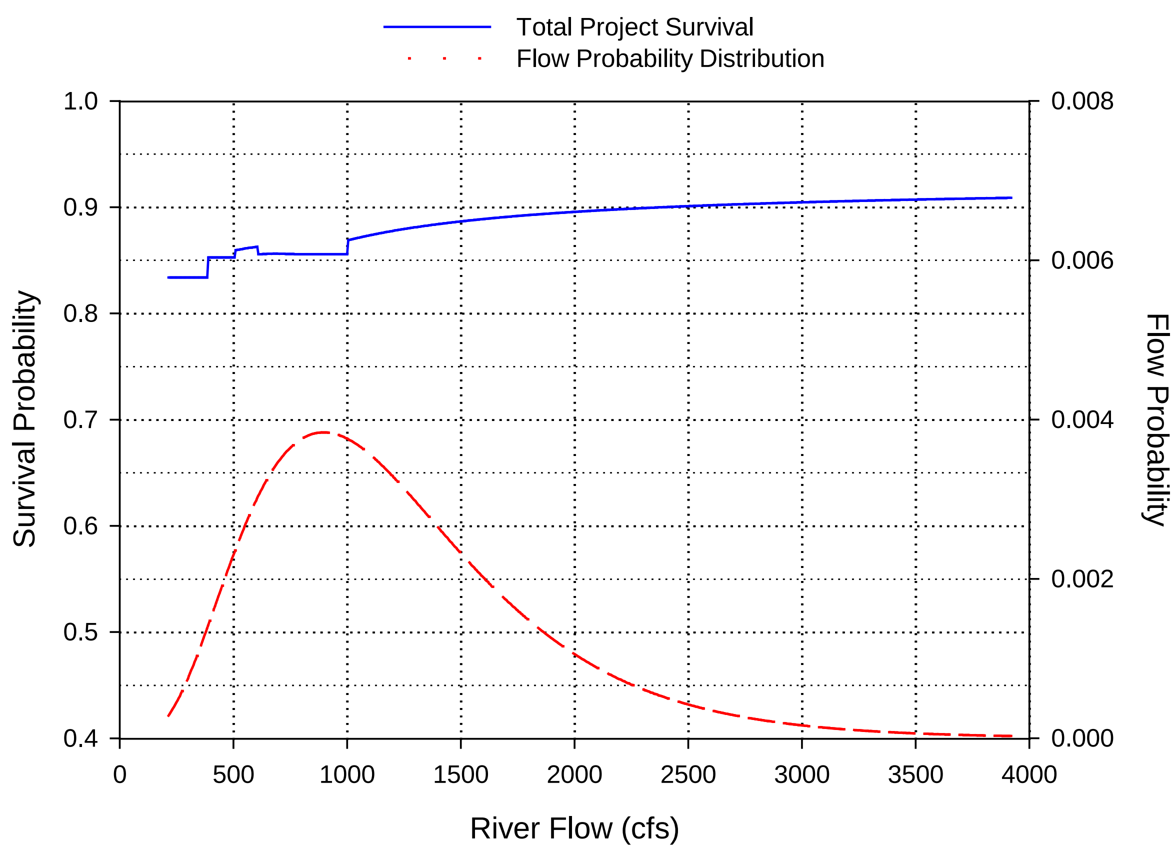

Figure 4-47. Total project survival for smolts and the flow probability distribution for May at the Sebec Project. Flow probabilities were estimated and plotted in 5 cfs increments.

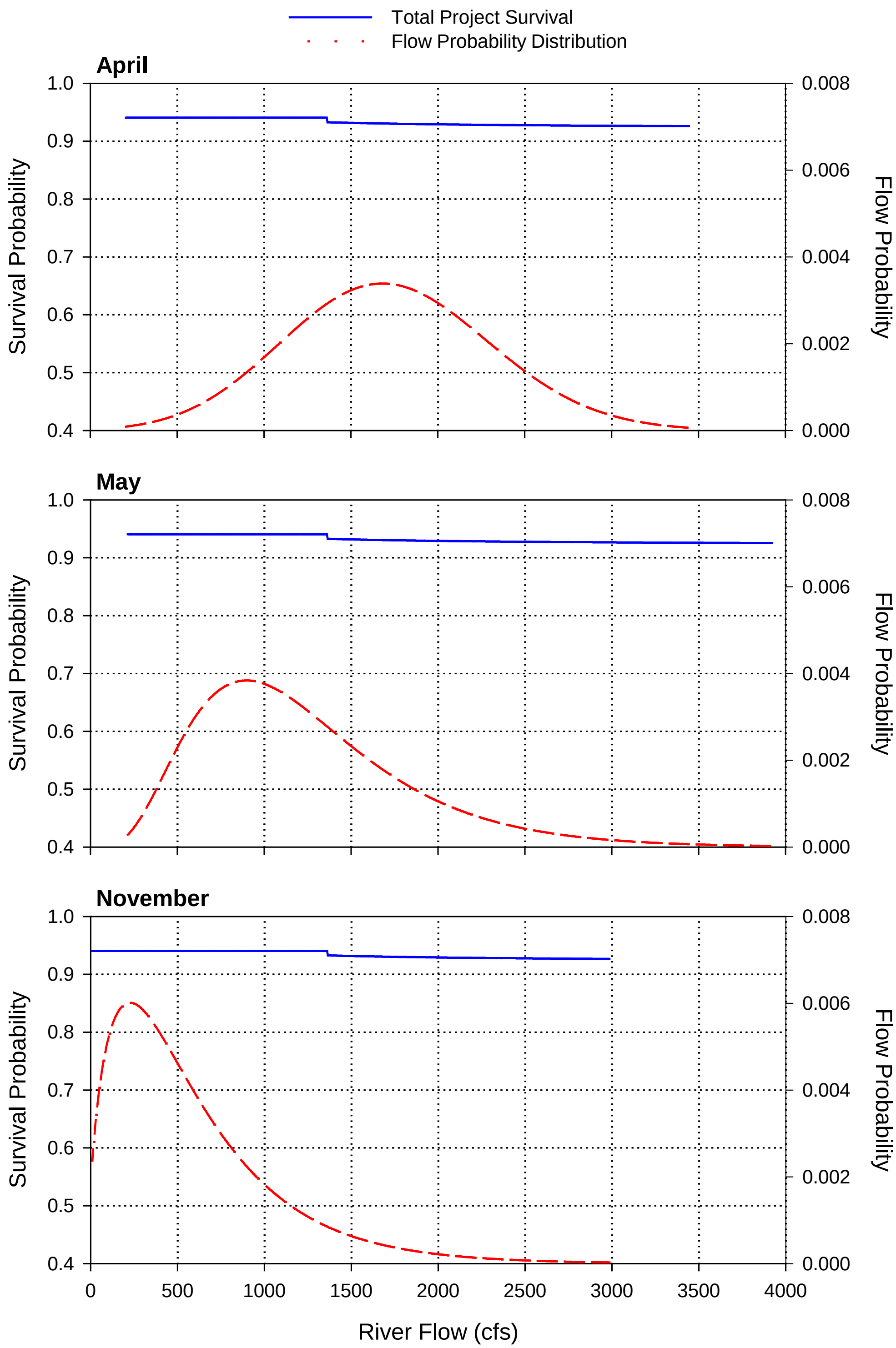

Figure 4-48. Total project survival for kelts and flow probability distributions for April, May, and November at the Sebec Project. Flow probabilities were estimated and plotted in 5 cfs increments.

4.18 Frankfort (FERC NO. 6618)

The Frankfort Hydroelectric Project is located on the Marsh Stream in the town of Frankfort. The reach below Frankfort is tidal and discharges into the Penobscot River below the lower most mainstem dam (Veazie). An aerial view of the Frankfort Project is provided in Figure 4-49. The Town of Frankfort owns the project and leases it to Mr. Christopher Anthony. Limited information and data were obtained from relevant documents identified during a search of the FERC online library. The project is exempt from FERC licensing.

According to the MDEP listing of Maine hydropower projects (MDEP 2010), the Frankfort Project is currently inoperable and shut down. When it was operable, Frankfort was a ROR facility. The estimated mean monthly flow at the project ranges from 50 cfs in August to 1150 cfs in April (Table 4-131).

4.18.1 Power Generating Facilities

The Frankfort project has a 250-ft dam that was constructed in 1921 with concrete and granite for use by a grist mill. The dam originally included 138-ft long spillway and a 9-ft wide flood gate. In the application for a FERC license exemption, the applicant indicated that a powerhouse with four Francis turbines would be installed with generating and hydraulic capacities of 550 kW and 730 cfs, respectively. However, Maine DEP and FERC databases indicate that the authorized generating capacity is currently 400 kW. No additional information on project or turbine design and operation was obtained for the Frankfort Project. The inake bar racks at Frankfort have 3.25 inch clear spacing.

Figure 4-49. Aerial view of the Frankfort Hydroelectric Project.

Table 4-131. Average monthly river discharge at the Frankfort Hydroelectric Project.

Month	Average Flow (cfs)
January	214
February	187
March	506
April	1151
May	423
June	170
July	76
August	49
September	71
October	125
November	364
December	362

4.18.2 Downstream Passage Facilities and Evaluations

Although documents obtained from a search of the FERC online library indicated that partial-depth overlays reducing the bar rack clear spacing to 1 inch were to be installed seasonally to reduce entrainment of Atlantic salmon smolts and juvenile river herring at Frankfort, NMFS stated that these measures have not been implemented and current clear bar spacing is 3.25 inches. The FWS also had requested a notch in the dam to allow downstream passage when spillway flow is less than 6 inches over the crest, but it could not be confirmed if this measure, or any other type of bypass, has been installed. The Frankfort Project is required to operate in a ROR mode with no impoundment fluctuations or changes to the Marsh Stream flow regime and minimum flow requirements are 70 cfs or inflow, whichever is less. No information was obtained indicating that downstream passage effectiveness or survival studies have been conducted at the Frankfort Project.

4.18.3 Upstream Passage Facilities

A Denil fish ladder has been installed at the Frankfort Project for passing anadromous species upstream.

4.18.4 Turbine Design and Operation Paramaters

The Frankfort Hydroelectric Project is located on Marsh Stream in Frankfort, Maine. The typical head at Frankfort varies between 12 and 16 ft due to fluctuations in tailwater levels from tidal changes and discharge from the lower most mainstem dam on the Penobscot River (Veazie). The Frankfort Project has a single Kaplan unit with a peak hydraulic capacity of 550 cfs. Table 4-132 summarizes the pertinent design and operational data used in the estimation of survival through the Frankfort turbine. Design parameters estimated for the Frankfort turbine include the flow angle approaching the blade, the hub diameter, and the leading edge blade thickness (Table 4-132). The leading edge blade thickness and hub diameter were estimated directly from the relationship with turbine diameter (Table 3-4). The flow angle was estimated based on a relationship between the blade tip speed components (Table 3-4). Based on a review of available literature and data, modifications or adjustments to the acquired and estimated parameters were not considered necessary.

Table 4-132. Pertinent design and operational parameters used to estimate turbine passage survival of smolts and kelts passing through the Frankfort turbine 1.

Design/Operational Parameters	Data Acquired/Estimated	Modified/Adjusted
Turbine Type	Kaplan	--
Flow (cfs)	550	--
Runner Diameter (ft)	6.6	--
Hub Diameter (ft)	2.4[1]	--
Turbine Speed (rpm)	155	--
Number Blades	4	--
Flow Angle (deg)	39[1]	--
Leading Edge Blade Thickness (mm)	16.5[1]	--

[1] Parameter was estimated.

4.18.5 Turbine Passage Survival

The results of the smolt survival predictions for the unit located at the Frankfort Hydroelectric station are located in Table 4-133 and Table 4-134. In addition to the turbine design and operational information presented above, other model data inputs (e.g., L/t ratio, K) used to calculate strike probability and survival for each life stage and length interval are provided in Appendix D.

Strike probabilities and turbine passage survival rates for smolts passing through the Frankfort turbine showed low sensitivity to changes in radial fish length (approach angle). Changes to K also resulted in relatively minor differences in smolt survival compared to the baseline estimates. When the changes in the two parameters were combined, differences in smolt survival from the baseline were larger and increased with fish length. Kelt survival rates demonstrated relatively high sensitivity to changes in fish approach angle and K, particularly when the changes in each parameter were combined.

Table 4-133. Turbine survival estimates for smolts passing through Frankfort Unit 1.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
130	0.148	0.966	0.177	0.959	0.114	0.974	0.959	0.972	0.951	0.978
140	0.159	0.962	0.191	0.955	0.123	0.971	0.955	0.969	0.946	0.976
150	0.170	0.959	0.204	0.951	0.131	0.968	0.951	0.966	0.941	0.974
160	0.182	0.955	0.218	0.946	0.140	0.965	0.946	0.962	0.935	0.971
170	0.193	0.951	0.232	0.941	0.149	0.962	0.941	0.959	0.930	0.969
180	0.205	0.947	0.245	0.937	0.158	0.959	0.937	0.956	0.924	0.966
190	0.216	0.943	0.259	0.932	0.166	0.956	0.932	0.953	0.918	0.964
200	0.227	0.939	0.273	0.927	0.175	0.953	0.927	0.949	0.913	0.961
210	0.239	0.935	0.286	0.922	0.184	0.950	0.922	0.946	0.907	0.958

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

Table 4-134. Turbine survival estimates for Kelts passing through Frankfort Unit 1.

Fish Length (mm)	Baseline Predictions		Modified Radial Fish Length[1]				Turbine Passage Survival for Modified K[2]		Compounded Turbine Passage Survival Estimate[3]	
			+10° Fish Approach Angle		-10° Fish Approach Angle					
	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	Strike Probability	Turbine Passage Survival	20% Higher K	20% Lower K	20% Higher K; +10° Fish Approach Angle	20% Lower K; -10° Fish Approach Angle
650	0.739	0.726	0.886	0.672	0.570	0.789	0.672	0.772	0.606	0.824
675	0.767	0.713	0.920	0.656	0.591	0.779	0.656	0.761	0.588	0.816
700	0.796	0.700	0.954	0.641	0.613	0.769	0.640	0.750	0.569	0.807
725	0.824	0.687	0.988	0.625	0.635	0.759	0.624	0.739	0.550	0.799
750	0.852	0.674	1.000	0.617	0.657	0.748	0.608	0.728	0.540	0.790
775	0.881	0.660	1.000	0.614	0.679	0.738	0.592	0.717	0.537	0.782
800	0.909	0.647	1.000	0.611	0.701	0.728	0.576	0.706	0.534	0.773

[1] Modifications to radial fish length result in changes to strike probability and turbine passage survival.
[2] Modifications to K result in changes to turbine passage survival, but not strike probability (i.e., strike probability is the same as the baseline).
[3] The compounded turbine passage survival estimates are based on the strike probabilities for the modified radial length.

4.18.6 Bypass Efficiency and Survival

Downstream passage effectiveness studies have not been conducted at the Frankfort Project for smolts or kelts. Because the Frankfort powerhouse has wide bar spacing (3.25-inch clear), it was assumed that bypass efficiency was 10% for smolts and 25% for kelts. Bypass survival for smolts and kelts was set at 99%. More information on the determination of bypass efficiencies and survival is provided in Section 3.1.3.

4.18.7 Spillway Passage

Direct spillway passage survival for smolts and kelts passing downstream at the Frankfort Project was assumed to be 97%. More detailed information on the estimation of spillway survival rates is provided in Sections 3.1.2.

4.18.8 Indirect Survival

Indirect survival for smolts and kelts passing downstream at the Frankfort Project was assumed to be 95% for fish passing through all available routes (spillway, bypass, and turbines). More detailed information on the estimation of indirect survival rates is provided in Sections 3.2.

4.18.9 Total Project Survival

Based on the direct survival rates estimated for the various downstream passage routes and the combined indirect survival estimate for all passage routes, total project survival for smolts is expected to range from 90.8 to 94.4% across the range of average monthly flows likely to occur at Frankfort (Table 4-135; Figure 4-50), with a mean of 92.0%. Mean total project survival for kelts was highest in April (74.0%) and lowest in May (68.4%) for the range of expected monthly average flows (Table 4-135; Figure 4-51). Minimum kelt survival was 53.5% for all three months and maximum survival was highest in May and November (94.1%) and lowest in April (90.8%).

Table 4-135. Mean, minimum, and maximum total project survival rates for smolts and kelts passing downstream at the Frankfort Project over the range of river flows estimated from the flow probability distributions for the expected migration periods of each life stage.

		Smolts			Kelts		
Month	**River Flow Range (cfs)**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
April	385 - 2835	--	--	--	0.740	0.535	0.908
May	70 - 1555	0.920	0.908	0.944	0.709	0.535	0.941
November	5 - 1680	--	--	--	0.724	0.535	0.941

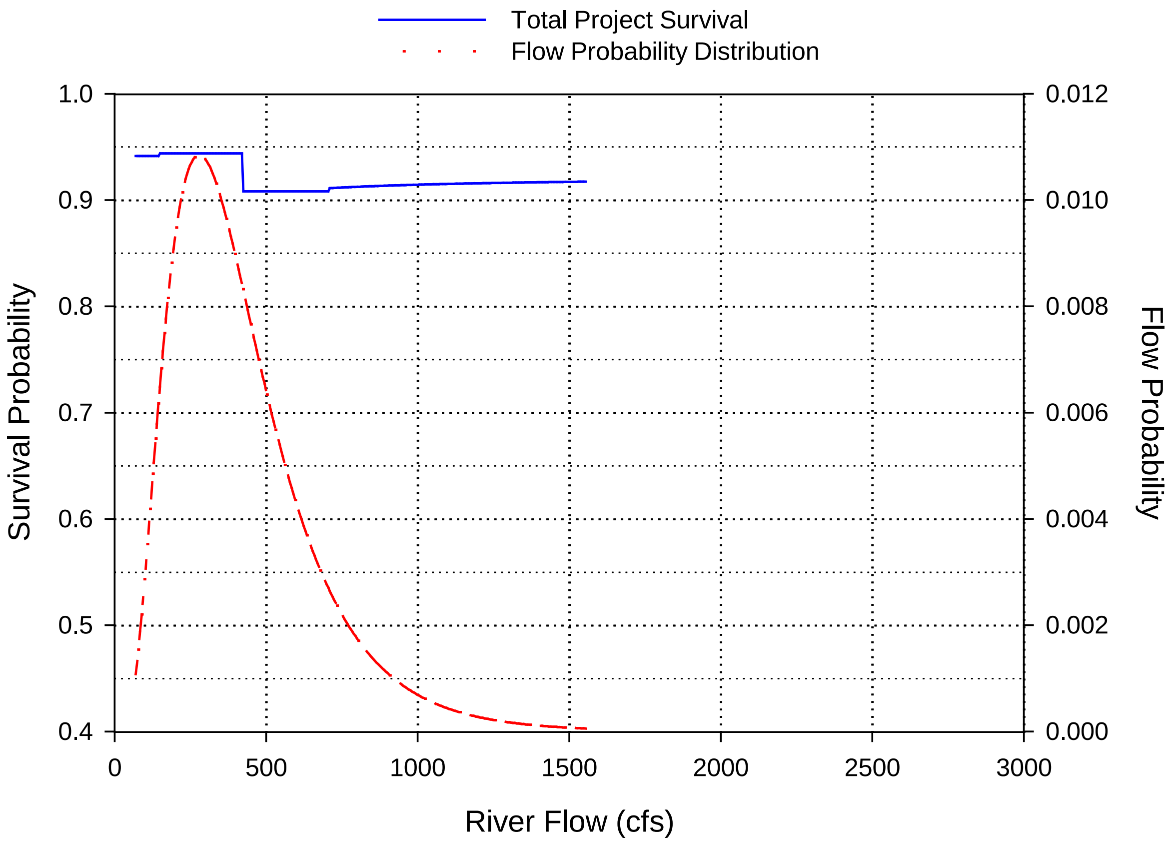

Figure 4-50. Total project survival for smolts and the flow probability distribution for May at the Frankfort Project. Flow probabilities were estimated and plotted in 5 cfs increments.

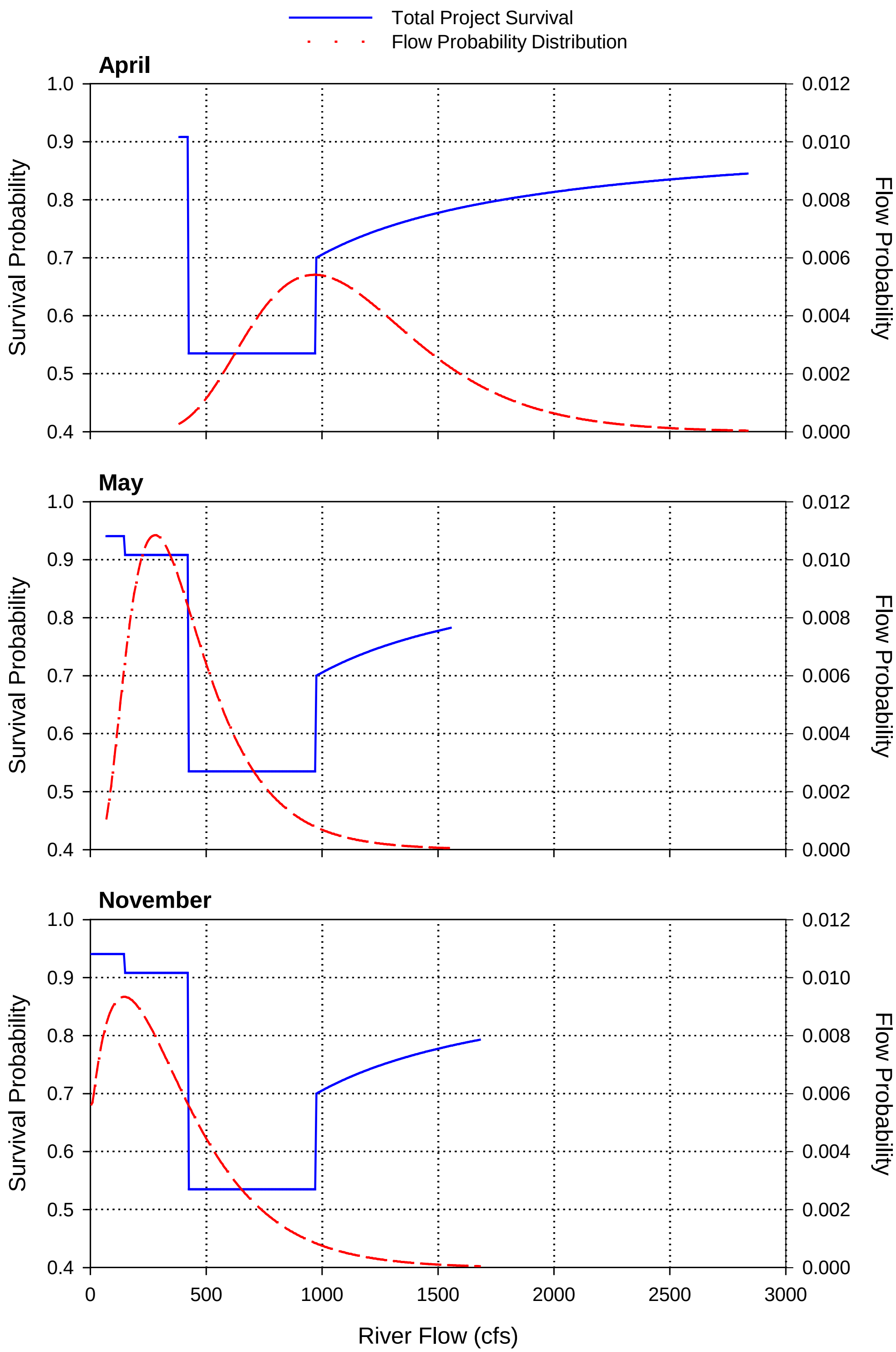

Figure 4-51. Total project survival for kelts and flow probability distributions for April, May, and November at the Frankfort Project. Flow probabilities were estimated and plotted in 5 cfs increments.

5 Comparison of Project Survival Rates for Atlantic Salmon Smolts Calculated from Field Studies and the Desktop Model

Several studies have investigated downstream passage of Atlantic salmon smolts and kelts at Penobscot River projects (Shepard 1991; BPHA 1993a, 1993b, 1994; Spicer et al. 1995; Holbrook 2007; Holbrook et al. 2011). Most of these studies have focused on movements of outmigrants primarily through the lower river reaches. Also, some of these studies have developed survival estimates for fish migrating through specified river reaches and/or an entire study area (i.e., release point to estuary) and not specifically for available passage routes (e.g., turbines, spillways, bypass systems) at individual projects. Reach-specific survival estimates do not allow the various sources of mortality (e.g., predation, turbine passage, stress or disease associated with sub-optimal migratory conditions and tagging and handling) that can be experienced by smolts and kelts to be differentiated. In particular, these studies do not provide data on direct or indirect mortality associated with available passage routes to be determined for a given project, even when the percent of fish using each passage route may be known. Despite the inability to isolate specific injury and mortality mechanisms, survival estimates for river reaches containing dams can be compared to the desktop model prediction for sites that field data are available.

In an evaluation of downstream movements of radio-tagged smolts, Shepard (1991) provided estimates of migration success for smolts released upstream of the Milford and Veazie projects in 1989 and upstream of the West Enfield Project in 1990. The goals of these studies were to determine passage routes, rates of downstream movement, and survival for fish passing each dam and through the entire study areas. In 1989, 38 tagged smolts were released about 1.6 miles upstream of the Milford Project and 10 smolts were released in the Veazie forebay. The 1990 study focused on passage at the West Enfield Project, with 59 tagged fish released about 8.4 miles upstream of the dam. With a final detection location positioned at the beginning of the tidal influence downstream of the Veazie Project, the 1989 study area extended about 10 miles downstream from the release location upstream of the Milford Project and the 1990 study area extended about 40 miles from the release location upstream of the West Enfield Project. An estimated 44% of smolts released in 1989 and 32% in 1990 completed migration downstream through the respective study areas. However, due to detection limitations at Veazie, these passage rates were believed to be 67 and 86% in 1989 and 1990, respectively. Also, fish that lost tags (i.e., regurgitation) during their outmigration could not be separated from direct and indirect mortalities that resulted from dam passage (i.e., through turbines, over spillways, or via other available routes). Therefore, the estimates of successful passage through the study areas for each year of study are likely conservative.

Using the average monthly flow for May in 1989 and 1990, estimates of survival from the desktop model were compared to the Shepard (1991) estimates of passage success generated from the radio telemetry data. Survival predictions for Milford, Great Works, and Veazie were multiplied to obtain an estimate for the study reach evaluated in 1989, and West Enfield, Stillwater/Orono (Stillwater Branch) or Milford/Great Works (mainstem branch), and Veazie were multiplied to obtain an estimate for the study reach evaluated in 1990. The model predictions produced a survival estimate of 81% for the 1989 study reach, compared to 67% estimated from the radio telemetry data, and estimates of 72% (mainstem passage after the Stillwater split) and 69% (Stillwater passage) for the 1990 study reach, compared to 86% estimated from the field data. These differences between model predictions and field data likely reflect weaknesses and limitations associated with the design and performance of the radio telemetry studies. In particular, the 1990 estimate of passage success was nearly 20% higher than the 1989 estimate despite higher river flows in 1989 (i.e., greater spillway passage) and a much longer study reach evaluated in 1990 (which included an additional dam to pass).

Spicer et al. (1995) evaluated the downstream migration characteristics of 30 radio-tagged smolts (1-yr old hatchery fish) released at Howland, Maine (below West Enfield Dam) in 1991. The study area extended 54 km from the release site to the most downstream tag detection location and included the Milford, Great Works, and Veazie hydroelectric projects. Initial movements indicated that most smolts migrated downstream in the main channel. However, about 47% of tag signals became stationary or ceased within 10 km of the release location. Only one fish was recorded more than 40 km from the release site and none were recorded at the most downstream receiver location. The authors attributed the large number of tags that became stationary within 10 km of the release site to fish not being physiologically prepared for migration, fish being too small for tagging (leading to high levels of tagging and handling-related stress), lost tags, transmitter battery failure, or predation. However, the intermittent nature of downstream movements in upper river reaches combined with predation and short battery life were cited as the most likely reasons for the relatively quick cessation of movement and lack of tag detections further downstream. The high attrition rate of tagged fish relatively close to the release site and the subsequent low numbers of fish that were detected at significant distances downstream, including only one fish passing the two of the three downstream dams, make it difficult to draw any definitive conclusions from this study on downstream passage survival at the three lower most dams (Milford, Great Works, and Veazie).

More recently, five years of field studies (2005-2006 and 2009-2011) have been conducted using acoustic telemetry techniques to examine migratory behavior and survival associated with specified river reaches, dam passage, and smolt condition (Holbrook 2007; Holbrook et al. 2011; Zydlewski and Stich 2011; Zydlewski and Stitch, unpublished data). During these studies, hatchery and wild smolts were released at several tributary and mainstem locations with tag detection stations located throughout the study reaches, which extended from the most upstream release points downstream into the Penobscot River estuary. Receiver locations allowed for survival and delay to be estimated at each hydro project within a study reach, but specific passage routes (turbine, spillway, bypass or sluice gates) at each dam could not be determined.

The estimated survival rates for the various release groups passing through river reaches with dams ranged from 71 to 96% for Howland, 80 to 89% for West Enfield, 75 to 100% for Milford, 91 to 100% for Great Works, and 96 to 100% for Veazie (Holbrook 2007). Based on these data, the author estimated that the Howland, West Enfield, and Milford accounted for 43 to 60% of smolt losses during the two study years. However, for some release groups, there were considerable losses of fish between the release location and the first dam encountered (losses from release location to first downstream receiver ranged from 3 to 72%). It was also demonstrated that travel rates through reaches with dams was slower than in free-flowing reaches for smolts that approached dams during the day. No difference in travel rates between free-flowing and dam reaches were evident for tagged fish that approached hydro projects at night. There was insufficient data to determine survival of smolts at hydro projects in the Stillwater Branch (Stillwater, Orono, and Gillman Falls), but 96% of fish in 2005 and 100% in 2006 that passed downstream through this section of the Penobscot River reached the estuary. Survival of tagged fish that reached the estuary was high and indicated that delayed mortality may not be significant issue at the lower river dams. The evaluation of smolt condition examined differences between release locations and wild and hatchery smolts. This analysis showed that survival was higher for fish released closer to the river mouth (99 km versus 143 km upstream). Also, there were not apparent differences in freshwater survival between hatchery and wild fish, or hatchery fish released in April and May, but there were differences in migration behavior between hatchery and wild fish.

To compare the field data to the theoretical approach, total project survival rates were calculated with the desktop model for the average May river flow for each project and study year for which field data were available (Table 5-1). Releases of tagged smolts for the field evaluations occurred in May and this also was the month that was used for the time period of migration for smolts in the desktop study. Project survival estimates were available for 10 projects over the five years of study (Table 5-1). Field data were collected during all five study years for West Enfield, Howland, Milford, Great Works, and Veazie, and four years of data were available for Stillwater and Orono and two years for Mattaceunk, Browns Mills, and Moosehead. Model predictions of project survival were not calculated for Mattaceunk because USGS flow data for the most relevant gage were not available for the two years (2010 and 2011) in which tagged fish were released upstream of this project. Survival estimates generated from the field data were reported for hatchery and/or wild fish releases for most projects and study years, but only combined estimates of survival for the two fish sources were available for most of the projects evaluated in 2010 and 2011. Also, project survival estimates from the 2009 data were provided for two release locations. It is assumed that data from multiple release locations were combined for some of the other study years.

Table 5-1. Summary of project survival estimates for Atlantic salmon smolts calculated from field data and the desktop model.

	Field Study Information and Survival Estimates			Desktop Model Survival Estimates		
Project	Study Year	Fish Source	Project Survival (95% CI)	Average May Flow (cfs)	Project Survival	Field Data Source
Moosehead	2010	W	0.89 (0.78 - 0.95)	264	0.717	Zydlewski and Stich (2011)
	2011	W	0.96 (0.87 - 0.99)	1,621	0.892	Zydlewski and Stich (2011)
Browns Mills	2010	W	0.94 (0.79 - 0.98)	301	0.789	Zydlewski and Stich (2011)
	2011	W	1.00 (--)	1,846	0.875	Zydlewski and Stich (2011)
West Enfield	2005	H	0.52 (0.22 - 0.81)	26,743	0.924	Holbrook et al. (2011)
	2005	W	0.91 (0.67 - 0.98)	26,743	0.924	Holbrook et al. (2011)
	2006	H	0.82 (0.72 - 0.89)	18,694	0.924	Holbrook et al. (2011)
	2006	W	0.87 (0.67 - 0.96)	18,694	0.924	Holbrook et al. (2011)
	2010	W	0.82 (0.67 - 0.91)	6,588	0.925	Zydlewski and Stich (2011)
	2011	W	0.90 (0.53 - 0.99)	29,363	0.924	Zydlewski and Stich (2011)
Howland	2005	H	0.79 (0.64 - 0.89)	8,720	0.917	Holbrook et al. (2011)
	2006	H	0.71 (0.59 - 0.81)	5,427	0.914	Holbrook et al. (2011)
	2009	H	0.94 (0.94 - 0.95)	3,440	0.909	Zydlewski and Stich (unpub.)
	2010	H/W	0.89 (0.76 - 0.95)	1,332	0.908	Zydlewski and Stich (2011)
	2011	H/W	0.91 (0.78 - 0.96)	8,251	0.917	Zydlewski and Stich (2011)
Milford	2005	H	0.92 (0.79 - 0.97)	23,933	0.918	Holbrook et al. (2011)
	2005	W	0.94 (0.42 - 1.00)	23,933	0.918	Holbrook et al. (2011)
	2006	H	0.82 (0.73 - 0.88)	16,730	0.916	Holbrook et al. (2011)
	2006	W	0.85 (0.55 - 0.96)	16,730	0.916	Holbrook et al. (2011)
	2009	H	0.96 (0.95 - 0.96)	11,545	0.913	Zydlewski and Stich (unpub.)
	2009	H	0.93 (0.83 - 0.98)	11,545	0.913	Zydlewski and Stich (unpub.)
	2010	H/W	0.88 (0.75 - 0.94)	6,436	0.903	Zydlewski and Stich (2011)
	2011	H/W	0.95 (0.87 - 0.98)	26,278	0.918	Zydlewski and Stich (2011)
Great Works	2005	H	0.95 (0.80 - 0.99)	23,933	0.867	Holbrook et al. (2011)
	2005	W	1.00 (--)	23,933	0.867	Holbrook et al. (2011)
	2006	H	0.99 (0.99 - 1.00)	16,730	0.843	Holbrook et al. (2011)
	2006	W	0.91 (0.56 - 0.99)	16,730	0.843	Holbrook et al. (2011)
	2009	H	0.93 (0.92 - 0.94)	11,545	0.807	Zydlewski and Stich (unpub.)
	2009	H	0.95 (0.85 - 0.98)	11,545	0.807	Zydlewski and Stich (unpub.)
	2010	H/W	0.97 (0.89 - 0.99)	6,436	0.824	Zydlewski and Stich (2011)
	2011	H/W	0.99 (0.96 - 1.00)	26,278	0.872	Zydlewski and Stich (2011)

Table 4.1. (continued)

	Field Study Information and Survival Estimates			Desktop Model Survival Estimates		
Project	Study Year	Fish Source	Project Survival (95% CI)	Average May Flow (cfs)	Project Survival	Field Data Source
Stillwater	2005	H	1.00 (--)	10,257	0.919	Holbrook et al. (2011)
	2005	W	0.85 (0.40 - 0.98)	10,257	0.919	Holbrook et al. (2011)
	2006	H	1.00 (--)	7,170	0.918	Holbrook et al. (2011)
	2009	H	1.00 (--)	4,855	0.916	Zydlewski and Stich (unpub.)
	2009	H	1.00 (--)	4,855	0.916	Zydlewski and Stich (unpub.)
Orono	2005	H	1.00 (--)	10,257	0.904	Holbrook et al. (2011)
	2005	W	1.00 (--)	10,257	0.904	Holbrook et al. (2011)
	2006	H	1.00 (--)	7,170	0.895	Holbrook et al. (2011)
	2006	W	1.00 (--)	7,170	0.895	Holbrook et al. (2011)
	2009	H	0.95 (0.94 - 0.96)	4,855	0.883	Zydlewski and Stich (unpub.)
	2009	H	0.71 (0.00 - 1.00)	4,855	0.883	Zydlewski and Stich (unpub.)
Veazie	2005	H	1.00 (--)	39,792	0.905	Holbrook et al. (2011)
	2005	W	1.00 (--)	39,792	0.905	Holbrook et al. (2011)
	2006	H	0.97 (0.90 - 0.99)	27,816	0.897	Holbrook et al. (2011)
	2006	W	1.00 (--)	27,816	0.897	Holbrook et al. (2011)
	2009	H	0.98 (0.97 - 0.98)	19,180	0.886	Zydlewski and Stich (unpub.)
	2009	H	1.00 (--)	19,180	0.886	Zydlewski and Stich (unpub.)
	2010	H/W	0.94 (0.83 - 0.98)	9,803	0.850	Zydlewski and Stich (2011)
	2011	H/W	0.96 (0.87 - 0.99)	43,691	0.906	Zydlewski and Stich (2011)

Project survival rates and the average May river flow were plotted by year to assess differences in the results from the two study approaches (Figure 5-1 to Figure 5-9). For most sites, the survival estimates calculated with the desktop model were lower than those produced by the field data due to studies not assessing indirect/ latent effects. However, desktop model estimates were greater than the field estimates for all fish releases examined for the West Enfield (Figure 5-4) and four of the five releases examined for Howland (Figure 5-7). Also, half of the desktop survival estimates for Milford were less than those generated from the field data, with the other half being higher. The magnitude of differences between survival rates estimated with the two techniques varied among study years and among the projects, with a range of about 0.002 to 0.400 (for a scale of 0.00 to 1.00), with most differences being between about 0.2 to 0.15. With the exception of Milford, the average difference between survival rates estimated from field and model data ranged from about 0.08 to 0.14 for each project. Survival estimates for Milford were generally similar between the two approaches, with an average difference of 0.04.

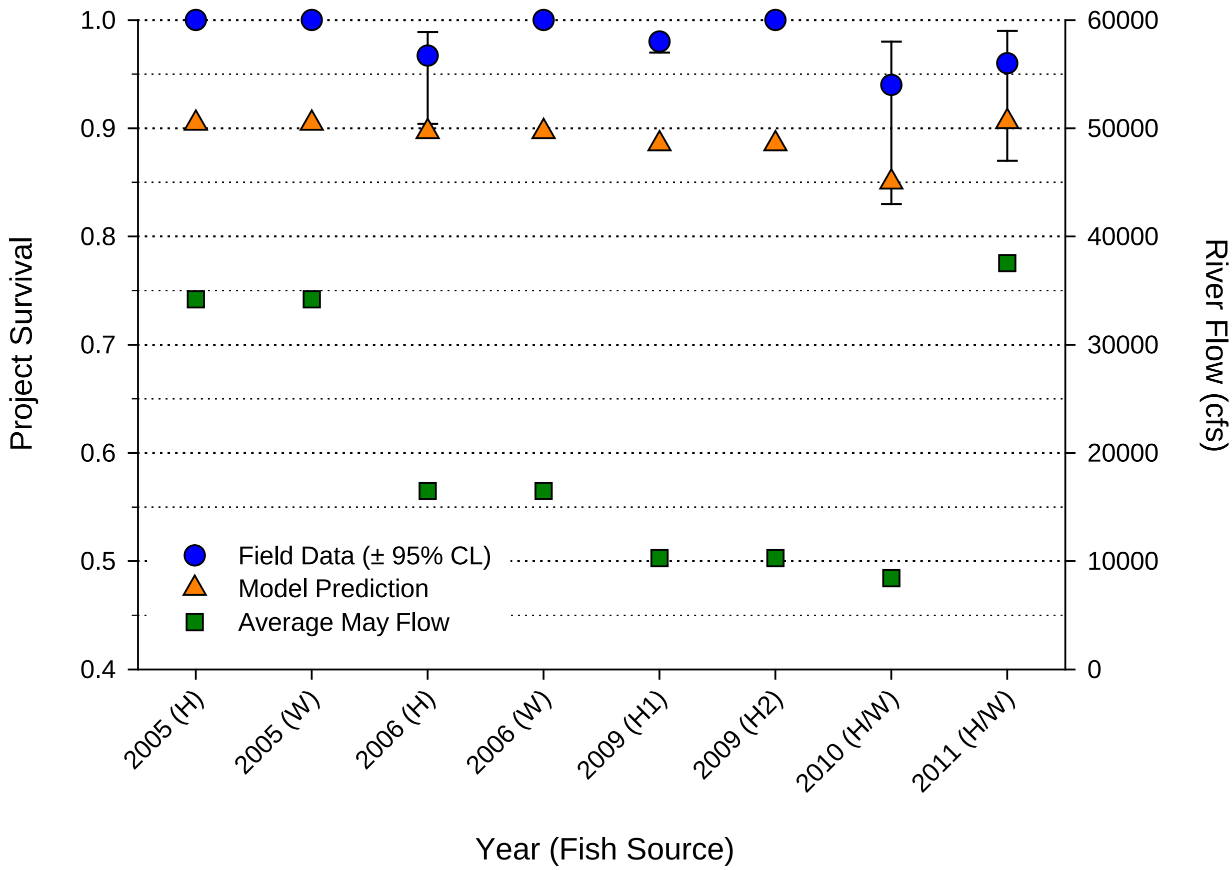

Figure 5-1. Project survival rates estimated from field data and with the desktop model for Atlantic salmon smolts passing downstream at the Veazie Hydroelectric Project. The model predictions for survival are based on the average monthly flow in May of each year that field studies were conducted. Depending on the study year, field data were used to calculate survival estimates for hatchery fish (H), wild fish (W), or both sources combined (H/W). Survival rates for hatchery fish evaluated in 2009 represent two release locations (H1, Pleasant River; H2, confluence of the Passadumkeag River with the Penobscot River).

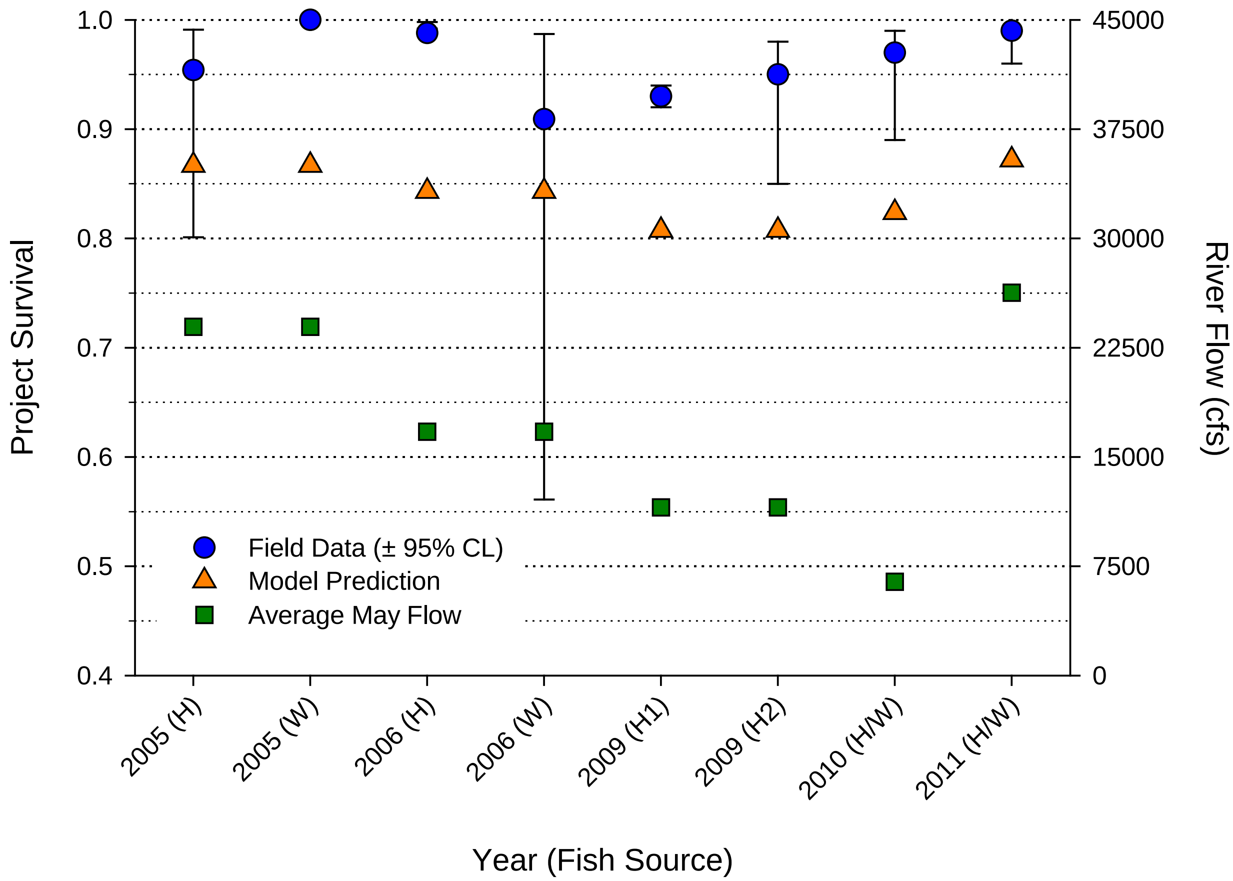

Figure 5-2. Project survival rates estimated from field data and the desktop model for Atlantic salmon smolts passing downstream at the Great Works Hydroelectric Project. The model predictions for survival are based on the average monthly flow in May of each year that field studies were conducted. Depending on the study year, field data were used to calculate survival estimates for hatchery fish (H), wild fish (W), or both sources combined (H/W). Survival rates for hatchery fish evaluated in 2009 represent two release locations (H1, Pleasant River; H2, confluence of the Passadumkeag River with the Penobscot River).

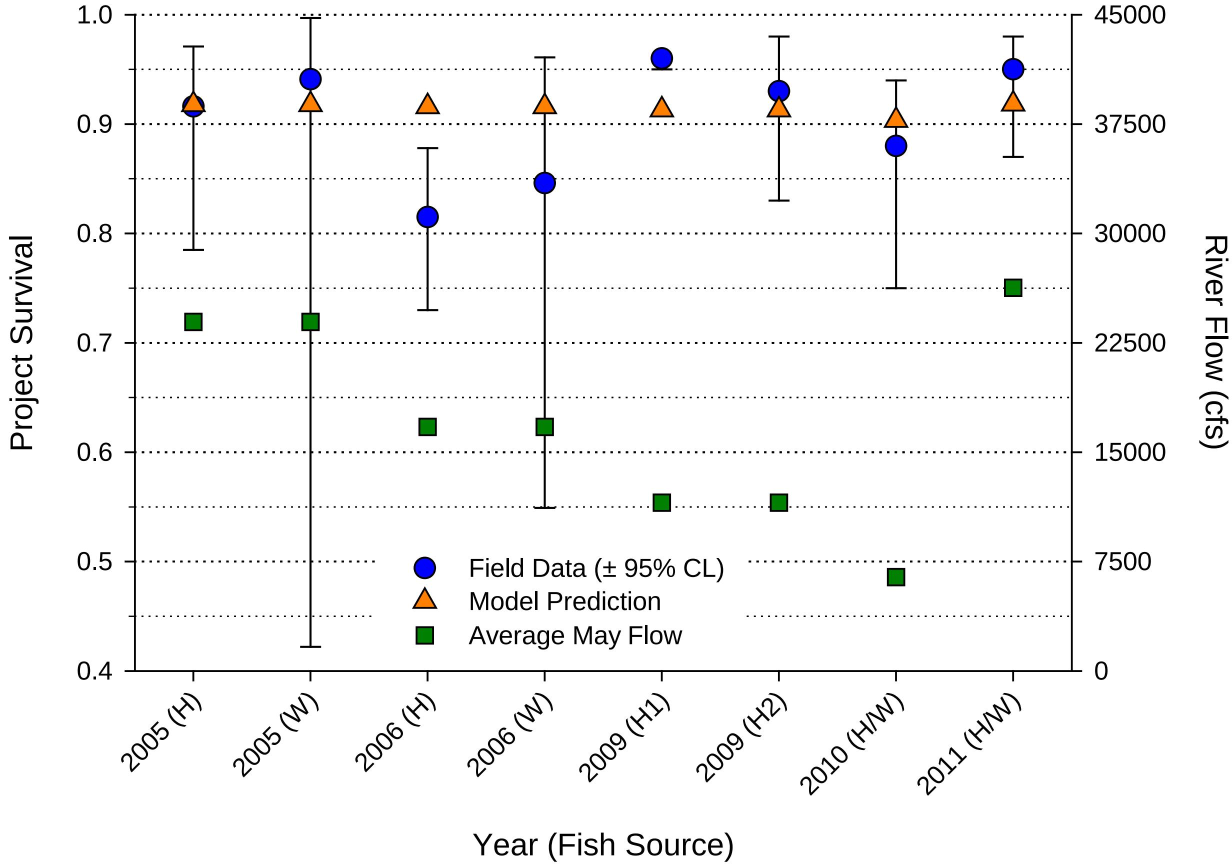

Figure 5-3. Project survival rates estimated from field data and the desktop model for Atlantic salmon smolts passing downstream at the Milford Hydroelectric Project. The model predictions for survival are based on the average monthly flow in May of each year that field studies were conducted. Depending on the study year, field data were used to calculate survival estimates for hatchery fish (H), wild fish (W), or both sources combined (H/W). Survival rates for hatchery fish evaluated in 2009 represent two release locations (H1, Pleasant River; H2, confluence of the Passadumkeag River with the Penobscot River).

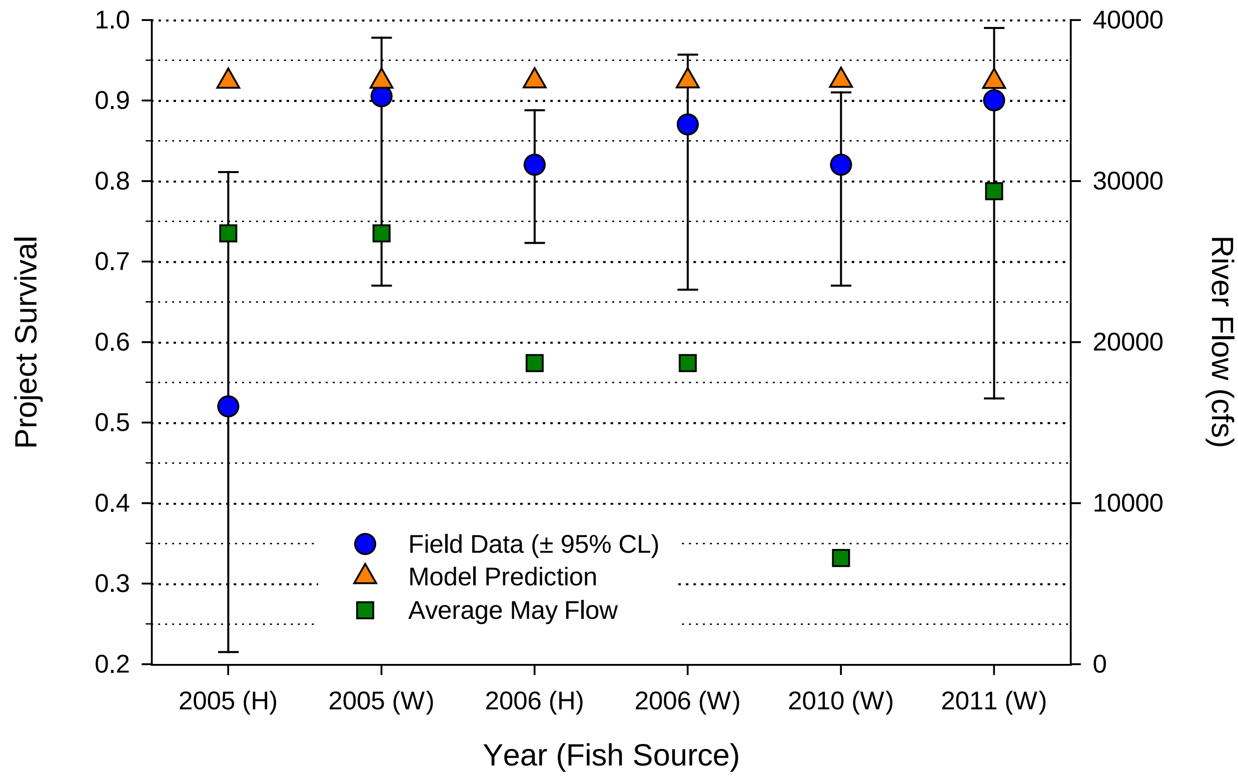

Figure 5-4. Project survival rates estimated from field data and the desktop model for Atlantic salmon smolts passing downstream at the West Enfield Hydroelectric Project. The model predictions for survival are based on the average monthly flow in May of each year that field studies were conducted. Depending on the study year, field data were used to calculate survival estimates for hatchery (H) and/or wild fish (W).

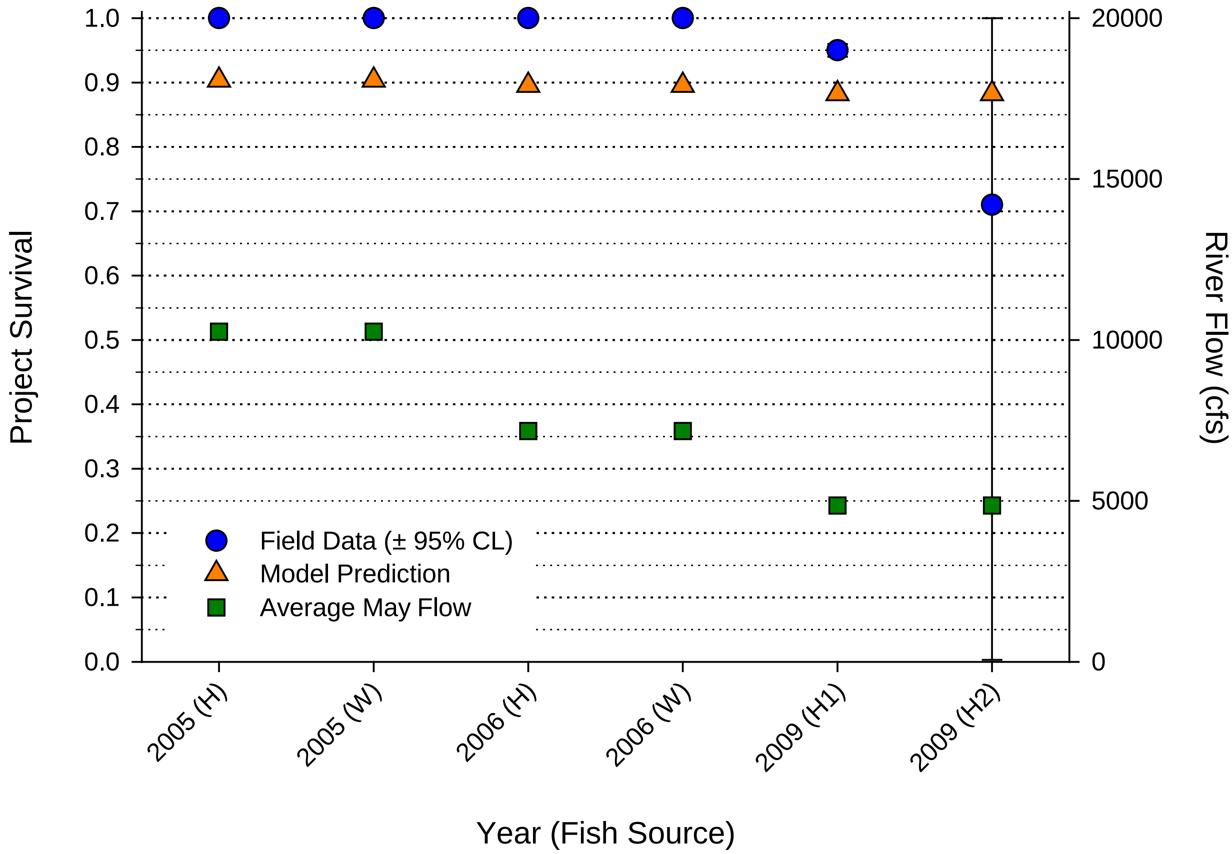

Figure 5-5. Project survival rates estimated from field data and the desktop model for Atlantic salmon smolts passing downstream at the Orono Hydroelectric Project. The model predictions for survival are based on the average monthly flow in May of each year that field studies were conducted. Depending on the study year, field data were used to calculate survival estimates for wild (W) and/or hatchery fish (H). Survival rates for hatchery fish evaluated in 2009 represent two release locations (H1, Pleasant River; H2, confluence of the Passadumkeag River with the Penobscot River).

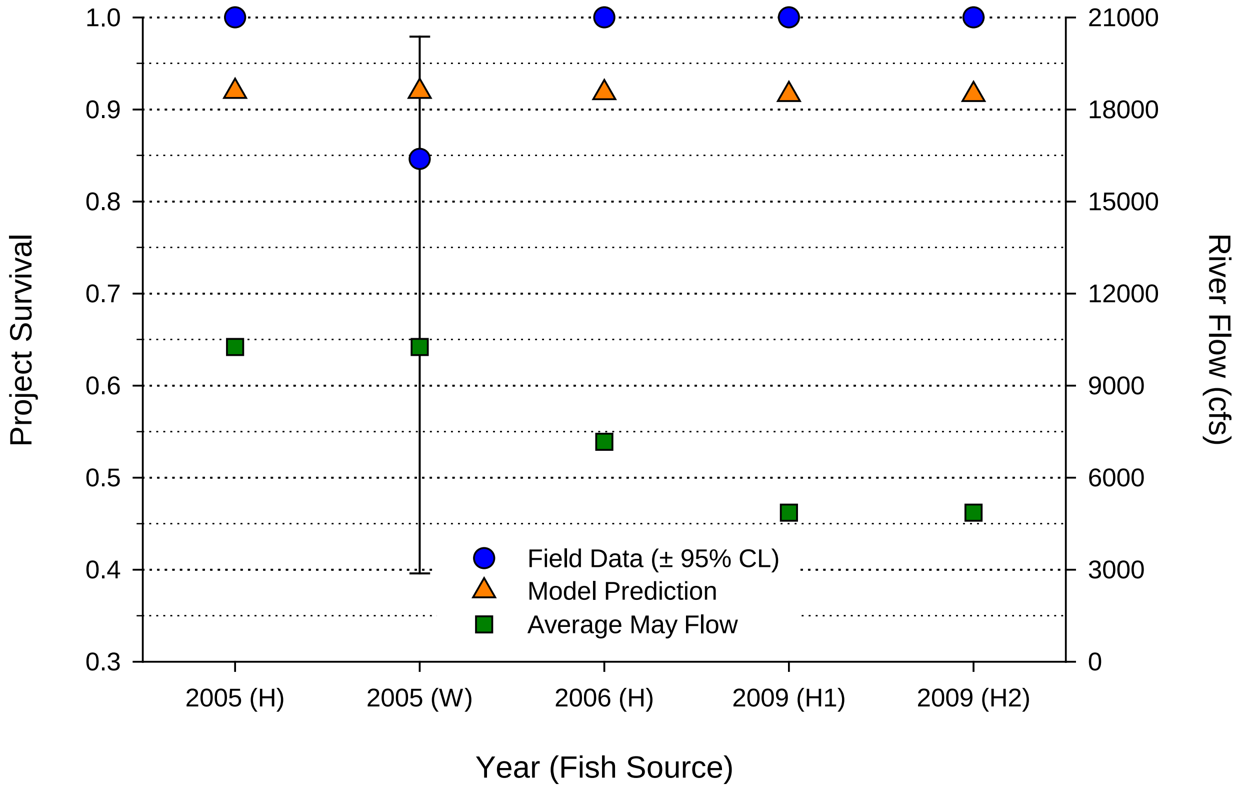

Figure 5-6. Project survival rates estimated from field data and the desktop model for Atlantic salmon smolts passing downstream at the Stillwater Hydroelectric Project. The model predictions for survival are based on the average monthly flow in May of each year that field studies were conducted. Depending on the study year, field data were used to calculate survival estimates for wild (W) and/or hatchery fish (H). Survival rates for hatchery fish evaluated in 2009 represent two release locations (H1, Pleasant River; H2, confluence of the Passadumkeag River with the Penobscot River).

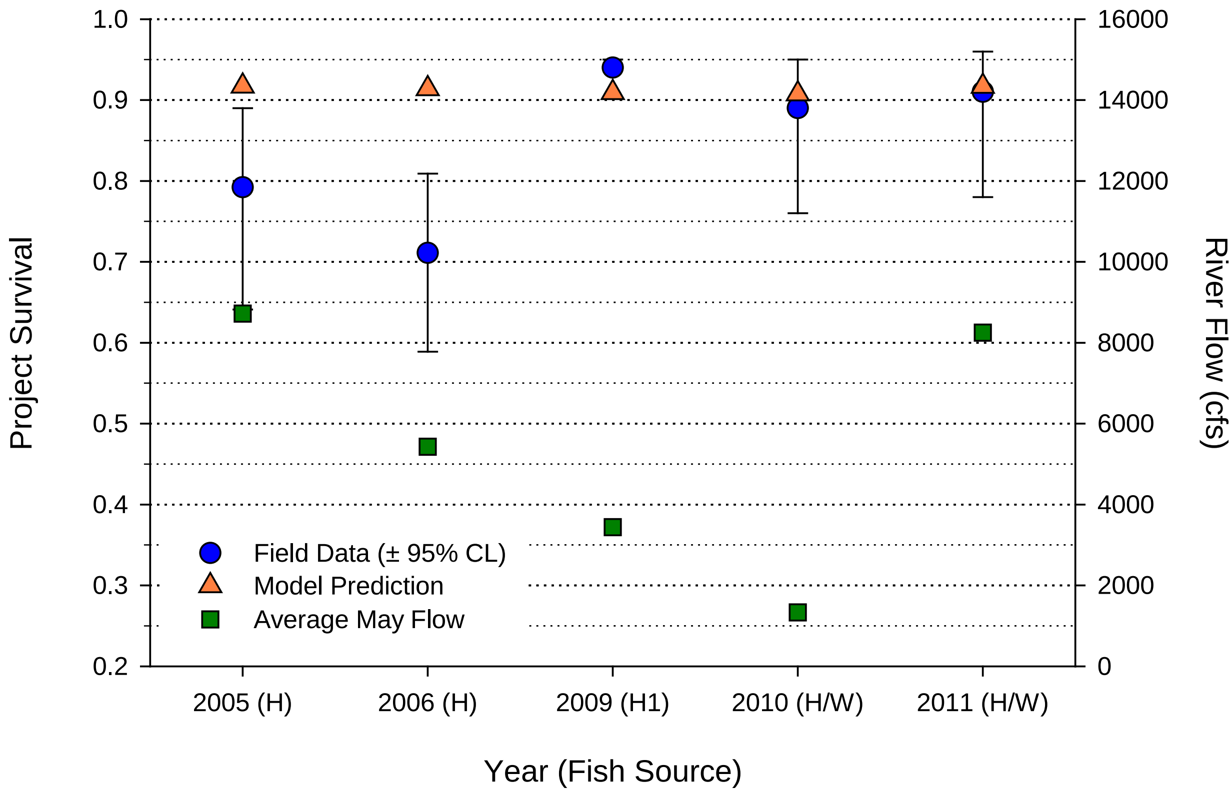

Figure 5-7. Project survival rates estimated from field data and the desktop model for Atlantic salmon smolts passing downstream at the Howland Hydroelectric Project. The model predictions for survival are based on the average monthly flow in May of each year that field studies were conducted. Depending on the study year, field data were used to calculate survival estimates for hatchery fish (H) or both hatchery and wild fish combined (H/W). The survival rate for hatchery fish evaluated in 2009 represents a release location in the Pleasant River (H1).

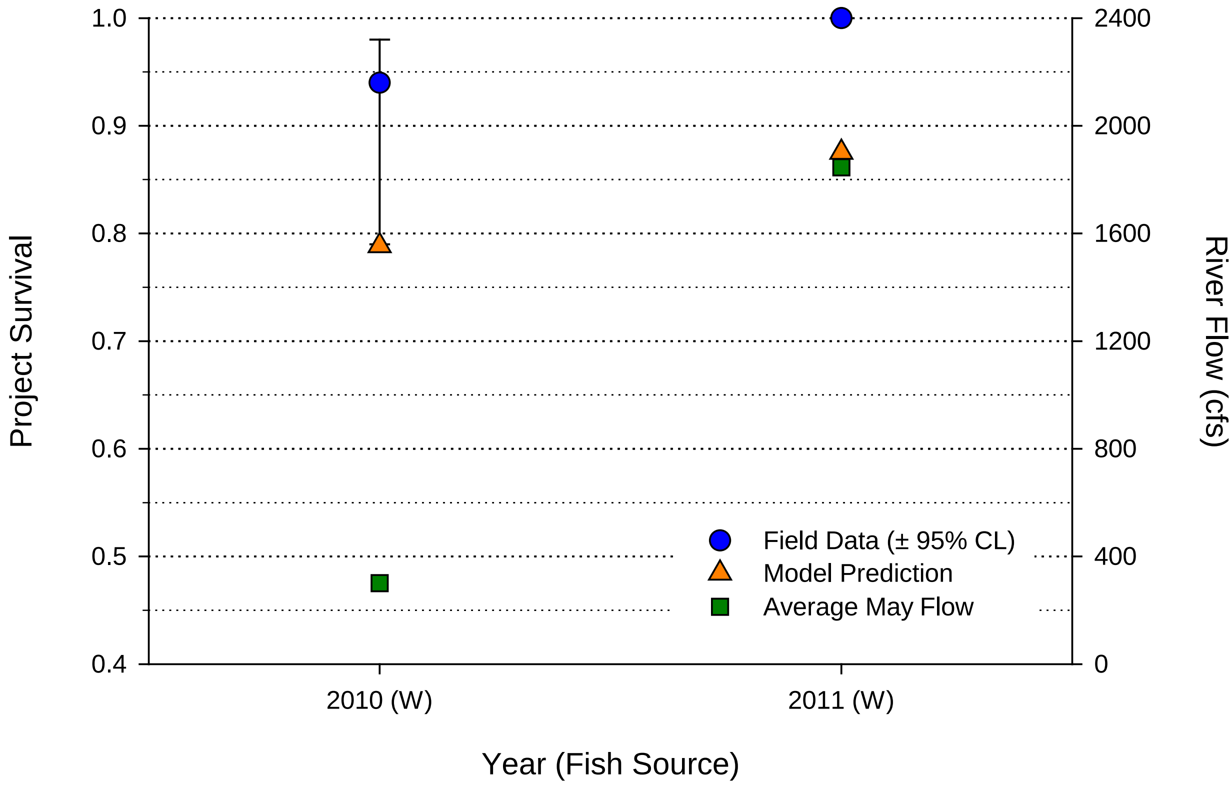

Figure 5-8. Project survival rates estimated from field data and the desktop model for Atlantic salmon smolts passing downstream at the Brown's Mills Hydroelectric Project. The model predictions for survival are based on the average monthly flow in May of each year that field studies were conducted. Field data for were only available for wild fish (W) at this project.

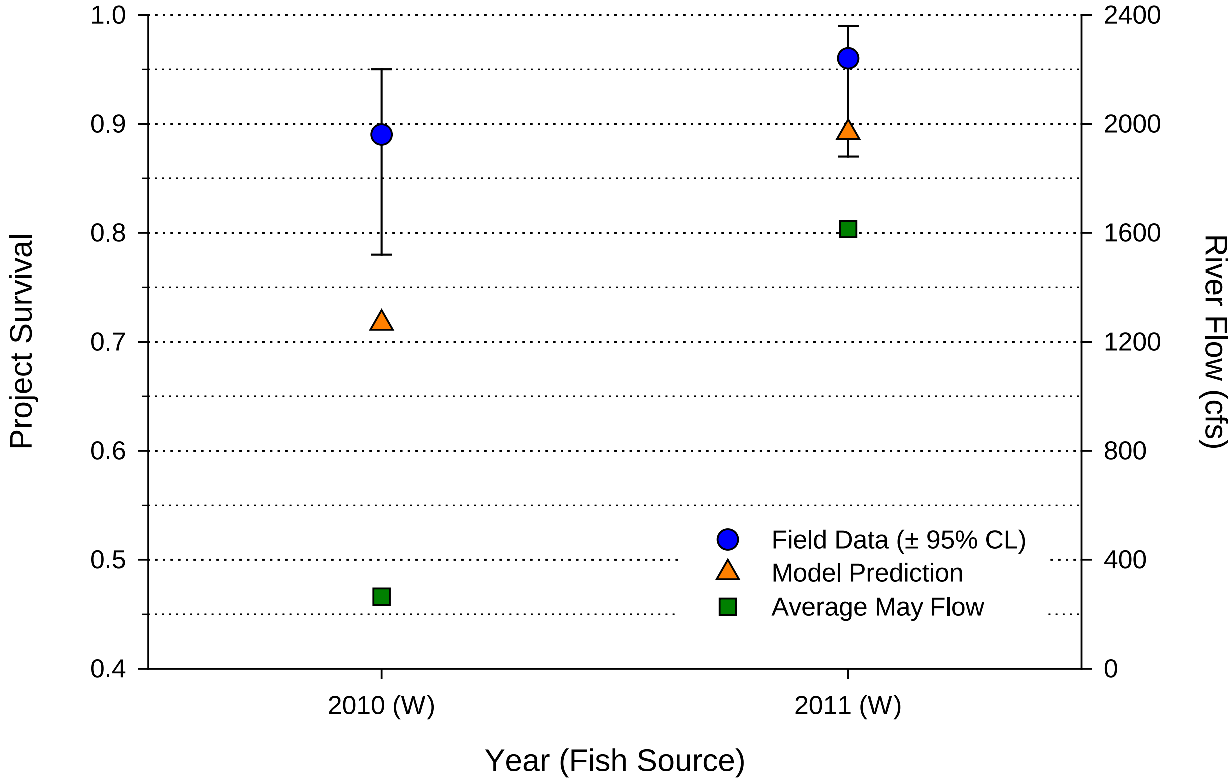

Figure 5-9. Project survival rates estimated from field data and the desktop model for Atlantic salmon smolts passing downstream at the Moosehead Hydroelectric Project. The model predictions for survival are based on the average monthly flow in May of each year that field studies were conducted. Field data were only available for wild fish (w) at this project.

6 Quality Assurance and Control of Survival Calculation Procedures and Results

Throughout the development of this report and its supporting data, there was an ongoing quality assurance and quality control (QA/QC) program focusing on several different levels of information and analysis. On a broad level, the assumptions, direction, and approach of the analysis were routinely evaluated. On a more detailed level, several different QA/QC procedures were utilized for each set of calculations including: reality check, computerized check, and replication of calculations. Ultimately, the development of the project survival model was an iterative process in which the approach and assumptions used were continually evaluated as to the validity of their approach and the need for modification.

A peer review was utilized as a means of completing an independent review of calculations, assumptions, and/or documentation by a person with a high level of technical experience. It focused on reading and reviewing pertinent documentation to ensure that assumptions and procedures used are reasonable. This document and its underlying methodology was repeatedly reviewed and checked in an iterative type process by a Senior Engineer specializing in hydraulic engineering and the design fish protection structures. Although there was peer review throughout the model development, specific issues which were focused on by the reviewer include the:

Applicability of the fish strike type model to individual projects and turbine type,

Development of means to estimate unknown turbine data (when unavailable from Project Owner),

Review of biological applicability of strike testing data to individual projects and turbine type

Approach to estimating physical limitations of turbines such as wicket gate and blade spacing interactions

Assumptions regarding the distribution of river flows to individual turbines

The “reality check” was used as a means to catch large errors in the estimation as well as to review for errors such as miscalculations. The reality check involved both a broad review of data trends as well as spot checks. Generally, the review of data trends looked at plots specific to an individual Project (such as overall fish survival as a function of total river flow) or compared values among projects (such as the radial velocities calculated for all the Francis type turbines) to evaluate if the trends among values are reasonable. The reality check was applied to all sets of data by the original author, a Senior engineer and a Senior biologist.

Replication of calculations is a reliable means of detecting computational errors. During the development of both the turbine survival models and the Project survival models, replication of calculations was used as a means of checking accuracy and identifying errors in formulas. Replication was achieved through the development of hand calculations based on the input data;

however, calculated independently of the model on paper, where possible. Replication was completed by the original author and reviewed by a senior engineer.

The final Survival model for each of the 15 projects is comprised of data referenced from many other spreadsheets. In addition, many sets of data are included in this report. Several review processes were implemented to check that proper data was utilized and imported into the calculations and report data tables. Spreadsheets which reference other sheets for data were often set up with additional data columns to compare the data referenced in the calculations to that directly calculated in the original spreadsheet. For example this meant that if modifications to the turbine survival values (calculated in the turbine survival model) were made, it would be immediately apparent in the Project survival model that the turbine survival values utilized were no longer current and required updating. Manual comparison checks by an independent reviewer were completed for each turbine survival model to verify that calculation cell references, parameter variations (sensitivity analysis), and modifications (wicket gate angle, 50% flow reduction, 100% strike assumption, etc.) were accurately executed. Finally, an independent reviewer completed a review of the spreadsheet values with those presented in the report as well as the pertinent turbine data tables to verify the accuracy data transfer.

Some computerized data checks were utilized; particularly in the Project survival model. As the Project survival model was capable of evaluation survival as a function of many thousand flow rates, it was important to ensure that the formulas were accounting for potential conditions throughout the full range of Project flows. As such, the model includes columns which check at every flow rate that the total flow allocation is equivalent to the total flow rate under consideration. In addition, it completes a check to ensure that the sum of all discharge probabilities is equal to one.

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APPENDIX A
PREDICTION MODELS FOR UNKNOWN TURBINE PARAMETERS

Data Estimatation and Regression Equations for Predicting Unknown Turbine Design Parameters

A series of turbine specific information is required to complete a strike prediction. Due to the geometric variation between a Francis and Kaplan/propeller turbine, the information requred varies for each type of turbine. In cases where information was either not known or not available, Alden developed a means for estimating unknown information.

Alden compiled information known about the Penobscot river basin turbines as well as information from previous projects and studies to obtain as much available infromation as possible. Additionally, Alden compiled a list of missing parameters for each turbine type. Missing infromation inlcuded:

- Turbine diameter; Francis, and Kaplan/propeller
- Wicket gate angle; Francis
- Angle of flow approach; Kaplan/propeller
- Leading edge blade thickness; Francis, and Kaplan/propeller
- Hub diameter; Kaplan/propeller
- Wicket gate trailing edge radius; Kaplan/propeller
- Number of blades

To estimate each of these parameters, information which closely relates was used in conjuntion with known infromation to develop relationships. In some cases such as the estimation of the hub diameter, it was found that there is a direct linear relationship to the turbine diameter. As such, the hub diameter and turbine diameter from known turbines was plotted to develop a mathematical relationship in the form of a regression equiation.

Data such as the turbine diameter was not directly estimated as the turbine diameter is a function of several factors. To estimate the turbine diameter, the radial (Francis) or axial (Kaplan/propeller) velocity, which is a function of the flow rate and the flow area, was used to develop a relationsip. Then the radial/axial velocity was plotted against the turbine diameter of known turbines to develop regression equations.

Using the regression equations, it was possible to take some known turbine data and estimate the remaining, unknown data. Figure A-1 through Figure A-7 show the data and plots used to develop the regression equations used to estimate unknown data.

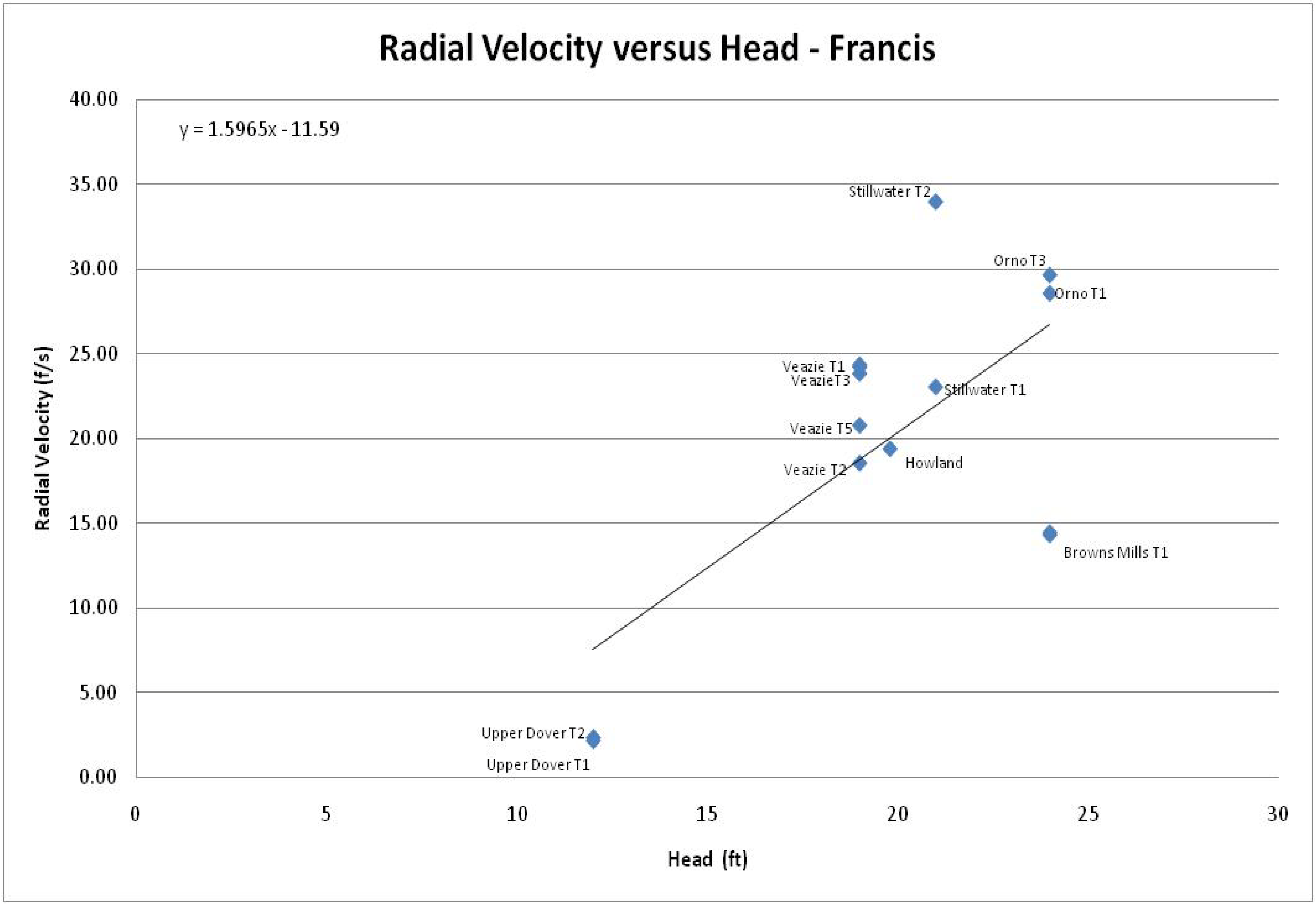


Figure A-1. Radial velocity as a function of head for Francis turbines.

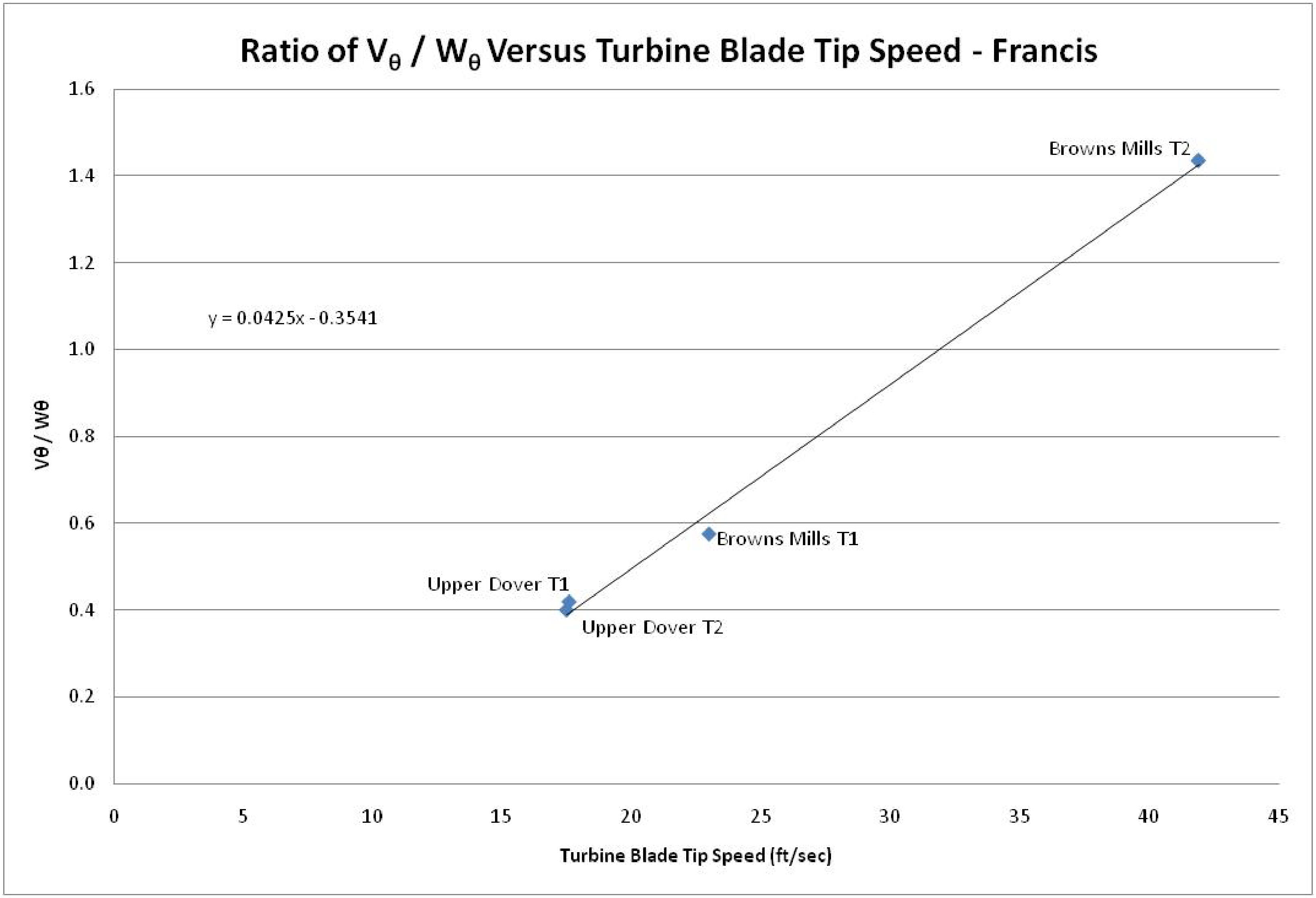


Figure A-2. Ratio of the turbine blade tip speed components as a function of the total blade tip speed for Francis turbines.

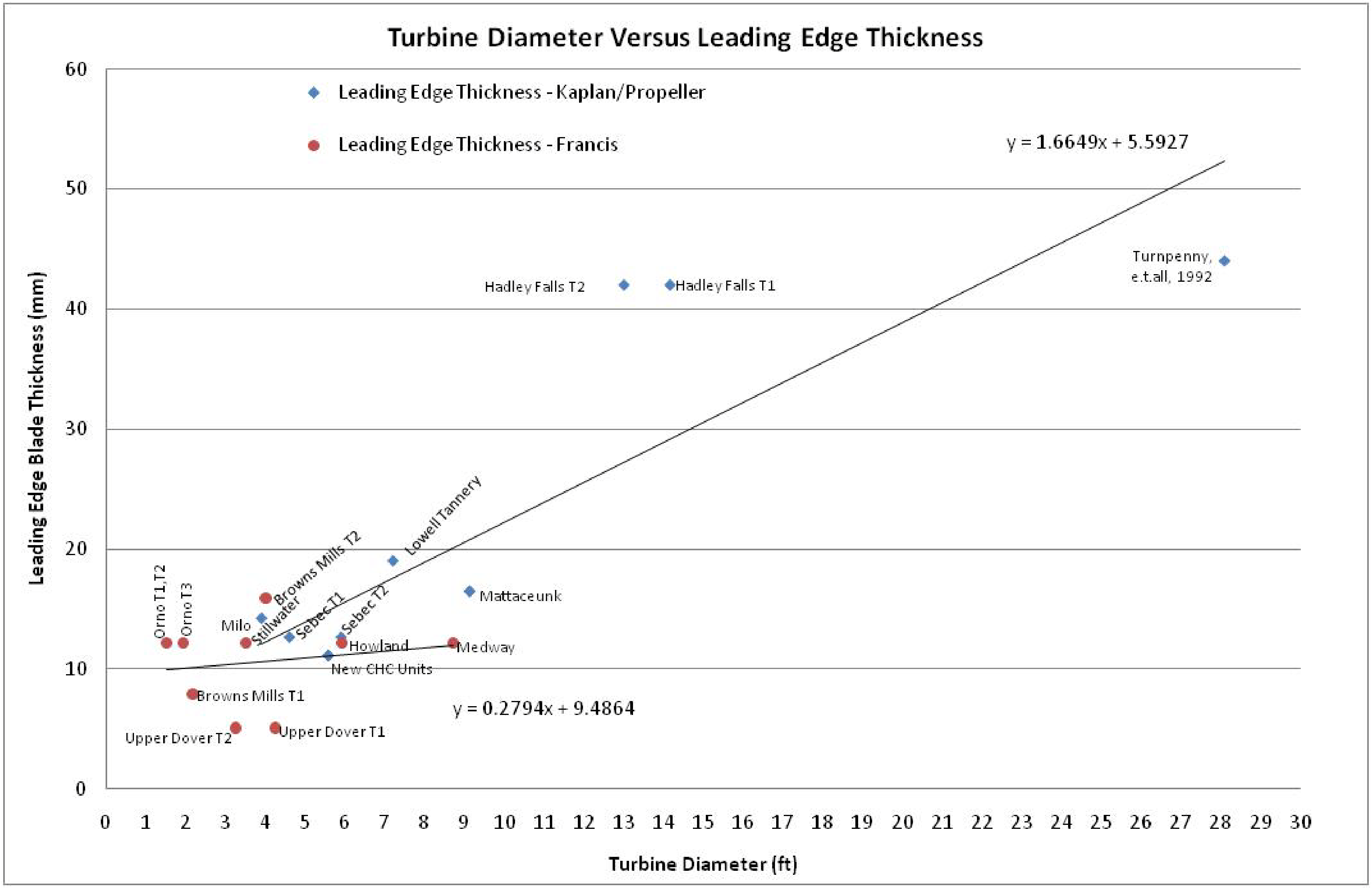


Figure A-3. Leading edge blade thickness as a function of turbine diameter for Francis and Kaplan/propeller turbines.

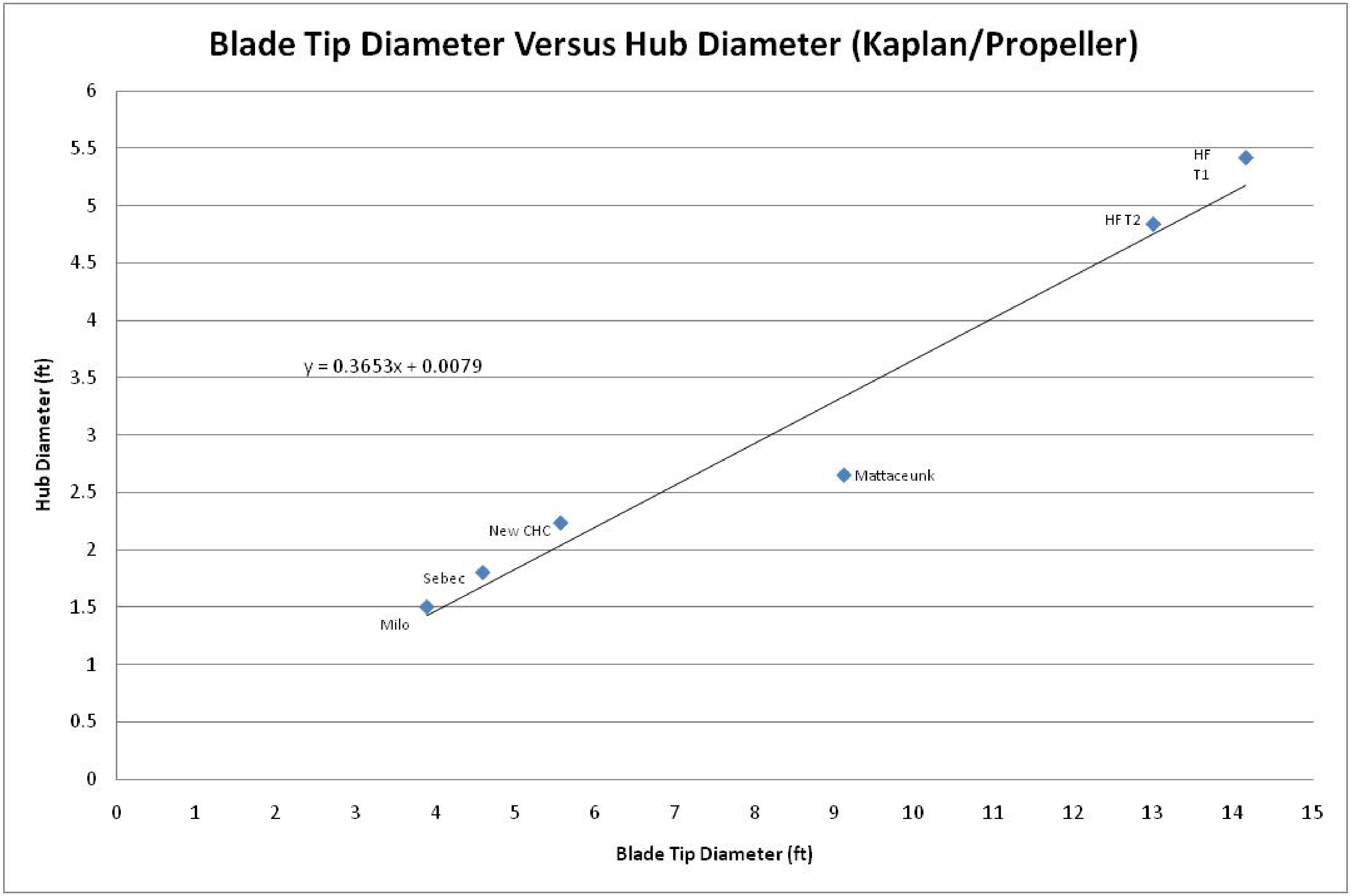


Figure A-4. Hub diameter as a function of turbine blade tip diameter for Kaplan/propeller turbines.

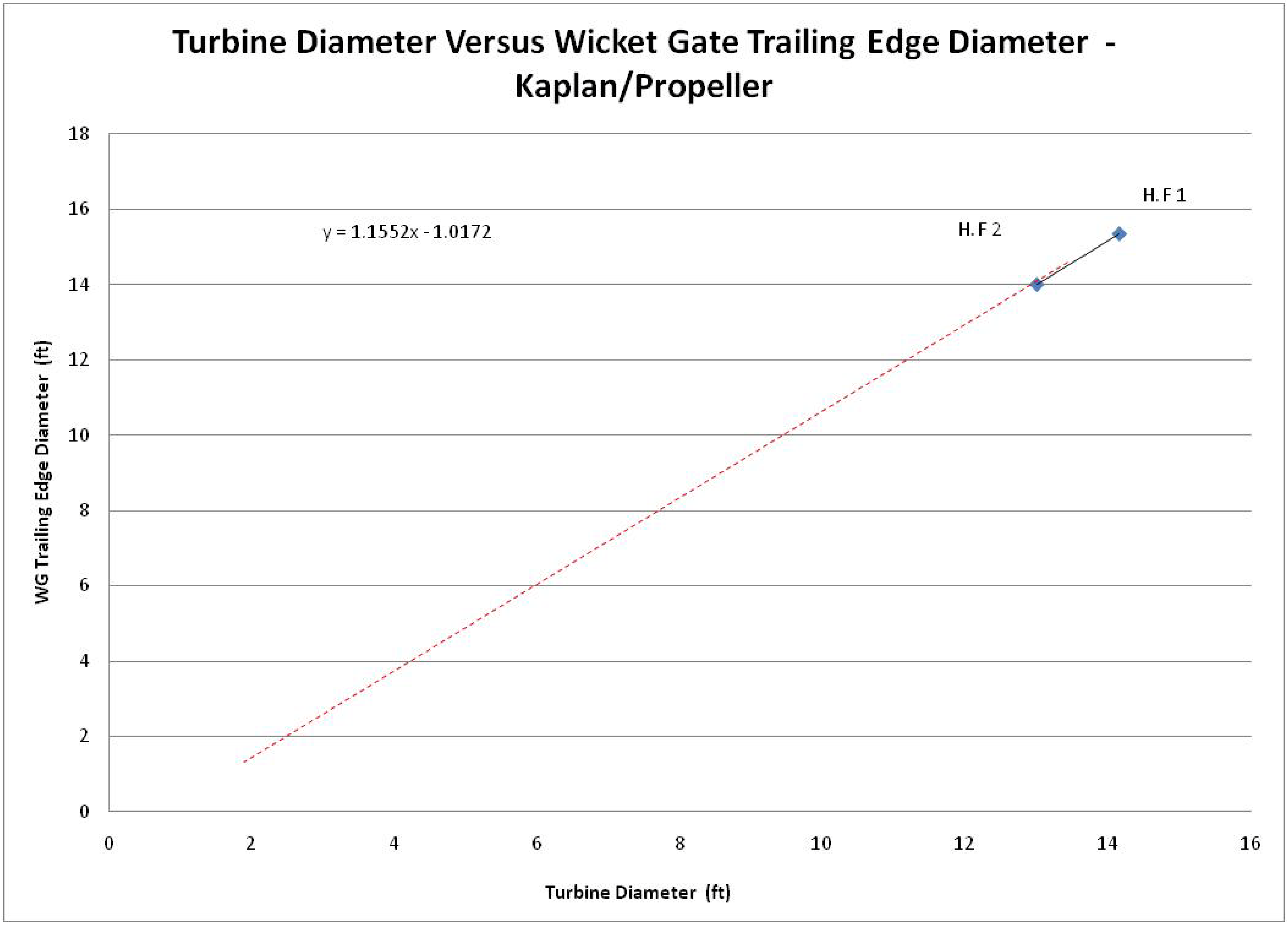


Figure A-5. Wicket gate trailing edge diameter as a function of turbine diameter for Kaplan/propeller turbines.

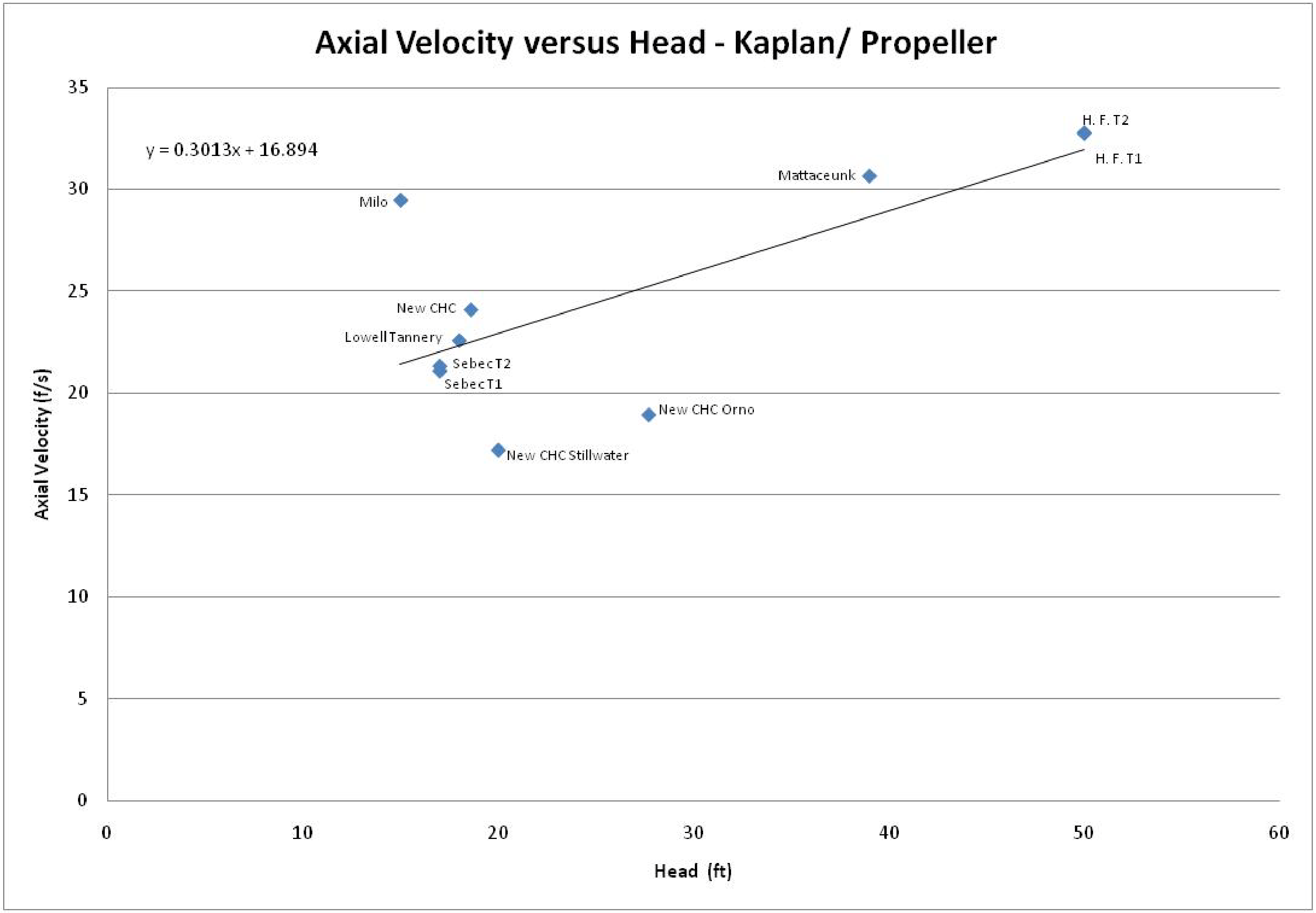


Figure A-6. Axial velocity as a function of head for Kaplan/propeller turbines.

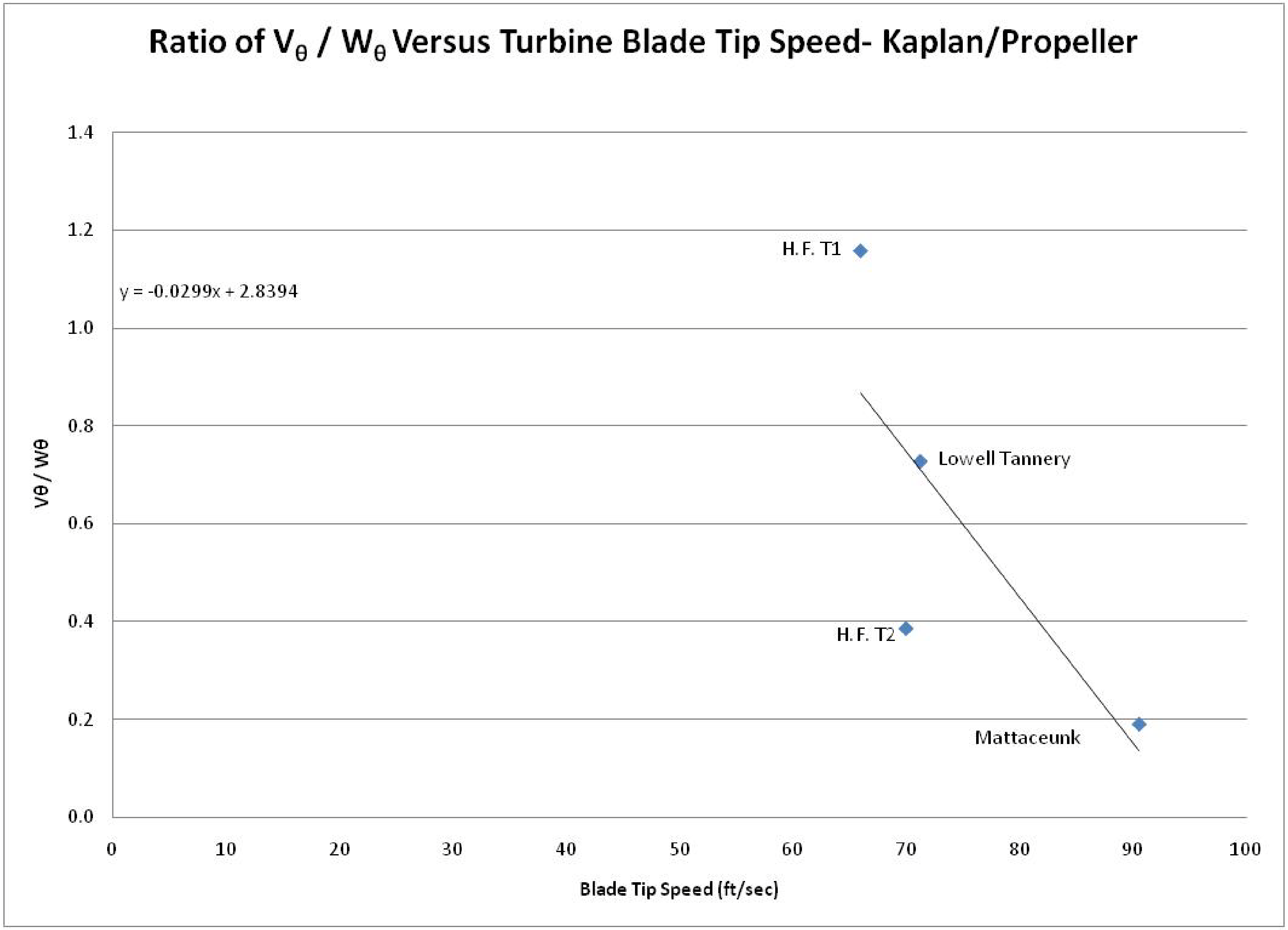


Figure A-7. Ratio of turbine blade tip speed components as a function of the total blade tip speed for Kaplan/propeller turbines.

APPENDIX B
SUMMARY OF COLUMBIA RIVER SPILLWAY PASSAGE SURVIVAL STUDY DATA

Table 7-1. Spillway survival data for studies conducted with juvenile salmonids at Columbia River projects.

Project	Year	Species	Min Head (ft)	Max Head (ft)	Max Test Spill (cfs)	Passage Survival (%)
Bonneville	2002	Chinook	50	55	7900	98.6
Bonneville	2002	Chinook	50	55	9800	99.0
Bonneville	2002	Chinook	54	58	6400	95.9
Bonneville	2002	Chinook	54	58	4800	97.9
Bonneville	2002	Chinook	60	64	6000	100.0
Bonneville	2002	Chinook	60	64	7900	100.0
Bonneville	2002	Chinook	60	65	6000	88.6
Bonneville	2002	Chinook	60	65	4100	90.5
Bonneville	1995	Chinook	60	60	12000	100.0
Bonneville	1995	Chinook	60	60	12000	100.0
Ice Harbor	2005	Chinook	96	97	8500	96.1
Ice Harbor	2005	Chinook	96	97	8500	96.9
Ice Harbor	2005	Chinook	96	97	8500	98.6
Ice Harbor	2005	Chinook	96	97	8500	98.9
Ice Harbor	2005	Chinook	96	97	8500	99.2
Ice Harbor	2004	Chinook	94	94	11900	100.0
Ice Harbor	2004	Chinook	92	96	4300	100.0
Ice Harbor	2004	Chinook	93	96	4300	93.7
Ice Harbor	2004	Chinook	93	99	5100	98.6
Ice Harbor	2004	Chinook	94	97	11900	95.0
Ice Harbor	2004	Chinook	94	97	11900	96.5
Ice Harbor	2004	Chinook	94	97	11900	99.7
Ice Harbor	2004	Chinook	94	98	5100	97.9
Ice Harbor	2004	Chinook	95	100	11900	99.7
Ice Harbor	2004	Chinook	95	96	3400	98.8
Ice Harbor	2004	Chinook	95	97	3400	98.8
Ice Harbor	2004	Chinook	99	100	11900	100.0
Ice Harbor	2003	Chinook	93	96	5100	98.7
Ice Harbor	2003	Chinook	94	96	8500	99.5
Ice Harbor	2003	Chinook	96	97	8500	98.7
Ice Harbor	2003	Chinook	98	100	13600	90.1
Ice Harbor	2003	rainbow trout	98	100	13600	92.5
Ice Harbor	2003	Chinook	98	99	3400	97.8
Little Goose	2009	Chinook	95.5	95.5	12800	95.3
Little Goose	2009	Chinook	96.5	96.5	8500	95.7
Little Goose	2009	Chinook	97.7	97.7	7200	99.2
Little Goose	2009	Chinook	97.7	97.7	7200	99.7
Little Goose	2007	Chinook	97.0	97.0	7000	96.7
Little Goose	2007	Chinook	97.1	97.1	7000	98.7
Little Goose	2007	Chinook	97.1	97.1	7000	98.8
Little Goose	2007	Chinook	97.1	97.1	7000	99.7
Little Goose	1997	steelhead	96	96	5600	100.0

Project	Year	Species	Min Head (ft)	Max Head (ft)	Max Test Spill (cfs)	Passage Survival (%)
Little Goose	1997	steelhead	96	96	5600	100.0
Little Goose	1997	steelhead	94	97	5600	98.0
Little Goose	1997	steelhead	94	97	5600	100.0
Little Goose	1997	steelhead	95	96	1800	99.0
Little Goose	1997	steelhead	95	96	1800	100.0
Little Goose	1997	steelhead	95	97	9500	98.3
Little Goose	1997	steelhead	95	97	9500	99.2
Little Goose	1997	steelhead	96	98	9500	100.0
Little Goose	1997	steelhead	96	98	9500	100.0
Lower Granite	2001	Chinook	97	98	5700	100.0
Lower Granite	2001	Chinook	97	99	7000	98.1
Lower Granite	2000	Chinook	97	101	3400	97.6
Lower Granite	1996	Chinook	100	100	3400	97.5
Lower Monumental	2005	Chinook	97	97	8500	94.9
Lower Monumental	2005	Chinook	97	97	8500	96.0
Lower Monumental	2005	Chinook	97	97	8500	99.8
Lower Monumental	2005	Chinook	97	97	8500	100.0
North Fork (OR)	2001	Chinook/coho	135	135	2000	76.2
North Fork (OR)	2001	steelhead	135	135	700	81.0
North Fork (OR)	2001	Chinook/coho	135	135	700	83.4
North Fork (OR)	2001	Chinook/coho	135	135	2000	83.9
North Fork (OR)	2001	steelhead	135	135	700	87.5
North Fork (OR)	2001	Chinook/coho	135	135	700	91.3
North Fork (OR)	2001	steelhead	135	135	2000	93.1
North Fork (OR)	2001	steelhead	135	135	2000	99.9
Rock Island	2001	Chinook	39	43	2500	99.0
Rock Island	2001	Chinook	39	43	2500	99.0
Rock Island	2000	Chinook	40	43	2500	99.0
Rock Island	2000	Chinook	40	43	2500	100.0
Rock Island	1999	Chinook	41	49	2500	99.5
Rock Island	1999	Chinook	41	49	10000	99.5
Rock Island	1997	Chinook	40	42	1900	95.1
Rock Island	1997	Chinook	40	42	10000	98.4
The Dalles	2004	Chinook	76	81	17500	85.1
The Dalles	2004	Chinook	76	81	20400	96.1
The Dalles	2004	Chinook	76	81	20600	97.7
The Dalles	2004	Chinook	76	81	20400	97.8
The Dalles	2004	Chinook	76	81	20500	99.0
The Dalles	2004	Chinook	76	81	20100	99.0
The Dalles	2004	Chinook	76	81	20500	99.7
The Dalles	2004	Chinook	79	84	12400	95.9
The Dalles	2004	Chinook	79	84	12400	97.2
The Dalles	2004	Chinook	79	84	14700	98.6

Project	Year	Species	Min Head (ft)	Max Head (ft)	Max Test Spill (cfs)	Passage Survival (%)
The Dalles	2004	Chinook	79	84	14700	98.6
The Dalles	2004	Chinook	79	84	13200	99.3
The Dalles	2004	Chinook	79	84	12400	100.0
The Dalles	2004	Chinook	79	84	11000	100.0
The Dalles	2003	Chinook	74	78	9000	96.6
The Dalles	2003	Chinook	74	79	12000	99.9
The Dalles	2003	Chinook	74	80	12000	98.5
The Dalles	2003	Chinook	74	80	12000	99.3
The Dalles	2003	Chinook	75	79	9000	93.1
The Dalles	2003	Chinook	75	79	18000	97.3
The Dalles	2003	Chinook	75	79	9000	97.5
The Dalles	2003	Chinook	75	79	18000	97.8
The Dalles	2003	Chinook	75	80	18000	99.2
The Dalles	2003	Chinook	76	77	21000	95.1
The Dalles	2003	Chinook	76	78	21000	98.2
The Dalles	2003	Chinook	76	79	18000	99.2
The Dalles	2003	Chinook	76	79	18000	100.0
The Dalles	2003	Chinook	77	78	21000	98.2
The Dalles	2003	Chinook	77	79	18000	99.7
The Dalles	2003	Chinook	77	80	21000	93.1
The Dalles	2003	Chinook	80	84	4545	92.5
The Dalles	2003	Chinook	80	84	4500	96.5
The Dalles	2003	Chinook	80	84	12000	96.7
The Dalles	2003	Chinook	80	84	12000	96.9
The Dalles	2003	Chinook	80	84	12000	98.6
The Dalles	2003	Chinook	80	84	12000	99.5
The Dalles	2003	Chinook	80	84	12011	100.0
The Dalles	2003	Chinook	80	84	12000	100.0
The Dalles	2002	Chinook	75	80	6000	93.8
The Dalles	2002	Chinook	75	80	10500	97.4
The Dalles	2002	Chinook	75	80	7500	97.4
The Dalles	1995	Chinook	81	81	10500	95.5
The Dalles	1995	Chinook	81	81	4500	99.0
The Dalles	1995	Chinook	81	81	10500	99.3
Wanapum	2002	Chinook	81	82	12500	99.0
Wanapum	1999	Chinook	71	77	7500	97.6
Wanapum	1999	Chinook	71	77	7500	99.5
Wanapum	1999	Chinook	73	79	6000	97.6
Wanapum	1999	Chinook	73	79	6000	98.2
Wanapum	1999	Chinook	79	82	2800	98.3
Wanapum	1999	Chinook	79	82	2800	99.4
Wanapum	1998	Chinook	78	82	2800	99.0
Wanapum	1998	Chinook	78	82	2800	100.0
Wanapum	1998	Chinook	80	81	6000	97.6
Wanapum	1998	Chinook	80	81	6000	99.3

Project	Year	Species	Min Head (ft)	Max Head (ft)	Max Test Spill (cfs)	Passage Survival (%)
Wanapum	1998	Chinook	80	82	11500	92.8
Wanapum	1998	Chinook	80	82	11500	94.5
Wanapum	1996	Chinook	79	79	2000	92.0
Wanapum	1996	Chinook	79	79	4300	95.7
Wanapum	1996	Chinook	79	79	4000	96.9
Wanapum	1996	Chinook	79	79	4300	99.6
John Day	2008	Chinook	110	--	6200	100.0
John Day	2008	Chinook	110	--	9700	98.0
John Day	2010	Chinook	103	--	2400	99.3
John Day	2010	Chinook	104	--	4000	98.3

APPENDIX C

SUMMARY OF BYPASS EFFECTIVNESS STUDIES

Table B-1. Summary of bypass effectiveness data from field studies conducted with salmonids. Normal intake design refers to existing intake rack (typically perpendicular to approaching flow).

Project	Country	River	Species	Life Stage Evaluated	Intake Structure Design	Bar Clear Spacing (rounded to nearest 0.25 inches)	Bypass Efficiency (%)	Comments
Poutes	France	Allier	ATS	smolt	normal	1.25	90.0	
Crampagna	France	Ariege	ATS	smolt	normal	1.25	66.0	
Guilhot	France	Ariege	ATS	smolt	normal	1.25	75.0	
Las Mijanes	France	Ariege	ATS	smolt	normal	1.25	32.0	
Las Rives	France	Ariege	ATS	smolt	normal	1.50	49.0	
Camon	France	Garonne	ATS	smolt	normal	1.50	73.0	
Bedous	France	Gave d'Aspe	ATS	smolt	normal	1.25	55.0	
Soeix	France	Gave d'Aspe	ATS	smolt	normal	1.50	61.5	
Castetarbe	France	Gave de Pau	ATS	smolt	normal	1.00	100.0	
Baigts	France	Gave de Pau	ATS	smolt	normal	1.25	92.5	
St. Cricq	France	Gave d'Ossau	ATS	smolt	normal	1.00	79.0	
Halsou	France	Nive	ATS	smolt	normal	1.25	56.0	
Lower Robertson	USA	Ashuelot	ATS	smolt	unknown	2.00	7.0	
Cabot Station	USA	Connectucut	ATS	smolt	normal w/overlay	1.00	66.0	
Cabot Station	USA	Connectucut	ATS	smolt	normal w/overlay	1.00	38.0	
Cabot Station	USA	Connectucut	ATS	smolt	normal w/overlay	1.00	32.0	
Cabot Station	USA	Connectucut	ATS	smolt	normal w/overlay	1.00	55.0	Min estimate
Cabot Station	USA	Connectucut	ATS	smolt	normal w/overlay	1.00	75.0	Max estimate
Cabot Station	USA	Connectucut	ATS	smolt	normal w/overlay	1.00	57.0	
Cabot Station	USA	Connectucut	ATS	smolt	normal w/overlay	1.00	68.0	Min estimate
Cabot Station	USA	Connectucut	ATS	smolt	normal w/overlay	1.00	73.0	Max estimate
Holyoke	USA	Connectucut	ATS	smolt	normal w/floating louver	5.00	24.0	Bypass 326 cfs 2 to 8 ft deep floating louvers

Project	Country	River	Species	Life Stage Evaluated	Intake Structure Design	Bar Clear Spacing (rounded to nearest 0.25 inches)	Bypass Efficiency (%)	Comments
Holyoke	USA	Connectucut	ATS	smolt	normal	5.00	36.0	Bypass 500 cfs w/bascule gate insert; no structure at intake
Holyoke	USA	Connectucut	ATS	smolt	normal	5.00	88.0	Bypass 1200 cfs w/bascule gate insert; no structure at intake
Holyoke	USA	Connectucut	ATS	smolt	normal	5.00	68.0	Bypass 326 cfs w/floating boom & insert at bypass
Holyoke	USA	Connectucut	ATS	smolt	normal	5.00	75.0	Bypass 326 cfs w/floating boom & insert at bypass
Holyoke	USA	Connectucut	ATS	smolt	normal	5.00	43.0	Bypass 326 cfs w/trashrack overlay & weir at bypass
Holyoke	USA	Connectucut	ATS	smolt	normal	5.00	63.0	Bypass 326 cfs w/same design as 1994 studies
Bellows Falls	USA	Connectucut	ATS	smolt	angled wall	NA	94.0	
Gardner Falls	USA	Connectucut	ATS	smolt	louver	NA	72.0	
Gardner Falls	USA	Connectucut	ATS	smolt	louver	NA	28.0	
Vernon	USA	Connectucut	ATS	smolt	louver	NA	76.0	
Vernon	USA	Connectucut	ATS	smolt	louver	NA	73.0	
Vernon	USA	Connectucut	ATS	smolt	louver	NA	75.0	
McIndoes	USA	Connectucut	ATS	smolt	unknown	NA	33.3	
Wilder	USA	Connectucut	ATS	smolt	unknown	NA	91.0	Bypass flow: 200 CFS
Wilder	USA	Connectucut	ATS	smolt	unknown	NA	94.0	Bypass flow: 324 CFS
Wilder	USA	Connectucut	ATS	smolt	unknown	NA	96.0	Bypass flow: 550 CFS
Wilder	USA	Connectucut	ATS	smolt	unknown	NA	69.0	Bypass flow: 200 CFS
Wilder	USA	Connectucut	ATS	smolt	unknown	NA	71.0	Bypass flow: 324 CFS
Wilder	USA	Connectucut	ATS	smolt	unknown	NA	88.0	Bypass flow: 550 CFS
Deerfiled 2	USA	Deerfield	ATS	smolt	unknown	NA	20.0	
Deerfiled 2	USA	Deerfield	ATS	smolt	unknown	NA	15.0	
Deerfiled 2	USA	Deerfield	ATS	smolt	unknown	NA	44.0	
Deerfiled 2	USA	Deerfield	ATS	smolt	unknown	NA	60.0	
Deerfiled 3	USA	Deerfield	ATS	smolt	unknown	NA	78.0	
Deerfiled 3	USA	Deerfield	ATS	smolt	unknown	NA	41.0	

Project	Country	River	Species	Life Stage Evaluated	Intake Structure Design	Bar Clear Spacing (rounded to nearest 0.25 inches)	Bypass Efficiency (%)	Comments
Deerfiled 3	USA	Deerfield	ATS	smolt	unknown	NA	77.0	
Deerfiled 3	USA	Deerfield	ATS	smolt	unknown	NA	73.0	
Deerfiled 4	USA	Deerfield	ATS	smolt	unknown	NA	59.0	
Deerfiled 4	USA	Deerfield	ATS	smolt	unknown	NA	28.0	
Deerfiled 4	USA	Deerfield	ATS	smolt	unknown	NA	57.0	
Deerfiled 4	USA	Deerfield	ATS	smolt	unknown	NA	57.0	
Lowell	USA	Merrimack	ATS	smolt	normal	NA	15	
Lowell	USA	Merrimack	ATS	smolt	normal	NA	40	
Lowell	USA	Merrimack	ATS	smolt	normal	NA	42	
Ayers Island	USA	Pemigewasset	ATS	smolt	unknown	NA	54.0	
Ayers Island	USA	Pemigewasset	ATS	smolt	unknown	NA	61.0	
Ayers Island	USA	Pemigewasset	ATS	smolt	unknown	NA	100.0	
Mattaceunk	USA	Penobscot	ATS	smolt	normal	1.00	20.0	1-inch overlays
Mattaceunk	USA	Penobscot	ATS	kelt	normal	1.00	54.0	1-inch overlays
Mattaceunk	USA	Penobscot	ATS	smolt	normal	1.00	59.0	1-inch overlays
Mattaceunk	USA	Penobscot	ATS	smolt	normal	1.00	45.0	1-inch overlays
Mattaceunk	USA	Penobscot	ATS	smolt	normal	1.00	52.0	1-inch overlays
Mattaceunk	USA	Penobscot	ATS	smolt	normal	1.00	41.0	1-inch overlays
Mattaceunk	USA	Penobscot	ATS	smolt	normal	1.00	22.0	1-inch overlays
Mattaceunk	USA	Penobscot	ATS	smolt	normal	1.00	17.0	1-inch overlays
Orono	USA	Penobscot	ATS	smolt	normal	1.00	42.0	
West Enfield	USA	Penobscot	ATS	smolt	normal	NA	8.0	
West Enfield	USA	Penobscot	ATS	smolt	normal	NA	50.0	
Cataract (EChann)	USA	Saco	ATS	smolt	unknown	1.00	30.0	
Bar Mills	USA	Saco	ATS	smolt	angled submerged boom	NA	62.0	4-ft weighted boom

Project	Country	River	Species	Life Stage Evaluated	Intake Structure Design	Bar Clear Spacing (rounded to nearest 0.25 inches)	Bypass Efficiency (%)	Comments
Bar Mills	USA	Saco	ATS	smolt	angled submerged boom	NA	77.0	4 ft unweighted boom
Bar Mills	USA	Saco	ATS	smolt	angled bar rack	NA	79.0	8-ft boom
Lower Saranac	USA	Saranac	ATS	juv	angled bar rack	1.00	100.0	
Lower Saranac	USA	Saranac	ATS	juv	angled bar rack	1.00	100.0	
Pine Valley	USA	Souhegan	ATS	smolt	angled bar rack	1.00	96.0	1-inch overlays
Lower Village	USA	Sugar	ATS	smolt	overlay	0.50	81.5	
Essex 19	USA	Winooski	ATS	smolt	unknown	NA	27.0	
Essex 19	USA	Winooski	ATS	smolt	unknown	NA	6.0	
Garvins Falls	USA		ATS	smolt	louver	NA	88.0	
Amoskeag	USA		ATS	smolt	unknown	NA	67.0	
Amoskeag	USA		ATS	smolt	unknown	NA	76.0	
Amoskeag	USA		ATS	smolt	unknown	NA	71.0	
Amoskeag	USA		ATS	smolt	unknown	NA	74.0	
Amoskeag	USA		ATS	smolt	unknown	NA	64.0	
Moore Dam	USA		ATS	smolt	unknown	NA		
Prospect No. 3	USA	Rogue	RBT		unknown	NA	87.0	
Lower Saranac	USA	Saranac	STH	juv	angled bar rack	1.00	90.9	
Lower Saranac	USA	Saranac	STH	juv	angled bar rack	1.00	86.4	
Cavendish	USA	Black	TRT		unknown	1.50	46.0	Tested 1-2 hp flow inducer; mean of 3 trials
Cavendish	USA	Black	TRT		unknown	1.50	56.0	mean of 4 trials
Cavendish	USA	Black	TRT		unknown	1.50	17.0	Mean of 4 trials
Cavendish	USA	Black	TRT		unknown	1.50	63.0	Mean of 5 trials
Lockwood	USA	Kennebec	ATS	smolt	normal	2.0/3.5	18.0	

APPENDIX D
MODEL INPUT PARAMETERS AND STRIKE PROBABILITY AND TURBINE PASSAGE SURVIVAL ESTIMATES FOR ATLANTIC SALMON SMOLTS AND KELTS ENTRAINED AT PENOBSCOT RIVER HYDROPOWER PROJECTS

DEFINITIONS

Life stage – One of two migratory stages of sea-run Atlantic salmon: smolts (juveniles) and kelts (post-spawn adults).

Fish length – Represents fork length measured from the tip of the snout to the fork of the caudal fin. Length ranges for smolts and kelts provided by NMFS.

Fish Length to Blade Thickness Ratio (L/t) – Ratio of the fish length to the thickness of a turbine blade leading edge at its midpoint from tip to hub.

Predicted Slope (m) for L/t vs Strike Velocity – Slope of survival versus strike velocity for a specific L/t ratio. Based on experimental results (EPRI 2008, 2011), if strike velocity (V_{rel}) is less than V100 for a given L/t ratio, blade strike will not result in mortality (see Section 2.1.1.7 of the Phase 2 Preliminary Report for more detailed information on the development of this parameter).

L sin θ – The radial or axial projected fish length (depending on turbine type).

Blade strike probability – The probability that a fish of a given length passing through a turbine will be struck by a blade (see Section 2.1.1.1 of the Phase 2 Preliminary Report for more detailed information on calculating strike probability).

Max Strike Velocity for 100% Survival, V100 – The maximum velocity at which blade strike survival will be 100% for a given fish length and leading edge blade thickness (i.e., ratio of fish length to blade thickness, L/t) (see Section 2.1.1.7 of the Phase 2 Preliminary Report for more detailed information on the development of K).

Mortality coefficient, K – The proportion of fish stuck by a turbine blade that are mortally injured (see Section 2.1.1.7 of the Phase 2 Preliminary Report for more detailed information on the development of K).

Adjusted mortality coefficient, K – Adjustment factor (0.65) applied to K based on comparison of theoretical predictions of turbine passage survival to actual data from tests with the pilot-scale Alden turbine (as described in Section 2.1.1.7 of the Phase 2 Preliminary Report).

Mortality probability – Estimated percentage of fish that will be mortally injured passing through a given turbine.

Survival probability – Estimated percentage of fish that will survive passing through a given turbine. (100 – percent mortality)

Table D 2. Input parameters for the prediction of strike probability and mortality for Veazie units 16 and 17; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient , 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	84	0.11	4.8	0.50	0.32	4%	96%
	140	6.76	14.9	90	0.12	4.8	0.51	0.33	4%	96%
	150	7.24	15.4	97	0.13	4.8	0.53	0.34	4%	96%
	160	7.72	15.7	103	0.13	4.8	0.54	0.35	5%	95%
	170	8.21	16.1	109	0.14	4.8	0.55	0.36	5%	95%
	180	8.69	16.5	116	0.15	4.8	0.56	0.37	6%	94%
	190	9.17	16.8	122	0.16	4.8	0.58	0.37	6%	94%
	200	9.65	17.1	129	0.17	4.8	0.59	0.38	6%	94%
	210	10.14	17.4	135	0.18	4.8	0.60	0.39	7%	93%
Kelt	650	31.38	24.2	418	0.55	4.8	0.83	0.54	29%	71%
	675	32.59	24.5	435	0.57	4.8	0.84	0.54	31%	69%
	700	33.79	24.7	451	0.59	4.8	0.85	0.55	32%	68%
	725	35.00	24.9	467	0.61	4.8	0.85	0.55	34%	66%
	750	36.21	25.1	483	0.63	4.8	0.86	0.56	35%	65%
	775	37.41	25.3	499	0.65	4.8	0.87	0.56	37%	63%
	800	38.62	25.5	515	0.67	4.8	0.87	0.57	38%	62%

Table D 3. Input parameters for the prediction of strike probability and mortality for Veazie units 16 and 17; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	100	0.13	4.8	0.50	0.32	4%	96%
	140	6.76	14.9	107	0.14	4.8	0.51	0.33	5%	95%
	150	7.24	15.4	115	0.15	4.8	0.53	0.34	5%	95%
	160	7.72	15.7	123	0.16	4.8	0.54	0.35	6%	94%
	170	8.21	16.1	130	0.17	4.8	0.55	0.36	6%	94%
	180	8.69	16.5	138	0.18	4.8	0.56	0.37	7%	93%
	190	9.17	16.8	146	0.19	4.8	0.58	0.37	7%	93%
	200	9.65	17.1	153	0.20	4.8	0.59	0.38	8%	92%
	210	10.14	17.4	161	0.21	4.8	0.60	0.39	8%	92%
Kelt	650	31.38	24.2	498	0.65	4.8	0.83	0.54	35%	65%
	675	32.59	24.5	518	0.67	4.8	0.84	0.54	37%	63%
	700	33.79	24.7	537	0.70	4.8	0.85	0.55	38%	62%
	725	35.00	24.9	556	0.72	4.8	0.85	0.55	40%	60%
	750	36.21	25.1	575	0.75	4.8	0.86	0.56	42%	58%
	775	37.41	25.3	594	0.77	4.8	0.87	0.56	44%	56%
	800	38.62	25.5	613	0.80	4.8	0.87	0.57	45%	55%

Table D 4. Input parameters for the prediction of strike probability and mortality for Veazie units 16 and 17; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	65	0.08	4.8	0.50	0.32	3%	97%
	140	6.76	14.9	70	0.09	4.8	0.51	0.33	3%	97%
	150	7.24	15.4	75	0.10	4.8	0.53	0.34	3%	97%
	160	7.72	15.7	80	0.10	4.8	0.54	0.35	4%	96%
	170	8.21	16.1	85	0.11	4.8	0.55	0.36	4%	96%
	180	8.69	16.5	90	0.12	4.8	0.56	0.37	4%	96%
	190	9.17	16.8	95	0.12	4.8	0.58	0.37	5%	95%
	200	9.65	17.1	100	0.13	4.8	0.59	0.38	5%	95%
	210	10.14	17.4	105	0.14	4.8	0.60	0.39	5%	95%
Kelt	650	31.38	24.2	326	0.42	4.8	0.83	0.54	23%	77%
	675	32.59	24.5	338	0.44	4.8	0.84	0.54	24%	76%
	700	33.79	24.7	351	0.46	4.8	0.85	0.55	25%	75%
	725	35.00	24.9	363	0.47	4.8	0.85	0.55	26%	74%
	750	36.21	25.1	376	0.49	4.8	0.86	0.56	27%	73%
	775	37.41	25.3	388	0.51	4.8	0.87	0.56	29%	71%
	800	38.62	25.5	401	0.52	4.8	0.87	0.57	30%	70%

Table D 5. Input parameters for the prediction of strike probability and mortality for Veazie units 16 and 17; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	84	0.11	4.8	0.50	0.39	4%	96%
	140	6.76	14.9	90	0.12	4.8	0.51	0.40	5%	95%
	150	7.24	15.4	97	0.13	4.8	0.53	0.41	5%	95%
	160	7.72	15.7	103	0.13	4.8	0.54	0.42	6%	94%
	170	8.21	16.1	109	0.14	4.8	0.55	0.43	6%	94%
	180	8.69	16.5	116	0.15	4.8	0.56	0.44	7%	93%
	190	9.17	16.8	122	0.16	4.8	0.58	0.45	7%	93%
	200	9.65	17.1	129	0.17	4.8	0.59	0.46	8%	92%
	210	10.14	17.4	135	0.18	4.8	0.60	0.46	8%	92%
Kelt	650	31.38	24.2	418	0.55	4.8	0.83	0.65	35%	65%
	675	32.59	24.5	435	0.57	4.8	0.84	0.65	37%	63%
	700	33.79	24.7	451	0.59	4.8	0.85	0.66	39%	61%
	725	35.00	24.9	467	0.61	4.8	0.85	0.67	40%	60%
	750	36.21	25.1	483	0.63	4.8	0.86	0.67	42%	58%
	775	37.41	25.3	499	0.65	4.8	0.87	0.68	44%	56%
	800	38.62	25.5	515	0.67	4.8	0.87	0.68	46%	54%

Table D 6. Input parameters for the prediction of strike probability and mortality for Veazie units 16 and 17; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	84	0.11	4.8	0.50	0.27	3%	97%
	140	6.76	14.9	90	0.12	4.8	0.51	0.28	3%	97%
	150	7.24	15.4	97	0.13	4.8	0.53	0.28	4%	96%
	160	7.72	15.7	103	0.13	4.8	0.54	0.29	4%	96%
	170	8.21	16.1	109	0.14	4.8	0.55	0.30	4%	96%
	180	8.69	16.5	116	0.15	4.8	0.56	0.31	5%	95%
	190	9.17	16.8	122	0.16	4.8	0.58	0.31	5%	95%
	200	9.65	17.1	129	0.17	4.8	0.59	0.32	5%	95%
	210	10.14	17.4	135	0.18	4.8	0.60	0.32	6%	94%
Kelt	650	31.38	24.2	418	0.55	4.8	0.83	0.45	25%	75%
	675	32.59	24.5	435	0.57	4.8	0.84	0.45	26%	74%
	700	33.79	24.7	451	0.59	4.8	0.85	0.46	27%	73%
	725	35.00	24.9	467	0.61	4.8	0.85	0.46	28%	72%
	750	36.21	25.1	483	0.63	4.8	0.86	0.47	29%	71%
	775	37.41	25.3	499	0.65	4.8	0.87	0.47	31%	69%
	800	38.62	25.5	515	0.67	4.8	0.87	0.47	32%	68%

Table D 7. Input parameters for the prediction of strike probability and mortality for Veazie units 16 and 17; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	100	0.13	4.8	0.50	0.39	5%	95%
	140	6.76	14.9	107	0.14	4.8	0.51	0.40	6%	94%
	150	7.24	15.4	115	0.15	4.8	0.53	0.41	6%	94%
	160	7.72	15.7	123	0.16	4.8	0.54	0.42	7%	93%
	170	8.21	16.1	130	0.17	4.8	0.55	0.43	7%	93%
	180	8.69	16.5	138	0.18	4.8	0.56	0.44	8%	92%
	190	9.17	16.8	146	0.19	4.8	0.58	0.45	9%	91%
	200	9.65	17.1	153	0.20	4.8	0.59	0.46	9%	91%
	210	10.14	17.4	161	0.21	4.8	0.60	0.46	10%	90%
Kelt	650	31.38	24.2	498	0.65	4.8	0.83	0.65	42%	58%
	675	32.59	24.5	518	0.67	4.8	0.84	0.65	44%	56%
	700	33.79	24.7	537	0.70	4.8	0.85	0.66	46%	54%
	725	35.00	24.9	556	0.72	4.8	0.85	0.67	48%	52%
	750	36.21	25.1	575	0.75	4.8	0.86	0.67	50%	50%
	775	37.41	25.3	594	0.77	4.8	0.87	0.68	52%	48%
	800	38.62	25.5	613	0.80	4.8	0.87	0.68	54%	46%

Table D 8. Input parameters for the prediction of strike probability and mortality for Veazie units 16 and 17; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	65	0.08	4.8	0.50	0.27	2%	98%
	140	6.76	14.9	70	0.09	4.8	0.51	0.28	3%	97%
	150	7.24	15.4	75	0.10	4.8	0.53	0.28	3%	97%
	160	7.72	15.7	80	0.10	4.8	0.54	0.29	3%	97%
	170	8.21	16.1	85	0.11	4.8	0.55	0.30	3%	97%
	180	8.69	16.5	90	0.12	4.8	0.56	0.31	4%	96%
	190	9.17	16.8	95	0.12	4.8	0.58	0.31	4%	96%
	200	9.65	17.1	100	0.13	4.8	0.59	0.32	4%	96%
	210	10.14	17.4	105	0.14	4.8	0.60	0.32	4%	96%
Kelt	650	31.38	24.2	326	0.42	4.8	0.83	0.45	19%	81%
	675	32.59	24.5	338	0.44	4.8	0.84	0.45	20%	80%
	700	33.79	24.7	351	0.46	4.8	0.85	0.46	21%	79%
	725	35.00	24.9	363	0.47	4.8	0.85	0.46	22%	78%
	750	36.21	25.1	376	0.49	4.8	0.86	0.47	23%	77%
	775	37.41	25.3	388	0.51	4.8	0.87	0.47	24%	76%
	800	38.62	25.5	401	0.52	4.8	0.87	0.47	25%	75%

Table D 9. Input parameters for the prediction of strike probability and mortality for Veazie unit 1; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.18	18.5	92	0.42	4.8	0.51	0.33	14%	86%
	140	13.12	19.0	99	0.46	4.8	0.52	0.34	16%	84%
	150	14.05	19.4	106	0.49	4.8	0.53	0.35	17%	83%
	160	14.99	19.8	113	0.52	4.8	0.54	0.35	18%	82%
	170	15.93	20.1	120	0.56	4.8	0.55	0.36	20%	80%
	180	16.86	20.5	127	0.59	4.8	0.56	0.37	22%	78%
	190	17.80	20.8	134	0.62	4.8	0.57	0.37	23%	77%
	200	18.74	21.1	141	0.65	4.8	0.58	0.38	25%	75%
	210	19.67	21.4	148	0.69	4.8	0.59	0.38	26%	74%
Kelt	650	60.90	28.3	460	1.00	4.8	0.78	0.51	51%	49%
	675	63.24	28.5	477	1.00	4.8	0.78	0.51	51%	49%
	700	65.58	28.7	495	1.00	4.8	0.79	0.51	51%	49%
	725	67.92	28.9	513	1.00	4.8	0.80	0.52	52%	48%
	750	70.27	29.1	530	1.00	4.8	0.80	0.52	52%	48%
	775	72.61	29.3	548	1.00	4.8	0.81	0.52	52%	48%
	800	74.95	29.5	566	1.00	4.8	0.81	0.53	53%	47%

Table D 10. Input parameters for the prediction of strike probability and mortality for Veazie unit 1; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.18	18.5	106	0.49	4.8	0.51	0.33	16%	84%
	140	13.12	19.0	115	0.53	4.8	0.52	0.34	18%	82%
	150	14.05	19.4	123	0.57	4.8	0.53	0.35	20%	80%
	160	14.99	19.8	131	0.61	4.8	0.54	0.35	21%	79%
	170	15.93	20.1	139	0.64	4.8	0.55	0.36	23%	77%
	180	16.86	20.5	147	0.68	4.8	0.56	0.37	25%	75%
	190	17.80	20.8	156	0.72	4.8	0.57	0.37	27%	73%
	200	18.74	21.1	164	0.76	4.8	0.58	0.38	29%	71%
	210	19.67	21.4	172	0.79	4.8	0.59	0.38	30%	70%
Kelt	650	60.90	28.3	532	1.00	4.8	0.78	0.51	51%	49%
	675	63.24	28.5	553	1.00	4.8	0.78	0.51	51%	49%
	700	65.58	28.7	573	1.00	4.8	0.79	0.51	51%	49%
	725	67.92	28.9	594	1.00	4.8	0.80	0.52	52%	48%
	750	70.27	29.1	614	1.00	4.8	0.80	0.52	52%	48%
	775	72.61	29.3	635	1.00	4.8	0.81	0.52	52%	48%
	800	74.95	29.5	655	1.00	4.8	0.81	0.53	53%	47%

Table D 11. Input parameters for the prediction of strike probability and mortality for Veazie unit 1; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.18	18.5	75	0.34	4.8	0.51	0.33	11%	89%
	140	13.12	19.0	80	0.37	4.8	0.52	0.34	13%	87%
	150	14.05	19.4	86	0.40	4.8	0.53	0.35	14%	86%
	160	14.99	19.8	92	0.42	4.8	0.54	0.35	15%	85%
	170	15.93	20.1	98	0.45	4.8	0.55	0.36	16%	84%
	180	16.86	20.5	103	0.48	4.8	0.56	0.37	17%	83%
	190	17.80	20.8	109	0.50	4.8	0.57	0.37	19%	81%
	200	18.74	21.1	115	0.53	4.8	0.58	0.38	20%	80%
	210	19.67	21.4	120	0.56	4.8	0.59	0.38	21%	79%
Kelt	650	60.90	28.3	373	1.00	4.8	0.78	0.51	51%	49%
	675	63.24	28.5	387	1.00	4.8	0.78	0.51	51%	49%
	700	65.58	28.7	402	1.00	4.8	0.79	0.51	51%	49%
	725	67.92	28.9	416	1.00	4.8	0.80	0.52	52%	48%
	750	70.27	29.1	430	1.00	4.8	0.80	0.52	52%	48%
	775	72.61	29.3	445	1.00	4.8	0.81	0.52	52%	48%
	800	74.95	29.5	459	1.00	4.8	0.81	0.53	53%	47%

Table D 12. Input parameters for the prediction of strike probability and mortality for Veazie unit 1; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.18	18.5	92	0.42	4.8	0.51	0.40	17%	83%
	140	13.12	19.0	99	0.46	4.8	0.52	0.41	19%	81%
	150	14.05	19.4	106	0.49	4.8	0.53	0.42	20%	80%
	160	14.99	19.8	113	0.52	4.8	0.54	0.42	22%	78%
	170	15.93	20.1	120	0.56	4.8	0.55	0.43	24%	76%
	180	16.86	20.5	127	0.59	4.8	0.56	0.44	26%	74%
	190	17.80	20.8	134	0.62	4.8	0.57	0.45	28%	72%
	200	18.74	21.1	141	0.65	4.8	0.58	0.45	30%	70%
	210	19.67	21.4	148	0.69	4.8	0.59	0.46	32%	68%
Kelt	650	60.90	28.3	460	1.00	4.8	0.78	0.61	61%	39%
	675	63.24	28.5	477	1.00	4.8	0.78	0.61	61%	39%
	700	65.58	28.7	495	1.00	4.8	0.79	0.62	62%	38%
	725	67.92	28.9	513	1.00	4.8	0.80	0.62	62%	38%
	750	70.27	29.1	530	1.00	4.8	0.80	0.63	63%	37%
	775	72.61	29.3	548	1.00	4.8	0.81	0.63	63%	37%
	800	74.95	29.5	566	1.00	4.8	0.81	0.63	63%	37%

Table D 13. Input parameters for the prediction of strike probability and mortality for Veazie unit 1; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.18	18.5	92	0.42	4.8	0.51	0.28	12%	88%
	140	13.12	19.0	99	0.46	4.8	0.52	0.28	13%	87%
	150	14.05	19.4	106	0.49	4.8	0.53	0.29	14%	86%
	160	14.99	19.8	113	0.52	4.8	0.54	0.29	15%	85%
	170	15.93	20.1	120	0.56	4.8	0.55	0.30	17%	83%
	180	16.86	20.5	127	0.59	4.8	0.56	0.31	18%	82%
	190	17.80	20.8	134	0.62	4.8	0.57	0.31	19%	81%
	200	18.74	21.1	141	0.65	4.8	0.58	0.31	21%	79%
	210	19.67	21.4	148	0.69	4.8	0.59	0.32	22%	78%
Kelt	650	60.90	28.3	460	1.00	4.8	0.78	0.42	42%	58%
	675	63.24	28.5	477	1.00	4.8	0.78	0.42	42%	58%
	700	65.58	28.7	495	1.00	4.8	0.79	0.43	43%	57%
	725	67.92	28.9	513	1.00	4.8	0.80	0.43	43%	57%
	750	70.27	29.1	530	1.00	4.8	0.80	0.43	43%	57%
	775	72.61	29.3	548	1.00	4.8	0.81	0.44	44%	56%
	800	74.95	29.5	566	1.00	4.8	0.81	0.44	44%	56%

Table D 14. Input parameters for the prediction of strike probability and mortality for Veazie unit 1; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.18	18.5	106	0.49	4.8	0.51	0.40	20%	80%
	140	13.12	19.0	115	0.53	4.8	0.52	0.41	22%	78%
	150	14.05	19.4	123	0.57	4.8	0.53	0.42	24%	76%
	160	14.99	19.8	131	0.61	4.8	0.54	0.42	26%	74%
	170	15.93	20.1	139	0.64	4.8	0.55	0.43	28%	72%
	180	16.86	20.5	147	0.68	4.8	0.56	0.44	30%	70%
	190	17.80	20.8	156	0.72	4.8	0.57	0.45	32%	68%
	200	18.74	21.1	164	0.76	4.8	0.58	0.45	34%	66%
	210	19.67	21.4	172	0.79	4.8	0.59	0.46	37%	63%
Kelt	650	60.90	28.3	532	1.00	4.8	0.78	0.61	61%	39%
	675	63.24	28.5	553	1.00	4.8	0.78	0.61	61%	39%
	700	65.58	28.7	573	1.00	4.8	0.79	0.62	62%	38%
	725	67.92	28.9	594	1.00	4.8	0.80	0.62	62%	38%
	750	70.27	29.1	614	1.00	4.8	0.80	0.63	63%	37%
	775	72.61	29.3	635	1.00	4.8	0.81	0.63	63%	37%
	800	74.95	29.5	655	1.00	4.8	0.81	0.63	63%	37%

Table D 15. Input parameters for the prediction of strike probability and mortality for Veazie unit 1; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.18	18.5	75	0.34	4.8	0.51	0.28	10%	90%
	140	13.12	19.0	80	0.37	4.8	0.52	0.28	10%	90%
	150	14.05	19.4	86	0.40	4.8	0.53	0.29	11%	89%
	160	14.99	19.8	92	0.42	4.8	0.54	0.29	12%	88%
	170	15.93	20.1	98	0.45	4.8	0.55	0.30	14%	86%
	180	16.86	20.5	103	0.48	4.8	0.56	0.31	15%	85%
	190	17.80	20.8	109	0.50	4.8	0.57	0.31	16%	84%
	200	18.74	21.1	115	0.53	4.8	0.58	0.31	17%	83%
	210	19.67	21.4	120	0.56	4.8	0.59	0.32	18%	82%
Kelt	650	60.90	28.3	373	1.00	4.8	0.78	0.42	42%	58%
	675	63.24	28.5	387	1.00	4.8	0.78	0.42	42%	58%
	700	65.58	28.7	402	1.00	4.8	0.79	0.43	43%	57%
	725	67.92	28.9	416	1.00	4.8	0.80	0.43	43%	57%
	750	70.27	29.1	430	1.00	4.8	0.80	0.43	43%	57%
	775	72.61	29.3	445	1.00	4.8	0.81	0.44	44%	56%
	800	74.95	29.5	459	1.00	4.8	0.81	0.44	44%	56%

Table D 16. Input parameters for the prediction of strike probability and mortality for Veazie units 2,3,4,5,8,9,10,11,12,13, and 14; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.46	18.6	84	0.52	4.8	0.19	0.12	6%	94%
	140	13.42	19.1	90	0.56	4.8	0.20	0.13	7%	93%
	150	14.38	19.5	96	0.60	4.8	0.20	0.13	8%	92%
	160	15.34	19.9	103	0.64	4.8	0.21	0.13	8%	92%
	170	16.30	20.3	109	0.68	4.8	0.21	0.14	9%	91%
	180	17.26	20.6	116	0.72	4.8	0.21	0.14	10%	90%
	190	18.22	20.9	122	0.76	4.8	0.22	0.14	11%	89%
	200	19.18	21.3	129	0.80	4.8	0.22	0.14	11%	89%
	210	20.14	21.6	135	0.84	4.8	0.22	0.14	12%	88%
Kelt	650	62.32	28.4	418	1.00	4.8	0.29	0.19	19%	81%
	675	64.72	28.6	434	1.00	4.8	0.30	0.19	19%	81%
	700	67.12	28.9	450	1.00	4.8	0.30	0.19	19%	81%
	725	69.52	29.1	466	1.00	4.8	0.30	0.19	19%	81%
	750	71.91	29.3	482	1.00	4.8	0.30	0.20	20%	80%
	775	74.31	29.5	498	1.00	4.8	0.30	0.20	20%	80%
	800	76.71	29.7	514	1.00	4.8	0.31	0.20	20%	80%

Table D 17. Input parameters for the prediction of strike probability and mortality for Veazie units 2,3,4,5,8,9,10,11,12,13, and 14; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.46	18.6	100	0.62	4.8	0.19	0.12	8%	92%
	140	13.42	19.1	107	0.66	4.8	0.20	0.13	8%	92%
	150	14.38	19.5	115	0.71	4.8	0.20	0.13	9%	91%
	160	15.34	19.9	123	0.76	4.8	0.21	0.13	10%	90%
	170	16.30	20.3	130	0.81	4.8	0.21	0.14	11%	89%
	180	17.26	20.6	138	0.85	4.8	0.21	0.14	12%	88%
	190	18.22	20.9	146	0.90	4.8	0.22	0.14	13%	87%
	200	19.18	21.3	153	0.95	4.8	0.22	0.14	14%	86%
	210	20.14	21.6	161	1.00	4.8	0.22	0.14	14%	86%
Kelt	650	62.32	28.4	498	1.00	4.8	0.29	0.19	19%	81%
	675	64.72	28.6	517	1.00	4.8	0.30	0.19	19%	81%
	700	67.12	28.9	536	1.00	4.8	0.30	0.19	19%	81%
	725	69.52	29.1	555	1.00	4.8	0.30	0.19	19%	81%
	750	71.91	29.3	575	1.00	4.8	0.30	0.20	20%	80%
	775	74.31	29.5	594	1.00	4.8	0.30	0.20	20%	80%
	800	76.71	29.7	613	1.00	4.8	0.31	0.20	20%	80%

Table D 18. Input parameters for the prediction of strike probability and mortality for Veazie units 2,3,4,5,8,9,10,11,12,13, and 14; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.46	18.6	65	0.40	4.8	0.19	0.12	5%	95%
	140	13.42	19.1	70	0.43	4.8	0.20	0.13	6%	94%
	150	14.38	19.5	75	0.46	4.8	0.20	0.13	6%	94%
	160	15.34	19.9	80	0.50	4.8	0.21	0.13	7%	93%
	170	16.30	20.3	85	0.53	4.8	0.21	0.14	7%	93%
	180	17.26	20.6	90	0.56	4.8	0.21	0.14	8%	92%
	190	18.22	20.9	95	0.59	4.8	0.22	0.14	8%	92%
	200	19.18	21.3	100	0.62	4.8	0.22	0.14	9%	91%
	210	20.14	21.6	105	0.65	4.8	0.22	0.14	9%	91%
Kelt	650	62.32	28.4	325	1.00	4.8	0.29	0.19	19%	81%
	675	64.72	28.6	338	1.00	4.8	0.30	0.19	19%	81%
	700	67.12	28.9	350	1.00	4.8	0.30	0.19	19%	81%
	725	69.52	29.1	363	1.00	4.8	0.30	0.19	19%	81%
	750	71.91	29.3	375	1.00	4.8	0.30	0.20	20%	80%
	775	74.31	29.5	388	1.00	4.8	0.30	0.20	20%	80%
	800	76.71	29.7	400	1.00	4.8	0.31	0.20	20%	80%

Table D 19. Input parameters for the prediction of strike probability and mortality for Veazie units 2,3,4,5,8,9,10,11,12,13, and 14; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.46	18.6	84	0.52	4.8	0.19	0.15	8%	92%
	140	13.42	19.1	90	0.56	4.8	0.20	0.15	9%	91%
	150	14.38	19.5	96	0.60	4.8	0.20	0.16	9%	91%
	160	15.34	19.9	103	0.64	4.8	0.21	0.16	10%	90%
	170	16.30	20.3	109	0.68	4.8	0.21	0.16	11%	89%
	180	17.26	20.6	116	0.72	4.8	0.21	0.17	12%	88%
	190	18.22	20.9	122	0.76	4.8	0.22	0.17	13%	87%
	200	19.18	21.3	129	0.80	4.8	0.22	0.17	14%	86%
	210	20.14	21.6	135	0.84	4.8	0.22	0.17	14%	86%
Kelt	650	62.32	28.4	418	1.00	4.8	0.29	0.23	23%	77%
	675	64.72	28.6	434	1.00	4.8	0.30	0.23	23%	77%
	700	67.12	28.9	450	1.00	4.8	0.30	0.23	23%	77%
	725	69.52	29.1	466	1.00	4.8	0.30	0.23	23%	77%
	750	71.91	29.3	482	1.00	4.8	0.30	0.24	24%	76%
	775	74.31	29.5	498	1.00	4.8	0.30	0.24	24%	76%
	800	76.71	29.7	514	1.00	4.8	0.31	0.24	24%	76%

Table D 20. Input parameters for the prediction of strike probability and mortality for Veazie units 2,3,4,5,8,9,10,11,12,13, and 14; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.46	18.6	84	0.52	4.8	0.19	0.10	5%	95%
	140	13.42	19.1	90	0.56	4.8	0.20	0.11	6%	94%
	150	14.38	19.5	96	0.60	4.8	0.20	0.11	7%	93%
	160	15.34	19.9	103	0.64	4.8	0.21	0.11	7%	93%
	170	16.30	20.3	109	0.68	4.8	0.21	0.11	8%	92%
	180	17.26	20.6	116	0.72	4.8	0.21	0.12	8%	92%
	190	18.22	20.9	122	0.76	4.8	0.22	0.12	9%	91%
	200	19.18	21.3	129	0.80	4.8	0.22	0.12	9%	91%
	210	20.14	21.6	135	0.84	4.8	0.22	0.12	10%	90%
Kelt	650	62.32	28.4	418	1.00	4.8	0.29	0.16	16%	84%
	675	64.72	28.6	434	1.00	4.8	0.30	0.16	16%	84%
	700	67.12	28.9	450	1.00	4.8	0.30	0.16	16%	84%
	725	69.52	29.1	466	1.00	4.8	0.30	0.16	16%	84%
	750	71.91	29.3	482	1.00	4.8	0.30	0.16	16%	84%
	775	74.31	29.5	498	1.00	4.8	0.30	0.16	16%	84%
	800	76.71	29.7	514	1.00	4.8	0.31	0.17	17%	83%

Table D 21. Input parameters for the prediction of strike probability and mortality for Veazie units 2,3,4,5,8,9,10,11,12,13, and 14; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.46	18.6	100	0.62	4.8	0.19	0.15	9%	91%
	140	13.42	19.1	107	0.66	4.8	0.20	0.15	10%	90%
	150	14.38	19.5	115	0.71	4.8	0.20	0.16	11%	89%
	160	15.34	19.9	123	0.76	4.8	0.21	0.16	12%	88%
	170	16.30	20.3	130	0.81	4.8	0.21	0.16	13%	87%
	180	17.26	20.6	138	0.85	4.8	0.21	0.17	14%	86%
	190	18.22	20.9	146	0.90	4.8	0.22	0.17	15%	85%
	200	19.18	21.3	153	0.95	4.8	0.22	0.17	16%	84%
	210	20.14	21.6	161	1.00	4.8	0.22	0.17	17%	83%
Kelt	650	62.32	28.4	498	1.00	4.8	0.29	0.23	23%	77%
	675	64.72	28.6	517	1.00	4.8	0.30	0.23	23%	77%
	700	67.12	28.9	536	1.00	4.8	0.30	0.23	23%	77%
	725	69.52	29.1	555	1.00	4.8	0.30	0.23	23%	77%
	750	71.91	29.3	575	1.00	4.8	0.30	0.24	24%	76%
	775	74.31	29.5	594	1.00	4.8	0.30	0.24	24%	76%
	800	76.71	29.7	613	1.00	4.8	0.31	0.24	24%	76%

Table D 22. Input parameters for the prediction of strike probability and mortality for Veazie units 2,3,4,5,8,9,10,11,12,13, and 14; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.46	18.6	65	0.40	4.8	0.19	0.10	4%	96%
	140	13.42	19.1	70	0.43	4.8	0.20	0.11	5%	95%
	150	14.38	19.5	75	0.46	4.8	0.20	0.11	5%	95%
	160	15.34	19.9	80	0.50	4.8	0.21	0.11	6%	94%
	170	16.30	20.3	85	0.53	4.8	0.21	0.11	6%	94%
	180	17.26	20.6	90	0.56	4.8	0.21	0.12	6%	94%
	190	18.22	20.9	95	0.59	4.8	0.22	0.12	7%	93%
	200	19.18	21.3	100	0.62	4.8	0.22	0.12	7%	93%
	210	20.14	21.6	105	0.65	4.8	0.22	0.12	8%	92%
Kelt	650	62.32	28.4	325	1.00	4.8	0.29	0.16	16%	84%
	675	64.72	28.6	338	1.00	4.8	0.30	0.16	16%	84%
	700	67.12	28.9	350	1.00	4.8	0.30	0.16	16%	84%
	725	69.52	29.1	363	1.00	4.8	0.30	0.16	16%	84%
	750	71.91	29.3	375	1.00	4.8	0.30	0.16	16%	84%
	775	74.31	29.5	388	1.00	4.8	0.30	0.16	16%	84%
	800	76.71	29.7	400	1.00	4.8	0.31	0.17	17%	83%

Table D 23. Input parameters for the prediction of strike probability and mortality for Veazie unit 6; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.52	18.7	92	0.44	4.8	0.49	0.32	14%	86%
	140	13.49	19.1	99	0.47	4.8	0.50	0.32	15%	85%
	150	14.45	19.5	106	0.50	4.8	0.51	0.33	17%	83%
	160	15.41	19.9	113	0.54	4.8	0.52	0.34	18%	82%
	170	16.38	20.3	120	0.57	4.8	0.53	0.34	20%	80%
	180	17.34	20.6	127	0.60	4.8	0.54	0.35	21%	79%
	190	18.30	21.0	134	0.64	4.8	0.55	0.35	23%	77%
	200	19.27	21.3	141	0.67	4.8	0.55	0.36	24%	76%
	210	20.23	21.6	148	0.70	4.8	0.56	0.37	26%	74%
Kelt	650	62.62	28.4	460	1.00	4.8	0.74	0.48	48%	52%
	675	65.03	28.7	477	1.00	4.8	0.75	0.48	48%	52%
	700	67.43	28.9	495	1.00	4.8	0.75	0.49	49%	51%
	725	69.84	29.1	513	1.00	4.8	0.76	0.49	49%	51%
	750	72.25	29.3	530	1.00	4.8	0.76	0.50	50%	50%
	775	74.66	29.5	548	1.00	4.8	0.77	0.50	50%	50%
	800	77.07	29.7	566	1.00	4.8	0.77	0.50	50%	50%

Table D 24. Input parameters for the prediction of strike probability and mortality for Veazie unit 6; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.52	18.7	106	0.51	4.8	0.49	0.32	16%	84%
	140	13.49	19.1	115	0.54	4.8	0.50	0.32	18%	82%
	150	14.45	19.5	123	0.58	4.8	0.51	0.33	19%	81%
	160	15.41	19.9	131	0.62	4.8	0.52	0.34	21%	79%
	170	16.38	20.3	139	0.66	4.8	0.53	0.34	23%	77%
	180	17.34	20.6	147	0.70	4.8	0.54	0.35	24%	76%
	190	18.30	21.0	156	0.74	4.8	0.55	0.35	26%	74%
	200	19.27	21.3	164	0.78	4.8	0.55	0.36	28%	72%
	210	20.23	21.6	172	0.82	4.8	0.56	0.37	30%	70%
Kelt	650	62.62	28.4	532	1.00	4.8	0.74	0.48	48%	52%
	675	65.03	28.7	553	1.00	4.8	0.75	0.48	48%	52%
	700	67.43	28.9	573	1.00	4.8	0.75	0.49	49%	51%
	725	69.84	29.1	594	1.00	4.8	0.76	0.49	49%	51%
	750	72.25	29.3	614	1.00	4.8	0.76	0.50	50%	50%
	775	74.66	29.5	635	1.00	4.8	0.77	0.50	50%	50%
	800	77.07	29.7	655	1.00	4.8	0.77	0.50	50%	50%

Table D 25. Input parameters for the prediction of strike probability and mortality for Veazie unit 6; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.52	18.7	75	0.35	4.8	0.49	0.32	11%	89%
	140	13.49	19.1	80	0.38	4.8	0.50	0.32	12%	88%
	150	14.45	19.5	86	0.41	4.8	0.51	0.33	13%	87%
	160	15.41	19.9	92	0.44	4.8	0.52	0.34	15%	85%
	170	16.38	20.3	98	0.46	4.8	0.53	0.34	16%	84%
	180	17.34	20.6	103	0.49	4.8	0.54	0.35	17%	83%
	190	18.30	21.0	109	0.52	4.8	0.55	0.35	18%	82%
	200	19.27	21.3	115	0.54	4.8	0.55	0.36	20%	80%
	210	20.23	21.6	120	0.57	4.8	0.56	0.37	21%	79%
Kelt	650	62.62	28.4	373	1.00	4.8	0.74	0.48	48%	52%
	675	65.03	28.7	387	1.00	4.8	0.75	0.48	48%	52%
	700	67.43	28.9	402	1.00	4.8	0.75	0.49	49%	51%
	725	69.84	29.1	416	1.00	4.8	0.76	0.49	49%	51%
	750	72.25	29.3	430	1.00	4.8	0.76	0.50	50%	50%
	775	74.66	29.5	445	1.00	4.8	0.77	0.50	50%	50%
	800	77.07	29.7	459	1.00	4.8	0.77	0.50	50%	50%

Table D 26. Input parameters for the prediction of strike probability and mortality for Veazie unit 6; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.52	18.7	92	0.44	4.8	0.49	0.38	17%	83%
	140	13.49	19.1	99	0.47	4.8	0.50	0.39	18%	82%
	150	14.45	19.5	106	0.50	4.8	0.51	0.40	20%	80%
	160	15.41	19.9	113	0.54	4.8	0.52	0.40	22%	78%
	170	16.38	20.3	120	0.57	4.8	0.53	0.41	24%	76%
	180	17.34	20.6	127	0.60	4.8	0.54	0.42	25%	75%
	190	18.30	21.0	134	0.64	4.8	0.55	0.43	27%	73%
	200	19.27	21.3	141	0.67	4.8	0.55	0.43	29%	71%
	210	20.23	21.6	148	0.70	4.8	0.56	0.44	31%	69%
Kelt	650	62.62	28.4	460	1.00	4.8	0.74	0.58	58%	42%
	675	65.03	28.7	477	1.00	4.8	0.75	0.58	58%	42%
	700	67.43	28.9	495	1.00	4.8	0.75	0.59	59%	41%
	725	69.84	29.1	513	1.00	4.8	0.76	0.59	59%	41%
	750	72.25	29.3	530	1.00	4.8	0.76	0.59	59%	41%
	775	74.66	29.5	548	1.00	4.8	0.77	0.60	60%	40%
	800	77.07	29.7	566	1.00	4.8	0.77	0.60	60%	40%

Table D 27. Input parameters for the prediction of strike probability and mortality for Veazie unit 6; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.52	18.7	92	0.44	4.8	0.49	0.26	11%	89%
	140	13.49	19.1	99	0.47	4.8	0.50	0.27	13%	87%
	150	14.45	19.5	106	0.50	4.8	0.51	0.28	14%	86%
	160	15.41	19.9	113	0.54	4.8	0.52	0.28	15%	85%
	170	16.38	20.3	120	0.57	4.8	0.53	0.29	16%	84%
	180	17.34	20.6	127	0.60	4.8	0.54	0.29	18%	82%
	190	18.30	21.0	134	0.64	4.8	0.55	0.30	19%	81%
	200	19.27	21.3	141	0.67	4.8	0.55	0.30	20%	80%
	210	20.23	21.6	148	0.70	4.8	0.56	0.30	21%	79%
Kelt	650	62.62	28.4	460	1.00	4.8	0.74	0.40	40%	60%
	675	65.03	28.7	477	1.00	4.8	0.75	0.40	40%	60%
	700	67.43	28.9	495	1.00	4.8	0.75	0.41	41%	59%
	725	69.84	29.1	513	1.00	4.8	0.76	0.41	41%	59%
	750	72.25	29.3	530	1.00	4.8	0.76	0.41	41%	59%
	775	74.66	29.5	548	1.00	4.8	0.77	0.42	42%	58%
	800	77.07	29.7	566	1.00	4.8	0.77	0.42	42%	58%

Table D 28. Input parameters for the prediction of strike probability and mortality for Veazie unit 6; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.52	18.7	106	0.51	4.8	0.49	0.38	19%	81%
	140	13.49	19.1	115	0.54	4.8	0.50	0.39	21%	79%
	150	14.45	19.5	123	0.58	4.8	0.51	0.40	23%	77%
	160	15.41	19.9	131	0.62	4.8	0.52	0.40	25%	75%
	170	16.38	20.3	139	0.66	4.8	0.53	0.41	27%	73%
	180	17.34	20.6	147	0.70	4.8	0.54	0.42	29%	71%
	190	18.30	21.0	156	0.74	4.8	0.55	0.43	31%	69%
	200	19.27	21.3	164	0.78	4.8	0.55	0.43	34%	66%
	210	20.23	21.6	172	0.82	4.8	0.56	0.44	36%	64%
Kelt	650	62.62	28.4	532	1.00	4.8	0.74	0.58	58%	42%
	675	65.03	28.7	553	1.00	4.8	0.75	0.58	58%	42%
	700	67.43	28.9	573	1.00	4.8	0.75	0.59	59%	41%
	725	69.84	29.1	594	1.00	4.8	0.76	0.59	59%	41%
	750	72.25	29.3	614	1.00	4.8	0.76	0.59	59%	41%
	775	74.66	29.5	635	1.00	4.8	0.77	0.60	60%	40%
	800	77.07	29.7	655	1.00	4.8	0.77	0.60	60%	40%

Table D 29. Input parameters for the prediction of strike probability and mortality for Veazie unit 6; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.52	18.7	75	0.35	4.8	0.49	0.26	9%	91%
	140	13.49	19.1	80	0.38	4.8	0.50	0.27	10%	90%
	150	14.45	19.5	86	0.41	4.8	0.51	0.28	11%	89%
	160	15.41	19.9	92	0.44	4.8	0.52	0.28	12%	88%
	170	16.38	20.3	98	0.46	4.8	0.53	0.29	13%	87%
	180	17.34	20.6	103	0.49	4.8	0.54	0.29	14%	86%
	190	18.30	21.0	109	0.52	4.8	0.55	0.30	15%	85%
	200	19.27	21.3	115	0.54	4.8	0.55	0.30	16%	84%
	210	20.23	21.6	120	0.57	4.8	0.56	0.30	17%	83%
Kelt	650	62.62	28.4	373	1.00	4.8	0.74	0.40	40%	60%
	675	65.03	28.7	387	1.00	4.8	0.75	0.40	40%	60%
	700	67.43	28.9	402	1.00	4.8	0.75	0.41	41%	59%
	725	69.84	29.1	416	1.00	4.8	0.76	0.41	41%	59%
	750	72.25	29.3	430	1.00	4.8	0.76	0.41	41%	59%
	775	74.66	29.5	445	1.00	4.8	0.77	0.42	42%	58%
	800	77.07	29.7	459	1.00	4.8	0.77	0.42	42%	58%

Table D 30. Input parameters for the prediction of strike probability and mortality for Veazie unit 7; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.51	18.7	92	0.44	4.8	0.47	0.30	13%	87%
	140	13.47	19.1	99	0.48	4.8	0.48	0.31	15%	85%
	150	14.43	19.5	106	0.51	4.8	0.49	0.32	16%	84%
	160	15.39	19.9	113	0.55	4.8	0.50	0.32	18%	82%
	170	16.35	20.3	120	0.58	4.8	0.51	0.33	19%	81%
	180	17.32	20.6	127	0.61	4.8	0.52	0.34	21%	79%
	190	18.28	21.0	134	0.65	4.8	0.52	0.34	22%	78%
	200	19.24	21.3	141	0.68	4.8	0.53	0.35	24%	76%
	210	20.20	21.6	148	0.72	4.8	0.54	0.35	25%	75%
Kelt	650	62.53	28.4	460	1.00	4.8	0.71	0.46	46%	54%
	675	64.94	28.7	477	1.00	4.8	0.72	0.47	47%	53%
	700	67.34	28.9	495	1.00	4.8	0.72	0.47	47%	53%
	725	69.75	29.1	513	1.00	4.8	0.73	0.47	47%	53%
	750	72.15	29.3	530	1.00	4.8	0.73	0.48	48%	52%
	775	74.56	29.5	548	1.00	4.8	0.74	0.48	48%	52%
	800	76.96	29.7	566	1.00	4.8	0.74	0.48	48%	52%

Table D 31. Input parameters for the prediction of strike probability and mortality for Veazie unit 7; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.51	18.7	106	0.51	4.8	0.47	0.30	16%	84%
	140	13.47	19.1	115	0.55	4.8	0.48	0.31	17%	83%
	150	14.43	19.5	123	0.59	4.8	0.49	0.32	19%	81%
	160	15.39	19.9	131	0.63	4.8	0.50	0.32	20%	80%
	170	16.35	20.3	139	0.67	4.8	0.51	0.33	22%	78%
	180	17.32	20.6	147	0.71	4.8	0.52	0.34	24%	76%
	190	18.28	21.0	156	0.75	4.8	0.52	0.34	26%	74%
	200	19.24	21.3	164	0.79	4.8	0.53	0.35	27%	73%
	210	20.20	21.6	172	0.83	4.8	0.54	0.35	29%	71%
Kelt	650	62.53	28.4	532	1.00	4.8	0.71	0.46	46%	54%
	675	64.94	28.7	553	1.00	4.8	0.72	0.47	47%	53%
	700	67.34	28.9	573	1.00	4.8	0.72	0.47	47%	53%
	725	69.75	29.1	594	1.00	4.8	0.73	0.47	47%	53%
	750	72.15	29.3	614	1.00	4.8	0.73	0.48	48%	52%
	775	74.56	29.5	635	1.00	4.8	0.74	0.48	48%	52%
	800	76.96	29.7	655	1.00	4.8	0.74	0.48	48%	52%

Table D 32. Input parameters for the prediction of strike probability and mortality for Veazie unit 7; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.51	18.7	75	0.36	4.8	0.47	0.30	11%	89%
	140	13.47	19.1	80	0.39	4.8	0.48	0.31	12%	88%
	150	14.43	19.5	86	0.41	4.8	0.49	0.32	13%	87%
	160	15.39	19.9	92	0.44	4.8	0.50	0.32	14%	86%
	170	16.35	20.3	98	0.47	4.8	0.51	0.33	16%	84%
	180	17.32	20.6	103	0.50	4.8	0.52	0.34	17%	83%
	190	18.28	21.0	109	0.53	4.8	0.52	0.34	18%	82%
	200	19.24	21.3	115	0.55	4.8	0.53	0.35	19%	81%
	210	20.20	21.6	120	0.58	4.8	0.54	0.35	20%	80%
Kelt	650	62.53	28.4	373	1.00	4.8	0.71	0.46	46%	54%
	675	64.94	28.7	387	1.00	4.8	0.72	0.47	47%	53%
	700	67.34	28.9	402	1.00	4.8	0.72	0.47	47%	53%
	725	69.75	29.1	416	1.00	4.8	0.73	0.47	47%	53%
	750	72.15	29.3	430	1.00	4.8	0.73	0.48	48%	52%
	775	74.56	29.5	445	1.00	4.8	0.74	0.48	48%	52%
	800	76.96	29.7	459	1.00	4.8	0.74	0.48	48%	52%

Table D 33. Input parameters for the prediction of strike probability and mortality for Veazie unit 7; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.51	18.7	92	0.44	4.8	0.47	0.36	16%	84%
	140	13.47	19.1	99	0.48	4.8	0.48	0.37	18%	82%
	150	14.43	19.5	106	0.51	4.8	0.49	0.38	19%	81%
	160	15.39	19.9	113	0.55	4.8	0.50	0.39	21%	79%
	170	16.35	20.3	120	0.58	4.8	0.51	0.40	23%	77%
	180	17.32	20.6	127	0.61	4.8	0.52	0.40	25%	75%
	190	18.28	21.0	134	0.65	4.8	0.52	0.41	26%	74%
	200	19.24	21.3	141	0.68	4.8	0.53	0.42	28%	72%
	210	20.20	21.6	148	0.72	4.8	0.54	0.42	30%	70%
Kelt	650	62.53	28.4	460	1.00	4.8	0.71	0.55	55%	45%
	675	64.94	28.7	477	1.00	4.8	0.72	0.56	56%	44%
	700	67.34	28.9	495	1.00	4.8	0.72	0.56	56%	44%
	725	69.75	29.1	513	1.00	4.8	0.73	0.57	57%	43%
	750	72.15	29.3	530	1.00	4.8	0.73	0.57	57%	43%
	775	74.56	29.5	548	1.00	4.8	0.74	0.58	58%	42%
	800	76.96	29.7	566	1.00	4.8	0.74	0.58	58%	42%

Table D 34. Input parameters for the prediction of strike probability and mortality for Veazie unit 7; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.51	18.7	92	0.44	4.8	0.47	0.25	11%	89%
	140	13.47	19.1	99	0.48	4.8	0.48	0.26	12%	88%
	150	14.43	19.5	106	0.51	4.8	0.49	0.26	14%	86%
	160	15.39	19.9	113	0.55	4.8	0.50	0.27	15%	85%
	170	16.35	20.3	120	0.58	4.8	0.51	0.28	16%	84%
	180	17.32	20.6	127	0.61	4.8	0.52	0.28	17%	83%
	190	18.28	21.0	134	0.65	4.8	0.52	0.28	18%	82%
	200	19.24	21.3	141	0.68	4.8	0.53	0.29	20%	80%
	210	20.20	21.6	148	0.72	4.8	0.54	0.29	21%	79%
Kelt	650	62.53	28.4	460	1.00	4.8	0.71	0.39	39%	61%
	675	64.94	28.7	477	1.00	4.8	0.72	0.39	39%	61%
	700	67.34	28.9	495	1.00	4.8	0.72	0.39	39%	61%
	725	69.75	29.1	513	1.00	4.8	0.73	0.39	39%	61%
	750	72.15	29.3	530	1.00	4.8	0.73	0.40	40%	60%
	775	74.56	29.5	548	1.00	4.8	0.74	0.40	40%	60%
	800	76.96	29.7	566	1.00	4.8	0.74	0.40	40%	60%

Table D 35. Input parameters for the prediction of strike probability and mortality for Veazie unit 7; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.51	18.7	106	0.51	4.8	0.47	0.36	19%	81%
	140	13.47	19.1	115	0.55	4.8	0.48	0.37	21%	79%
	150	14.43	19.5	123	0.59	4.8	0.49	0.38	23%	77%
	160	15.39	19.9	131	0.63	4.8	0.50	0.39	25%	75%
	170	16.35	20.3	139	0.67	4.8	0.51	0.40	27%	73%
	180	17.32	20.6	147	0.71	4.8	0.52	0.40	29%	71%
	190	18.28	21.0	156	0.75	4.8	0.52	0.41	31%	69%
	200	19.24	21.3	164	0.79	4.8	0.53	0.42	33%	67%
	210	20.20	21.6	172	0.83	4.8	0.54	0.42	35%	65%
Kelt	650	62.53	28.4	532	1.00	4.8	0.71	0.55	55%	45%
	675	64.94	28.7	553	1.00	4.8	0.72	0.56	56%	44%
	700	67.34	28.9	573	1.00	4.8	0.72	0.56	56%	44%
	725	69.75	29.1	594	1.00	4.8	0.73	0.57	57%	43%
	750	72.15	29.3	614	1.00	4.8	0.73	0.57	57%	43%
	775	74.56	29.5	635	1.00	4.8	0.74	0.58	58%	42%
	800	76.96	29.7	655	1.00	4.8	0.74	0.58	58%	42%

Table D 36. Input parameters for the prediction of strike probability and mortality for Veazie unit 7; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.51	18.7	75	0.36	4.8	0.47	0.25	9%	91%
	140	13.47	19.1	80	0.39	4.8	0.48	0.26	10%	90%
	150	14.43	19.5	86	0.41	4.8	0.49	0.26	11%	89%
	160	15.39	19.9	92	0.44	4.8	0.50	0.27	12%	88%
	170	16.35	20.3	98	0.47	4.8	0.51	0.28	13%	87%
	180	17.32	20.6	103	0.50	4.8	0.52	0.28	14%	86%
	190	18.28	21.0	109	0.53	4.8	0.52	0.28	15%	85%
	200	19.24	21.3	115	0.55	4.8	0.53	0.29	16%	84%
	210	20.20	21.6	120	0.58	4.8	0.54	0.29	17%	83%
Kelt	650	62.53	28.4	373	1.00	4.8	0.71	0.39	39%	61%
	675	64.94	28.7	387	1.00	4.8	0.72	0.39	39%	61%
	700	67.34	28.9	402	1.00	4.8	0.72	0.39	39%	61%
	725	69.75	29.1	416	1.00	4.8	0.73	0.39	39%	61%
	750	72.15	29.3	430	1.00	4.8	0.73	0.40	40%	60%
	775	74.56	29.5	445	1.00	4.8	0.74	0.40	40%	60%
	800	76.96	29.7	459	1.00	4.8	0.74	0.40	40%	60%

Table D 37. Input parameters for the prediction of strike probability and mortality for Veazie unit 15; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.94	18.4	92	0.35	4.8	0.30	0.19	7%	93%
	140	12.86	18.8	99	0.38	4.8	0.30	0.20	7%	93%
	150	13.78	19.3	106	0.40	4.8	0.31	0.20	8%	92%
	160	14.70	19.6	113	0.43	4.8	0.32	0.21	9%	91%
	170	15.62	20.0	120	0.46	4.8	0.32	0.21	10%	90%
	180	16.54	20.4	127	0.48	4.8	0.33	0.21	10%	90%
	190	17.46	20.7	134	0.51	4.8	0.33	0.22	11%	89%
	200	18.38	21.0	141	0.54	4.8	0.34	0.22	12%	88%
	210	19.30	21.3	148	0.56	4.8	0.34	0.22	13%	87%
Kelt	650	59.72	28.1	460	1.00	4.8	0.45	0.29	29%	71%
	675	62.02	28.4	477	1.00	4.8	0.46	0.30	30%	70%
	700	64.32	28.6	495	1.00	4.8	0.46	0.30	30%	70%
	725	66.62	28.8	513	1.00	4.8	0.46	0.30	30%	70%
	750	68.91	29.0	530	1.00	4.8	0.47	0.30	30%	70%
	775	71.21	29.2	548	1.00	4.8	0.47	0.31	31%	69%
	800	73.51	29.4	566	1.00	4.8	0.47	0.31	31%	69%

Table D 38. Input parameters for the prediction of strike probability and mortality for Veazie unit 15; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.94	18.4	106	0.40	4.8	0.30	0.19	8%	92%
	140	12.86	18.8	115	0.43	4.8	0.30	0.20	9%	91%
	150	13.78	19.3	123	0.47	4.8	0.31	0.20	9%	91%
	160	14.70	19.6	131	0.50	4.8	0.32	0.21	10%	90%
	170	15.62	20.0	139	0.53	4.8	0.32	0.21	11%	89%
	180	16.54	20.4	147	0.56	4.8	0.33	0.21	12%	88%
	190	17.46	20.7	156	0.59	4.8	0.33	0.22	13%	87%
	200	18.38	21.0	164	0.62	4.8	0.34	0.22	14%	86%
	210	19.30	21.3	172	0.65	4.8	0.34	0.22	15%	85%
Kelt	650	59.72	28.1	532	1.00	4.8	0.45	0.29	29%	71%
	675	62.02	28.4	553	1.00	4.8	0.46	0.30	30%	70%
	700	64.32	28.6	573	1.00	4.8	0.46	0.30	30%	70%
	725	66.62	28.8	594	1.00	4.8	0.46	0.30	30%	70%
	750	68.91	29.0	614	1.00	4.8	0.47	0.30	30%	70%
	775	71.21	29.2	635	1.00	4.8	0.47	0.31	31%	69%
	800	73.51	29.4	655	1.00	4.8	0.47	0.31	31%	69%

Table D 39. Input parameters for the prediction of strike probability and mortality for Veazie unit 15; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.94	18.4	75	0.28	4.8	0.30	0.19	5%	95%
	140	12.86	18.8	80	0.30	4.8	0.30	0.20	6%	94%
	150	13.78	19.3	86	0.33	4.8	0.31	0.20	7%	93%
	160	14.70	19.6	92	0.35	4.8	0.32	0.21	7%	93%
	170	15.62	20.0	98	0.37	4.8	0.32	0.21	8%	92%
	180	16.54	20.4	103	0.39	4.8	0.33	0.21	8%	92%
	190	17.46	20.7	109	0.41	4.8	0.33	0.22	9%	91%
	200	18.38	21.0	115	0.43	4.8	0.34	0.22	10%	90%
	210	19.30	21.3	120	0.46	4.8	0.34	0.22	10%	90%
Kelt	650	59.72	28.1	373	1.00	4.8	0.45	0.29	29%	71%
	675	62.02	28.4	387	1.00	4.8	0.46	0.30	30%	70%
	700	64.32	28.6	402	1.00	4.8	0.46	0.30	30%	70%
	725	66.62	28.8	416	1.00	4.8	0.46	0.30	30%	70%
	750	68.91	29.0	430	1.00	4.8	0.47	0.30	30%	70%
	775	71.21	29.2	445	1.00	4.8	0.47	0.31	31%	69%
	800	73.51	29.4	459	1.00	4.8	0.47	0.31	31%	69%

Table D 40. Input parameters for the prediction of strike probability and mortality for Veazie unit 15; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.94	18.4	92	0.35	4.8	0.30	0.23	8%	92%
	140	12.86	18.8	99	0.38	4.8	0.30	0.24	9%	91%
	150	13.78	19.3	106	0.40	4.8	0.31	0.24	10%	90%
	160	14.70	19.6	113	0.43	4.8	0.32	0.25	11%	89%
	170	15.62	20.0	120	0.46	4.8	0.32	0.25	11%	89%
	180	16.54	20.4	127	0.48	4.8	0.33	0.26	12%	88%
	190	17.46	20.7	134	0.51	4.8	0.33	0.26	13%	87%
	200	18.38	21.0	141	0.54	4.8	0.34	0.26	14%	86%
	210	19.30	21.3	148	0.56	4.8	0.34	0.27	15%	85%
Kelt	650	59.72	28.1	460	1.00	4.8	0.45	0.35	35%	65%
	675	62.02	28.4	477	1.00	4.8	0.46	0.36	36%	64%
	700	64.32	28.6	495	1.00	4.8	0.46	0.36	36%	64%
	725	66.62	28.8	513	1.00	4.8	0.46	0.36	36%	64%
	750	68.91	29.0	530	1.00	4.8	0.47	0.36	36%	64%
	775	71.21	29.2	548	1.00	4.8	0.47	0.37	37%	63%
	800	73.51	29.4	566	1.00	4.8	0.47	0.37	37%	63%

Table D 41. Input parameters for the prediction of strike probability and mortality for Veazie unit 15; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.94	18.4	92	0.35	4.8	0.30	0.16	6%	94%
	140	12.86	18.8	99	0.38	4.8	0.30	0.16	6%	94%
	150	13.78	19.3	106	0.40	4.8	0.31	0.17	7%	93%
	160	14.70	19.6	113	0.43	4.8	0.32	0.17	7%	93%
	170	15.62	20.0	120	0.46	4.8	0.32	0.17	8%	92%
	180	16.54	20.4	127	0.48	4.8	0.33	0.18	9%	91%
	190	17.46	20.7	134	0.51	4.8	0.33	0.18	9%	91%
	200	18.38	21.0	141	0.54	4.8	0.34	0.18	10%	90%
	210	19.30	21.3	148	0.56	4.8	0.34	0.19	10%	90%
Kelt	650	59.72	28.1	460	1.00	4.8	0.45	0.25	25%	75%
	675	62.02	28.4	477	1.00	4.8	0.46	0.25	25%	75%
	700	64.32	28.6	495	1.00	4.8	0.46	0.25	25%	75%
	725	66.62	28.8	513	1.00	4.8	0.46	0.25	25%	75%
	750	68.91	29.0	530	1.00	4.8	0.47	0.25	25%	75%
	775	71.21	29.2	548	1.00	4.8	0.47	0.25	25%	75%
	800	73.51	29.4	566	1.00	4.8	0.47	0.26	26%	74%

Table D 42. Input parameters for the prediction of strike probability and mortality for Veazie unit 15; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.94	18.4	106	0.40	4.8	0.30	0.23	9%	91%
	140	12.86	18.8	115	0.43	4.8	0.30	0.24	10%	90%
	150	13.78	19.3	123	0.47	4.8	0.31	0.24	11%	89%
	160	14.70	19.6	131	0.50	4.8	0.32	0.25	12%	88%
	170	15.62	20.0	139	0.53	4.8	0.32	0.25	13%	87%
	180	16.54	20.4	147	0.56	4.8	0.33	0.26	14%	86%
	190	17.46	20.7	156	0.59	4.8	0.33	0.26	15%	85%
	200	18.38	21.0	164	0.62	4.8	0.34	0.26	16%	84%
	210	19.30	21.3	172	0.65	4.8	0.34	0.27	17%	83%
Kelt	650	59.72	28.1	532	1.00	4.8	0.45	0.35	35%	65%
	675	62.02	28.4	553	1.00	4.8	0.46	0.36	36%	64%
	700	64.32	28.6	573	1.00	4.8	0.46	0.36	36%	64%
	725	66.62	28.8	594	1.00	4.8	0.46	0.36	36%	64%
	750	68.91	29.0	614	1.00	4.8	0.47	0.36	36%	64%
	775	71.21	29.2	635	1.00	4.8	0.47	0.37	37%	63%
	800	73.51	29.4	655	1.00	4.8	0.47	0.37	37%	63%

Table D 43. Input parameters for the prediction of strike probability and mortality for Veazie unit 15; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.94	18.4	75	0.28	4.8	0.30	0.16	5%	95%
	140	12.86	18.8	80	0.30	4.8	0.30	0.16	5%	95%
	150	13.78	19.3	86	0.33	4.8	0.31	0.17	5%	95%
	160	14.70	19.6	92	0.35	4.8	0.32	0.17	6%	94%
	170	15.62	20.0	98	0.37	4.8	0.32	0.17	6%	94%
	180	16.54	20.4	103	0.39	4.8	0.33	0.18	7%	93%
	190	17.46	20.7	109	0.41	4.8	0.33	0.18	7%	93%
	200	18.38	21.0	115	0.43	4.8	0.34	0.18	8%	92%
	210	19.30	21.3	120	0.46	4.8	0.34	0.19	8%	92%
Kelt	650	59.72	28.1	373	1.00	4.8	0.45	0.25	25%	75%
	675	62.02	28.4	387	1.00	4.8	0.46	0.25	25%	75%
	700	64.32	28.6	402	1.00	4.8	0.46	0.25	25%	75%
	725	66.62	28.8	416	1.00	4.8	0.46	0.25	25%	75%
	750	68.91	29.0	430	1.00	4.8	0.47	0.25	25%	75%
	775	71.21	29.2	445	1.00	4.8	0.47	0.25	25%	75%
	800	73.51	29.4	459	1.00	4.8	0.47	0.26	26%	74%

Table D 44. Input parameters for the prediction of strike probability and mortality for Great Works units 4,5,9,10 and 11; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.39	16.3	76	1.00	4.8	0.06	0.04	4%	96%
	140	9.04	16.7	82	1.00	4.8	0.06	0.04	4%	96%
	150	9.69	17.1	88	1.00	4.8	0.06	0.04	4%	96%
	160	10.33	17.5	94	1.00	4.8	0.06	0.04	4%	96%
	170	10.98	17.9	100	1.00	4.8	0.06	0.04	4%	96%
	180	11.62	18.2	106	1.00	4.8	0.06	0.04	4%	96%
	190	12.27	18.6	112	1.00	4.8	0.06	0.04	4%	96%
	200	12.91	18.9	117	1.00	4.8	0.06	0.04	4%	96%
	210	13.56	19.2	123	1.00	4.8	0.07	0.04	4%	96%
Kelt	650	41.97	26.0	381	1.00	4.8	0.09	0.06	6%	94%
	675	43.59	26.2	396	1.00	4.8	0.09	0.06	6%	94%
	700	45.20	26.5	411	1.00	4.8	0.09	0.06	6%	94%
	725	46.81	26.7	425	1.00	4.8	0.09	0.06	6%	94%
	750	48.43	26.9	440	1.00	4.8	0.09	0.06	6%	94%
	775	50.04	27.1	455	1.00	4.8	0.09	0.06	6%	94%
	800	51.66	27.3	470	1.00	4.8	0.09	0.06	6%	94%

Table D 45. Input parameters for the prediction of strike probability and mortality for Great Works units 4,5,9, 10 and 11; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.39	16.3	93	1.00	4.8	0.06	0.04	4%	96%
	140	9.04	16.7	101	1.00	4.8	0.06	0.04	4%	96%
	150	9.69	17.1	108	1.00	4.8	0.06	0.04	4%	96%
	160	10.33	17.5	115	1.00	4.8	0.06	0.04	4%	96%
	170	10.98	17.9	122	1.00	4.8	0.06	0.04	4%	96%
	180	11.62	18.2	129	1.00	4.8	0.06	0.04	4%	96%
	190	12.27	18.6	137	1.00	4.8	0.06	0.04	4%	96%
	200	12.91	18.9	144	1.00	4.8	0.06	0.04	4%	96%
	210	13.56	19.2	151	1.00	4.8	0.07	0.04	4%	96%
Kelt	650	41.97	26.0	467	1.00	4.8	0.09	0.06	6%	94%
	675	43.59	26.2	485	1.00	4.8	0.09	0.06	6%	94%
	700	45.20	26.5	503	1.00	4.8	0.09	0.06	6%	94%
	725	46.81	26.7	521	1.00	4.8	0.09	0.06	6%	94%
	750	48.43	26.9	539	1.00	4.8	0.09	0.06	6%	94%
	775	50.04	27.1	557	1.00	4.8	0.09	0.06	6%	94%
	800	51.66	27.3	575	1.00	4.8	0.09	0.06	6%	94%

Table D 46. Input parameters for the prediction of strike probability and mortality for Great Works units 4,5,9,10 and 11; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.39	16.3	57	1.00	4.8	0.06	0.04	4%	96%
	140	9.04	16.7	61	1.00	4.8	0.06	0.04	4%	96%
	150	9.69	17.1	66	1.00	4.8	0.06	0.04	4%	96%
	160	10.33	17.5	70	1.00	4.8	0.06	0.04	4%	96%
	170	10.98	17.9	74	1.00	4.8	0.06	0.04	4%	96%
	180	11.62	18.2	79	1.00	4.8	0.06	0.04	4%	96%
	190	12.27	18.6	83	1.00	4.8	0.06	0.04	4%	96%
	200	12.91	18.9	87	1.00	4.8	0.06	0.04	4%	96%
	210	13.56	19.2	92	1.00	4.8	0.07	0.04	4%	96%
Kelt	650	41.97	26.0	284	1.00	4.8	0.09	0.06	6%	94%
	675	43.59	26.2	295	1.00	4.8	0.09	0.06	6%	94%
	700	45.20	26.5	306	1.00	4.8	0.09	0.06	6%	94%
	725	46.81	26.7	317	1.00	4.8	0.09	0.06	6%	94%
	750	48.43	26.9	328	1.00	4.8	0.09	0.06	6%	94%
	775	50.04	27.1	339	1.00	4.8	0.09	0.06	6%	94%
	800	51.66	27.3	350	1.00	4.8	0.09	0.06	6%	94%

Table D 47. Input parameters for the prediction of strike probability and mortality for Great Works units 4,5,9,10 and 11; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.39	16.3	76	1.00	4.8	0.06	0.04	4%	96%
	140	9.04	16.7	82	1.00	4.8	0.06	0.04	4%	96%
	150	9.69	17.1	88	1.00	4.8	0.06	0.05	5%	95%
	160	10.33	17.5	94	1.00	4.8	0.06	0.05	5%	95%
	170	10.98	17.9	100	1.00	4.8	0.06	0.05	5%	95%
	180	11.62	18.2	106	1.00	4.8	0.06	0.05	5%	95%
	190	12.27	18.6	112	1.00	4.8	0.06	0.05	5%	95%
	200	12.91	18.9	117	1.00	4.8	0.06	0.05	5%	95%
	210	13.56	19.2	123	1.00	4.8	0.07	0.05	5%	95%
Kelt	650	41.97	26.0	381	1.00	4.8	0.09	0.07	7%	93%
	675	43.59	26.2	396	1.00	4.8	0.09	0.07	7%	93%
	700	45.20	26.5	411	1.00	4.8	0.09	0.07	7%	93%
	725	46.81	26.7	425	1.00	4.8	0.09	0.07	7%	93%
	750	48.43	26.9	440	1.00	4.8	0.09	0.07	7%	93%
	775	50.04	27.1	455	1.00	4.8	0.09	0.07	7%	93%
	800	51.66	27.3	470	1.00	4.8	0.09	0.07	7%	93%

Table D 48. Input parameters for the prediction of strike probability and mortality for Great Works units 4,5,9,10 and 11; K - 20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.39	16.3	76	1.00	4.8	0.06	0.03	3%	97%
	140	9.04	16.7	82	1.00	4.8	0.06	0.03	3%	97%
	150	9.69	17.1	88	1.00	4.8	0.06	0.03	3%	97%
	160	10.33	17.5	94	1.00	4.8	0.06	0.03	3%	97%
	170	10.98	17.9	100	1.00	4.8	0.06	0.03	3%	97%
	180	11.62	18.2	106	1.00	4.8	0.06	0.03	3%	97%
	190	12.27	18.6	112	1.00	4.8	0.06	0.03	3%	97%
	200	12.91	18.9	117	1.00	4.8	0.06	0.03	3%	97%
	210	13.56	19.2	123	1.00	4.8	0.07	0.04	4%	96%
Kelt	650	41.97	26.0	381	1.00	4.8	0.09	0.05	5%	95%
	675	43.59	26.2	396	1.00	4.8	0.09	0.05	5%	95%
	700	45.20	26.5	411	1.00	4.8	0.09	0.05	5%	95%
	725	46.81	26.7	425	1.00	4.8	0.09	0.05	5%	95%
	750	48.43	26.9	440	1.00	4.8	0.09	0.05	5%	95%
	775	50.04	27.1	455	1.00	4.8	0.09	0.05	5%	95%
	800	51.66	27.3	470	1.00	4.8	0.09	0.05	5%	95%

Table D 49. Input parameters for the prediction of strike probability and mortality for Great Works units 4,5,9,10 and 11; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.39	16.3	93	1.00	4.8	0.06	0.04	4%	96%
	140	9.04	16.7	101	1.00	4.8	0.06	0.04	4%	96%
	150	9.69	17.1	108	1.00	4.8	0.06	0.05	5%	95%
	160	10.33	17.5	115	1.00	4.8	0.06	0.05	5%	95%
	170	10.98	17.9	122	1.00	4.8	0.06	0.05	5%	95%
	180	11.62	18.2	129	1.00	4.8	0.06	0.05	5%	95%
	190	12.27	18.6	137	1.00	4.8	0.06	0.05	5%	95%
	200	12.91	18.9	144	1.00	4.8	0.06	0.05	5%	95%
	210	13.56	19.2	151	1.00	4.8	0.07	0.05	5%	95%
Kelt	650	41.97	26.0	467	1.00	4.8	0.09	0.07	7%	93%
	675	43.59	26.2	485	1.00	4.8	0.09	0.07	7%	93%
	700	45.20	26.5	503	1.00	4.8	0.09	0.07	7%	93%
	725	46.81	26.7	521	1.00	4.8	0.09	0.07	7%	93%
	750	48.43	26.9	539	1.00	4.8	0.09	0.07	7%	93%
	775	50.04	27.1	557	1.00	4.8	0.09	0.07	7%	93%
	800	51.66	27.3	575	1.00	4.8	0.09	0.07	7%	93%

Table D 50. Input parameters for the prediction of strike probability and mortality for Great Works units 4,5,9,10 and 11; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.39	16.3	57	1.00	4.8	0.06	0.03	3%	97%
	140	9.04	16.7	61	1.00	4.8	0.06	0.03	3%	97%
	150	9.69	17.1	66	1.00	4.8	0.06	0.03	3%	97%
	160	10.33	17.5	70	1.00	4.8	0.06	0.03	3%	97%
	170	10.98	17.9	74	1.00	4.8	0.06	0.03	3%	97%
	180	11.62	18.2	79	1.00	4.8	0.06	0.03	3%	97%
	190	12.27	18.6	83	1.00	4.8	0.06	0.03	3%	97%
	200	12.91	18.9	87	1.00	4.8	0.06	0.03	3%	97%
	210	13.56	19.2	92	1.00	4.8	0.07	0.04	4%	96%
Kelt	650	41.97	26.0	284	1.00	4.8	0.09	0.05	5%	95%
	675	43.59	26.2	295	1.00	4.8	0.09	0.05	5%	95%
	700	45.20	26.5	306	1.00	4.8	0.09	0.05	5%	95%
	725	46.81	26.7	317	1.00	4.8	0.09	0.05	5%	95%
	750	48.43	26.9	328	1.00	4.8	0.09	0.05	5%	95%
	775	50.04	27.1	339	1.00	4.8	0.09	0.05	5%	95%
	800	51.66	27.3	350	1.00	4.8	0.09	0.05	5%	95%

Table D 51. Input parameters for the prediction of strike probability and mortality for Great Works unit 6; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	40	1.00	4.8	0.19	0.12	12%	88%
	140	13.44	19.1	43	1.00	4.8	0.20	0.13	13%	87%
	150	14.40	19.5	47	1.00	4.8	0.20	0.13	13%	87%
	160	15.36	19.9	50	1.00	4.8	0.20	0.13	13%	87%
	170	16.32	20.3	53	1.00	4.8	0.21	0.14	14%	86%
	180	17.28	20.6	56	1.00	4.8	0.21	0.14	14%	86%
	190	18.24	21.0	59	1.00	4.8	0.21	0.14	14%	86%
	200	19.20	21.3	62	1.00	4.8	0.22	0.14	14%	86%
	210	20.16	21.6	65	1.00	4.8	0.22	0.14	14%	86%
Kelt	650	62.39	28.4	202	1.00	4.8	0.29	0.19	19%	81%
	675	64.79	28.6	210	1.00	4.8	0.29	0.19	19%	81%
	700	67.19	28.9	217	1.00	4.8	0.30	0.19	19%	81%
	725	69.59	29.1	225	1.00	4.8	0.30	0.19	19%	81%
	750	71.99	29.3	233	1.00	4.8	0.30	0.20	20%	80%
	775	74.39	29.5	241	1.00	4.8	0.30	0.20	20%	80%
	800	76.79	29.7	248	1.00	4.8	0.30	0.20	20%	80%

Table D 52. Input parameters for the prediction of strike probability and mortality for Great Works Great Works unit 6; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	61	1.00	4.8	0.19	0.12	12%	88%
	140	13.44	19.1	66	1.00	4.8	0.20	0.13	13%	87%
	150	14.40	19.5	71	1.00	4.8	0.20	0.13	13%	87%
	160	15.36	19.9	75	1.00	4.8	0.20	0.13	13%	87%
	170	16.32	20.3	80	1.00	4.8	0.21	0.14	14%	86%
	180	17.28	20.6	85	1.00	4.8	0.21	0.14	14%	86%
	190	18.24	21.0	89	1.00	4.8	0.21	0.14	14%	86%
	200	19.20	21.3	94	1.00	4.8	0.22	0.14	14%	86%
	210	20.16	21.6	99	1.00	4.8	0.22	0.14	14%	86%
Kelt	650	62.39	28.4	306	1.00	4.8	0.29	0.19	19%	81%
	675	64.79	28.6	318	1.00	4.8	0.29	0.19	19%	81%
	700	67.19	28.9	330	1.00	4.8	0.30	0.19	19%	81%
	725	69.59	29.1	341	1.00	4.8	0.30	0.19	19%	81%
	750	71.99	29.3	353	1.00	4.8	0.30	0.20	20%	80%
	775	74.39	29.5	365	1.00	4.8	0.30	0.20	20%	80%
	800	76.79	29.7	377	1.00	4.8	0.30	0.20	20%	80%

Table D 53. Input parameters for the prediction of strike probability and mortality for Great Works Great Works unit 6; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	18	0.54	4.8	0.19	0.12	7%	93%
	140	13.44	19.1	20	0.58	4.8	0.20	0.13	7%	93%
	150	14.40	19.5	21	0.62	4.8	0.20	0.13	8%	92%
	160	15.36	19.9	23	0.66	4.8	0.20	0.13	9%	91%
	170	16.32	20.3	24	0.70	4.8	0.21	0.14	9%	91%
	180	17.28	20.6	25	0.74	4.8	0.21	0.14	10%	90%
	190	18.24	21.0	27	0.79	4.8	0.21	0.14	11%	89%
	200	19.20	21.3	28	0.83	4.8	0.22	0.14	12%	88%
	210	20.16	21.6	30	0.87	4.8	0.22	0.14	12%	88%
Kelt	650	62.39	28.4	91	1.00	4.8	0.29	0.19	19%	81%
	675	64.79	28.6	95	1.00	4.8	0.29	0.19	19%	81%
	700	67.19	28.9	99	1.00	4.8	0.30	0.19	19%	81%
	725	69.59	29.1	102	1.00	4.8	0.30	0.19	19%	81%
	750	71.99	29.3	106	1.00	4.8	0.30	0.20	20%	80%
	775	74.39	29.5	109	1.00	4.8	0.30	0.20	20%	80%
	800	76.79	29.7	113	1.00	4.8	0.30	0.20	20%	80%

Table D 54. Input parameters for the prediction of strike probability and mortality for Great Works Great Works unit 6; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	40	1.00	4.8	0.19	0.15	15%	85%
	140	13.44	19.1	43	1.00	4.8	0.20	0.15	15%	85%
	150	14.40	19.5	47	1.00	4.8	0.20	0.16	16%	84%
	160	15.36	19.9	50	1.00	4.8	0.20	0.16	16%	84%
	170	16.32	20.3	53	1.00	4.8	0.21	0.16	16%	84%
	180	17.28	20.6	56	1.00	4.8	0.21	0.16	16%	84%
	190	18.24	21.0	59	1.00	4.8	0.21	0.17	17%	83%
	200	19.20	21.3	62	1.00	4.8	0.22	0.17	17%	83%
	210	20.16	21.6	65	1.00	4.8	0.22	0.17	17%	83%
Kelt	650	62.39	28.4	202	1.00	4.8	0.29	0.23	23%	77%
	675	64.79	28.6	210	1.00	4.8	0.29	0.23	23%	77%
	700	67.19	28.9	217	1.00	4.8	0.30	0.23	23%	77%
	725	69.59	29.1	225	1.00	4.8	0.30	0.23	23%	77%
	750	71.99	29.3	233	1.00	4.8	0.30	0.23	23%	77%
	775	74.39	29.5	241	1.00	4.8	0.30	0.24	24%	76%
	800	76.79	29.7	248	1.00	4.8	0.30	0.24	24%	76%

Table D 55. Input parameters for the prediction of strike probability and mortality for Great Works Great Works unit 6; K - 20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	40	1.00	4.8	0.19	0.10	10%	90%
	140	13.44	19.1	43	1.00	4.8	0.20	0.11	11%	89%
	150	14.40	19.5	47	1.00	4.8	0.20	0.11	11%	89%
	160	15.36	19.9	50	1.00	4.8	0.20	0.11	11%	89%
	170	16.32	20.3	53	1.00	4.8	0.21	0.11	11%	89%
	180	17.28	20.6	56	1.00	4.8	0.21	0.11	11%	89%
	190	18.24	21.0	59	1.00	4.8	0.21	0.12	12%	88%
	200	19.20	21.3	62	1.00	4.8	0.22	0.12	12%	88%
	210	20.16	21.6	65	1.00	4.8	0.22	0.12	12%	88%
Kelt	650	62.39	28.4	202	1.00	4.8	0.29	0.16	16%	84%
	675	64.79	28.6	210	1.00	4.8	0.29	0.16	16%	84%
	700	67.19	28.9	217	1.00	4.8	0.30	0.16	16%	84%
	725	69.59	29.1	225	1.00	4.8	0.30	0.16	16%	84%
	750	71.99	29.3	233	1.00	4.8	0.30	0.16	16%	84%
	775	74.39	29.5	241	1.00	4.8	0.30	0.16	16%	84%
	800	76.79	29.7	248	1.00	4.8	0.30	0.16	16%	84%

Table D 56. Input parameters for the prediction of strike probability and mortality for Great Works Great Works unit 6; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	61	1.00	4.8	0.19	0.15	15%	85%
	140	13.44	19.1	66	1.00	4.8	0.20	0.15	15%	85%
	150	14.40	19.5	71	1.00	4.8	0.20	0.16	16%	84%
	160	15.36	19.9	75	1.00	4.8	0.20	0.16	16%	84%
	170	16.32	20.3	80	1.00	4.8	0.21	0.16	16%	84%
	180	17.28	20.6	85	1.00	4.8	0.21	0.16	16%	84%
	190	18.24	21.0	89	1.00	4.8	0.21	0.17	17%	83%
	200	19.20	21.3	94	1.00	4.8	0.22	0.17	17%	83%
	210	20.16	21.6	99	1.00	4.8	0.22	0.17	17%	83%
Kelt	650	62.39	28.4	306	1.00	4.8	0.29	0.23	23%	77%
	675	64.79	28.6	318	1.00	4.8	0.29	0.23	23%	77%
	700	67.19	28.9	330	1.00	4.8	0.30	0.23	23%	77%
	725	69.59	29.1	341	1.00	4.8	0.30	0.23	23%	77%
	750	71.99	29.3	353	1.00	4.8	0.30	0.23	23%	77%
	775	74.39	29.5	365	1.00	4.8	0.30	0.24	24%	76%
	800	76.79	29.7	377	1.00	4.8	0.30	0.24	24%	76%

Table D 57. Input parameters for the prediction of strike probability and mortality for Great Works units Great Works unit 6; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	18	0.54	4.8	0.19	0.10	6%	94%
	140	13.44	19.1	20	0.58	4.8	0.20	0.11	6%	94%
	150	14.40	19.5	21	0.62	4.8	0.20	0.11	7%	93%
	160	15.36	19.9	23	0.66	4.8	0.20	0.11	7%	93%
	170	16.32	20.3	24	0.70	4.8	0.21	0.11	8%	92%
	180	17.28	20.6	25	0.74	4.8	0.21	0.11	9%	91%
	190	18.24	21.0	27	0.79	4.8	0.21	0.12	9%	91%
	200	19.20	21.3	28	0.83	4.8	0.22	0.12	10%	90%
	210	20.16	21.6	30	0.87	4.8	0.22	0.12	10%	90%
Kelt	650	62.39	28.4	91	1.00	4.8	0.29	0.16	16%	84%
	675	64.79	28.6	95	1.00	4.8	0.29	0.16	16%	84%
	700	67.19	28.9	99	1.00	4.8	0.30	0.16	16%	84%
	725	69.59	29.1	102	1.00	4.8	0.30	0.16	16%	84%
	750	71.99	29.3	106	1.00	4.8	0.30	0.16	16%	84%
	775	74.39	29.5	109	1.00	4.8	0.30	0.16	16%	84%
	800	76.79	29.7	113	1.00	4.8	0.30	0.16	16%	84%

Table D 58. Input parameters for the prediction of strike probability and mortality for Great Works units 7, and 8; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	69	1.00	4.8	0.10	0.06	6%	94%
	140	13.44	19.1	74	1.00	4.8	0.10	0.07	7%	93%
	150	14.40	19.5	79	1.00	4.8	0.10	0.07	7%	93%
	160	15.36	19.9	84	1.00	4.8	0.11	0.07	7%	93%
	170	16.32	20.3	90	1.00	4.8	0.11	0.07	7%	93%
	180	17.28	20.6	95	1.00	4.8	0.11	0.07	7%	93%
	190	18.24	21.0	100	1.00	4.8	0.11	0.07	7%	93%
	200	19.20	21.3	105	1.00	4.8	0.11	0.07	7%	93%
	210	20.16	21.6	111	1.00	4.8	0.11	0.07	7%	93%
Kelt	650	62.39	28.4	343	1.00	4.8	0.15	0.10	10%	90%
	675	64.79	28.6	356	1.00	4.8	0.15	0.10	10%	90%
	700	67.19	28.9	369	1.00	4.8	0.15	0.10	10%	90%
	725	69.59	29.1	382	1.00	4.8	0.15	0.10	10%	90%
	750	71.99	29.3	395	1.00	4.8	0.16	0.10	10%	90%
	775	74.39	29.5	409	1.00	4.8	0.16	0.10	10%	90%
	800	76.79	29.7	422	1.00	4.8	0.16	0.10	10%	90%

Table D 59. Input parameters for the prediction of strike probability and mortality for Great Works units 7, and 8; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	87	1.00	4.8	0.10	0.06	6%	94%
	140	13.44	19.1	93	1.00	4.8	0.10	0.07	7%	93%
	150	14.40	19.5	100	1.00	4.8	0.10	0.07	7%	93%
	160	15.36	19.9	107	1.00	4.8	0.11	0.07	7%	93%
	170	16.32	20.3	113	1.00	4.8	0.11	0.07	7%	93%
	180	17.28	20.6	120	1.00	4.8	0.11	0.07	7%	93%
	190	18.24	21.0	127	1.00	4.8	0.11	0.07	7%	93%
	200	19.20	21.3	133	1.00	4.8	0.11	0.07	7%	93%
	210	20.16	21.6	140	1.00	4.8	0.11	0.07	7%	93%
Kelt	650	62.39	28.4	433	1.00	4.8	0.15	0.10	10%	90%
	675	64.79	28.6	450	1.00	4.8	0.15	0.10	10%	90%
	700	67.19	28.9	467	1.00	4.8	0.15	0.10	10%	90%
	725	69.59	29.1	483	1.00	4.8	0.15	0.10	10%	90%
	750	71.99	29.3	500	1.00	4.8	0.16	0.10	10%	90%
	775	74.39	29.5	517	1.00	4.8	0.16	0.10	10%	90%
	800	76.79	29.7	533	1.00	4.8	0.16	0.10	10%	90%

Table D 60. Input parameters for the prediction of strike probability and mortality for Great Works units units 7, and 8; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	48	0.95	4.8	0.10	0.06	6%	94%
	140	13.44	19.1	52	1.00	4.8	0.10	0.07	7%	93%
	150	14.40	19.5	56	1.00	4.8	0.10	0.07	7%	93%
	160	15.36	19.9	59	1.00	4.8	0.11	0.07	7%	93%
	170	16.32	20.3	63	1.00	4.8	0.11	0.07	7%	93%
	180	17.28	20.6	67	1.00	4.8	0.11	0.07	7%	93%
	190	18.24	21.0	71	1.00	4.8	0.11	0.07	7%	93%
	200	19.20	21.3	74	1.00	4.8	0.11	0.07	7%	93%
	210	20.16	21.6	78	1.00	4.8	0.11	0.07	7%	93%
Kelt	650	62.39	28.4	242	1.00	4.8	0.15	0.10	10%	90%
	675	64.79	28.6	251	1.00	4.8	0.15	0.10	10%	90%
	700	67.19	28.9	260	1.00	4.8	0.15	0.10	10%	90%
	725	69.59	29.1	269	1.00	4.8	0.15	0.10	10%	90%
	750	71.99	29.3	279	1.00	4.8	0.16	0.10	10%	90%
	775	74.39	29.5	288	1.00	4.8	0.16	0.10	10%	90%
	800	76.79	29.7	297	1.00	4.8	0.16	0.10	10%	90%

Table D 61. Input parameters for the prediction of strike probability and mortality for Great Works units units 7, and 8; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	69	1.00	4.8	0.10	0.08	8%	92%
	140	13.44	19.1	74	1.00	4.8	0.10	0.08	8%	92%
	150	14.40	19.5	79	1.00	4.8	0.10	0.08	8%	92%
	160	15.36	19.9	84	1.00	4.8	0.11	0.08	8%	92%
	170	16.32	20.3	90	1.00	4.8	0.11	0.08	8%	92%
	180	17.28	20.6	95	1.00	4.8	0.11	0.09	9%	91%
	190	18.24	21.0	100	1.00	4.8	0.11	0.09	9%	91%
	200	19.20	21.3	105	1.00	4.8	0.11	0.09	9%	91%
	210	20.16	21.6	111	1.00	4.8	0.11	0.09	9%	91%
Kelt	650	62.39	28.4	343	1.00	4.8	0.15	0.12	12%	88%
	675	64.79	28.6	356	1.00	4.8	0.15	0.12	12%	88%
	700	67.19	28.9	369	1.00	4.8	0.15	0.12	12%	88%
	725	69.59	29.1	382	1.00	4.8	0.15	0.12	12%	88%
	750	71.99	29.3	395	1.00	4.8	0.16	0.12	12%	88%
	775	74.39	29.5	409	1.00	4.8	0.16	0.12	12%	88%
	800	76.79	29.7	422	1.00	4.8	0.16	0.12	12%	88%

Table D 62. Input parameters for the prediction of strike probability and mortality for Great Works units units 7, and 8; K - 20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	69	1.00	4.8	0.10	0.05	5%	95%
	140	13.44	19.1	74	1.00	4.8	0.10	0.06	6%	94%
	150	14.40	19.5	79	1.00	4.8	0.10	0.06	6%	94%
	160	15.36	19.9	84	1.00	4.8	0.11	0.06	6%	94%
	170	16.32	20.3	90	1.00	4.8	0.11	0.06	6%	94%
	180	17.28	20.6	95	1.00	4.8	0.11	0.06	6%	94%
	190	18.24	21.0	100	1.00	4.8	0.11	0.06	6%	94%
	200	19.20	21.3	105	1.00	4.8	0.11	0.06	6%	94%
	210	20.16	21.6	111	1.00	4.8	0.11	0.06	6%	94%
Kelt	650	62.39	28.4	343	1.00	4.8	0.15	0.08	8%	92%
	675	64.79	28.6	356	1.00	4.8	0.15	0.08	8%	92%
	700	67.19	28.9	369	1.00	4.8	0.15	0.08	8%	92%
	725	69.59	29.1	382	1.00	4.8	0.15	0.08	8%	92%
	750	71.99	29.3	395	1.00	4.8	0.16	0.08	8%	92%
	775	74.39	29.5	409	1.00	4.8	0.16	0.09	9%	91%
	800	76.79	29.7	422	1.00	4.8	0.16	0.09	9%	91%

Table D 63. Input parameters for the prediction of strike probability and mortality for Great Works units units 7, and 8; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	87	1.00	4.8	0.10	0.08	8%	92%
	140	13.44	19.1	93	1.00	4.8	0.10	0.08	8%	92%
	150	14.40	19.5	100	1.00	4.8	0.10	0.08	8%	92%
	160	15.36	19.9	107	1.00	4.8	0.11	0.08	8%	92%
	170	16.32	20.3	113	1.00	4.8	0.11	0.08	8%	92%
	180	17.28	20.6	120	1.00	4.8	0.11	0.09	9%	91%
	190	18.24	21.0	127	1.00	4.8	0.11	0.09	9%	91%
	200	19.20	21.3	133	1.00	4.8	0.11	0.09	9%	91%
	210	20.16	21.6	140	1.00	4.8	0.11	0.09	9%	91%
Kelt	650	62.39	28.4	433	1.00	4.8	0.15	0.12	12%	88%
	675	64.79	28.6	450	1.00	4.8	0.15	0.12	12%	88%
	700	67.19	28.9	467	1.00	4.8	0.15	0.12	12%	88%
	725	69.59	29.1	483	1.00	4.8	0.15	0.12	12%	88%
	750	71.99	29.3	500	1.00	4.8	0.16	0.12	12%	88%
	775	74.39	29.5	517	1.00	4.8	0.16	0.12	12%	88%
	800	76.79	29.7	533	1.00	4.8	0.16	0.12	12%	88%

Table D 64. Input parameters for the prediction of strike probability and mortality for Great Works units units 7, and 8; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	12.48	18.7	48	0.95	4.8	0.10	0.05	5%	95%
	140	13.44	19.1	52	1.00	4.8	0.10	0.06	6%	94%
	150	14.40	19.5	56	1.00	4.8	0.10	0.06	6%	94%
	160	15.36	19.9	59	1.00	4.8	0.11	0.06	6%	94%
	170	16.32	20.3	63	1.00	4.8	0.11	0.06	6%	94%
	180	17.28	20.6	67	1.00	4.8	0.11	0.06	6%	94%
	190	18.24	21.0	71	1.00	4.8	0.11	0.06	6%	94%
	200	19.20	21.3	74	1.00	4.8	0.11	0.06	6%	94%
	210	20.16	21.6	78	1.00	4.8	0.11	0.06	6%	94%
Kelt	650	62.39	28.4	242	1.00	4.8	0.15	0.08	8%	92%
	675	64.79	28.6	251	1.00	4.8	0.15	0.08	8%	92%
	700	67.19	28.9	260	1.00	4.8	0.15	0.08	8%	92%
	725	69.59	29.1	269	1.00	4.8	0.15	0.08	8%	92%
	750	71.99	29.3	279	1.00	4.8	0.16	0.08	8%	92%
	775	74.39	29.5	288	1.00	4.8	0.16	0.09	9%	91%
	800	76.79	29.7	297	1.00	4.8	0.16	0.09	9%	91%

Table D 65. Input parameters for the prediction of strike probability and mortality for Great Works units 1,2, and 3; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.06	15.2	83	0.13	4.8	0.60	0.39	5%	95%
	140	7.60	15.7	89	0.14	4.8	0.62	0.40	6%	94%
	150	8.15	16.1	95	0.15	4.8	0.63	0.41	6%	94%
	160	8.69	16.5	102	0.16	4.8	0.65	0.42	7%	93%
	170	9.23	16.8	108	0.17	4.8	0.66	0.43	8%	92%
	180	9.78	17.2	114	0.18	4.8	0.68	0.44	8%	92%
	190	10.32	17.5	121	0.19	4.8	0.69	0.45	9%	91%
	200	10.86	17.8	127	0.20	4.8	0.70	0.46	9%	91%
	210	11.41	18.1	133	0.22	4.8	0.71	0.46	10%	90%
Kelt	650	35.30	25.0	413	0.67	4.8	0.98	0.64	43%	57%
	675	36.66	25.2	429	0.69	4.8	0.99	0.65	45%	55%
	700	38.02	25.4	445	0.72	4.8	1.00	0.65	47%	53%
	725	39.38	25.6	461	0.74	4.8	1.00	0.65	48%	52%
	750	40.73	25.8	477	0.77	4.8	1.00	0.65	50%	50%
	775	42.09	26.0	492	0.79	4.8	1.00	0.65	52%	48%
	800	43.45	26.2	508	0.82	4.8	1.00	0.65	53%	47%

Table D 66. Input parameters for the prediction of strike probability and mortality for Great Works units 1,2, and 3; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.06	15.2	99	0.16	4.8	0.60	0.39	6%	94%
	140	7.60	15.7	106	0.17	4.8	0.62	0.40	7%	93%
	150	8.15	16.1	114	0.18	4.8	0.63	0.41	8%	92%
	160	8.69	16.5	122	0.20	4.8	0.65	0.42	8%	92%
	170	9.23	16.8	129	0.21	4.8	0.66	0.43	9%	91%
	180	9.78	17.2	137	0.22	4.8	0.68	0.44	10%	90%
	190	10.32	17.5	144	0.23	4.8	0.69	0.45	10%	90%
	200	10.86	17.8	152	0.24	4.8	0.70	0.46	11%	89%
	210	11.41	18.1	160	0.26	4.8	0.71	0.46	12%	88%
Kelt	650	35.30	25.0	494	0.80	4.8	0.98	0.64	51%	49%
	675	36.66	25.2	513	0.83	4.8	0.99	0.65	53%	47%
	700	38.02	25.4	532	0.86	4.8	1.00	0.65	56%	44%
	725	39.38	25.6	551	0.89	4.8	1.00	0.65	58%	42%
	750	40.73	25.8	570	0.92	4.8	1.00	0.65	60%	40%
	775	42.09	26.0	589	0.95	4.8	1.00	0.65	62%	38%
	800	43.4489	26.2	608	0.98	4.8	1.00	0.65	64%	36%

Table D 67. Input parameters for the prediction of strike probability and mortality for Great Works units 1,2, and 3; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.06	15.2	64	0.10	4.8	0.60	0.39	4%	96%
	140	7.60	15.7	69	0.11	4.8	0.62	0.40	4%	96%
	150	8.15	16.1	74	0.12	4.8	0.63	0.41	5%	95%
	160	8.69	16.5	79	0.13	4.8	0.65	0.42	5%	95%
	170	9.23	16.8	84	0.13	4.8	0.66	0.43	6%	94%
	180	9.78	17.2	88	0.14	4.8	0.68	0.44	6%	94%
	190	10.32	17.5	93	0.15	4.8	0.69	0.45	7%	93%
	200	10.86	17.8	98	0.16	4.8	0.70	0.46	7%	93%
	210	11.41	18.1	103	0.17	4.8	0.71	0.46	8%	92%
Kelt	650	35.30	25.0	320	0.52	4.8	0.98	0.64	33%	67%
	675	36.66	25.2	332	0.53	4.8	0.99	0.65	35%	65%
	700	38.02	25.4	344	0.55	4.8	1.00	0.65	36%	64%
	725	39.38	25.6	356	0.57	4.8	1.00	0.65	37%	63%
	750	40.73	25.8	369	0.59	4.8	1.00	0.65	39%	61%
	775	42.09	26.0	381	0.61	4.8	1.00	0.65	40%	60%
	800	43.45	26.2	393	0.63	4.8	1.00	0.65	41%	59%

Table D 68. Input parameters for the prediction of strike probability and mortality for Great Works units 1,2, and 3; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.06	15.2	83	0.13	4.8	0.60	0.47	6%	94%
	140	7.60	15.7	89	0.14	4.8	0.62	0.48	7%	93%
	150	8.15	16.1	95	0.15	4.8	0.63	0.49	8%	92%
	160	8.69	16.5	102	0.16	4.8	0.65	0.51	8%	92%
	170	9.23	16.8	108	0.17	4.8	0.66	0.52	9%	91%
	180	9.78	17.2	114	0.18	4.8	0.68	0.53	10%	90%
	190	10.32	17.5	121	0.19	4.8	0.69	0.54	10%	90%
	200	10.86	17.8	127	0.20	4.8	0.70	0.55	11%	89%
	210	11.41	18.1	133	0.22	4.8	0.71	0.56	12%	88%
Kelt	650	35.30	25.0	413	0.67	4.8	0.98	0.77	51%	49%
	675	36.66	25.2	429	0.69	4.8	0.99	0.78	54%	46%
	700	38.02	25.4	445	0.72	4.8	1.00	0.78	56%	44%
	725	39.38	25.6	461	0.74	4.8	1.00	0.78	58%	42%
	750	40.73	25.8	477	0.77	4.8	1.00	0.78	60%	40%
	775	42.09	26.0	492	0.79	4.8	1.00	0.78	62%	38%
	800	43.45	26.2	508	0.82	4.8	1.00	0.78	64%	36%

Table D 69. Input parameters for the prediction of strike probability and mortality for Great Works units 1,2, and 3; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.06	15.2	83	0.13	4.8	0.60	0.33	4%	96%
	140	7.60	15.7	89	0.14	4.8	0.62	0.33	5%	95%
	150	8.15	16.1	95	0.15	4.8	0.63	0.34	5%	95%
	160	8.69	16.5	102	0.16	4.8	0.65	0.35	6%	94%
	170	9.23	16.8	108	0.17	4.8	0.66	0.36	6%	94%
	180	9.78	17.2	114	0.18	4.8	0.68	0.37	7%	93%
	190	10.32	17.5	121	0.19	4.8	0.69	0.37	7%	93%
	200	10.86	17.8	127	0.20	4.8	0.70	0.38	8%	92%
	210	11.41	18.1	133	0.22	4.8	0.71	0.39	8%	92%
Kelt	650	35.30	25.0	413	0.67	4.8	0.98	0.53	36%	64%
	675	36.66	25.2	429	0.69	4.8	0.99	0.54	37%	63%
	700	38.02	25.4	445	0.72	4.8	1.00	0.54	39%	61%
	725	39.38	25.6	461	0.74	4.8	1.00	0.54	40%	60%
	750	40.73	25.8	477	0.77	4.8	1.00	0.54	42%	58%
	775	42.09	26.0	492	0.79	4.8	1.00	0.54	43%	57%
	800	43.45	26.2	508	0.82	4.8	1.00	0.54	44%	56%

Table D 70. Input parameters for the prediction of strike probability and mortality for Great Works units 1,2, and 3; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.06	15.2	99	0.16	4.8	0.60	0.47	7%	93%
	140	7.60	15.7	106	0.17	4.8	0.62	0.48	8%	92%
	150	8.15	16.1	114	0.18	4.8	0.63	0.49	9%	91%
	160	8.69	16.5	122	0.20	4.8	0.65	0.51	10%	90%
	170	9.23	16.8	129	0.21	4.8	0.66	0.52	11%	89%
	180	9.78	17.2	137	0.22	4.8	0.68	0.53	12%	88%
	190	10.32	17.5	144	0.23	4.8	0.69	0.54	13%	87%
	200	10.86	17.8	152	0.24	4.8	0.70	0.55	13%	87%
	210	11.41	18.1	160	0.26	4.8	0.71	0.56	14%	86%
Kelt	650	35.30	25.0	494	0.80	4.8	0.98	0.77	61%	39%
	675	36.66	25.2	513	0.83	4.8	0.99	0.78	64%	36%
	700	38.02	25.4	532	0.86	4.8	1.00	0.78	67%	33%
	725	39.38	25.6	551	0.89	4.8	1.00	0.78	69%	31%
	750	40.73	25.8	570	0.92	4.8	1.00	0.78	72%	28%
	775	42.09	26.0	589	0.95	4.8	1.00	0.78	74%	26%
	800	43.45	26.2	608	0.98	4.8	1.00	0.78	76%	24%

Table D 71. Input parameters for the prediction of strike probability and mortality for Great Works units 1,2, and 3; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.06	15.2	64	0.10	4.8	0.60	0.33	3%	97%
	140	7.60	15.7	69	0.11	4.8	0.62	0.33	4%	96%
	150	8.15	16.1	74	0.12	4.8	0.63	0.34	4%	96%
	160	8.69	16.5	79	0.13	4.8	0.65	0.35	4%	96%
	170	9.23	16.8	84	0.13	4.8	0.66	0.36	5%	95%
	180	9.78	17.2	88	0.14	4.8	0.68	0.37	5%	95%
	190	10.32	17.5	93	0.15	4.8	0.69	0.37	6%	94%
	200	10.86	17.8	98	0.16	4.8	0.70	0.38	6%	94%
	210	11.41	18.1	103	0.17	4.8	0.71	0.39	6%	94%
Kelt	650	35.30	25.0	320	0.52	4.8	0.98	0.53	27%	73%
	675	36.66	25.2	332	0.53	4.8	0.99	0.54	29%	71%
	700	38.02	25.4	344	0.55	4.8	1.00	0.54	30%	70%
	725	39.38	25.6	356	0.57	4.8	1.00	0.54	31%	69%
	750	40.73	25.8	369	0.59	4.8	1.00	0.54	32%	68%
	775	42.09	26.0	381	0.61	4.8	1.00	0.54	33%	67%
	800	43.45	26.2	393	0.63	4.8	1.00	0.54	34%	66%

Table D 72. Input parameters for the prediction of strike probability and mortality for Milford unit 3; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	92	0.10	4.8	0.56	0.37	4%	96%
	140	6.76	14.9	99	0.11	4.8	0.58	0.38	4%	96%
	150	7.24	15.4	106	0.11	4.8	0.60	0.39	4%	96%
	160	7.73	15.7	113	0.12	4.8	0.61	0.40	5%	95%
	170	8.21	16.1	120	0.13	4.8	0.63	0.41	5%	95%
	180	8.69	16.5	127	0.14	4.8	0.64	0.42	6%	94%
	190	9.17	16.8	134	0.14	4.8	0.65	0.42	6%	94%
	200	9.66	17.1	142	0.15	4.8	0.67	0.43	7%	93%
	210	10.14	17.4	149	0.16	4.8	0.68	0.44	7%	93%
Kelt	650	31.39	24.2	460	0.49	4.8	0.94	0.61	30%	70%
	675	32.59	24.5	478	0.51	4.8	0.95	0.62	32%	68%
	700	33.80	24.7	495	0.53	4.8	0.96	0.62	33%	67%
	725	35.01	24.9	513	0.55	4.8	0.97	0.63	35%	65%
	750	36.21	25.1	531	0.57	4.8	0.98	0.64	36%	64%
	775	37.42	25.3	548	0.59	4.8	0.98	0.64	38%	62%
	800	38.63	25.5	566	0.61	4.8	0.99	0.65	39%	61%

Table D 73. Input parameters for the prediction of strike probability and mortality for Milford unit 3; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	107	0.11	4.8	0.56	0.37	4%	96%
	140	6.76	14.9	115	0.12	4.8	0.58	0.38	5%	95%
	150	7.24	15.4	123	0.13	4.8	0.60	0.39	5%	95%
	160	7.73	15.7	131	0.14	4.8	0.61	0.40	6%	94%
	170	8.21	16.1	139	0.15	4.8	0.63	0.41	6%	94%
	180	8.69	16.5	148	0.16	4.8	0.64	0.42	7%	93%
	190	9.17	16.8	156	0.17	4.8	0.65	0.42	7%	93%
	200	9.66	17.1	164	0.18	4.8	0.67	0.43	8%	92%
	210	10.14	17.4	172	0.18	4.8	0.68	0.44	8%	92%
Kelt	650	31.39	24.2	533	0.57	4.8	0.94	0.61	35%	65%
	675	32.59	24.5	553	0.59	4.8	0.95	0.62	37%	63%
	700	33.80	24.7	574	0.62	4.8	0.96	0.62	38%	62%
	725	35.01	24.9	594	0.64	4.8	0.97	0.63	40%	60%
	750	36.21	25.1	615	0.66	4.8	0.98	0.64	42%	58%
	775	37.42	25.3	635	0.68	4.8	0.98	0.64	44%	56%
	800	38.6287	25.5	656	0.70	4.8	0.99	0.65	45%	55%

Table D 74. Input parameters for the prediction of strike probability and mortality for Milford unit 3; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	75	0.08	4.8	0.56	0.37	3%	97%
	140	6.76	14.9	80	0.09	4.8	0.58	0.38	3%	97%
	150	7.24	15.4	86	0.09	4.8	0.60	0.39	4%	96%
	160	7.73	15.7	92	0.10	4.8	0.61	0.40	4%	96%
	170	8.21	16.1	98	0.10	4.8	0.63	0.41	4%	96%
	180	8.69	16.5	103	0.11	4.8	0.64	0.42	5%	95%
	190	9.17	16.8	109	0.12	4.8	0.65	0.42	5%	95%
	200	9.66	17.1	115	0.12	4.8	0.67	0.43	5%	95%
	210	10.14	17.4	121	0.13	4.8	0.68	0.44	6%	94%
Kelt	650	31.39	24.2	373	0.40	4.8	0.94	0.61	25%	75%
	675	32.59	24.5	388	0.42	4.8	0.95	0.62	26%	74%
	700	33.80	24.7	402	0.43	4.8	0.96	0.62	27%	73%
	725	35.01	24.9	416	0.45	4.8	0.97	0.63	28%	72%
	750	36.21	25.1	431	0.46	4.8	0.98	0.64	29%	71%
	775	37.42	25.3	445	0.48	4.8	0.98	0.64	31%	69%
	800	38.63	25.5	459	0.49	4.8	0.99	0.65	32%	68%

Table D 75. Input parameters for the prediction of strike probability and mortality for Milford unit 3; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	92	0.10	4.8	0.56	0.44	4%	96%
	140	6.76	14.9	99	0.11	4.8	0.58	0.45	5%	95%
	150	7.24	15.4	106	0.11	4.8	0.60	0.47	5%	95%
	160	7.73	15.7	113	0.12	4.8	0.61	0.48	6%	94%
	170	8.21	16.1	120	0.13	4.8	0.63	0.49	6%	94%
	180	8.69	16.5	127	0.14	4.8	0.64	0.50	7%	93%
	190	9.17	16.8	134	0.14	4.8	0.65	0.51	7%	93%
	200	9.66	17.1	142	0.15	4.8	0.67	0.52	8%	92%
	210	10.14	17.4	149	0.16	4.8	0.68	0.53	8%	92%
Kelt	650	31.39	24.2	460	0.49	4.8	0.94	0.74	36%	64%
	675	32.59	24.5	478	0.51	4.8	0.95	0.74	38%	62%
	700	33.80	24.7	495	0.53	4.8	0.96	0.75	40%	60%
	725	35.01	24.9	513	0.55	4.8	0.97	0.76	42%	58%
	750	36.21	25.1	531	0.57	4.8	0.98	0.76	43%	57%
	775	37.42	25.3	548	0.59	4.8	0.98	0.77	45%	55%
	800	38.63	25.5	566	0.61	4.8	0.99	0.77	47%	53%

Table D 76. Input parameters for the prediction of strike probability and mortality for Milford unit 3; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	92	0.10	4.8	0.56	0.31	3%	97%
	140	6.76	14.9	99	0.11	4.8	0.58	0.31	3%	97%
	150	7.24	15.4	106	0.11	4.8	0.60	0.32	4%	96%
	160	7.73	15.7	113	0.12	4.8	0.61	0.33	4%	96%
	170	8.21	16.1	120	0.13	4.8	0.63	0.34	4%	96%
	180	8.69	16.5	127	0.14	4.8	0.64	0.35	5%	95%
	190	9.17	16.8	134	0.14	4.8	0.65	0.35	5%	95%
	200	9.66	17.1	142	0.15	4.8	0.67	0.36	5%	95%
	210	10.14	17.4	149	0.16	4.8	0.68	0.37	6%	94%
Kelt	650	31.39	24.2	460	0.49	4.8	0.94	0.51	25%	75%
	675	32.59	24.5	478	0.51	4.8	0.95	0.52	26%	74%
	700	33.80	24.7	495	0.53	4.8	0.96	0.52	28%	72%
	725	35.01	24.9	513	0.55	4.8	0.97	0.52	29%	71%
	750	36.21	25.1	531	0.57	4.8	0.98	0.53	30%	70%
	775	37.42	25.3	548	0.59	4.8	0.98	0.53	31%	69%
	800	38.63	25.5	566	0.61	4.8	0.99	0.54	33%	67%

Table D 77. Input parameters for the prediction of strike probability and mortality for Milford unit 3; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	107	0.11	4.8	0.56	0.44	5%	95%
	140	6.76	14.9	115	0.12	4.8	0.58	0.45	6%	94%
	150	7.24	15.4	123	0.13	4.8	0.60	0.47	6%	94%
	160	7.73	15.7	131	0.14	4.8	0.61	0.48	7%	93%
	170	8.21	16.1	139	0.15	4.8	0.63	0.49	7%	93%
	180	8.69	16.5	148	0.16	4.8	0.64	0.50	8%	92%
	190	9.17	16.8	156	0.17	4.8	0.65	0.51	9%	91%
	200	9.66	17.1	164	0.18	4.8	0.67	0.52	9%	91%
	210	10.14	17.4	172	0.18	4.8	0.68	0.53	10%	90%
Kelt	650	31.39	24.2	533	0.57	4.8	0.94	0.74	42%	58%
	675	32.59	24.5	553	0.59	4.8	0.95	0.74	44%	56%
	700	33.80	24.7	574	0.62	4.8	0.96	0.75	46%	54%
	725	35.01	24.9	594	0.64	4.8	0.97	0.76	48%	52%
	750	36.21	25.1	615	0.66	4.8	0.98	0.76	50%	50%
	775	37.42	25.3	635	0.68	4.8	0.98	0.77	52%	48%
	800	38.63	25.5	656	0.70	4.8	0.99	0.77	55%	45%

Table D 78. Input parameters for the prediction of strike probability and mortality for Milford unit 3; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	75	0.08	4.8	0.56	0.31	2%	98%
	140	6.76	14.9	80	0.09	4.8	0.58	0.31	3%	97%
	150	7.24	15.4	86	0.09	4.8	0.60	0.32	3%	97%
	160	7.73	15.7	92	0.10	4.8	0.61	0.33	3%	97%
	170	8.21	16.1	98	0.10	4.8	0.63	0.34	4%	96%
	180	8.69	16.5	103	0.11	4.8	0.64	0.35	4%	96%
	190	9.17	16.8	109	0.12	4.8	0.65	0.35	4%	96%
	200	9.66	17.1	115	0.12	4.8	0.67	0.36	4%	96%
	210	10.14	17.4	121	0.13	4.8	0.68	0.37	5%	95%
Kelt	650	31.39	24.2	373	0.40	4.8	0.94	0.51	20%	80%
	675	32.59	24.5	388	0.42	4.8	0.95	0.52	21%	79%
	700	33.80	24.7	402	0.43	4.8	0.96	0.52	22%	78%
	725	35.01	24.9	416	0.45	4.8	0.97	0.52	23%	77%
	750	36.21	25.1	431	0.46	4.8	0.98	0.53	24%	76%
	775	37.42	25.3	445	0.48	4.8	0.98	0.53	26%	74%
	800	38.63	25.5	459	0.49	4.8	0.99	0.54	27%	73%

Table D 79. Input parameters for the prediction of strike probability and mortality for Milford units 4,5,6; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	94	0.10	4.8	0.60	0.39	4%	96%
	140	6.76	14.9	101	0.10	4.8	0.62	0.40	4%	96%
	150	7.24	15.4	108	0.11	4.8	0.63	0.41	5%	95%
	160	7.73	15.7	115	0.12	4.8	0.65	0.42	5%	95%
	170	8.21	16.1	122	0.13	4.8	0.66	0.43	5%	95%
	180	8.69	16.5	130	0.13	4.8	0.68	0.44	6%	94%
	190	9.17	16.8	137	0.14	4.8	0.69	0.45	6%	94%
	200	9.66	17.1	144	0.15	4.8	0.71	0.46	7%	93%
	210	10.14	17.4	151	0.16	4.8	0.72	0.47	7%	93%
Kelt	650	31.39	24.2	468	0.49	4.8	1.00	0.65	32%	68%
	675	32.59	24.5	486	0.50	4.8	1.00	0.65	33%	67%
	700	33.80	24.7	504	0.52	4.8	1.00	0.65	34%	66%
	725	35.01	24.9	522	0.54	4.8	1.00	0.65	35%	65%
	750	36.21	25.1	540	0.56	4.8	1.00	0.65	36%	64%
	775	37.42	25.3	558	0.58	4.8	1.00	0.65	38%	62%
	800	38.63	25.5	576	0.60	4.8	1.00	0.65	39%	61%

Table D 80. Input parameters for the prediction of strike probability and mortality for Milford units 4,5,6; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	108	0.11	4.8	0.60	0.39	4%	96%
	140	6.76	14.9	116	0.12	4.8	0.62	0.40	5%	95%
	150	7.24	15.4	124	0.13	4.8	0.63	0.41	5%	95%
	160	7.73	15.7	133	0.14	4.8	0.65	0.42	6%	94%
	170	8.21	16.1	141	0.15	4.8	0.66	0.43	6%	94%
	180	8.69	16.5	149	0.15	4.8	0.68	0.44	7%	93%
	190	9.17	16.8	158	0.16	4.8	0.69	0.45	7%	93%
	200	9.66	17.1	166	0.17	4.8	0.71	0.46	8%	92%
	210	10.14	17.4	174	0.18	4.8	0.72	0.47	8%	92%
Kelt	650	31.39	24.2	539	0.56	4.8	1.00	0.65	36%	64%
	675	32.59	24.5	560	0.58	4.8	1.00	0.65	38%	62%
	700	33.80	24.7	581	0.60	4.8	1.00	0.65	39%	61%
	725	35.01	24.9	602	0.62	4.8	1.00	0.65	41%	59%
	750	36.21	25.1	622	0.64	4.8	1.00	0.65	42%	58%
	775	37.42	25.3	643	0.67	4.8	1.00	0.65	43%	57%
	800	38.6287	25.5	664	0.69	4.8	1.00	0.65	45%	55%

Table D 81. Input parameters for the prediction of strike probability and mortality for Milford units 4,5,6; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	77	0.08	4.8	0.60	0.39	3%	97%
	140	6.76	14.9	82	0.09	4.8	0.62	0.40	3%	97%
	150	7.24	15.4	88	0.09	4.8	0.63	0.41	4%	96%
	160	7.73	15.7	94	0.10	4.8	0.65	0.42	4%	96%
	170	8.21	16.1	100	0.10	4.8	0.66	0.43	4%	96%
	180	8.69	16.5	106	0.11	4.8	0.68	0.44	5%	95%
	190	9.17	16.8	112	0.12	4.8	0.69	0.45	5%	95%
	200	9.66	17.1	118	0.12	4.8	0.71	0.46	6%	94%
	210	10.14	17.4	124	0.13	4.8	0.72	0.47	6%	94%
Kelt	650	31.39	24.2	383	0.40	4.8	1.00	0.65	26%	74%
	675	32.59	24.5	397	0.41	4.8	1.00	0.65	27%	73%
	700	33.80	24.7	412	0.43	4.8	1.00	0.65	28%	72%
	725	35.01	24.9	427	0.44	4.8	1.00	0.65	29%	71%
	750	36.21	25.1	442	0.46	4.8	1.00	0.65	30%	70%
	775	37.42	25.3	456	0.47	4.8	1.00	0.65	31%	69%
	800	38.63	25.5	471	0.49	4.8	1.00	0.65	32%	68%

Table D 82. Input parameters for the prediction of strike probability and mortality for Milford units 4,5,6; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	94	0.10	4.8	0.60	0.47	5%	95%
	140	6.76	14.9	101	0.10	4.8	0.62	0.48	5%	95%
	150	7.24	15.4	108	0.11	4.8	0.63	0.49	6%	94%
	160	7.73	15.7	115	0.12	4.8	0.65	0.51	6%	94%
	170	8.21	16.1	122	0.13	4.8	0.66	0.52	7%	93%
	180	8.69	16.5	130	0.13	4.8	0.68	0.53	7%	93%
	190	9.17	16.8	137	0.14	4.8	0.69	0.54	8%	92%
	200	9.66	17.1	144	0.15	4.8	0.71	0.55	8%	92%
	210	10.14	17.4	151	0.16	4.8	0.72	0.56	9%	91%
Kelt	650	31.39	24.2	468	0.49	4.8	1.00	0.78	38%	62%
	675	32.59	24.5	486	0.50	4.8	1.00	0.78	39%	61%
	700	33.80	24.7	504	0.52	4.8	1.00	0.78	41%	59%
	725	35.01	24.9	522	0.54	4.8	1.00	0.78	42%	58%
	750	36.21	25.1	540	0.56	4.8	1.00	0.78	44%	56%
	775	37.42	25.3	558	0.58	4.8	1.00	0.78	45%	55%
	800	38.63	25.5	576	0.60	4.8	1.00	0.78	47%	53%

Table D 83. Input parameters for the prediction of strike probability and mortality for Milford units 4,5,6; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	94	0.10	4.8	0.60	0.32	3%	97%
	140	6.76	14.9	101	0.10	4.8	0.62	0.33	3%	97%
	150	7.24	15.4	108	0.11	4.8	0.63	0.34	4%	96%
	160	7.73	15.7	115	0.12	4.8	0.65	0.35	4%	96%
	170	8.21	16.1	122	0.13	4.8	0.66	0.36	5%	95%
	180	8.69	16.5	130	0.13	4.8	0.68	0.37	5%	95%
	190	9.17	16.8	137	0.14	4.8	0.69	0.38	5%	95%
	200	9.66	17.1	144	0.15	4.8	0.71	0.38	6%	94%
	210	10.14	17.4	151	0.16	4.8	0.72	0.39	6%	94%
Kelt	650	31.39	24.2	468	0.49	4.8	1.00	0.54	26%	74%
	675	32.59	24.5	486	0.50	4.8	1.00	0.54	27%	73%
	700	33.80	24.7	504	0.52	4.8	1.00	0.54	28%	72%
	725	35.01	24.9	522	0.54	4.8	1.00	0.54	29%	71%
	750	36.21	25.1	540	0.56	4.8	1.00	0.54	30%	70%
	775	37.42	25.3	558	0.58	4.8	1.00	0.54	31%	69%
	800	38.63	25.5	576	0.60	4.8	1.00	0.54	32%	68%

Table D 84. Input parameters for the prediction of strike probability and mortality for Milford units 4,5,6; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	108	0.11	4.8	0.60	0.47	5%	95%
	140	6.76	14.9	116	0.12	4.8	0.62	0.48	6%	94%
	150	7.24	15.4	124	0.13	4.8	0.63	0.49	6%	94%
	160	7.73	15.7	133	0.14	4.8	0.65	0.51	7%	93%
	170	8.21	16.1	141	0.15	4.8	0.66	0.52	8%	92%
	180	8.69	16.5	149	0.15	4.8	0.68	0.53	8%	92%
	190	9.17	16.8	158	0.16	4.8	0.69	0.54	9%	91%
	200	9.66	17.1	166	0.17	4.8	0.71	0.55	9%	91%
	210	10.14	17.4	174	0.18	4.8	0.72	0.56	10%	90%
Kelt	650	31.39	24.2	539	0.56	4.8	1.00	0.78	44%	56%
	675	32.59	24.5	560	0.58	4.8	1.00	0.78	45%	55%
	700	33.80	24.7	581	0.60	4.8	1.00	0.78	47%	53%
	725	35.01	24.9	602	0.62	4.8	1.00	0.78	49%	51%
	750	36.21	25.1	622	0.64	4.8	1.00	0.78	50%	50%
	775	37.42	25.3	643	0.67	4.8	1.00	0.78	52%	48%
	800	38.63	25.5	664	0.69	4.8	1.00	0.78	54%	46%

Table D 85. Input parameters for the prediction of strike probability and mortality for Milford units 4,5,6; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.28	14.5	77	0.08	4.8	0.60	0.32	3%	97%
	140	6.76	14.9	82	0.09	4.8	0.62	0.33	3%	97%
	150	7.24	15.4	88	0.09	4.8	0.63	0.34	3%	97%
	160	7.73	15.7	94	0.10	4.8	0.65	0.35	3%	97%
	170	8.21	16.1	100	0.10	4.8	0.66	0.36	4%	96%
	180	8.69	16.5	106	0.11	4.8	0.68	0.37	4%	96%
	190	9.17	16.8	112	0.12	4.8	0.69	0.38	4%	96%
	200	9.66	17.1	118	0.12	4.8	0.71	0.38	5%	95%
	210	10.14	17.4	124	0.13	4.8	0.72	0.39	5%	95%
Kelt	650	31.39	24.2	383	0.40	4.8	1.00	0.54	21%	79%
	675	32.59	24.5	397	0.41	4.8	1.00	0.54	22%	78%
	700	33.80	24.7	412	0.43	4.8	1.00	0.54	23%	77%
	725	35.01	24.9	427	0.44	4.8	1.00	0.54	24%	76%
	750	36.21	25.1	442	0.46	4.8	1.00	0.54	25%	75%
	775	37.42	25.3	456	0.47	4.8	1.00	0.54	26%	74%
	800	38.63	25.5	471	0.49	4.8	1.00	0.54	26%	74%

Table D 86. Input parameters for the prediction of strike probability and mortality for Milford units 7,8 baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	113	0.24	4.8	1.00	0.65	16%	84%
	140	12.53	18.7	121	0.26	4.8	1.00	0.65	17%	83%
	150	13.42	19.1	130	0.28	4.8	1.00	0.65	18%	82%
	160	14.32	19.5	139	0.29	4.8	1.00	0.65	19%	81%
	170	15.21	19.9	147	0.31	4.8	1.00	0.65	20%	80%
	180	16.11	20.2	156	0.33	4.8	1.00	0.65	21%	79%
	190	17.00	20.5	165	0.35	4.8	1.00	0.65	23%	77%
	200	17.90	20.8	173	0.37	4.8	1.00	0.65	24%	76%
	210	18.79	21.1	182	0.39	4.8	1.00	0.65	25%	75%
Kelt	650	58.16	28.0	563	1.00	4.8	1.00	0.65	65%	35%
	675	60.40	28.2	585	1.00	4.8	1.00	0.65	65%	35%
	700	62.63	28.4	606	1.00	4.8	1.00	0.65	65%	35%
	725	64.87	28.6	628	1.00	4.8	1.00	0.65	65%	35%
	750	67.11	28.8	650	1.00	4.8	1.00	0.65	65%	35%
	775	69.35	29.0	671	1.00	4.8	1.00	0.65	65%	35%
	800	71.58	29.2	693	1.00	4.8	1.00	0.65	65%	35%

Table D 87. Input parameters for the prediction of strike probability and mortality for Milford units 7,8 fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	122	0.26	4.8	1.00	0.65	17%	83%
	140	12.53	18.7	132	0.28	4.8	1.00	0.65	18%	82%
	150	13.42	19.1	141	0.30	4.8	1.00	0.65	19%	81%
	160	14.32	19.5	150	0.32	4.8	1.00	0.65	21%	79%
	170	15.21	19.9	160	0.34	4.8	1.00	0.65	22%	78%
	180	16.11	20.2	169	0.36	4.8	1.00	0.65	23%	77%
	190	17.00	20.5	179	0.38	4.8	1.00	0.65	25%	75%
	200	17.90	20.8	188	0.40	4.8	1.00	0.65	26%	74%
	210	18.79	21.1	197	0.42	4.8	1.00	0.65	27%	73%
Kelt	650	58.16	28.0	611	1.00	4.8	1.00	0.65	65%	35%
	675	60.40	28.2	634	1.00	4.8	1.00	0.65	65%	35%
	700	62.63	28.4	658	1.00	4.8	1.00	0.65	65%	35%
	725	64.87	28.6	681	1.00	4.8	1.00	0.65	65%	35%
	750	67.11	28.8	705	1.00	4.8	1.00	0.65	65%	35%
	775	69.35	29.0	728	1.00	4.8	1.00	0.65	65%	35%
	800	71.58	29.2	752	1.00	4.8	1.00	0.65	65%	35%

Table D 88. Input parameters for the prediction of strike probability and mortality for Milford units 7,8 fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	100	0.21	4.8	1.00	0.65	14%	86%
	140	12.53	18.7	107	0.23	4.8	1.00	0.65	15%	85%
	150	13.42	19.1	115	0.24	4.8	1.00	0.65	16%	84%
	160	14.32	19.5	123	0.26	4.8	1.00	0.65	17%	83%
	170	15.21	19.9	130	0.28	4.8	1.00	0.65	18%	82%
	180	16.11	20.2	138	0.29	4.8	1.00	0.65	19%	81%
	190	17.00	20.5	146	0.31	4.8	1.00	0.65	20%	80%
	200	17.90	20.8	153	0.32	4.8	1.00	0.65	21%	79%
	210	18.79	21.1	161	0.34	4.8	1.00	0.65	22%	78%
Kelt	650	58.16	28.0	498	1.00	4.8	1.00	0.65	65%	35%
	675	60.40	28.2	517	1.00	4.8	1.00	0.65	65%	35%
	700	62.63	28.4	536	1.00	4.8	1.00	0.65	65%	35%
	725	64.87	28.6	555	1.00	4.8	1.00	0.65	65%	35%
	750	67.11	28.8	575	1.00	4.8	1.00	0.65	65%	35%
	775	69.35	29.0	594	1.00	4.8	1.00	0.65	65%	35%
	800	71.58	29.2	613	1.00	4.8	1.00	0.65	65%	35%

Table D 89. Input parameters for the prediction of strike probability and mortality for Milford units 7,8 K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	113	0.24	4.8	1.00	0.78	19%	81%
	140	12.53	18.7	121	0.26	4.8	1.00	0.78	20%	80%
	150	13.42	19.1	130	0.28	4.8	1.00	0.78	21%	79%
	160	14.32	19.5	139	0.29	4.8	1.00	0.78	23%	77%
	170	15.21	19.9	147	0.31	4.8	1.00	0.78	24%	76%
	180	16.11	20.2	156	0.33	4.8	1.00	0.78	26%	74%
	190	17.00	20.5	165	0.35	4.8	1.00	0.78	27%	73%
	200	17.90	20.8	173	0.37	4.8	1.00	0.78	29%	71%
	210	18.79	21.1	182	0.39	4.8	1.00	0.78	30%	70%
Kelt	650	58.16	28.0	563	1.00	4.8	1.00	0.78	78%	22%
	675	60.40	28.2	585	1.00	4.8	1.00	0.78	78%	22%
	700	62.63	28.4	606	1.00	4.8	1.00	0.78	78%	22%
	725	64.87	28.6	628	1.00	4.8	1.00	0.78	78%	22%
	750	67.11	28.8	650	1.00	4.8	1.00	0.78	78%	22%
	775	69.35	29.0	671	1.00	4.8	1.00	0.78	78%	22%
	800	71.58	29.2	693	1.00	4.8	1.00	0.78	78%	22%

Table D 90. Input parameters for the prediction of strike probability and mortality for Milford units 7,8 K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	113	0.24	4.8	1.00	0.54	13%	87%
	140	12.53	18.7	121	0.26	4.8	1.00	0.54	14%	86%
	150	13.42	19.1	130	0.28	4.8	1.00	0.54	15%	85%
	160	14.32	19.5	139	0.29	4.8	1.00	0.54	16%	84%
	170	15.21	19.9	147	0.31	4.8	1.00	0.54	17%	83%
	180	16.11	20.2	156	0.33	4.8	1.00	0.54	18%	82%
	190	17.00	20.5	165	0.35	4.8	1.00	0.54	19%	81%
	200	17.90	20.8	173	0.37	4.8	1.00	0.54	20%	80%
	210	18.79	21.1	182	0.39	4.8	1.00	0.54	21%	79%
Kelt	650	58.16	28.0	563	1.00	4.8	1.00	0.54	54%	46%
	675	60.40	28.2	585	1.00	4.8	1.00	0.54	54%	46%
	700	62.63	28.4	606	1.00	4.8	1.00	0.54	54%	46%
	725	64.87	28.6	628	1.00	4.8	1.00	0.54	54%	46%
	750	67.11	28.8	650	1.00	4.8	1.00	0.54	54%	46%
	775	69.35	29.0	671	1.00	4.8	1.00	0.54	54%	46%
	800	71.58	29.2	693	1.00	4.8	1.00	0.54	54%	46%

Table D 91. Input parameters for the prediction of strike probability and mortality for Milford units 7,8 compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	122	0.26	4.8	1.00	0.78	20%	80%
	140	12.53	18.7	132	0.28	4.8	1.00	0.78	22%	78%
	150	13.42	19.1	141	0.30	4.8	1.00	0.78	23%	77%
	160	14.32	19.5	150	0.32	4.8	1.00	0.78	25%	75%
	170	15.21	19.9	160	0.34	4.8	1.00	0.78	26%	74%
	180	16.11	20.2	169	0.36	4.8	1.00	0.78	28%	72%
	190	17.00	20.5	179	0.38	4.8	1.00	0.78	29%	71%
	200	17.90	20.8	188	0.40	4.8	1.00	0.78	31%	69%
	210	18.79	21.1	197	0.42	4.8	1.00	0.78	33%	67%
Kelt	650	58.16	28.0	611	1.00	4.8	1.00	0.78	78%	22%
	675	60.40	28.2	634	1.00	4.8	1.00	0.78	78%	22%
	700	62.63	28.4	658	1.00	4.8	1.00	0.78	78%	22%
	725	64.87	28.6	681	1.00	4.8	1.00	0.78	78%	22%
	750	67.11	28.8	705	1.00	4.8	1.00	0.78	78%	22%
	775	69.35	29.0	728	1.00	4.8	1.00	0.78	78%	22%
	800	71.58	29.2	752	1.00	4.8	1.00	0.78	78%	22%

Table D 92. Input parameters for the prediction of strike probability and mortality for Milford units 7, 8 compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	100	0.21	4.8	1.00	0.54	11%	89%
	140	12.53	18.7	107	0.23	4.8	1.00	0.54	12%	88%
	150	13.42	19.1	115	0.24	4.8	1.00	0.54	13%	87%
	160	14.32	19.5	123	0.26	4.8	1.00	0.54	14%	86%
	170	15.21	19.9	130	0.28	4.8	1.00	0.54	15%	85%
	180	16.11	20.2	138	0.29	4.8	1.00	0.54	16%	84%
	190	17.00	20.5	146	0.31	4.8	1.00	0.54	17%	83%
	200	17.90	20.8	153	0.32	4.8	1.00	0.54	18%	82%
	210	18.79	21.1	161	0.34	4.8	1.00	0.54	18%	82%
Kelt	650	58.16	28.0	498	1.00	4.8	1.00	0.54	54%	46%
	675	60.40	28.2	517	1.00	4.8	1.00	0.54	54%	46%
	700	62.63	28.4	536	1.00	4.8	1.00	0.54	54%	46%
	725	64.87	28.6	555	1.00	4.8	1.00	0.54	54%	46%
	750	67.11	28.8	575	1.00	4.8	1.00	0.54	54%	46%
	775	69.35	29.0	594	1.00	4.8	1.00	0.54	54%	46%
	800	71.58	29.2	613	1.00	4.8	1.00	0.54	54%	46%

Table D 93. Input parameters for the prediction of strike probability and mortality for West Enfield unit 1; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	3.89	11.6	75	0.04	4.8	0.93	0.60	2%	98%
	140	4.19	12.0	80	0.04	4.8	0.96	0.63	3%	97%
	150	4.49	12.5	86	0.05	4.8	1.00	0.65	3%	97%
	160	4.79	12.9	92	0.05	4.8	1.00	0.65	3%	97%
	170	5.09	13.2	98	0.05	4.8	1.00	0.65	3%	97%
	180	5.39	13.6	103	0.05	4.8	1.00	0.65	4%	96%
	190	5.69	13.9	109	0.06	4.8	1.00	0.65	4%	96%
	200	5.99	14.2	115	0.06	4.8	1.00	0.65	4%	96%
	210	6.29	14.5	120	0.06	4.8	1.00	0.65	4%	96%
Kelt	650	19.46	21.3	373	0.20	4.8	1.00	0.65	13%	87%
	675	20.21	21.6	387	0.21	4.8	1.00	0.65	13%	87%
	700	20.96	21.8	402	0.21	4.8	1.00	0.65	14%	86%
	725	21.71	22.0	416	0.22	4.8	1.00	0.65	14%	86%
	750	22.46	22.2	430	0.23	4.8	1.00	0.65	15%	85%
	775	23.21	22.4	445	0.24	4.8	1.00	0.65	15%	85%
	800	23.95	22.6	459	0.24	4.8	1.00	0.65	16%	84%

Table D 94. Input parameters for the prediction of strike probability and mortality for West Enfield unit 1; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	3.89	11.6	92	0.05	4.8	0.93	0.60	3%	97%
	140	4.19	12.0	99	0.05	4.8	0.96	0.63	3%	97%
	150	4.49	12.5	106	0.06	4.8	1.00	0.65	4%	96%
	160	4.79	12.9	113	0.06	4.8	1.00	0.65	4%	96%
	170	5.09	13.2	120	0.06	4.8	1.00	0.65	4%	96%
	180	5.39	13.6	127	0.07	4.8	1.00	0.65	4%	96%
	190	5.69	13.9	134	0.07	4.8	1.00	0.65	5%	95%
	200	5.99	14.2	141	0.07	4.8	1.00	0.65	5%	95%
	210	6.29	14.5	148	0.08	4.8	1.00	0.65	5%	95%
Kelt	650	19.46	21.3	460	0.24	4.8	1.00	0.65	16%	84%
	675	20.21	21.6	477	0.25	4.8	1.00	0.65	16%	84%
	700	20.96	21.8	495	0.26	4.8	1.00	0.65	17%	83%
	725	21.71	22.0	513	0.27	4.8	1.00	0.65	18%	82%
	750	22.46	22.2	530	0.28	4.8	1.00	0.65	18%	82%
	775	23.21	22.4	548	0.29	4.8	1.00	0.65	19%	81%
	800	23.9546	22.6	566	0.30	4.8	1.00	0.65	19%	81%

Table D 95. Input parameters for the prediction of strike probability and mortality for West Enfield unit 1; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	3.89	11.6	55	0.03	4.8	0.93	0.60	2%	98%
	140	4.19	12.0	59	0.03	4.8	0.96	0.63	2%	98%
	150	4.49	12.5	63	0.03	4.8	1.00	0.65	2%	98%
	160	4.79	12.9	68	0.04	4.8	1.00	0.65	2%	98%
	170	5.09	13.2	72	0.04	4.8	1.00	0.65	2%	98%
	180	5.39	13.6	76	0.04	4.8	1.00	0.65	3%	97%
	190	5.69	13.9	80	0.04	4.8	1.00	0.65	3%	97%
	200	5.99	14.2	85	0.04	4.8	1.00	0.65	3%	97%
	210	6.29	14.5	89	0.05	4.8	1.00	0.65	3%	97%
Kelt	650	19.46	21.3	275	0.15	4.8	1.00	0.65	9%	91%
	675	20.21	21.6	285	0.15	4.8	1.00	0.65	10%	90%
	700	20.96	21.8	296	0.16	4.8	1.00	0.65	10%	90%
	725	21.71	22.0	306	0.16	4.8	1.00	0.65	11%	89%
	750	22.46	22.2	317	0.17	4.8	1.00	0.65	11%	89%
	775	23.21	22.4	328	0.17	4.8	1.00	0.65	11%	89%
	800	23.95	22.6	338	0.18	4.8	1.00	0.65	12%	88%

Table D 96. Input parameters for the prediction of strike probability and mortality for West Enfield unit 1; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	3.89	11.6	75	0.04	4.8	0.93	0.72	3%	97%
	140	4.19	12.0	80	0.04	4.8	0.96	0.75	3%	97%
	150	4.49	12.5	86	0.05	4.8	1.00	0.78	4%	96%
	160	4.79	12.9	92	0.05	4.8	1.00	0.78	4%	96%
	170	5.09	13.2	98	0.05	4.8	1.00	0.78	4%	96%
	180	5.39	13.6	103	0.05	4.8	1.00	0.78	4%	96%
	190	5.69	13.9	109	0.06	4.8	1.00	0.78	5%	95%
	200	5.99	14.2	115	0.06	4.8	1.00	0.78	5%	95%
	210	6.29	14.5	120	0.06	4.8	1.00	0.78	5%	95%
Kelt	650	19.46	21.3	373	0.20	4.8	1.00	0.78	15%	85%
	675	20.21	21.6	387	0.21	4.8	1.00	0.78	16%	84%
	700	20.96	21.8	402	0.21	4.8	1.00	0.78	17%	83%
	725	21.71	22.0	416	0.22	4.8	1.00	0.78	17%	83%
	750	22.46	22.2	430	0.23	4.8	1.00	0.78	18%	82%
	775	23.21	22.4	445	0.24	4.8	1.00	0.78	18%	82%
	800	23.95	22.6	459	0.24	4.8	1.00	0.78	19%	81%

Table D 97. Input parameters for the prediction of strike probability and mortality for West Enfield unit 1; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	3.89	11.6	75	0.04	4.8	0.93	0.50	2%	98%
	140	4.19	12.0	80	0.04	4.8	0.96	0.52	2%	98%
	150	4.49	12.5	86	0.05	4.8	1.00	0.54	2%	98%
	160	4.79	12.9	92	0.05	4.8	1.00	0.54	3%	97%
	170	5.09	13.2	98	0.05	4.8	1.00	0.54	3%	97%
	180	5.39	13.6	103	0.05	4.8	1.00	0.54	3%	97%
	190	5.69	13.9	109	0.06	4.8	1.00	0.54	3%	97%
	200	5.99	14.2	115	0.06	4.8	1.00	0.54	3%	97%
	210	6.29	14.5	120	0.06	4.8	1.00	0.54	3%	97%
Kelt	650	19.46	21.3	373	0.20	4.8	1.00	0.54	11%	89%
	675	20.21	21.6	387	0.21	4.8	1.00	0.54	11%	89%
	700	20.96	21.8	402	0.21	4.8	1.00	0.54	12%	88%
	725	21.71	22.0	416	0.22	4.8	1.00	0.54	12%	88%
	750	22.46	22.2	430	0.23	4.8	1.00	0.54	12%	88%
	775	23.21	22.4	445	0.24	4.8	1.00	0.54	13%	87%
	800	23.95	22.6	459	0.24	4.8	1.00	0.54	13%	87%

Table D 98. Input parameters for the prediction of strike probability and mortality for West Enfield unit 1; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	3.89	11.6	92	0.05	4.8	0.93	0.72	4%	96%
	140	4.19	12.0	99	0.05	4.8	0.96	0.75	4%	96%
	150	4.49	12.5	106	0.06	4.8	1.00	0.78	4%	96%
	160	4.79	12.9	113	0.06	4.8	1.00	0.78	5%	95%
	170	5.09	13.2	120	0.06	4.8	1.00	0.78	5%	95%
	180	5.39	13.6	127	0.07	4.8	1.00	0.78	5%	95%
	190	5.69	13.9	134	0.07	4.8	1.00	0.78	6%	94%
	200	5.99	14.2	141	0.07	4.8	1.00	0.78	6%	94%
	210	6.29	14.5	148	0.08	4.8	1.00	0.78	6%	94%
Kelt	650	19.46	21.3	460	0.24	4.8	1.00	0.78	19%	81%
	675	20.21	21.6	477	0.25	4.8	1.00	0.78	20%	80%
	700	20.96	21.8	495	0.26	4.8	1.00	0.78	20%	80%
	725	21.71	22.0	513	0.27	4.8	1.00	0.78	21%	79%
	750	22.46	22.2	530	0.28	4.8	1.00	0.78	22%	78%
	775	23.21	22.4	548	0.29	4.8	1.00	0.78	23%	77%
	800	23.95	22.6	566	0.30	4.8	1.00	0.78	23%	77%

Table D 99. Input parameters for the prediction of strike probability and mortality for West Enfield unit 1; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	3.89	11.6	55	0.03	4.8	0.93	0.50	1%	99%
	140	4.19	12.0	59	0.03	4.8	0.96	0.52	2%	98%
	150	4.49	12.5	63	0.03	4.8	1.00	0.54	2%	98%
	160	4.79	12.9	68	0.04	4.8	1.00	0.54	2%	98%
	170	5.09	13.2	72	0.04	4.8	1.00	0.54	2%	98%
	180	5.39	13.6	76	0.04	4.8	1.00	0.54	2%	98%
	190	5.69	13.9	80	0.04	4.8	1.00	0.54	2%	98%
	200	5.99	14.2	85	0.04	4.8	1.00	0.54	2%	98%
	210	6.29	14.5	89	0.05	4.8	1.00	0.54	3%	97%
Kelt	650	19.46	21.3	275	0.15	4.8	1.00	0.54	8%	92%
	675	20.21	21.6	285	0.15	4.8	1.00	0.54	8%	92%
	700	20.96	21.8	296	0.16	4.8	1.00	0.54	8%	92%
	725	21.71	22.0	306	0.16	4.8	1.00	0.54	9%	91%
	750	22.46	22.2	317	0.17	4.8	1.00	0.54	9%	91%
	775	23.21	22.4	328	0.17	4.8	1.00	0.54	9%	91%
	800	23.95	22.6	338	0.18	4.8	1.00	0.54	10%	90%

Table D 100. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 3, and 4; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	119	0.35	4.8	1.00	0.65	23%	77%
	140	6.74	14.9	128	0.38	4.8	1.00	0.65	25%	75%
	150	7.22	15.3	137	0.41	4.8	1.00	0.65	26%	74%
	160	7.70	15.7	146	0.43	4.8	1.00	0.65	28%	72%
	170	8.18	16.1	155	0.46	4.8	1.00	0.65	30%	70%
	180	8.66	16.4	164	0.49	4.8	1.00	0.65	32%	68%
	190	9.14	16.8	173	0.51	4.8	1.00	0.65	33%	67%
	200	9.62	17.1	182	0.54	4.8	1.00	0.65	35%	65%
	210	10.10	17.4	192	0.57	4.8	1.00	0.65	37%	63%
Kelt	650	31.27	24.2	593	1.00	4.8	1.00	0.65	65%	35%
	675	32.48	24.5	616	1.00	4.8	1.00	0.65	65%	35%
	700	33.68	24.7	639	1.00	4.8	1.00	0.65	65%	35%
	725	34.88	24.9	662	1.00	4.8	1.00	0.65	65%	35%
	750	36.08	25.1	684	1.00	4.8	1.00	0.65	65%	35%
	775	37.29	25.3	707	1.00	4.8	1.00	0.65	65%	35%
	800	38.49	25.5	730	1.00	4.8	1.00	0.65	65%	35%

Table D 101. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 3, and 4; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	126	0.37	4.8	1.00	0.65	24%	76%
	140	6.74	14.9	136	0.40	4.8	1.00	0.65	26%	74%
	150	7.22	15.3	145	0.43	4.8	1.00	0.65	28%	72%
	160	7.70	15.7	155	0.46	4.8	1.00	0.65	30%	70%
	170	8.18	16.1	165	0.49	4.8	1.00	0.65	32%	68%
	180	8.66	16.4	175	0.52	4.8	1.00	0.65	34%	66%
	190	9.14	16.8	184	0.55	4.8	1.00	0.65	35%	65%
	200	9.62	17.1	194	0.57	4.8	1.00	0.65	37%	63%
	210	10.10	17.4	204	0.60	4.8	1.00	0.65	39%	61%
Kelt	650	31.27	24.2	630	1.00	4.8	1.00	0.65	65%	35%
	675	32.48	24.5	655	1.00	4.8	1.00	0.65	65%	35%
	700	33.68	24.7	679	1.00	4.8	1.00	0.65	65%	35%
	725	34.88	24.9	703	1.00	4.8	1.00	0.65	65%	35%
	750	36.08	25.1	727	1.00	4.8	1.00	0.65	65%	35%
	775	37.29	25.3	751	1.00	4.8	1.00	0.65	65%	35%
	800	38.49	25.5	776	1.00	4.8	1.00	0.65	65%	35%

Table D 102. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 3, and 4; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	108	0.32	4.8	1.00	0.65	21%	79%
	140	6.74	14.9	116	0.34	4.8	1.00	0.65	22%	78%
	150	7.22	15.3	124	0.37	4.8	1.00	0.65	24%	76%
	160	7.70	15.7	132	0.39	4.8	1.00	0.65	26%	74%
	170	8.18	16.1	141	0.42	4.8	1.00	0.65	27%	73%
	180	8.66	16.4	149	0.44	4.8	1.00	0.65	29%	71%
	190	9.14	16.8	157	0.47	4.8	1.00	0.65	30%	70%
	200	9.62	17.1	166	0.49	4.8	1.00	0.65	32%	68%
	210	10.10	17.4	174	0.52	4.8	1.00	0.65	33%	67%
Kelt	650	31.27	24.2	538	1.00	4.8	1.00	0.65	65%	35%
	675	32.48	24.5	559	1.00	4.8	1.00	0.65	65%	35%
	700	33.68	24.7	579	1.00	4.8	1.00	0.65	65%	35%
	725	34.88	24.9	600	1.00	4.8	1.00	0.65	65%	35%
	750	36.08	25.1	621	1.00	4.8	1.00	0.65	65%	35%
	775	37.29	25.3	641	1.00	4.8	1.00	0.65	65%	35%
	800	38.49	25.5	662	1.00	4.8	1.00	0.65	65%	35%

Table D 103. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 3, and 4; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	119	0.35	4.8	1.00	0.78	27%	73%
	140	6.74	14.9	128	0.38	4.8	1.00	0.78	30%	70%
	150	7.22	15.3	137	0.41	4.8	1.00	0.78	32%	68%
	160	7.70	15.7	146	0.43	4.8	1.00	0.78	34%	66%
	170	8.18	16.1	155	0.46	4.8	1.00	0.78	36%	64%
	180	8.66	16.4	164	0.49	4.8	1.00	0.78	38%	62%
	190	9.14	16.8	173	0.51	4.8	1.00	0.78	40%	60%
	200	9.62	17.1	182	0.54	4.8	1.00	0.78	42%	58%
	210	10.10	17.4	192	0.57	4.8	1.00	0.78	44%	56%
Kelt	650	31.27	24.2	593	1.00	4.8	1.00	0.78	78%	22%
	675	32.48	24.5	616	1.00	4.8	1.00	0.78	78%	22%
	700	33.68	24.7	639	1.00	4.8	1.00	0.78	78%	22%
	725	34.88	24.9	662	1.00	4.8	1.00	0.78	78%	22%
	750	36.08	25.1	684	1.00	4.8	1.00	0.78	78%	22%
	775	37.29	25.3	707	1.00	4.8	1.00	0.78	78%	22%
	800	38.49	25.5	730	1.00	4.8	1.00	0.78	78%	22%

Table D 104. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 3, and 4; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	119	0.35	4.8	1.00	0.54	19%	81%
	140	6.74	14.9	128	0.38	4.8	1.00	0.54	21%	79%
	150	7.22	15.3	137	0.41	4.8	1.00	0.54	22%	78%
	160	7.70	15.7	146	0.43	4.8	1.00	0.54	23%	77%
	170	8.18	16.1	155	0.46	4.8	1.00	0.54	25%	75%
	180	8.66	16.4	164	0.49	4.8	1.00	0.54	26%	74%
	190	9.14	16.8	173	0.51	4.8	1.00	0.54	28%	72%
	200	9.62	17.1	182	0.54	4.8	1.00	0.54	29%	71%
	210	10.10	17.4	192	0.57	4.8	1.00	0.54	31%	69%
Kelt	650	31.27	24.2	593	1.00	4.8	1.00	0.54	54%	46%
	675	32.48	24.5	616	1.00	4.8	1.00	0.54	54%	46%
	700	33.68	24.7	639	1.00	4.8	1.00	0.54	54%	46%
	725	34.88	24.9	662	1.00	4.8	1.00	0.54	54%	46%
	750	36.08	25.1	684	1.00	4.8	1.00	0.54	54%	46%
	775	37.29	25.3	707	1.00	4.8	1.00	0.54	54%	46%
	800	38.49	25.5	730	1.00	4.8	1.00	0.54	54%	46%

Table D 105. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 3, and 4; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	126	0.37	4.8	1.00	0.78	29%	71%
	140	6.74	14.9	136	0.40	4.8	1.00	0.78	31%	69%
	150	7.22	15.3	145	0.43	4.8	1.00	0.78	34%	66%
	160	7.70	15.7	155	0.46	4.8	1.00	0.78	36%	64%
	170	8.18	16.1	165	0.49	4.8	1.00	0.78	38%	62%
	180	8.66	16.4	175	0.52	4.8	1.00	0.78	40%	60%
	190	9.14	16.8	184	0.55	4.8	1.00	0.78	43%	57%
	200	9.62	17.1	194	0.57	4.8	1.00	0.78	45%	55%
	210	10.10	17.4	204	0.60	4.8	1.00	0.78	47%	53%
Kelt	650	31.27	24.2	630	1.00	4.8	1.00	0.78	78%	22%
	675	32.48	24.5	655	1.00	4.8	1.00	0.78	78%	22%
	700	33.68	24.7	679	1.00	4.8	1.00	0.78	78%	22%
	725	34.88	24.9	703	1.00	4.8	1.00	0.78	78%	22%
	750	36.08	25.1	727	1.00	4.8	1.00	0.78	78%	22%
	775	37.29	25.3	751	1.00	4.8	1.00	0.78	78%	22%
	800	38.49	25.5	776	1.00	4.8	1.00	0.78	78%	22%

Table D 106. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 3, and 4; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	108	0.32	4.8	1.00	0.54	17%	83%
	140	6.74	14.9	116	0.34	4.8	1.00	0.54	19%	81%
	150	7.22	15.3	124	0.37	4.8	1.00	0.54	20%	80%
	160	7.70	15.7	132	0.39	4.8	1.00	0.54	21%	79%
	170	8.18	16.1	141	0.42	4.8	1.00	0.54	23%	77%
	180	8.66	16.4	149	0.44	4.8	1.00	0.54	24%	76%
	190	9.14	16.8	157	0.47	4.8	1.00	0.54	25%	75%
	200	9.62	17.1	166	0.49	4.8	1.00	0.54	27%	73%
	210	10.10	17.4	174	0.52	4.8	1.00	0.54	28%	72%
Kelt	650	31.27	24.2	538	1.00	4.8	1.00	0.54	54%	46%
	675	32.48	24.5	559	1.00	4.8	1.00	0.54	54%	46%
	700	33.68	24.7	579	1.00	4.8	1.00	0.54	54%	46%
	725	34.88	24.9	600	1.00	4.8	1.00	0.54	54%	46%
	750	36.08	25.1	621	1.00	4.8	1.00	0.54	54%	46%
	775	37.29	25.3	641	1.00	4.8	1.00	0.54	54%	46%
	800	38.49	25.5	662	1.00	4.8	1.00	0.54	54%	46%

Table D 107. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 1, and 2; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	119	0.35	4.8	1.00	0.65	23%	77%
	140	6.74	14.9	128	0.38	4.8	1.00	0.65	25%	75%
	150	7.22	15.3	137	0.40	4.8	1.00	0.65	26%	74%
	160	7.70	15.7	146	0.43	4.8	1.00	0.65	28%	72%
	170	8.18	16.1	155	0.46	4.8	1.00	0.65	30%	70%
	180	8.66	16.4	164	0.49	4.8	1.00	0.65	32%	68%
	190	9.14	16.8	173	0.51	4.8	1.00	0.65	33%	67%
	200	9.62	17.1	182	0.54	4.8	1.00	0.65	35%	65%
	210	10.10	17.4	192	0.57	4.8	1.00	0.65	37%	63%
Kelt	650	31.27	24.2	593	1.00	4.8	1.00	0.65	65%	35%
	675	32.48	24.5	616	1.00	4.8	1.00	0.65	65%	35%
	700	33.68	24.7	639	1.00	4.8	1.00	0.65	65%	35%
	725	34.88	24.9	662	1.00	4.8	1.00	0.65	65%	35%
	750	36.08	25.1	684	1.00	4.8	1.00	0.65	65%	35%
	775	37.29	25.3	707	1.00	4.8	1.00	0.65	65%	35%
	800	38.49	25.5	730	1.00	4.8	1.00	0.65	65%	35%

Table D 108. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 1, and 2; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	126	0.37	4.8	1.00	0.65	24%	76%
	140	6.74	14.9	136	0.40	4.8	1.00	0.65	26%	74%
	150	7.22	15.3	145	0.43	4.8	1.00	0.65	28%	72%
	160	7.70	15.7	155	0.46	4.8	1.00	0.65	30%	70%
	170	8.18	16.1	165	0.49	4.8	1.00	0.65	32%	68%
	180	8.66	16.4	175	0.52	4.8	1.00	0.65	34%	66%
	190	9.14	16.8	184	0.54	4.8	1.00	0.65	35%	65%
	200	9.62	17.1	194	0.57	4.8	1.00	0.65	37%	63%
	210	10.10	17.4	204	0.60	4.8	1.00	0.65	39%	61%
Kelt	650	31.27	24.2	630	1.00	4.8	1.00	0.65	65%	35%
	675	32.48	24.5	655	1.00	4.8	1.00	0.65	65%	35%
	700	33.68	24.7	679	1.00	4.8	1.00	0.65	65%	35%
	725	34.88	24.9	703	1.00	4.8	1.00	0.65	65%	35%
	750	36.08	25.1	727	1.00	4.8	1.00	0.65	65%	35%
	775	37.29	25.3	751	1.00	4.8	1.00	0.65	65%	35%
	800	38.49	25.5	776	1.00	4.8	1.00	0.65	65%	35%

Table D 109. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 1, and 2; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	108	0.32	4.8	1.00	0.65	21%	79%
	140	6.74	14.9	116	0.34	4.8	1.00	0.65	22%	78%
	150	7.22	15.3	124	0.37	4.8	1.00	0.65	24%	76%
	160	7.70	15.7	132	0.39	4.8	1.00	0.65	25%	75%
	170	8.18	16.1	141	0.42	4.8	1.00	0.65	27%	73%
	180	8.66	16.4	149	0.44	4.8	1.00	0.65	29%	71%
	190	9.14	16.8	157	0.46	4.8	1.00	0.65	30%	70%
	200	9.62	17.1	166	0.49	4.8	1.00	0.65	32%	68%
	210	10.10	17.4	174	0.51	4.8	1.00	0.65	33%	67%
Kelt	650	31.27	24.2	538	1.00	4.8	1.00	0.65	65%	35%
	675	32.48	24.5	559	1.00	4.8	1.00	0.65	65%	35%
	700	33.68	24.7	579	1.00	4.8	1.00	0.65	65%	35%
	725	34.88	24.9	600	1.00	4.8	1.00	0.65	65%	35%
	750	36.08	25.1	621	1.00	4.8	1.00	0.65	65%	35%
	775	37.29	25.3	641	1.00	4.8	1.00	0.65	65%	35%
	800	38.49	25.5	662	1.00	4.8	1.00	0.65	65%	35%

Table D 110. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 1, and 2; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	119	0.35	4.8	1.00	0.78	27%	73%
	140	6.74	14.9	128	0.38	4.8	1.00	0.78	29%	71%
	150	7.22	15.3	137	0.40	4.8	1.00	0.78	32%	68%
	160	7.70	15.7	146	0.43	4.8	1.00	0.78	34%	66%
	170	8.18	16.1	155	0.46	4.8	1.00	0.78	36%	64%
	180	8.66	16.4	164	0.49	4.8	1.00	0.78	38%	62%
	190	9.14	16.8	173	0.51	4.8	1.00	0.78	40%	60%
	200	9.62	17.1	182	0.54	4.8	1.00	0.78	42%	58%
	210	10.10	17.4	192	0.57	4.8	1.00	0.78	44%	56%
Kelt	650	31.27	24.2	593	1.00	4.8	1.00	0.78	78%	22%
	675	32.48	24.5	616	1.00	4.8	1.00	0.78	78%	22%
	700	33.68	24.7	639	1.00	4.8	1.00	0.78	78%	22%
	725	34.88	24.9	662	1.00	4.8	1.00	0.78	78%	22%
	750	36.08	25.1	684	1.00	4.8	1.00	0.78	78%	22%
	775	37.29	25.3	707	1.00	4.8	1.00	0.78	78%	22%
	800	38.49	25.5	730	1.00	4.8	1.00	0.78	78%	22%

Table D 111. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 1, and 2; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	119	0.35	4.8	1.00	0.54	19%	81%
	140	6.74	14.9	128	0.38	4.8	1.00	0.54	20%	80%
	150	7.22	15.3	137	0.40	4.8	1.00	0.54	22%	78%
	160	7.70	15.7	146	0.43	4.8	1.00	0.54	23%	77%
	170	8.18	16.1	155	0.46	4.8	1.00	0.54	25%	75%
	180	8.66	16.4	164	0.49	4.8	1.00	0.54	26%	74%
	190	9.14	16.8	173	0.51	4.8	1.00	0.54	28%	72%
	200	9.62	17.1	182	0.54	4.8	1.00	0.54	29%	71%
	210	10.10	17.4	192	0.57	4.8	1.00	0.54	31%	69%
Kelt	650	31.27	24.2	593	1.00	4.8	1.00	0.54	54%	46%
	675	32.48	24.5	616	1.00	4.8	1.00	0.54	54%	46%
	700	33.68	24.7	639	1.00	4.8	1.00	0.54	54%	46%
	725	34.88	24.9	662	1.00	4.8	1.00	0.54	54%	46%
	750	36.08	25.1	684	1.00	4.8	1.00	0.54	54%	46%
	775	37.29	25.3	707	1.00	4.8	1.00	0.54	54%	46%
	800	38.49	25.5	730	1.00	4.8	1.00	0.54	54%	46%

Table D 112. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 1, and 2; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	126	0.37	4.8	1.00	0.78	29%	71%
	140	6.74	14.9	136	0.40	4.8	1.00	0.78	31%	69%
	150	7.22	15.3	145	0.43	4.8	1.00	0.78	34%	66%
	160	7.70	15.7	155	0.46	4.8	1.00	0.78	36%	64%
	170	8.18	16.1	165	0.49	4.8	1.00	0.78	38%	62%
	180	8.66	16.4	175	0.52	4.8	1.00	0.78	40%	60%
	190	9.14	16.8	184	0.54	4.8	1.00	0.78	42%	58%
	200	9.62	17.1	194	0.57	4.8	1.00	0.78	45%	55%
	210	10.10	17.4	204	0.60	4.8	1.00	0.78	47%	53%
Kelt	650	31.27	24.2	630	1.00	4.8	1.00	0.78	78%	22%
	675	32.48	24.5	655	1.00	4.8	1.00	0.78	78%	22%
	700	33.68	24.7	679	1.00	4.8	1.00	0.78	78%	22%
	725	34.88	24.9	703	1.00	4.8	1.00	0.78	78%	22%
	750	36.08	25.1	727	1.00	4.8	1.00	0.78	78%	22%
	775	37.29	25.3	751	1.00	4.8	1.00	0.78	78%	22%
	800	38.49	25.5	776	1.00	4.8	1.00	0.78	78%	22%

Table D 113. Input parameters for the prediction of strike probability and mortality for Mattaceunk units 1, and 2; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	6.25	14.5	108	0.32	4.8	1.00	0.54	17%	83%
	140	6.74	14.9	116	0.34	4.8	1.00	0.54	19%	81%
	150	7.22	15.3	124	0.37	4.8	1.00	0.54	20%	80%
	160	7.70	15.7	132	0.39	4.8	1.00	0.54	21%	79%
	170	8.18	16.1	141	0.42	4.8	1.00	0.54	23%	77%
	180	8.66	16.4	149	0.44	4.8	1.00	0.54	24%	76%
	190	9.14	16.8	157	0.46	4.8	1.00	0.54	25%	75%
	200	9.62	17.1	166	0.49	4.8	1.00	0.54	26%	74%
	210	10.10	17.4	174	0.51	4.8	1.00	0.54	28%	72%
Kelt	650	31.27	24.2	538	1.00	4.8	1.00	0.54	54%	46%
	675	32.48	24.5	559	1.00	4.8	1.00	0.54	54%	46%
	700	33.68	24.7	579	1.00	4.8	1.00	0.54	54%	46%
	725	34.88	24.9	600	1.00	4.8	1.00	0.54	54%	46%
	750	36.08	25.1	621	1.00	4.8	1.00	0.54	54%	46%
	775	37.29	25.3	641	1.00	4.8	1.00	0.54	54%	46%
	800	38.49	25.5	662	1.00	4.8	1.00	0.54	54%	46%

Table D 114. Input parameters for the prediction of strike probability and mortality for Orono unit 1; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	65	1.00	4.8	0.16	0.10	10%	90%
	140	11.48	18.2	70	1.00	4.8	0.16	0.11	11%	89%
	150	12.30	18.6	75	1.00	4.8	0.17	0.11	11%	89%
	160	13.12	19.0	80	1.00	4.8	0.17	0.11	11%	89%
	170	13.94	19.3	85	1.00	4.8	0.17	0.11	11%	89%
	180	14.76	19.7	90	1.00	4.8	0.18	0.11	11%	89%
	190	15.58	20.0	95	1.00	4.8	0.18	0.12	12%	88%
	200	16.40	20.3	100	1.00	4.8	0.18	0.12	12%	88%
	210	17.22	20.6	105	1.00	4.8	0.19	0.12	12%	88%
Kelt	650	53.31	27.5	327	1.00	4.8	0.25	0.16	16%	84%
	675	55.36	27.7	339	1.00	4.8	0.25	0.16	16%	84%
	700	57.41	27.9	352	1.00	4.8	0.25	0.16	16%	84%
	725	59.47	28.1	364	1.00	4.8	0.25	0.16	16%	84%
	750	61.52	28.3	377	1.00	4.8	0.25	0.17	17%	83%
	775	63.57	28.5	389	1.00	4.8	0.26	0.17	17%	83%
	800	65.62	28.7	402	1.00	4.8	0.26	0.17	17%	83%

Table D 115. Input parameters for the prediction of strike probability and mortality for Orono unit 1; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	84	1.00	4.8	0.16	0.10	10%	90%
	140	11.48	18.2	90	1.00	4.8	0.16	0.11	11%	89%
	150	12.30	18.6	97	1.00	4.8	0.17	0.11	11%	89%
	160	13.12	19.0	103	1.00	4.8	0.17	0.11	11%	89%
	170	13.94	19.3	110	1.00	4.8	0.17	0.11	11%	89%
	180	14.76	19.7	116	1.00	4.8	0.18	0.11	11%	89%
	190	15.58	20.0	123	1.00	4.8	0.18	0.12	12%	88%
	200	16.40	20.3	129	1.00	4.8	0.18	0.12	12%	88%
	210	17.22	20.6	135	1.00	4.8	0.19	0.12	12%	88%
Kelt	650	53.31	27.5	419	1.00	4.8	0.25	0.16	16%	84%
	675	55.36	27.7	435	1.00	4.8	0.25	0.16	16%	84%
	700	57.41	27.9	451	1.00	4.8	0.25	0.16	16%	84%
	725	59.47	28.1	468	1.00	4.8	0.25	0.16	16%	84%
	750	61.52	28.3	484	1.00	4.8	0.25	0.17	17%	83%
	775	63.57	28.5	500	1.00	4.8	0.26	0.17	17%	83%
	800	65.62	28.7	516	1.00	4.8	0.26	0.17	17%	83%

Table D 116. Input parameters for the prediction of strike probability and mortality for Orono unit 1; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	45	0.81	4.8	0.16	0.10	8%	92%
	140	11.48	18.2	48	0.87	4.8	0.16	0.11	9%	91%
	150	12.30	18.6	52	0.94	4.8	0.17	0.11	10%	90%
	160	13.12	19.0	55	1.00	4.8	0.17	0.11	11%	89%
	170	13.94	19.3	59	1.00	4.8	0.17	0.11	11%	89%
	180	14.76	19.7	62	1.00	4.8	0.18	0.11	11%	89%
	190	15.58	20.0	65	1.00	4.8	0.18	0.12	12%	88%
	200	16.40	20.3	69	1.00	4.8	0.18	0.12	12%	88%
	210	17.22	20.6	72	1.00	4.8	0.19	0.12	12%	88%
Kelt	650	53.31	27.5	224	1.00	4.8	0.25	0.16	16%	84%
	675	55.36	27.7	233	1.00	4.8	0.25	0.16	16%	84%
	700	57.41	27.9	241	1.00	4.8	0.25	0.16	16%	84%
	725	59.47	28.1	250	1.00	4.8	0.25	0.16	16%	84%
	750	61.52	28.3	258	1.00	4.8	0.25	0.17	17%	83%
	775	63.57	28.5	267	1.00	4.8	0.26	0.17	17%	83%
	800	65.62	28.7	276	1.00	4.8	0.26	0.17	17%	83%

Table D 117. Input parameters for the prediction of strike probability and mortality for Orono unit 1; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	65	1.00	4.8	0.16	0.12	12%	88%
	140	11.48	18.2	70	1.00	4.8	0.16	0.13	13%	87%
	150	12.30	18.6	75	1.00	4.8	0.17	0.13	13%	87%
	160	13.12	19.0	80	1.00	4.8	0.17	0.13	13%	87%
	170	13.94	19.3	85	1.00	4.8	0.17	0.14	14%	86%
	180	14.76	19.7	90	1.00	4.8	0.18	0.14	14%	86%
	190	15.58	20.0	95	1.00	4.8	0.18	0.14	14%	86%
	200	16.40	20.3	100	1.00	4.8	0.18	0.14	14%	86%
	210	17.22	20.6	105	1.00	4.8	0.19	0.14	14%	86%
Kelt	650	53.31	27.5	327	1.00	4.8	0.25	0.19	19%	81%
	675	55.36	27.7	339	1.00	4.8	0.25	0.19	19%	81%
	700	57.41	27.9	352	1.00	4.8	0.25	0.20	20%	80%
	725	59.47	28.1	364	1.00	4.8	0.25	0.20	20%	80%
	750	61.52	28.3	377	1.00	4.8	0.25	0.20	20%	80%
	775	63.57	28.5	389	1.00	4.8	0.26	0.20	20%	80%
	800	65.62	28.7	402	1.00	4.8	0.26	0.20	20%	80%

Table D 118. Input parameters for the prediction of strike probability and mortality for Orono unit 1; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	65	1.00	4.8	0.16	0.09	9%	91%
	140	11.48	18.2	70	1.00	4.8	0.16	0.09	9%	91%
	150	12.30	18.6	75	1.00	4.8	0.17	0.09	9%	91%
	160	13.12	19.0	80	1.00	4.8	0.17	0.09	9%	91%
	170	13.94	19.3	85	1.00	4.8	0.17	0.09	9%	91%
	180	14.76	19.7	90	1.00	4.8	0.18	0.10	10%	90%
	190	15.58	20.0	95	1.00	4.8	0.18	0.10	10%	90%
	200	16.40	20.3	100	1.00	4.8	0.18	0.10	10%	90%
	210	17.22	20.6	105	1.00	4.8	0.19	0.10	10%	90%
Kelt	650	53.31	27.5	327	1.00	4.8	0.25	0.13	13%	87%
	675	55.36	27.7	339	1.00	4.8	0.25	0.13	13%	87%
	700	57.41	27.9	352	1.00	4.8	0.25	0.14	14%	86%
	725	59.47	28.1	364	1.00	4.8	0.25	0.14	14%	86%
	750	61.52	28.3	377	1.00	4.8	0.25	0.14	14%	86%
	775	63.57	28.5	389	1.00	4.8	0.26	0.14	14%	86%
	800	65.62	28.7	402	1.00	4.8	0.26	0.14	14%	86%

Table D 119. Input parameters for the prediction of strike probability and mortality for Orono unit 1; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	84	1.00	4.8	0.16	0.12	12%	88%
	140	11.48	18.2	90	1.00	4.8	0.16	0.13	13%	87%
	150	12.30	18.6	97	1.00	4.8	0.17	0.13	13%	87%
	160	13.12	19.0	103	1.00	4.8	0.17	0.13	13%	87%
	170	13.94	19.3	110	1.00	4.8	0.17	0.14	14%	86%
	180	14.76	19.7	116	1.00	4.8	0.18	0.14	14%	86%
	190	15.58	20.0	123	1.00	4.8	0.18	0.14	14%	86%
	200	16.40	20.3	129	1.00	4.8	0.18	0.14	14%	86%
	210	17.22	20.6	135	1.00	4.8	0.19	0.14	14%	86%
Kelt	650	53.31	27.5	419	1.00	4.8	0.25	0.19	19%	81%
	675	55.36	27.7	435	1.00	4.8	0.25	0.19	19%	81%
	700	57.41	27.9	451	1.00	4.8	0.25	0.20	20%	80%
	725	59.47	28.1	468	1.00	4.8	0.25	0.20	20%	80%
	750	61.52	28.3	484	1.00	4.8	0.25	0.20	20%	80%
	775	63.57	28.5	500	1.00	4.8	0.26	0.20	20%	80%
	800	65.62	28.7	516	1.00	4.8	0.26	0.20	20%	80%

Table D 120. Input parameters for the prediction of strike probability and mortality for Orono unit 1; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	45	0.81	4.8	0.16	0.09	7%	93%
	140	11.48	18.2	48	0.87	4.8	0.16	0.09	8%	92%
	150	12.30	18.6	52	0.94	4.8	0.17	0.09	8%	92%
	160	13.12	19.0	55	1.00	4.8	0.17	0.09	9%	91%
	170	13.94	19.3	59	1.00	4.8	0.17	0.09	9%	91%
	180	14.76	19.7	62	1.00	4.8	0.18	0.10	10%	90%
	190	15.58	20.0	65	1.00	4.8	0.18	0.10	10%	90%
	200	16.40	20.3	69	1.00	4.8	0.18	0.10	10%	90%
	210	17.22	20.6	72	1.00	4.8	0.19	0.10	10%	90%
Kelt	650	53.31	27.5	224	1.00	4.8	0.25	0.13	13%	87%
	675	55.36	27.7	233	1.00	4.8	0.25	0.13	13%	87%
	700	57.41	27.9	241	1.00	4.8	0.25	0.14	14%	86%
	725	59.47	28.1	250	1.00	4.8	0.25	0.14	14%	86%
	750	61.52	28.3	258	1.00	4.8	0.25	0.14	14%	86%
	775	63.57	28.5	267	1.00	4.8	0.26	0.14	14%	86%
	800	65.62	28.7	276	1.00	4.8	0.26	0.14	14%	86%

Table D 121. Input parameters for the prediction of strike probability and mortality for Orono unit 2; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	1.00	4.8	0.13	0.08	8%	92%
	140	11.48	18.2	81	1.00	4.8	0.13	0.09	9%	91%
	150	12.30	18.6	87	1.00	4.8	0.14	0.09	9%	91%
	160	13.12	19.0	93	1.00	4.8	0.14	0.09	9%	91%
	170	13.94	19.3	98	1.00	4.8	0.14	0.09	9%	91%
	180	14.76	19.7	104	1.00	4.8	0.15	0.09	9%	91%
	190	15.58	20.0	110	1.00	4.8	0.15	0.10	10%	90%
	200	16.40	20.3	116	1.00	4.8	0.15	0.10	10%	90%
	210	17.22	20.6	122	1.00	4.8	0.15	0.10	10%	90%
Kelt	650	53.31	27.5	376	1.00	4.8	0.20	0.13	13%	87%
	675	55.36	27.7	391	1.00	4.8	0.20	0.13	13%	87%
	700	57.41	27.9	405	1.00	4.8	0.21	0.13	13%	87%
	725	59.47	28.1	420	1.00	4.8	0.21	0.13	13%	87%
	750	61.52	28.3	434	1.00	4.8	0.21	0.14	14%	86%
	775	63.57	28.5	449	1.00	4.8	0.21	0.14	14%	86%
	800	65.62	28.7	463	1.00	4.8	0.21	0.14	14%	86%

Table D 122. Input parameters for the prediction of strike probability and mortality for Orono unit 2; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	93	1.00	4.8	0.13	0.08	8%	92%
	140	11.48	18.2	100	1.00	4.8	0.13	0.09	9%	91%
	150	12.30	18.6	107	1.00	4.8	0.14	0.09	9%	91%
	160	13.12	19.0	114	1.00	4.8	0.14	0.09	9%	91%
	170	13.94	19.3	121	1.00	4.8	0.14	0.09	9%	91%
	180	14.76	19.7	128	1.00	4.8	0.15	0.09	9%	91%
	190	15.58	20.0	135	1.00	4.8	0.15	0.10	10%	90%
	200	16.40	20.3	142	1.00	4.8	0.15	0.10	10%	90%
	210	17.22	20.6	150	1.00	4.8	0.15	0.10	10%	90%
Kelt	650	53.31	27.5	463	1.00	4.8	0.20	0.13	13%	87%
	675	55.36	27.7	481	1.00	4.8	0.20	0.13	13%	87%
	700	57.41	27.9	498	1.00	4.8	0.21	0.13	13%	87%
	725	59.47	28.1	516	1.00	4.8	0.21	0.13	13%	87%
	750	61.52	28.3	534	1.00	4.8	0.21	0.14	14%	86%
	775	63.57	28.5	552	1.00	4.8	0.21	0.14	14%	86%
	800	65.62	28.7	570	1.00	4.8	0.21	0.14	14%	86%

Table D 123. Input parameters for the prediction of strike probability and mortality for Orono unit 2; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	56	0.90	4.8	0.13	0.08	8%	92%
	140	11.48	18.2	60	0.97	4.8	0.13	0.09	8%	92%
	150	12.30	18.6	64	1.00	4.8	0.14	0.09	9%	91%
	160	13.12	19.0	69	1.00	4.8	0.14	0.09	9%	91%
	170	13.94	19.3	73	1.00	4.8	0.14	0.09	9%	91%
	180	14.76	19.7	77	1.00	4.8	0.15	0.09	9%	91%
	190	15.58	20.0	81	1.00	4.8	0.15	0.10	10%	90%
	200	16.40	20.3	86	1.00	4.8	0.15	0.10	10%	90%
	210	17.22	20.6	90	1.00	4.8	0.15	0.10	10%	90%
Kelt	650	53.31	27.5	279	1.00	4.8	0.20	0.13	13%	87%
	675	55.36	27.7	289	1.00	4.8	0.20	0.13	13%	87%
	700	57.41	27.9	300	1.00	4.8	0.21	0.13	13%	87%
	725	59.47	28.1	311	1.00	4.8	0.21	0.13	13%	87%
	750	61.52	28.3	322	1.00	4.8	0.21	0.14	14%	86%
	775	63.57	28.5	332	1.00	4.8	0.21	0.14	14%	86%
	800	65.62	28.7	343	1.00	4.8	0.21	0.14	14%	86%

Table D 124. Input parameters for the prediction of strike probability and mortality for Orono unit 2; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	1.00	4.8	0.13	0.10	10%	90%
	140	11.48	18.2	81	1.00	4.8	0.13	0.10	10%	90%
	150	12.30	18.6	87	1.00	4.8	0.14	0.11	11%	89%
	160	13.12	19.0	93	1.00	4.8	0.14	0.11	11%	89%
	170	13.94	19.3	98	1.00	4.8	0.14	0.11	11%	89%
	180	14.76	19.7	104	1.00	4.8	0.15	0.11	11%	89%
	190	15.58	20.0	110	1.00	4.8	0.15	0.12	12%	88%
	200	16.40	20.3	116	1.00	4.8	0.15	0.12	12%	88%
	210	17.22	20.6	122	1.00	4.8	0.15	0.12	12%	88%
Kelt	650	53.31	27.5	376	1.00	4.8	0.20	0.16	16%	84%
	675	55.36	27.7	391	1.00	4.8	0.20	0.16	16%	84%
	700	57.41	27.9	405	1.00	4.8	0.21	0.16	16%	84%
	725	59.47	28.1	420	1.00	4.8	0.21	0.16	16%	84%
	750	61.52	28.3	434	1.00	4.8	0.21	0.16	16%	84%
	775	63.57	28.5	449	1.00	4.8	0.21	0.16	16%	84%
	800	65.62	28.7	463	1.00	4.8	0.21	0.17	17%	83%

Table D 125. Input parameters for the prediction of strike probability and mortality for Orono unit 2; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	1.00	4.8	0.13	0.07	7%	93%
	140	11.48	18.2	81	1.00	4.8	0.13	0.07	7%	93%
	150	12.30	18.6	87	1.00	4.8	0.14	0.07	7%	93%
	160	13.12	19.0	93	1.00	4.8	0.14	0.08	8%	92%
	170	13.94	19.3	98	1.00	4.8	0.14	0.08	8%	92%
	180	14.76	19.7	104	1.00	4.8	0.15	0.08	8%	92%
	190	15.58	20.0	110	1.00	4.8	0.15	0.08	8%	92%
	200	16.40	20.3	116	1.00	4.8	0.15	0.08	8%	92%
	210	17.22	20.6	122	1.00	4.8	0.15	0.08	8%	92%
Kelt	650	53.31	27.5	376	1.00	4.8	0.20	0.11	11%	89%
	675	55.36	27.7	391	1.00	4.8	0.20	0.11	11%	89%
	700	57.41	27.9	405	1.00	4.8	0.21	0.11	11%	89%
	725	59.47	28.1	420	1.00	4.8	0.21	0.11	11%	89%
	750	61.52	28.3	434	1.00	4.8	0.21	0.11	11%	89%
	775	63.57	28.5	449	1.00	4.8	0.21	0.11	11%	89%
	800	65.62	28.7	463	1.00	4.8	0.21	0.11	11%	89%

Table D 126. Input parameters for the prediction of strike probability and mortality for Orono unit 2; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	93	1.00	4.8	0.13	0.10	10%	90%
	140	11.48	18.2	100	1.00	4.8	0.13	0.10	10%	90%
	150	12.30	18.6	107	1.00	4.8	0.14	0.11	11%	89%
	160	13.12	19.0	114	1.00	4.8	0.14	0.11	11%	89%
	170	13.94	19.3	121	1.00	4.8	0.14	0.11	11%	89%
	180	14.76	19.7	128	1.00	4.8	0.15	0.11	11%	89%
	190	15.58	20.0	135	1.00	4.8	0.15	0.12	12%	88%
	200	16.40	20.3	142	1.00	4.8	0.15	0.12	12%	88%
	210	17.22	20.6	150	1.00	4.8	0.15	0.12	12%	88%
Kelt	650	53.31	27.5	463	1.00	4.8	0.20	0.16	16%	84%
	675	55.36	27.7	481	1.00	4.8	0.20	0.16	16%	84%
	700	57.41	27.9	498	1.00	4.8	0.21	0.16	16%	84%
	725	59.47	28.1	516	1.00	4.8	0.21	0.16	16%	84%
	750	61.52	28.3	534	1.00	4.8	0.21	0.16	16%	84%
	775	63.57	28.5	552	1.00	4.8	0.21	0.16	16%	84%
	800	65.62	28.7	570	1.00	4.8	0.21	0.17	17%	83%

Table D 127. Input parameters for the prediction of strike probability and mortality for Orono unit 2; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	56	0.90	4.8	0.13	0.07	6%	94%
	140	11.48	18.2	60	0.97	4.8	0.13	0.07	7%	93%
	150	12.30	18.6	64	1.00	4.8	0.14	0.07	7%	93%
	160	13.12	19.0	69	1.00	4.8	0.14	0.08	8%	92%
	170	13.94	19.3	73	1.00	4.8	0.14	0.08	8%	92%
	180	14.76	19.7	77	1.00	4.8	0.15	0.08	8%	92%
	190	15.58	20.0	81	1.00	4.8	0.15	0.08	8%	92%
	200	16.40	20.3	86	1.00	4.8	0.15	0.08	8%	92%
	210	17.22	20.6	90	1.00	4.8	0.15	0.08	8%	92%
Kelt	650	53.31	27.5	279	1.00	4.8	0.20	0.11	11%	89%
	675	55.36	27.7	289	1.00	4.8	0.20	0.11	11%	89%
	700	57.41	27.9	300	1.00	4.8	0.21	0.11	11%	89%
	725	59.47	28.1	311	1.00	4.8	0.21	0.11	11%	89%
	750	61.52	28.3	322	1.00	4.8	0.21	0.11	11%	89%
	775	63.57	28.5	332	1.00	4.8	0.21	0.11	11%	89%
	800	65.62	28.7	343	1.00	4.8	0.21	0.11	11%	89%

Table D 128. Input parameters for the prediction of strike probability and mortality for Orono units 3, and 4; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	52	0.85	4.8	0.22	0.14	12%	88%
	140	11.48	18.2	56	0.92	4.8	0.22	0.14	13%	87%
	150	12.30	18.6	60	0.98	4.8	0.23	0.15	14%	86%
	160	13.12	19.0	64	1.00	4.8	0.23	0.15	15%	85%
	170	13.94	19.3	68	1.00	4.8	0.24	0.15	15%	85%
	180	14.76	19.7	72	1.00	4.8	0.24	0.16	16%	84%
	190	15.58	20.0	76	1.00	4.8	0.24	0.16	16%	84%
	200	16.40	20.3	80	1.00	4.8	0.25	0.16	16%	84%
	210	17.22	20.6	84	1.00	4.8	0.25	0.16	16%	84%
Kelt	650	53.31	27.5	259	1.00	4.8	0.33	0.22	22%	78%
	675	55.36	27.7	269	1.00	4.8	0.34	0.22	22%	78%
	700	57.41	27.9	279	1.00	4.8	0.34	0.22	22%	78%
	725	59.47	28.1	289	1.00	4.8	0.34	0.22	22%	78%
	750	61.52	28.3	299	1.00	4.8	0.35	0.22	22%	78%
	775	63.57	28.5	309	1.00	4.8	0.35	0.23	23%	77%
	800	65.62	28.7	319	1.00	4.8	0.35	0.23	23%	77%

Table D 129. Input parameters for the prediction of strike probability and mortality for Orono units 3, and 4; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	72	1.00	4.8	0.22	0.14	14%	86%
	140	11.48	18.2	77	1.00	4.8	0.22	0.14	14%	86%
	150	12.30	18.6	83	1.00	4.8	0.23	0.15	15%	85%
	160	13.12	19.0	88	1.00	4.8	0.23	0.15	15%	85%
	170	13.94	19.3	94	1.00	4.8	0.24	0.15	15%	85%
	180	14.76	19.7	99	1.00	4.8	0.24	0.16	16%	84%
	190	15.58	20.0	105	1.00	4.8	0.24	0.16	16%	84%
	200	16.40	20.3	110	1.00	4.8	0.25	0.16	16%	84%
	210	17.22	20.6	116	1.00	4.8	0.25	0.16	16%	84%
Kelt	650	53.31	27.5	359	1.00	4.8	0.33	0.22	22%	78%
	675	55.36	27.7	373	1.00	4.8	0.34	0.22	22%	78%
	700	57.41	27.9	386	1.00	4.8	0.34	0.22	22%	78%
	725	59.47	28.1	400	1.00	4.8	0.34	0.22	22%	78%
	750	61.52	28.3	414	1.00	4.8	0.35	0.22	22%	78%
	775	63.57	28.5	428	1.00	4.8	0.35	0.23	23%	77%
	800	65.62	28.7	442	1.00	4.8	0.35	0.23	23%	77%

Table D 130. Input parameters for the prediction of strike probability and mortality for Orono units 3, and 4; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	30	0.50	4.8	0.22	0.14	7%	93%
	140	11.48	18.2	33	0.54	4.8	0.22	0.14	8%	92%
	150	12.30	18.6	35	0.58	4.8	0.23	0.15	8%	92%
	160	13.12	19.0	37	0.61	4.8	0.23	0.15	9%	91%
	170	13.94	19.3	40	0.65	4.8	0.24	0.15	10%	90%
	180	14.76	19.7	42	0.69	4.8	0.24	0.16	11%	89%
	190	15.58	20.0	44	0.73	4.8	0.24	0.16	12%	88%
	200	16.40	20.3	47	0.77	4.8	0.25	0.16	12%	88%
	210	17.22	20.6	49	0.81	4.8	0.25	0.16	13%	87%
Kelt	650	53.31	27.5	152	1.00	4.8	0.33	0.22	22%	78%
	675	55.36	27.7	158	1.00	4.8	0.34	0.22	22%	78%
	700	57.41	27.9	163	1.00	4.8	0.34	0.22	22%	78%
	725	59.47	28.1	169	1.00	4.8	0.34	0.22	22%	78%
	750	61.52	28.3	175	1.00	4.8	0.35	0.22	22%	78%
	775	63.57	28.5	181	1.00	4.8	0.35	0.23	23%	77%
	800	65.62	28.7	187	1.00	4.8	0.35	0.23	23%	77%

Table D 131. Input parameters for the prediction of strike probability and mortality for Orono units 3, and 4; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	52	0.85	4.8	0.22	0.17	14%	86%
	140	11.48	18.2	56	0.92	4.8	0.22	0.17	16%	84%
	150	12.30	18.6	60	0.98	4.8	0.23	0.18	17%	83%
	160	13.12	19.0	64	1.00	4.8	0.23	0.18	18%	82%
	170	13.94	19.3	68	1.00	4.8	0.24	0.18	18%	82%
	180	14.76	19.7	72	1.00	4.8	0.24	0.19	19%	81%
	190	15.58	20.0	76	1.00	4.8	0.24	0.19	19%	81%
	200	16.40	20.3	80	1.00	4.8	0.25	0.19	19%	81%
	210	17.22	20.6	84	1.00	4.8	0.25	0.20	20%	80%
Kelt	650	53.31	27.5	259	1.00	4.8	0.33	0.26	26%	74%
	675	55.36	27.7	269	1.00	4.8	0.34	0.26	26%	74%
	700	57.41	27.9	279	1.00	4.8	0.34	0.27	27%	73%
	725	59.47	28.1	289	1.00	4.8	0.34	0.27	27%	73%
	750	61.52	28.3	299	1.00	4.8	0.35	0.27	27%	73%
	775	63.57	28.5	309	1.00	4.8	0.35	0.27	27%	73%
	800	65.62	28.7	319	1.00	4.8	0.35	0.27	27%	73%

Table D 132. Input parameters for the prediction of strike probability and mortality for Orono units 3, and 4; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	52	0.85	4.8	0.22	0.12	10%	90%
	140	11.48	18.2	56	0.92	4.8	0.22	0.12	11%	89%
	150	12.30	18.6	60	0.98	4.8	0.23	0.12	12%	88%
	160	13.12	19.0	64	1.00	4.8	0.23	0.13	13%	87%
	170	13.94	19.3	68	1.00	4.8	0.24	0.13	13%	87%
	180	14.76	19.7	72	1.00	4.8	0.24	0.13	13%	87%
	190	15.58	20.0	76	1.00	4.8	0.24	0.13	13%	87%
	200	16.40	20.3	80	1.00	4.8	0.25	0.13	13%	87%
	210	17.22	20.6	84	1.00	4.8	0.25	0.14	14%	86%
Kelt	650	53.31	27.5	259	1.00	4.8	0.33	0.18	18%	82%
	675	55.36	27.7	269	1.00	4.8	0.34	0.18	18%	82%
	700	57.41	27.9	279	1.00	4.8	0.34	0.18	18%	82%
	725	59.47	28.1	289	1.00	4.8	0.34	0.19	19%	81%
	750	61.52	28.3	299	1.00	4.8	0.35	0.19	19%	81%
	775	63.57	28.5	309	1.00	4.8	0.35	0.19	19%	81%
	800	65.62	28.7	319	1.00	4.8	0.35	0.19	19%	81%

Table D 133. Input parameters for the prediction of strike probability and mortality for Orono units 3, and 4; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	72	1.00	4.8	0.22	0.17	17%	83%
	140	11.48	18.2	77	1.00	4.8	0.22	0.17	17%	83%
	150	12.30	18.6	83	1.00	4.8	0.23	0.18	18%	82%
	160	13.12	19.0	88	1.00	4.8	0.23	0.18	18%	82%
	170	13.94	19.3	94	1.00	4.8	0.24	0.18	18%	82%
	180	14.76	19.7	99	1.00	4.8	0.24	0.19	19%	81%
	190	15.58	20.0	105	1.00	4.8	0.24	0.19	19%	81%
	200	16.40	20.3	110	1.00	4.8	0.25	0.19	19%	81%
	210	17.22	20.6	116	1.00	4.8	0.25	0.20	20%	80%
Kelt	650	53.31	27.5	359	1.00	4.8	0.33	0.26	26%	74%
	675	55.36	27.7	373	1.00	4.8	0.34	0.26	26%	74%
	700	57.41	27.9	386	1.00	4.8	0.34	0.27	27%	73%
	725	59.47	28.1	400	1.00	4.8	0.34	0.27	27%	73%
	750	61.52	28.3	414	1.00	4.8	0.35	0.27	27%	73%
	775	63.57	28.5	428	1.00	4.8	0.35	0.27	27%	73%
	800	65.62	28.7	442	1.00	4.8	0.35	0.27	27%	73%

Table D 134. Input parameters for the prediction of strike probability and mortality for Orono units 3, and 4; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	30	0.50	4.8	0.22	0.12	6%	94%
	140	11.48	18.2	33	0.54	4.8	0.22	0.12	6%	94%
	150	12.30	18.6	35	0.58	4.8	0.23	0.12	7%	93%
	160	13.12	19.0	37	0.61	4.8	0.23	0.13	8%	92%
	170	13.94	19.3	40	0.65	4.8	0.24	0.13	8%	92%
	180	14.76	19.7	42	0.69	4.8	0.24	0.13	9%	91%
	190	15.58	20.0	44	0.73	4.8	0.24	0.13	10%	90%
	200	16.40	20.3	47	0.77	4.8	0.25	0.13	10%	90%
	210	17.22	20.6	49	0.81	4.8	0.25	0.14	11%	89%
Kelt	650	53.31	27.5	152	1.00	4.8	0.33	0.18	18%	82%
	675	55.36	27.7	158	1.00	4.8	0.34	0.18	18%	82%
	700	57.41	27.9	163	1.00	4.8	0.34	0.18	18%	82%
	725	59.47	28.1	169	1.00	4.8	0.34	0.19	19%	81%
	750	61.52	28.3	175	1.00	4.8	0.35	0.19	19%	81%
	775	63.57	28.5	181	1.00	4.8	0.35	0.19	19%	81%
	800	65.62	28.7	187	1.00	4.8	0.35	0.19	19%	81%

Table D 135. Input parameters for the prediction of strike probability and mortality for Orono units 5,6,7; baseline prediction

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	113	0.22	4.8	1.00	0.65	14%	86%
	140	12.53	18.7	121	0.23	4.8	1.00	0.65	15%	85%
	150	13.42	19.1	130	0.25	4.8	1.00	0.65	16%	84%
	160	14.32	19.5	139	0.27	4.8	1.00	0.65	17%	83%
	170	15.21	19.9	147	0.29	4.8	1.00	0.65	19%	81%
	180	16.11	20.2	156	0.30	4.8	1.00	0.65	20%	80%
	190	17.00	20.5	165	0.32	4.8	1.00	0.65	21%	79%
	200	17.90	20.8	173	0.34	4.8	1.00	0.65	22%	78%
	210	18.79	21.1	182	0.35	4.8	1.00	0.65	23%	77%
Kelt	650	58.16	28.0	563	1.00	4.8	1.00	0.65	65%	35%
	675	60.40	28.2	585	1.00	4.8	1.00	0.65	65%	35%
	700	62.63	28.4	606	1.00	4.8	1.00	0.65	65%	35%
	725	64.87	28.6	628	1.00	4.8	1.00	0.65	65%	35%
	750	67.11	28.8	650	1.00	4.8	1.00	0.65	65%	35%
	775	69.35	29.0	671	1.00	4.8	1.00	0.65	65%	35%
	800	71.58	29.2	693	1.00	4.8	1.00	0.65	65%	35%

Table D 136. Input parameters for the prediction of strike probability and mortality for Orono units 5,6,7; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	122	0.24	4.8	1.00	0.65	15%	85%
	140	12.53	18.7	132	0.25	4.8	1.00	0.65	17%	83%
	150	13.42	19.1	141	0.27	4.8	1.00	0.65	18%	82%
	160	14.32	19.5	150	0.29	4.8	1.00	0.65	19%	81%
	170	15.21	19.9	160	0.31	4.8	1.00	0.65	20%	80%
	180	16.11	20.2	169	0.33	4.8	1.00	0.65	21%	79%
	190	17.00	20.5	179	0.35	4.8	1.00	0.65	22%	78%
	200	17.90	20.8	188	0.36	4.8	1.00	0.65	24%	76%
	210	18.79	21.1	197	0.38	4.8	1.00	0.65	25%	75%
Kelt	650	58.16	28.0	611	1.00	4.8	1.00	0.65	65%	35%
	675	60.40	28.2	634	1.00	4.8	1.00	0.65	65%	35%
	700	62.63	28.4	658	1.00	4.8	1.00	0.65	65%	35%
	725	64.87	28.6	681	1.00	4.8	1.00	0.65	65%	35%
	750	67.11	28.8	705	1.00	4.8	1.00	0.65	65%	35%
	775	69.35	29.0	728	1.00	4.8	1.00	0.65	65%	35%
	800	71.58	29.2	752	1.00	4.8	1.00	0.65	65%	35%

Table D 137. Input parameters for the prediction of strike probability and mortality for Orono units 5,6,7; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	100	0.19	4.8	1.00	0.65	13%	87%
	140	12.53	18.7	107	0.21	4.8	1.00	0.65	14%	86%
	150	13.42	19.1	115	0.22	4.8	1.00	0.65	14%	86%
	160	14.32	19.5	123	0.24	4.8	1.00	0.65	15%	85%
	170	15.21	19.9	130	0.25	4.8	1.00	0.65	16%	84%
	180	16.11	20.2	138	0.27	4.8	1.00	0.65	17%	83%
	190	17.00	20.5	146	0.28	4.8	1.00	0.65	18%	82%
	200	17.90	20.8	153	0.30	4.8	1.00	0.65	19%	81%
	210	18.79	21.1	161	0.31	4.8	1.00	0.65	20%	80%
Kelt	650	58.16	28.0	498	0.96	4.8	1.00	0.65	63%	37%
	675	60.40	28.2	517	1.00	4.8	1.00	0.65	65%	35%
	700	62.63	28.4	536	1.00	4.8	1.00	0.65	65%	35%
	725	64.87	28.6	555	1.00	4.8	1.00	0.65	65%	35%
	750	67.11	28.8	575	1.00	4.8	1.00	0.65	65%	35%
	775	69.35	29.0	594	1.00	4.8	1.00	0.65	65%	35%
	800	71.58	29.2	613	1.00	4.8	1.00	0.65	65%	35%

Table D 138. Input parameters for the prediction of strike probability and mortality for Orono units 5,6,7; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	113	0.22	4.8	1.00	0.78	17%	83%
	140	12.53	18.7	121	0.23	4.8	1.00	0.78	18%	82%
	150	13.42	19.1	130	0.25	4.8	1.00	0.78	20%	80%
	160	14.32	19.5	139	0.27	4.8	1.00	0.78	21%	79%
	170	15.21	19.9	147	0.29	4.8	1.00	0.78	22%	78%
	180	16.11	20.2	156	0.30	4.8	1.00	0.78	24%	76%
	190	17.00	20.5	165	0.32	4.8	1.00	0.78	25%	75%
	200	17.90	20.8	173	0.34	4.8	1.00	0.78	26%	74%
	210	18.79	21.1	182	0.35	4.8	1.00	0.78	27%	73%
Kelt	650	58.16	28.0	563	1.00	4.8	1.00	0.78	78%	22%
	675	60.40	28.2	585	1.00	4.8	1.00	0.78	78%	22%
	700	62.63	28.4	606	1.00	4.8	1.00	0.78	78%	22%
	725	64.87	28.6	628	1.00	4.8	1.00	0.78	78%	22%
	750	67.11	28.8	650	1.00	4.8	1.00	0.78	78%	22%
	775	69.35	29.0	671	1.00	4.8	1.00	0.78	78%	22%
	800	71.58	29.2	693	1.00	4.8	1.00	0.78	78%	22%

Table D 139. Input parameters for the prediction of strike probability and mortality for Orono units 5,6,7; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	113	0.22	4.8	1.00	0.54	12%	88%
	140	12.53	18.7	121	0.23	4.8	1.00	0.54	13%	87%
	150	13.42	19.1	130	0.25	4.8	1.00	0.54	14%	86%
	160	14.32	19.5	139	0.27	4.8	1.00	0.54	15%	85%
	170	15.21	19.9	147	0.29	4.8	1.00	0.54	15%	85%
	180	16.11	20.2	156	0.30	4.8	1.00	0.54	16%	84%
	190	17.00	20.5	165	0.32	4.8	1.00	0.54	17%	83%
	200	17.90	20.8	173	0.34	4.8	1.00	0.54	18%	82%
	210	18.79	21.1	182	0.35	4.8	1.00	0.54	19%	81%
Kelt	650	58.16	28.0	563	1.00	4.8	1.00	0.54	54%	46%
	675	60.40	28.2	585	1.00	4.8	1.00	0.54	54%	46%
	700	62.63	28.4	606	1.00	4.8	1.00	0.54	54%	46%
	725	64.87	28.6	628	1.00	4.8	1.00	0.54	54%	46%
	750	67.11	28.8	650	1.00	4.8	1.00	0.54	54%	46%
	775	69.35	29.0	671	1.00	4.8	1.00	0.54	54%	46%
	800	71.58	29.2	693	1.00	4.8	1.00	0.54	54%	46%

Table D 140. Input parameters for the prediction of strike probability and mortality for Orono units 5,6,7; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	122	0.24	4.8	1.00	0.78	18%	82%
	140	12.53	18.7	132	0.25	4.8	1.00	0.78	20%	80%
	150	13.42	19.1	141	0.27	4.8	1.00	0.78	21%	79%
	160	14.32	19.5	150	0.29	4.8	1.00	0.78	23%	77%
	170	15.21	19.9	160	0.31	4.8	1.00	0.78	24%	76%
	180	16.11	20.2	169	0.33	4.8	1.00	0.78	26%	74%
	190	17.00	20.5	179	0.35	4.8	1.00	0.78	27%	73%
	200	17.90	20.8	188	0.36	4.8	1.00	0.78	28%	72%
	210	18.79	21.1	197	0.38	4.8	1.00	0.78	30%	70%
Kelt	650	58.16	28.0	611	1.00	4.8	1.00	0.78	78%	22%
	675	60.40	28.2	634	1.00	4.8	1.00	0.78	78%	22%
	700	62.63	28.4	658	1.00	4.8	1.00	0.78	78%	22%
	725	64.87	28.6	681	1.00	4.8	1.00	0.78	78%	22%
	750	67.11	28.8	705	1.00	4.8	1.00	0.78	78%	22%
	775	69.35	29.0	728	1.00	4.8	1.00	0.78	78%	22%
	800	71.58	29.2	752	1.00	4.8	1.00	0.78	78%	22%

Table D 141. Input parameters for the prediction of strike probability and mortality for Orono units 5,6,7; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	100	0.19	4.8	1.00	0.54	10%	90%
	140	12.53	18.7	107	0.21	4.8	1.00	0.54	11%	89%
	150	13.42	19.1	115	0.22	4.8	1.00	0.54	12%	88%
	160	14.32	19.5	123	0.24	4.8	1.00	0.54	13%	87%
	170	15.21	19.9	130	0.25	4.8	1.00	0.54	14%	86%
	180	16.11	20.2	138	0.27	4.8	1.00	0.54	14%	86%
	190	17.00	20.5	146	0.28	4.8	1.00	0.54	15%	85%
	200	17.90	20.8	153	0.30	4.8	1.00	0.54	16%	84%
	210	18.79	21.1	161	0.31	4.8	1.00	0.54	17%	83%
Kelt	650	58.16	28.0	498	0.96	4.8	1.00	0.54	52%	48%
	675	60.40	28.2	517	1.00	4.8	1.00	0.54	54%	46%
	700	62.63	28.4	536	1.00	4.8	1.00	0.54	54%	46%
	725	64.87	28.6	555	1.00	4.8	1.00	0.54	54%	46%
	750	67.11	28.8	575	1.00	4.8	1.00	0.54	54%	46%
	775	69.35	29.0	594	1.00	4.8	1.00	0.54	54%	46%
	800	71.58	29.2	613	1.00	4.8	1.00	0.54	54%	46%

Table D 142. Input parameters for the prediction of strike probability and mortality for Stillwater units 1, 2, and 3; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	0.74	4.8	0.01	0.01	1%	99%
	140	11.48	18.2	80	0.80	4.8	0.02	0.01	1%	99%
	150	12.30	18.6	86	0.86	4.8	0.02	0.01	1%	99%
	160	13.12	19.0	92	0.91	4.8	0.02	0.01	1%	99%
	170	13.94	19.3	98	0.97	4.8	0.02	0.01	1%	99%
	180	14.76	19.7	103	1.00	4.8	0.02	0.01	1%	99%
	190	15.58	20.0	109	1.00	4.8	0.02	0.01	1%	99%
	200	16.40	20.3	115	1.00	4.8	0.02	0.01	1%	99%
	210	17.22	20.6	120	1.00	4.8	0.02	0.01	1%	99%
Kelt	650	53.31	27.5	373	1.00	4.8	0.02	0.01	1%	99%
	675	55.36	27.7	387	1.00	4.8	0.02	0.01	1%	99%
	700	57.41	27.9	402	1.00	4.8	0.02	0.01	1%	99%
	725	59.47	28.1	416	1.00	4.8	0.02	0.02	2%	98%
	750	61.52	28.3	430	1.00	4.8	0.02	0.02	2%	98%
	775	63.57	28.5	445	1.00	4.8	0.02	0.02	2%	98%
	800	65.62	28.7	459	1.00	4.8	0.02	0.02	2%	98%

Table D 143. Input parameters for the prediction of strike probability and mortality for Stillwater units 1, 2, and 3; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	92	0.92	4.8	0.01	0.01	1%	99%
	140	11.48	18.2	99	0.99	4.8	0.02	0.01	1%	99%
	150	12.30	18.6	106	1.00	4.8	0.02	0.01	1%	99%
	160	13.12	19.0	113	1.00	4.8	0.02	0.01	1%	99%
	170	13.94	19.3	120	1.00	4.8	0.02	0.01	1%	99%
	180	14.76	19.7	127	1.00	4.8	0.02	0.01	1%	99%
	190	15.58	20.0	134	1.00	4.8	0.02	0.01	1%	99%
	200	16.40	20.3	141	1.00	4.8	0.02	0.01	1%	99%
	210	17.22	20.6	148	1.00	4.8	0.02	0.01	1%	99%
Kelt	650	53.31	27.5	460	1.00	4.8	0.02	0.01	1%	99%
	675	55.36	27.7	477	1.00	4.8	0.02	0.01	1%	99%
	700	57.41	27.9	495	1.00	4.8	0.02	0.01	1%	99%
	725	59.47	28.1	513	1.00	4.8	0.02	0.02	2%	98%
	750	61.52	28.3	530	1.00	4.8	0.02	0.02	2%	98%
	775	63.57	28.5	548	1.00	4.8	0.02	0.02	2%	98%
	800	65.62	28.7	566	1.00	4.8	0.02	0.02	2%	98%

Table D 144. Input parameters for the prediction of strike probability and mortality for Stillwater units 1, 2, and 3; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	55	0.55	4.8	0.01	0.01	1%	99%
	140	11.48	18.2	59	0.59	4.8	0.02	0.01	1%	99%
	150	12.30	18.6	63	0.63	4.8	0.02	0.01	1%	99%
	160	13.12	19.0	68	0.67	4.8	0.02	0.01	1%	99%
	170	13.94	19.3	72	0.72	4.8	0.02	0.01	1%	99%
	180	14.76	19.7	76	0.76	4.8	0.02	0.01	1%	99%
	190	15.58	20.0	80	0.80	4.8	0.02	0.01	1%	99%
	200	16.40	20.3	85	0.84	4.8	0.02	0.01	1%	99%
	210	17.22	20.6	89	0.88	4.8	0.02	0.01	1%	99%
Kelt	650	53.31	27.5	275	1.00	4.8	0.02	0.01	1%	99%
	675	55.36	27.7	285	1.00	4.8	0.02	0.01	1%	99%
	700	57.41	27.9	296	1.00	4.8	0.02	0.01	1%	99%
	725	59.47	28.1	306	1.00	4.8	0.02	0.02	2%	98%
	750	61.52	28.3	317	1.00	4.8	0.02	0.02	2%	98%
	775	63.57	28.5	328	1.00	4.8	0.02	0.02	2%	98%
	800	65.62	28.7	338	1.00	4.8	0.02	0.02	2%	98%

Table D 145. Input parameters for the prediction of strike probability and mortality for Stillwater units 1, 2, and 3; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	0.74	4.8	0.01	0.01	1%	99%
	140	11.48	18.2	80	0.80	4.8	0.02	0.01	1%	99%
	150	12.30	18.6	86	0.86	4.8	0.02	0.01	1%	99%
	160	13.12	19.0	92	0.91	4.8	0.02	0.01	1%	99%
	170	13.94	19.3	98	0.97	4.8	0.02	0.01	1%	99%
	180	14.76	19.7	103	1.00	4.8	0.02	0.01	1%	99%
	190	15.58	20.0	109	1.00	4.8	0.02	0.01	1%	99%
	200	16.40	20.3	115	1.00	4.8	0.02	0.01	1%	99%
	210	17.22	20.6	120	1.00	4.8	0.02	0.01	1%	99%
Kelt	650	53.31	27.5	373	1.00	4.8	0.02	0.02	2%	98%
	675	55.36	27.7	387	1.00	4.8	0.02	0.02	2%	98%
	700	57.41	27.9	402	1.00	4.8	0.02	0.02	2%	98%
	725	59.47	28.1	416	1.00	4.8	0.02	0.02	2%	98%
	750	61.52	28.3	430	1.00	4.8	0.02	0.02	2%	98%
	775	63.57	28.5	445	1.00	4.8	0.02	0.02	2%	98%
	800	65.62	28.7	459	1.00	4.8	0.02	0.02	2%	98%

Table D 146. Input parameters for the prediction of strike probability and mortality for Stillwater units 1, 2, and 3; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	0.74	4.8	0.01	0.01	1%	99%
	140	11.48	18.2	80	0.80	4.8	0.02	0.01	1%	99%
	150	12.30	18.6	86	0.86	4.8	0.02	0.01	1%	99%
	160	13.12	19.0	92	0.91	4.8	0.02	0.01	1%	99%
	170	13.94	19.3	98	0.97	4.8	0.02	0.01	1%	99%
	180	14.76	19.7	103	1.00	4.8	0.02	0.01	1%	99%
	190	15.58	20.0	109	1.00	4.8	0.02	0.01	1%	99%
	200	16.40	20.3	115	1.00	4.8	0.02	0.01	1%	99%
	210	17.22	20.6	120	1.00	4.8	0.02	0.01	1%	99%
Kelt	650	53.31	27.5	373	1.00	4.8	0.02	0.01	1%	99%
	675	55.36	27.7	387	1.00	4.8	0.02	0.01	1%	99%
	700	57.41	27.9	402	1.00	4.8	0.02	0.01	1%	99%
	725	59.47	28.1	416	1.00	4.8	0.02	0.01	1%	99%
	750	61.52	28.3	430	1.00	4.8	0.02	0.01	1%	99%
	775	63.57	28.5	445	1.00	4.8	0.02	0.01	1%	99%
	800	65.62	28.7	459	1.00	4.8	0.02	0.01	1%	99%

Table D 147. Input parameters for the prediction of strike probability and mortality for Stillwater units 1, 2, and 3; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	0.74	4.8	0.01	0.01	1%	99%
	140	11.48	18.2	80	0.80	4.8	0.02	0.01	1%	99%
	150	12.30	18.6	86	0.86	4.8	0.02	0.01	1%	99%
	160	13.12	19.0	92	0.91	4.8	0.02	0.01	1%	99%
	170	13.94	19.3	98	0.97	4.8	0.02	0.01	1%	99%
	180	14.76	19.7	103	1.00	4.8	0.02	0.01	1%	99%
	190	15.58	20.0	109	1.00	4.8	0.02	0.01	1%	99%
	200	16.40	20.3	115	1.00	4.8	0.02	0.01	1%	99%
	210	17.22	20.6	120	1.00	4.8	0.02	0.01	1%	99%
Kelt	650	53.31	27.5	373	1.00	4.8	0.02	0.02	2%	98%
	675	55.36	27.7	387	1.00	4.8	0.02	0.02	2%	98%
	700	57.41	27.9	402	1.00	4.8	0.02	0.02	2%	98%
	725	59.47	28.1	416	1.00	4.8	0.02	0.02	2%	98%
	750	61.52	28.3	430	1.00	4.8	0.02	0.02	2%	98%
	775	63.57	28.5	445	1.00	4.8	0.02	0.02	2%	98%
	800	65.62	28.7	459	1.00	4.8	0.02	0.02	2%	98%

Table D 148. Input parameters for the prediction of strike probability and mortality for Stillwater units 1, 2, and 3; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	55	0.55	4.8	0.01	0.01	0%	100%
	140	11.48	18.2	59	0.59	4.8	0.02	0.01	0%	100%
	150	12.30	18.6	63	0.63	4.8	0.02	0.01	1%	99%
	160	13.12	19.0	68	0.67	4.8	0.02	0.01	1%	99%
	170	13.94	19.3	72	0.72	4.8	0.02	0.01	1%	99%
	180	14.76	19.7	76	0.76	4.8	0.02	0.01	1%	99%
	190	15.58	20.0	80	0.80	4.8	0.02	0.01	1%	99%
	200	16.40	20.3	85	0.84	4.8	0.02	0.01	1%	99%
	210	17.22	20.6	89	0.88	4.8	0.02	0.01	1%	99%
Kelt	650	53.31	27.5	275	1.00	4.8	0.02	0.01	1%	99%
	675	55.36	27.7	285	1.00	4.8	0.02	0.01	1%	99%
	700	57.41	27.9	296	1.00	4.8	0.02	0.01	1%	99%
	725	59.47	28.1	306	1.00	4.8	0.02	0.01	1%	99%
	750	61.52	28.3	317	1.00	4.8	0.02	0.01	1%	99%
	775	63.57	28.5	328	1.00	4.8	0.02	0.01	1%	99%
	800	65.62	28.7	338	1.00	4.8	0.02	0.01	1%	99%

Table D 149. Input parameters for the prediction of strike probability and mortality for Stillwater unit 4; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	0.61	4.8	0.18	0.12	7%	93%
	140	11.48	18.2	80	0.65	4.8	0.19	0.12	8%	92%
	150	12.30	18.6	86	0.70	4.8	0.19	0.13	9%	91%
	160	13.12	19.0	92	0.74	4.8	0.20	0.13	10%	90%
	170	13.94	19.3	98	0.79	4.8	0.20	0.13	10%	90%
	180	14.76	19.7	103	0.84	4.8	0.20	0.13	11%	89%
	190	15.58	20.0	109	0.88	4.8	0.21	0.14	12%	88%
	200	16.40	20.3	115	0.93	4.8	0.21	0.14	13%	87%
	210	17.22	20.6	120	0.98	4.8	0.21	0.14	14%	86%
Kelt	650	53.31	27.5	373	1.00	4.8	0.29	0.19	19%	81%
	675	55.36	27.7	387	1.00	4.8	0.29	0.19	19%	81%
	700	57.41	27.9	402	1.00	4.8	0.29	0.19	19%	81%
	725	59.47	28.1	416	1.00	4.8	0.29	0.19	19%	81%
	750	61.52	28.3	430	1.00	4.8	0.29	0.19	19%	81%
	775	63.57	28.5	445	1.00	4.8	0.30	0.19	19%	81%
	800	65.62	28.7	459	1.00	4.8	0.30	0.19	19%	81%

Table D 150. Input parameters for the prediction of strike probability and mortality for Stillwater unit 4; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	92	0.75	4.8	0.18	0.12	9%	91%
	140	11.48	18.2	99	0.80	4.8	0.19	0.12	10%	90%
	150	12.30	18.6	106	0.86	4.8	0.19	0.13	11%	89%
	160	13.12	19.0	113	0.92	4.8	0.20	0.13	12%	88%
	170	13.94	19.3	120	0.98	4.8	0.20	0.13	13%	87%
	180	14.76	19.7	127	1.00	4.8	0.20	0.13	13%	87%
	190	15.58	20.0	134	1.00	4.8	0.21	0.14	14%	86%
	200	16.40	20.3	141	1.00	4.8	0.21	0.14	14%	86%
	210	17.22	20.6	148	1.00	4.8	0.21	0.14	14%	86%
Kelt	650	53.31	27.5	460	1.00	4.8	0.29	0.19	19%	81%
	675	55.36	27.7	477	1.00	4.8	0.29	0.19	19%	81%
	700	57.41	27.9	495	1.00	4.8	0.29	0.19	19%	81%
	725	59.47	28.1	513	1.00	4.8	0.29	0.19	19%	81%
	750	61.52	28.3	530	1.00	4.8	0.29	0.19	19%	81%
	775	63.57	28.5	548	1.00	4.8	0.30	0.19	19%	81%
	800	65.62	28.7	566	1.00	4.8	0.30	0.19	19%	81%

Table D 151. Input parameters for the prediction of strike probability and mortality for Stillwater unit 4; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	55	0.45	4.8	0.18	0.12	5%	95%
	140	11.48	18.2	59	0.48	4.8	0.19	0.12	6%	94%
	150	12.30	18.6	63	0.51	4.8	0.19	0.13	6%	94%
	160	13.12	19.0	68	0.55	4.8	0.20	0.13	7%	93%
	170	13.94	19.3	72	0.58	4.8	0.20	0.13	8%	92%
	180	14.76	19.7	76	0.62	4.8	0.20	0.13	8%	92%
	190	15.58	20.0	80	0.65	4.8	0.21	0.14	9%	91%
	200	16.40	20.3	85	0.69	4.8	0.21	0.14	9%	91%
	210	17.22	20.6	89	0.72	4.8	0.21	0.14	10%	90%
Kelt	650	53.31	27.5	275	1.00	4.8	0.29	0.19	19%	81%
	675	55.36	27.7	285	1.00	4.8	0.29	0.19	19%	81%
	700	57.41	27.9	296	1.00	4.8	0.29	0.19	19%	81%
	725	59.47	28.1	306	1.00	4.8	0.29	0.19	19%	81%
	750	61.52	28.3	317	1.00	4.8	0.29	0.19	19%	81%
	775	63.57	28.5	328	1.00	4.8	0.30	0.19	19%	81%
	800	65.62	28.7	338	1.00	4.8	0.30	0.19	19%	81%

Table D 152. Input parameters for the prediction of strike probability and mortality for Stillwater unit 4; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	0.61	4.8	0.18	0.14	9%	91%
	140	11.48	18.2	80	0.65	4.8	0.19	0.15	10%	90%
	150	12.30	18.6	86	0.70	4.8	0.19	0.15	11%	89%
	160	13.12	19.0	92	0.74	4.8	0.20	0.15	11%	89%
	170	13.94	19.3	98	0.79	4.8	0.20	0.16	12%	88%
	180	14.76	19.7	103	0.84	4.8	0.20	0.16	13%	87%
	190	15.58	20.0	109	0.88	4.8	0.21	0.16	14%	86%
	200	16.40	20.3	115	0.93	4.8	0.21	0.16	15%	85%
	210	17.22	20.6	120	0.98	4.8	0.21	0.17	16%	84%
Kelt	650	53.31	27.5	373	1.00	4.8	0.29	0.22	22%	78%
	675	55.36	27.7	387	1.00	4.8	0.29	0.22	22%	78%
	700	57.41	27.9	402	1.00	4.8	0.29	0.23	23%	77%
	725	59.47	28.1	416	1.00	4.8	0.29	0.23	23%	77%
	750	61.52	28.3	430	1.00	4.8	0.29	0.23	23%	77%
	775	63.57	28.5	445	1.00	4.8	0.30	0.23	23%	77%
	800	65.62	28.7	459	1.00	4.8	0.30	0.23	23%	77%

Table D 153. Input parameters for the prediction of strike probability and mortality for Stillwater unit 4; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	0.61	4.8	0.18	0.10	6%	94%
	140	11.48	18.2	80	0.65	4.8	0.19	0.10	7%	93%
	150	12.30	18.6	86	0.70	4.8	0.19	0.10	7%	93%
	160	13.12	19.0	92	0.74	4.8	0.20	0.11	8%	92%
	170	13.94	19.3	98	0.79	4.8	0.20	0.11	9%	91%
	180	14.76	19.7	103	0.84	4.8	0.20	0.11	9%	91%
	190	15.58	20.0	109	0.88	4.8	0.21	0.11	10%	90%
	200	16.40	20.3	115	0.93	4.8	0.21	0.11	11%	89%
	210	17.22	20.6	120	0.98	4.8	0.21	0.12	11%	89%
Kelt	650	53.31	27.5	373	1.00	4.8	0.29	0.15	15%	85%
	675	55.36	27.7	387	1.00	4.8	0.29	0.16	16%	84%
	700	57.41	27.9	402	1.00	4.8	0.29	0.16	16%	84%
	725	59.47	28.1	416	1.00	4.8	0.29	0.16	16%	84%
	750	61.52	28.3	430	1.00	4.8	0.29	0.16	16%	84%
	775	63.57	28.5	445	1.00	4.8	0.30	0.16	16%	84%
	800	65.62	28.7	459	1.00	4.8	0.30	0.16	16%	84%

Table D 154. Input parameters for the prediction of strike probability and mortality for Stillwater unit 4; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	92	0.75	4.8	0.18	0.14	11%	89%
	140	11.48	18.2	99	0.80	4.8	0.19	0.15	12%	88%
	150	12.30	18.6	106	0.86	4.8	0.19	0.15	13%	87%
	160	13.12	19.0	113	0.92	4.8	0.20	0.15	14%	86%
	170	13.94	19.3	120	0.98	4.8	0.20	0.16	15%	85%
	180	14.76	19.7	127	1.00	4.8	0.20	0.16	16%	84%
	190	15.58	20.0	134	1.00	4.8	0.21	0.16	16%	84%
	200	16.40	20.3	141	1.00	4.8	0.21	0.16	16%	84%
	210	17.22	20.6	148	1.00	4.8	0.21	0.17	17%	83%
Kelt	650	53.31	27.5	460	1.00	4.8	0.29	0.22	22%	78%
	675	55.36	27.7	477	1.00	4.8	0.29	0.22	22%	78%
	700	57.41	27.9	495	1.00	4.8	0.29	0.23	23%	77%
	725	59.47	28.1	513	1.00	4.8	0.29	0.23	23%	77%
	750	61.52	28.3	530	1.00	4.8	0.29	0.23	23%	77%
	775	63.57	28.5	548	1.00	4.8	0.30	0.23	23%	77%
	800	65.62	28.7	566	1.00	4.8	0.30	0.23	23%	77%

Table D 155. Input parameters for the prediction of strike probability and mortality for Stillwater unit 4; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	55	0.45	4.8	0.18	0.10	4%	96%
	140	11.48	18.2	59	0.48	4.8	0.19	0.10	5%	95%
	150	12.30	18.6	63	0.51	4.8	0.19	0.10	5%	95%
	160	13.12	19.0	68	0.55	4.8	0.20	0.11	6%	94%
	170	13.94	19.3	72	0.58	4.8	0.20	0.11	6%	94%
	180	14.76	19.7	76	0.62	4.8	0.20	0.11	7%	93%
	190	15.58	20.0	80	0.65	4.8	0.21	0.11	7%	93%
	200	16.40	20.3	85	0.69	4.8	0.21	0.11	8%	92%
	210	17.22	20.6	89	0.72	4.8	0.21	0.12	8%	92%
Kelt	650	53.31	27.5	275	1.00	4.8	0.29	0.15	15%	85%
	675	55.36	27.7	285	1.00	4.8	0.29	0.16	16%	84%
	700	57.41	27.9	296	1.00	4.8	0.29	0.16	16%	84%
	725	59.47	28.1	306	1.00	4.8	0.29	0.16	16%	84%
	750	61.52	28.3	317	1.00	4.8	0.29	0.16	16%	84%
	775	63.57	28.5	328	1.00	4.8	0.30	0.16	16%	84%
	800	65.62	28.7	338	1.00	4.8	0.30	0.16	16%	84%

Table D 156. Input parameters for the prediction of strike probability and mortality for Stillwater unit 5,6,7 baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	113	0.22	4.8	1.00	0.65	14%	86%
	140	12.53	18.7	121	0.24	4.8	1.00	0.65	15%	85%
	150	13.42	19.1	130	0.26	4.8	1.00	0.65	17%	83%
	160	14.32	19.5	139	0.27	4.8	1.00	0.65	18%	82%
	170	15.21	19.9	147	0.29	4.8	1.00	0.65	19%	81%
	180	16.11	20.2	156	0.31	4.8	1.00	0.65	20%	80%
	190	17.00	20.5	165	0.32	4.8	1.00	0.65	21%	79%
	200	17.90	20.8	173	0.34	4.8	1.00	0.65	22%	78%
	210	18.79	21.1	182	0.36	4.8	1.00	0.65	23%	77%
Kelt	650	58.16	28.0	563	1.00	4.8	1.00	0.65	65%	35%
	675	60.40	28.2	585	1.00	4.8	1.00	0.65	65%	35%
	700	62.63	28.4	606	1.00	4.8	1.00	0.65	65%	35%
	725	64.87	28.6	628	1.00	4.8	1.00	0.65	65%	35%
	750	67.11	28.8	650	1.00	4.8	1.00	0.65	65%	35%
	775	69.35	29.0	671	1.00	4.8	1.00	0.65	65%	35%
	800	71.58	29.2	693	1.00	4.8	1.00	0.65	65%	35%

Table D 157 Input parameters for the prediction of strike probability and mortality for Stillwater unit 5,6,7; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	122	0.24	4.8	1.00	0.65	16%	84%
	140	12.53	18.7	132	0.26	4.8	1.00	0.65	17%	83%
	150	13.42	19.1	141	0.28	4.8	1.00	0.65	18%	82%
	160	14.32	19.5	150	0.30	4.8	1.00	0.65	19%	81%
	170	15.21	19.9	160	0.31	4.8	1.00	0.65	20%	80%
	180	16.11	20.2	169	0.33	4.8	1.00	0.65	22%	78%
	190	17.00	20.5	179	0.35	4.8	1.00	0.65	23%	77%
	200	17.90	20.8	188	0.37	4.8	1.00	0.65	24%	76%
	210	18.79	21.1	197	0.39	4.8	1.00	0.65	25%	75%
Kelt	650	58.16	28.0	611	1.00	4.8	1.00	0.65	65%	35%
	675	60.40	28.2	634	1.00	4.8	1.00	0.65	65%	35%
	700	62.63	28.4	658	1.00	4.8	1.00	0.65	65%	35%
	725	64.87	28.6	681	1.00	4.8	1.00	0.65	65%	35%
	750	67.11	28.8	705	1.00	4.8	1.00	0.65	65%	35%
	775	69.35	29.0	728	1.00	4.8	1.00	0.65	65%	35%
	800	71.58	29.2	752	1.00	4.8	1.00	0.65	65%	35%

Table D 158. Input parameters for the prediction of strike probability and mortality for Stillwater unit 5,6,7; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	100	0.20	4.8	1.00	0.65	13%	87%
	140	12.53	18.7	107	0.21	4.8	1.00	0.65	14%	86%
	150	13.42	19.1	115	0.23	4.8	1.00	0.65	15%	85%
	160	14.32	19.5	123	0.24	4.8	1.00	0.65	16%	84%
	170	15.21	19.9	130	0.26	4.8	1.00	0.65	17%	83%
	180	16.11	20.2	138	0.27	4.8	1.00	0.65	18%	82%
	190	17.00	20.5	146	0.29	4.8	1.00	0.65	19%	81%
	200	17.90	20.8	153	0.30	4.8	1.00	0.65	20%	80%
	210	18.79	21.1	161	0.32	4.8	1.00	0.65	21%	79%
Kelt	650	58.16	28.0	498	0.98	4.8	1.00	0.65	64%	36%
	675	60.40	28.2	517	1.00	4.8	1.00	0.65	65%	35%
	700	62.63	28.4	536	1.00	4.8	1.00	0.65	65%	35%
	725	64.87	28.6	555	1.00	4.8	1.00	0.65	65%	35%
	750	67.11	28.8	575	1.00	4.8	1.00	0.65	65%	35%
	775	69.35	29.0	594	1.00	4.8	1.00	0.65	65%	35%
	800	71.58	29.2	613	1.00	4.8	1.00	0.65	65%	35%

Table D 159. Input parameters for the prediction of strike probability and mortality for Stillwater unit 5,6,7; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	113	0.22	4.8	1.00	0.78	17%	83%
	140	12.53	18.7	121	0.24	4.8	1.00	0.78	19%	81%
	150	13.42	19.1	130	0.26	4.8	1.00	0.78	20%	80%
	160	14.32	19.5	139	0.27	4.8	1.00	0.78	21%	79%
	170	15.21	19.9	147	0.29	4.8	1.00	0.78	23%	77%
	180	16.11	20.2	156	0.31	4.8	1.00	0.78	24%	76%
	190	17.00	20.5	165	0.32	4.8	1.00	0.78	25%	75%
	200	17.90	20.8	173	0.34	4.8	1.00	0.78	27%	73%
	210	18.79	21.1	182	0.36	4.8	1.00	0.78	28%	72%
Kelt	650	58.16	28.0	563	1.00	4.8	1.00	0.78	78%	22%
	675	60.40	28.2	585	1.00	4.8	1.00	0.78	78%	22%
	700	62.63	28.4	606	1.00	4.8	1.00	0.78	78%	22%
	725	64.87	28.6	628	1.00	4.8	1.00	0.78	78%	22%
	750	67.11	28.8	650	1.00	4.8	1.00	0.78	78%	22%
	775	69.35	29.0	671	1.00	4.8	1.00	0.78	78%	22%
	800	71.58	29.2	693	1.00	4.8	1.00	0.78	78%	22%

Table D 160. Input parameters for the prediction of strike probability and mortality for Stillwater unit 5,6,7; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	113	0.22	4.8	1.00	0.54	12%	88%
	140	12.53	18.7	121	0.24	4.8	1.00	0.54	13%	87%
	150	13.42	19.1	130	0.26	4.8	1.00	0.54	14%	86%
	160	14.32	19.5	139	0.27	4.8	1.00	0.54	15%	85%
	170	15.21	19.9	147	0.29	4.8	1.00	0.54	16%	84%
	180	16.11	20.2	156	0.31	4.8	1.00	0.54	17%	83%
	190	17.00	20.5	165	0.32	4.8	1.00	0.54	18%	82%
	200	17.90	20.8	173	0.34	4.8	1.00	0.54	18%	82%
	210	18.79	21.1	182	0.36	4.8	1.00	0.54	19%	81%
Kelt	650	58.16	28.0	563	1.00	4.8	1.00	0.54	54%	46%
	675	60.40	28.2	585	1.00	4.8	1.00	0.54	54%	46%
	700	62.63	28.4	606	1.00	4.8	1.00	0.54	54%	46%
	725	64.87	28.6	628	1.00	4.8	1.00	0.54	54%	46%
	750	67.11	28.8	650	1.00	4.8	1.00	0.54	54%	46%
	775	69.35	29.0	671	1.00	4.8	1.00	0.54	54%	46%
	800	71.58	29.2	693	1.00	4.8	1.00	0.54	54%	46%

Table D 161. Input parameters for the prediction of strike probability and mortality for Stillwater unit 5,6,7; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	122	0.24	4.8	1.00	0.78	19%	81%
	140	12.53	18.7	132	0.26	4.8	1.00	0.78	20%	80%
	150	13.42	19.1	141	0.28	4.8	1.00	0.78	22%	78%
	160	14.32	19.5	150	0.30	4.8	1.00	0.78	23%	77%
	170	15.21	19.9	160	0.31	4.8	1.00	0.78	24%	76%
	180	16.11	20.2	169	0.33	4.8	1.00	0.78	26%	74%
	190	17.00	20.5	179	0.35	4.8	1.00	0.78	27%	73%
	200	17.90	20.8	188	0.37	4.8	1.00	0.78	29%	71%
	210	18.79	21.1	197	0.39	4.8	1.00	0.78	30%	70%
Kelt	650	58.16	28.0	611	1.00	4.8	1.00	0.78	78%	22%
	675	60.40	28.2	634	1.00	4.8	1.00	0.78	78%	22%
	700	62.63	28.4	658	1.00	4.8	1.00	0.78	78%	22%
	725	64.87	28.6	681	1.00	4.8	1.00	0.78	78%	22%
	750	67.11	28.8	705	1.00	4.8	1.00	0.78	78%	22%
	775	69.35	29.0	728	1.00	4.8	1.00	0.78	78%	22%
	800	71.58	29.2	752	1.00	4.8	1.00	0.78	78%	22%

Table D 162. Input parameters for the prediction of strike probability and mortality for Stillwater unit 5,6,7; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	11.63	18.2	100	0.20	4.8	1.00	0.54	11%	89%
	140	12.53	18.7	107	0.21	4.8	1.00	0.54	11%	89%
	150	13.42	19.1	115	0.23	4.8	1.00	0.54	12%	88%
	160	14.32	19.5	123	0.24	4.8	1.00	0.54	13%	87%
	170	15.21	19.9	130	0.26	4.8	1.00	0.54	14%	86%
	180	16.11	20.2	138	0.27	4.8	1.00	0.54	15%	85%
	190	17.00	20.5	146	0.29	4.8	1.00	0.54	15%	85%
	200	17.90	20.8	153	0.30	4.8	1.00	0.54	16%	84%
	210	18.79	21.1	161	0.32	4.8	1.00	0.54	17%	83%
Kelt	650	58.16	28.0	498	0.98	4.8	1.00	0.54	53%	47%
	675	60.40	28.2	517	1.00	4.8	1.00	0.54	54%	46%
	700	62.63	28.4	536	1.00	4.8	1.00	0.54	54%	46%
	725	64.87	28.6	555	1.00	4.8	1.00	0.54	54%	46%
	750	67.11	28.8	575	1.00	4.8	1.00	0.54	54%	46%
	775	69.35	29.0	594	1.00	4.8	1.00	0.54	54%	46%
	800	71.58	29.2	613	1.00	4.8	1.00	0.54	54%	46%

Table D 163. Input parameters for the prediction of strike probability and mortality for Medway units 1, 2, 3 and 4; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	35	0.39	4.8	0.19	0.13	5%	95%
	140	11.48	18.2	37	0.42	4.8	0.20	0.13	5%	95%
	150	12.30	18.6	40	0.45	4.8	0.20	0.13	6%	94%
	160	13.12	19.0	43	0.48	4.8	0.21	0.14	7%	93%
	170	13.94	19.3	45	0.51	4.8	0.21	0.14	7%	93%
	180	14.76	19.7	48	0.54	4.8	0.22	0.14	8%	92%
	190	15.58	20.0	51	0.57	4.8	0.22	0.14	8%	92%
	200	16.40	20.3	53	0.60	4.8	0.22	0.14	9%	91%
	210	17.22	20.6	56	0.63	4.8	0.23	0.15	9%	91%
Kelt	650	53.31	27.5	174	1.00	4.8	0.30	0.20	20%	80%
	675	55.36	27.7	181	1.00	4.8	0.30	0.20	20%	80%
	700	57.41	27.9	187	1.00	4.8	0.31	0.20	20%	80%
	725	59.47	28.1	194	1.00	4.8	0.31	0.20	20%	80%
	750	61.52	28.3	201	1.00	4.8	0.31	0.20	20%	80%
	775	63.57	28.5	207	1.00	4.8	0.31	0.20	20%	80%
	800	65.62	28.7	214	1.00	4.8	0.31	0.20	20%	80%

Table D 164. Input parameters for the prediction of strike probability and mortality for Medway units 1, 2, 3 and 4; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	56	0.63	4.8	0.19	0.13	8%	92%
	140	11.48	18.2	60	0.68	4.8	0.20	0.13	9%	91%
	150	12.30	18.6	65	0.73	4.8	0.20	0.13	10%	90%
	160	13.12	19.0	69	0.78	4.8	0.21	0.14	10%	90%
	170	13.94	19.3	73	0.83	4.8	0.21	0.14	11%	89%
	180	14.76	19.7	78	0.87	4.8	0.22	0.14	12%	88%
	190	15.58	20.0	82	0.92	4.8	0.22	0.14	13%	87%
	200	16.40	20.3	86	0.97	4.8	0.22	0.14	14%	86%
	210	17.22	20.6	90	1.00	4.8	0.23	0.15	15%	85%
Kelt	650	53.31	27.5	280	1.00	4.8	0.30	0.20	20%	80%
	675	55.36	27.7	291	1.00	4.8	0.30	0.20	20%	80%
	700	57.41	27.9	301	1.00	4.8	0.31	0.20	20%	80%
	725	59.47	28.1	312	1.00	4.8	0.31	0.20	20%	80%
	750	61.52	28.3	323	1.00	4.8	0.31	0.20	20%	80%
	775	63.57	28.5	334	1.00	4.8	0.31	0.20	20%	80%
	800	65.62	28.7	345	1.00	4.8	0.31	0.20	20%	80%

Table D 165. Input parameters for the prediction of strike probability and mortality for Medway units 1, 2, 3 and 4; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	12	0.14	4.8	0.19	0.13	2%	98%
	140	11.48	18.2	13	0.15	4.8	0.20	0.13	2%	98%
	150	12.30	18.6	14	0.16	4.8	0.20	0.13	2%	98%
	160	13.12	19.0	15	0.17	4.8	0.21	0.14	2%	98%
	170	13.94	19.3	16	0.18	4.8	0.21	0.14	3%	97%
	180	14.76	19.7	17	0.19	4.8	0.22	0.14	3%	97%
	190	15.58	20.0	18	0.21	4.8	0.22	0.14	3%	97%
	200	16.40	20.3	19	0.22	4.8	0.22	0.14	3%	97%
	210	17.22	20.6	20	0.23	4.8	0.23	0.15	3%	97%
Kelt	650	53.31	27.5	62	0.70	4.8	0.30	0.20	14%	86%
	675	55.36	27.7	65	0.73	4.8	0.30	0.20	14%	86%
	700	57.41	27.9	67	0.76	4.8	0.31	0.20	15%	85%
	725	59.47	28.1	70	0.79	4.8	0.31	0.20	16%	84%
	750	61.52	28.3	72	0.81	4.8	0.31	0.20	16%	84%
	775	63.57	28.5	74	0.84	4.8	0.31	0.20	17%	83%
	800	65.62	28.7	77	0.87	4.8	0.31	0.20	18%	82%

Table D 166. Input parameters for the prediction of strike probability and mortality for Medway units 1, 2, 3 and 4; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	35	0.39	4.8	0.19	0.15	6%	94%
	140	11.48	18.2	37	0.42	4.8	0.20	0.16	7%	93%
	150	12.30	18.6	40	0.45	4.8	0.20	0.16	7%	93%
	160	13.12	19.0	43	0.48	4.8	0.21	0.16	8%	92%
	170	13.94	19.3	45	0.51	4.8	0.21	0.17	8%	92%
	180	14.76	19.7	48	0.54	4.8	0.22	0.17	9%	91%
	190	15.58	20.0	51	0.57	4.8	0.22	0.17	10%	90%
	200	16.40	20.3	53	0.60	4.8	0.22	0.17	10%	90%
	210	17.22	20.6	56	0.63	4.8	0.23	0.18	11%	89%
Kelt	650	53.31	27.5	174	1.00	4.8	0.30	0.23	23%	77%
	675	55.36	27.7	181	1.00	4.8	0.30	0.24	24%	76%
	700	57.41	27.9	187	1.00	4.8	0.31	0.24	24%	76%
	725	59.47	28.1	194	1.00	4.8	0.31	0.24	24%	76%
	750	61.52	28.3	201	1.00	4.8	0.31	0.24	24%	76%
	775	63.57	28.5	207	1.00	4.8	0.31	0.24	24%	76%
	800	65.62	28.7	214	1.00	4.8	0.31	0.25	25%	75%

Table D 167 Input parameters for the prediction of strike probability and mortality for Medway units 1, 2, 3 and 4; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	35	0.39	4.8	0.19	0.11	4%	96%
	140	11.48	18.2	37	0.42	4.8	0.20	0.11	5%	95%
	150	12.30	18.6	40	0.45	4.8	0.20	0.11	5%	95%
	160	13.12	19.0	43	0.48	4.8	0.21	0.11	5%	95%
	170	13.94	19.3	45	0.51	4.8	0.21	0.11	6%	94%
	180	14.76	19.7	48	0.54	4.8	0.22	0.12	6%	94%
	190	15.58	20.0	51	0.57	4.8	0.22	0.12	7%	93%
	200	16.40	20.3	53	0.60	4.8	0.22	0.12	7%	93%
	210	17.22	20.6	56	0.63	4.8	0.23	0.12	8%	92%
Kelt	650	53.31	27.5	174	1.00	4.8	0.30	0.16	16%	84%
	675	55.36	27.7	181	1.00	4.8	0.30	0.16	16%	84%
	700	57.41	27.9	187	1.00	4.8	0.31	0.17	17%	83%
	725	59.47	28.1	194	1.00	4.8	0.31	0.17	17%	83%
	750	61.52	28.3	201	1.00	4.8	0.31	0.17	17%	83%
	775	63.57	28.5	207	1.00	4.8	0.31	0.17	17%	83%
	800	65.62	28.7	214	1.00	4.8	0.31	0.17	17%	83%

Table D 168. Input parameters for the prediction of strike probability and mortality for Medway units 1, 2, 3 and 4; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	56	0.63	4.8	0.19	0.15	10%	90%
	140	11.48	18.2	60	0.68	4.8	0.20	0.16	11%	89%
	150	12.30	18.6	65	0.73	4.8	0.20	0.16	12%	88%
	160	13.12	19.0	69	0.78	4.8	0.21	0.16	13%	87%
	170	13.94	19.3	73	0.83	4.8	0.21	0.17	14%	86%
	180	14.76	19.7	78	0.87	4.8	0.22	0.17	15%	85%
	190	15.58	20.0	82	0.92	4.8	0.22	0.17	16%	84%
	200	16.40	20.3	86	0.97	4.8	0.22	0.17	17%	83%
	210	17.22	20.6	90	1.00	4.8	0.23	0.18	18%	82%
Kelt	650	53.31	27.5	280	1.00	4.8	0.30	0.23	23%	77%
	675	55.36	27.7	291	1.00	4.8	0.30	0.24	24%	76%
	700	57.41	27.9	301	1.00	4.8	0.31	0.24	24%	76%
	725	59.47	28.1	312	1.00	4.8	0.31	0.24	24%	76%
	750	61.52	28.3	323	1.00	4.8	0.31	0.24	24%	76%
	775	63.57	28.5	334	1.00	4.8	0.31	0.24	24%	76%
	800	65.62	28.7	345	1.00	4.8	0.31	0.25	25%	75%

Table D 169. Input parameters for the prediction of strike probability and mortality for Medway units 1, 2, 3 and 4; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	12	0.14	4.8	0.19	0.11	1%	99%
	140	11.48	18.2	13	0.15	4.8	0.20	0.11	2%	98%
	150	12.30	18.6	14	0.16	4.8	0.20	0.11	2%	98%
	160	13.12	19.0	15	0.17	4.8	0.21	0.11	2%	98%
	170	13.94	19.3	16	0.18	4.8	0.21	0.11	2%	98%
	180	14.76	19.7	17	0.19	4.8	0.22	0.12	2%	98%
	190	15.58	20.0	18	0.21	4.8	0.22	0.12	2%	98%
	200	16.40	20.3	19	0.22	4.8	0.22	0.12	3%	97%
	210	17.22	20.6	20	0.23	4.8	0.23	0.12	3%	97%
Kelt	650	53.31	27.5	62	0.70	4.8	0.30	0.16	11%	89%
	675	55.36	27.7	65	0.73	4.8	0.30	0.16	12%	88%
	700	57.41	27.9	67	0.76	4.8	0.31	0.17	13%	87%
	725	59.47	28.1	70	0.79	4.8	0.31	0.17	13%	87%
	750	61.52	28.3	72	0.81	4.8	0.31	0.17	14%	86%
	775	63.57	28.5	74	0.84	4.8	0.31	0.17	14%	86%
	800	65.62	28.7	77	0.87	4.8	0.31	0.17	15%	85%

Table D 170. Input parameters for the prediction of strike probability and mortality for Howland units 1, 2, and 3; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	0.35	4.8	0.32	0.21	7%	93%
	140	11.48	18.2	80	0.38	4.8	0.33	0.21	8%	92%
	150	12.30	18.6	86	0.41	4.8	0.33	0.22	9%	91%
	160	13.12	19.0	92	0.43	4.8	0.34	0.22	10%	90%
	170	13.94	19.3	98	0.46	4.8	0.35	0.23	10%	90%
	180	14.76	19.7	103	0.49	4.8	0.35	0.23	11%	89%
	190	15.58	20.0	109	0.52	4.8	0.36	0.23	12%	88%
	200	16.40	20.3	115	0.54	4.8	0.37	0.24	13%	87%
	210	17.22	20.6	120	0.57	4.8	0.37	0.24	14%	86%
Kelt	650	53.31	27.5	373	1.00	4.8	0.49	0.32	32%	68%
	675	55.36	27.7	387	1.00	4.8	0.50	0.32	32%	68%
	700	57.41	27.9	402	1.00	4.8	0.50	0.33	33%	67%
	725	59.47	28.1	416	1.00	4.8	0.51	0.33	33%	67%
	750	61.52	28.3	430	1.00	4.8	0.51	0.33	33%	67%
	775	63.57	28.5	445	1.00	4.8	0.51	0.33	33%	67%
	800	65.62	28.7	459	1.00	4.8	0.52	0.34	34%	66%

Table D 171 Input parameters for the prediction of strike probability and mortality for Howland units 1, 2, and 3; fish angle +10 deg..

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	92	0.44	4.8	0.32	0.21	9%	91%
	140	11.48	18.2	99	0.47	4.8	0.33	0.21	10%	90%
	150	12.30	18.6	106	0.50	4.8	0.33	0.22	11%	89%
	160	13.12	19.0	113	0.54	4.8	0.34	0.22	12%	88%
	170	13.94	19.3	120	0.57	4.8	0.35	0.23	13%	87%
	180	14.76	19.7	127	0.60	4.8	0.35	0.23	14%	86%
	190	15.58	20.0	134	0.64	4.8	0.36	0.23	15%	85%
	200	16.40	20.3	141	0.67	4.8	0.37	0.24	16%	84%
	210	17.22	20.6	148	0.70	4.8	0.37	0.24	17%	83%
Kelt	650	53.31	27.5	460	1.00	4.8	0.49	0.32	32%	68%
	675	55.36	27.7	477	1.00	4.8	0.50	0.32	32%	68%
	700	57.41	27.9	495	1.00	4.8	0.50	0.33	33%	67%
	725	59.47	28.1	513	1.00	4.8	0.51	0.33	33%	67%
	750	61.52	28.3	530	1.00	4.8	0.51	0.33	33%	67%
	775	63.57	28.5	548	1.00	4.8	0.51	0.33	33%	67%
	800	65.62	28.7	566	1.00	4.8	0.52	0.34	34%	66%

Table D 172. Input parameters for the prediction of strike probability and mortality for Howland units 1, 2, and 3; fish angle - 10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	55	0.26	4.8	0.32	0.21	5%	95%
	140	11.48	18.2	59	0.28	4.8	0.33	0.21	6%	94%
	150	12.30	18.6	63	0.30	4.8	0.33	0.22	7%	93%
	160	13.12	19.0	68	0.32	4.8	0.34	0.22	7%	93%
	170	13.94	19.3	72	0.34	4.8	0.35	0.23	8%	92%
	180	14.76	19.7	76	0.36	4.8	0.35	0.23	8%	92%
	190	15.58	20.0	80	0.38	4.8	0.36	0.23	9%	91%
	200	16.40	20.3	85	0.40	4.8	0.37	0.24	10%	90%
	210	17.22	20.6	89	0.42	4.8	0.37	0.24	10%	90%
Kelt	650	53.31	27.5	275	1.00	4.8	0.49	0.32	32%	68%
	675	55.36	27.7	285	1.00	4.8	0.50	0.32	32%	68%
	700	57.41	27.9	296	1.00	4.8	0.50	0.33	33%	67%
	725	59.47	28.1	306	1.00	4.8	0.51	0.33	33%	67%
	750	61.52	28.3	317	1.00	4.8	0.51	0.33	33%	67%
	775	63.57	28.5	328	1.00	4.8	0.51	0.33	33%	67%
	800	65.62	28.7	338	1.00	4.8	0.52	0.34	34%	66%

Table D 173. Input parameters for the prediction of strike probability and mortality for Howland units 1, 2, and 3; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	0.35	4.8	0.32	0.25	9%	91%
	140	11.48	18.2	80	0.38	4.8	0.33	0.26	10%	90%
	150	12.30	18.6	86	0.41	4.8	0.33	0.26	11%	89%
	160	13.12	19.0	92	0.43	4.8	0.34	0.27	12%	88%
	170	13.94	19.3	98	0.46	4.8	0.35	0.27	13%	87%
	180	14.76	19.7	103	0.49	4.8	0.35	0.28	14%	86%
	190	15.58	20.0	109	0.52	4.8	0.36	0.28	15%	85%
	200	16.40	20.3	115	0.54	4.8	0.37	0.29	16%	84%
	210	17.22	20.6	120	0.57	4.8	0.37	0.29	17%	83%
Kelt	650	53.31	27.5	373	1.00	4.8	0.49	0.39	39%	61%
	675	55.36	27.7	387	1.00	4.8	0.50	0.39	39%	61%
	700	57.41	27.9	402	1.00	4.8	0.50	0.39	39%	61%
	725	59.47	28.1	416	1.00	4.8	0.51	0.40	40%	60%
	750	61.52	28.3	430	1.00	4.8	0.51	0.40	40%	60%
	775	63.57	28.5	445	1.00	4.8	0.51	0.40	40%	60%
	800	65.62	28.7	459	1.00	4.8	0.52	0.40	40%	60%

Table D 174. Input parameters for the prediction of strike probability and mortality for Howland units 1, 2, and 3; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	75	0.35	4.8	0.32	0.17	6%	94%
	140	11.48	18.2	80	0.38	4.8	0.33	0.18	7%	93%
	150	12.30	18.6	86	0.41	4.8	0.33	0.18	7%	93%
	160	13.12	19.0	92	0.43	4.8	0.34	0.19	8%	92%
	170	13.94	19.3	98	0.46	4.8	0.35	0.19	9%	91%
	180	14.76	19.7	103	0.49	4.8	0.35	0.19	9%	91%
	190	15.58	20.0	109	0.52	4.8	0.36	0.20	10%	90%
	200	16.40	20.3	115	0.54	4.8	0.37	0.20	11%	89%
	210	17.22	20.6	120	0.57	4.8	0.37	0.20	11%	89%
Kelt	650	53.31	27.5	373	1.00	4.8	0.49	0.27	27%	73%
	675	55.36	27.7	387	1.00	4.8	0.50	0.27	27%	73%
	700	57.41	27.9	402	1.00	4.8	0.50	0.27	27%	73%
	725	59.47	28.1	416	1.00	4.8	0.51	0.27	27%	73%
	750	61.52	28.3	430	1.00	4.8	0.51	0.28	28%	72%
	775	63.57	28.5	445	1.00	4.8	0.51	0.28	28%	72%
	800	65.62	28.7	459	1.00	4.8	0.52	0.28	28%	72%

Table D 175. Input parameters for the prediction of strike probability and mortality for Howland units 1, 2, and 3; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	92	0.44	4.8	0.32	0.25	11%	89%
	140	11.48	18.2	99	0.47	4.8	0.33	0.26	12%	88%
	150	12.30	18.6	106	0.50	4.8	0.33	0.26	13%	87%
	160	13.12	19.0	113	0.54	4.8	0.34	0.27	14%	86%
	170	13.94	19.3	120	0.57	4.8	0.35	0.27	15%	85%
	180	14.76	19.7	127	0.60	4.8	0.35	0.28	17%	83%
	190	15.58	20.0	134	0.64	4.8	0.36	0.28	18%	82%
	200	16.40	20.3	141	0.67	4.8	0.37	0.29	19%	81%
	210	17.22	20.6	148	0.70	4.8	0.37	0.29	20%	80%
Kelt	650	53.31	27.5	460	1.00	4.8	0.49	0.39	39%	61%
	675	55.36	27.7	477	1.00	4.8	0.50	0.39	39%	61%
	700	57.41	27.9	495	1.00	4.8	0.50	0.39	39%	61%
	725	59.47	28.1	513	1.00	4.8	0.51	0.40	40%	60%
	750	61.52	28.3	530	1.00	4.8	0.51	0.40	40%	60%
	775	63.57	28.5	548	1.00	4.8	0.51	0.40	40%	60%
	800	65.62	28.7	566	1.00	4.8	0.52	0.40	40%	60%

Table D 176. Input parameters for the prediction of strike probability and mortality for Howland units 1, 2, and 3; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	10.66	17.7	55	0.26	4.8	0.32	0.17	4%	96%
	140	11.48	18.2	59	0.28	4.8	0.33	0.18	5%	95%
	150	12.30	18.6	63	0.30	4.8	0.33	0.18	5%	95%
	160	13.12	19.0	68	0.32	4.8	0.34	0.19	6%	94%
	170	13.94	19.3	72	0.34	4.8	0.35	0.19	6%	94%
	180	14.76	19.7	76	0.36	4.8	0.35	0.19	7%	93%
	190	15.58	20.0	80	0.38	4.8	0.36	0.20	7%	93%
	200	16.40	20.3	85	0.40	4.8	0.37	0.20	8%	92%
	210	17.22	20.6	89	0.42	4.8	0.37	0.20	8%	92%
Kelt	650	53.31	27.5	275	1.00	4.8	0.49	0.27	27%	73%
	675	55.36	27.7	285	1.00	4.8	0.50	0.27	27%	73%
	700	57.41	27.9	296	1.00	4.8	0.50	0.27	27%	73%
	725	59.47	28.1	306	1.00	4.8	0.51	0.27	27%	73%
	750	61.52	28.3	317	1.00	4.8	0.51	0.28	28%	72%
	775	63.57	28.5	328	1.00	4.8	0.51	0.28	28%	72%
	800	65.62	28.7	338	1.00	4.8	0.52	0.28	28%	72%

Table D 177 Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 2; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	16.35	20.3	113	1.00	4.8	0.29	0.19	19%	81%
	140	17.61	20.7	121	1.00	4.8	0.30	0.19	19%	81%
	150	18.87	21.2	130	1.00	4.8	0.30	0.20	20%	80%
	160	20.13	21.6	139	1.00	4.8	0.31	0.20	20%	80%
	170	21.38	21.9	147	1.00	4.8	0.31	0.20	20%	80%
	180	22.64	22.3	156	1.00	4.8	0.32	0.21	21%	79%
	190	23.90	22.6	165	1.00	4.8	0.32	0.21	21%	79%
	200	25.16	22.9	173	1.00	4.8	0.33	0.21	21%	79%
	210	26.42	23.2	182	1.00	4.8	0.33	0.22	22%	78%
Kelt	650	81.76	30.0	563	1.00	4.8	0.43	0.28	28%	72%
	675	84.91	30.3	585	1.00	4.8	0.43	0.28	28%	72%
	700	88.05	30.5	606	1.00	4.8	0.44	0.28	28%	72%
	725	91.19	30.7	628	1.00	4.8	0.44	0.29	29%	71%
	750	94.34	30.9	650	1.00	4.8	0.44	0.29	29%	71%
	775	97.48	31.1	671	1.00	4.8	0.45	0.29	29%	71%
	800	100.63	31.3	693	1.00	4.8	0.45	0.29	29%	71%

Table D 178 Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 2; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	16.35	20.3	122	1.00	4.8	0.29	0.19	19%	81%
	140	17.61	20.7	132	1.00	4.8	0.30	0.19	19%	81%
	150	18.87	21.2	141	1.00	4.8	0.30	0.20	20%	80%
	160	20.13	21.6	150	1.00	4.8	0.31	0.20	20%	80%
	170	21.38	21.9	160	1.00	4.8	0.31	0.20	20%	80%
	180	22.64	22.3	169	1.00	4.8	0.32	0.21	21%	79%
	190	23.90	22.6	179	1.00	4.8	0.32	0.21	21%	79%
	200	25.16	22.9	188	1.00	4.8	0.33	0.21	21%	79%
	210	26.42	23.2	197	1.00	4.8	0.33	0.22	22%	78%
Kelt	650	81.76	30.0	611	1.00	4.8	0.43	0.28	28%	72%
	675	84.91	30.3	634	1.00	4.8	0.43	0.28	28%	72%
	700	88.05	30.5	658	1.00	4.8	0.44	0.28	28%	72%
	725	91.19	30.7	681	1.00	4.8	0.44	0.29	29%	71%
	750	94.34	30.9	705	1.00	4.8	0.44	0.29	29%	71%
	775	97.48	31.1	728	1.00	4.8	0.45	0.29	29%	71%
	800	100.63	31.3	752	1.00	4.8	0.45	0.29	29%	71%

Table D 179. Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 2; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	16.35	20.3	100	1.00	4.8	0.29	0.19	19%	81%
	140	17.61	20.7	107	1.00	4.8	0.30	0.19	19%	81%
	150	18.87	21.2	115	1.00	4.8	0.30	0.20	20%	80%
	160	20.13	21.6	123	1.00	4.8	0.31	0.20	20%	80%
	170	21.38	21.9	130	1.00	4.8	0.31	0.20	20%	80%
	180	22.64	22.3	138	1.00	4.8	0.32	0.21	21%	79%
	190	23.90	22.6	146	1.00	4.8	0.32	0.21	21%	79%
	200	25.16	22.9	153	1.00	4.8	0.33	0.21	21%	79%
	210	26.42	23.2	161	1.00	4.8	0.33	0.22	22%	78%
Kelt	650	81.76	30.0	498	1.00	4.8	0.43	0.28	28%	72%
	675	84.91	30.3	517	1.00	4.8	0.43	0.28	28%	72%
	700	88.05	30.5	536	1.00	4.8	0.44	0.28	28%	72%
	725	91.19	30.7	555	1.00	4.8	0.44	0.29	29%	71%
	750	94.34	30.9	575	1.00	4.8	0.44	0.29	29%	71%
	775	97.48	31.1	594	1.00	4.8	0.45	0.29	29%	71%
	800	100.63	31.3	613	1.00	4.8	0.45	0.29	29%	71%

Table D 180. Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 2; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	16.35	20.3	113	1.00	4.8	0.29	0.23	23%	77%
	140	17.61	20.7	121	1.00	4.8	0.30	0.23	23%	77%
	150	18.87	21.2	130	1.00	4.8	0.30	0.24	24%	76%
	160	20.13	21.6	139	1.00	4.8	0.31	0.24	24%	76%
	170	21.38	21.9	147	1.00	4.8	0.31	0.25	25%	75%
	180	22.64	22.3	156	1.00	4.8	0.32	0.25	25%	75%
	190	23.90	22.6	165	1.00	4.8	0.32	0.25	25%	75%
	200	25.16	22.9	173	1.00	4.8	0.33	0.26	26%	74%
	210	26.42	23.2	182	1.00	4.8	0.33	0.26	26%	74%
Kelt	650	81.76	30.0	563	1.00	4.8	0.43	0.34	34%	66%
	675	84.91	30.3	585	1.00	4.8	0.43	0.34	34%	66%
	700	88.05	30.5	606	1.00	4.8	0.44	0.34	34%	66%
	725	91.19	30.7	628	1.00	4.8	0.44	0.34	34%	66%
	750	94.34	30.9	650	1.00	4.8	0.44	0.35	35%	65%
	775	97.48	31.1	671	1.00	4.8	0.45	0.35	35%	65%
	800	100.63	31.3	693	1.00	4.8	0.45	0.35	35%	65%

Table D 181 Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 2; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	16.35	20.3	113	1.00	4.8	0.29	0.16	16%	84%
	140	17.61	20.7	121	1.00	4.8	0.30	0.16	16%	84%
	150	18.87	21.2	130	1.00	4.8	0.30	0.16	16%	84%
	160	20.13	21.6	139	1.00	4.8	0.31	0.17	17%	83%
	170	21.38	21.9	147	1.00	4.8	0.31	0.17	17%	83%
	180	22.64	22.3	156	1.00	4.8	0.32	0.17	17%	83%
	190	23.90	22.6	165	1.00	4.8	0.32	0.18	18%	82%
	200	25.16	22.9	173	1.00	4.8	0.33	0.18	18%	82%
	210	26.42	23.2	182	1.00	4.8	0.33	0.18	18%	82%
Kelt	650	81.76	30.0	563	1.00	4.8	0.43	0.23	23%	77%
	675	84.91	30.3	585	1.00	4.8	0.43	0.24	24%	76%
	700	88.05	30.5	606	1.00	4.8	0.44	0.24	24%	76%
	725	91.19	30.7	628	1.00	4.8	0.44	0.24	24%	76%
	750	94.34	30.9	650	1.00	4.8	0.44	0.24	24%	76%
	775	97.48	31.1	671	1.00	4.8	0.45	0.24	24%	76%
	800	100.63	31.3	693	1.00	4.8	0.45	0.24	24%	76%

Table D 182. Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 2; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	16.35	20.3	122	1.00	4.8	0.29	0.23	23%	77%
	140	17.61	20.7	132	1.00	4.8	0.30	0.23	23%	77%
	150	18.87	21.2	141	1.00	4.8	0.30	0.24	24%	76%
	160	20.13	21.6	150	1.00	4.8	0.31	0.24	24%	76%
	170	21.38	21.9	160	1.00	4.8	0.31	0.25	25%	75%
	180	22.64	22.3	169	1.00	4.8	0.32	0.25	25%	75%
	190	23.90	22.6	179	1.00	4.8	0.32	0.25	25%	75%
	200	25.16	22.9	188	1.00	4.8	0.33	0.26	26%	74%
	210	26.42	23.2	197	1.00	4.8	0.33	0.26	26%	74%
Kelt	650	81.76	30.0	611	1.00	4.8	0.43	0.34	34%	66%
	675	84.91	30.3	634	1.00	4.8	0.43	0.34	34%	66%
	700	88.05	30.5	658	1.00	4.8	0.44	0.34	34%	66%
	725	91.19	30.7	681	1.00	4.8	0.44	0.34	34%	66%
	750	94.34	30.9	705	1.00	4.8	0.44	0.35	35%	65%
	775	97.48	31.1	728	1.00	4.8	0.45	0.35	35%	65%
	800	100.63	31.3	752	1.00	4.8	0.45	0.35	35%	65%

Table D 183. Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 2; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	16.35	20.3	100	1.00	4.8	0.29	0.16	16%	84%
	140	17.61	20.7	107	1.00	4.8	0.30	0.16	16%	84%
	150	18.87	21.2	115	1.00	4.8	0.30	0.16	16%	84%
	160	20.13	21.6	123	1.00	4.8	0.31	0.17	17%	83%
	170	21.38	21.9	130	1.00	4.8	0.31	0.17	17%	83%
	180	22.64	22.3	138	1.00	4.8	0.32	0.17	17%	83%
	190	23.90	22.6	146	1.00	4.8	0.32	0.18	18%	82%
	200	25.16	22.9	153	1.00	4.8	0.33	0.18	18%	82%
	210	26.42	23.2	161	1.00	4.8	0.33	0.18	18%	82%
Kelt	650	81.76	30.0	498	1.00	4.8	0.43	0.23	23%	77%
	675	84.91	30.3	517	1.00	4.8	0.43	0.24	24%	76%
	700	88.05	30.5	536	1.00	4.8	0.44	0.24	24%	76%
	725	91.19	30.7	555	1.00	4.8	0.44	0.24	24%	76%
	750	94.34	30.9	575	1.00	4.8	0.44	0.24	24%	76%
	775	97.48	31.1	594	1.00	4.8	0.45	0.24	24%	76%
	800	100.63	31.3	613	1.00	4.8	0.45	0.24	24%	76%

Table D 184 Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 1; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.19	16.1	65	0.79	4.8	0.32	0.21	17%	83%
	140	8.82	16.6	70	0.86	4.8	0.33	0.22	19%	81%
	150	9.45	17.0	75	0.92	4.8	0.34	0.22	20%	80%
	160	10.08	17.4	80	0.98	4.8	0.35	0.23	22%	78%
	170	10.71	17.7	85	1.00	4.8	0.36	0.23	23%	77%
	180	11.34	18.1	90	1.00	4.8	0.36	0.24	24%	76%
	190	11.97	18.4	95	1.00	4.8	0.37	0.24	24%	76%
	200	12.60	18.7	100	1.00	4.8	0.38	0.24	24%	76%
	210	13.23	19.0	105	1.00	4.8	0.38	0.25	25%	75%
Kelt	650	40.94	25.9	325	1.00	4.8	0.52	0.34	34%	66%
	675	42.52	26.1	338	1.00	4.8	0.53	0.34	34%	66%
	700	44.09	26.3	350	1.00	4.8	0.53	0.34	34%	66%
	725	45.67	26.5	363	1.00	4.8	0.53	0.35	35%	65%
	750	47.24	26.7	375	1.00	4.8	0.54	0.35	35%	65%
	775	48.82	26.9	388	1.00	4.8	0.54	0.35	35%	65%
	800	50.39	27.1	400	1.00	4.8	0.55	0.35	35%	65%

Table D 185 Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 1; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.19	16.1	84	1.00	4.8	0.32	0.21	21%	79%
	140	8.82	16.6	90	1.00	4.8	0.33	0.22	22%	78%
	150	9.45	17.0	96	1.00	4.8	0.34	0.22	22%	78%
	160	10.08	17.4	103	1.00	4.8	0.35	0.23	23%	77%
	170	10.71	17.7	109	1.00	4.8	0.36	0.23	23%	77%
	180	11.34	18.1	116	1.00	4.8	0.36	0.24	24%	76%
	190	11.97	18.4	122	1.00	4.8	0.37	0.24	24%	76%
	200	12.60	18.7	129	1.00	4.8	0.38	0.24	24%	76%
	210	13.23	19.0	135	1.00	4.8	0.38	0.25	25%	75%
Kelt	650	40.94	25.9	418	1.00	4.8	0.52	0.34	34%	66%
	675	42.52	26.1	434	1.00	4.8	0.53	0.34	34%	66%
	700	44.09	26.3	450	1.00	4.8	0.53	0.34	34%	66%
	725	45.67	26.5	466	1.00	4.8	0.53	0.35	35%	65%
	750	47.24	26.7	482	1.00	4.8	0.54	0.35	35%	65%
	775	48.82	26.9	498	1.00	4.8	0.54	0.35	35%	65%
	800	50.39	27.1	514	1.00	4.8	0.55	0.35	35%	65%

Table D 186. Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 1; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.19	16.1	44	0.54	4.8	0.32	0.21	11%	89%
	140	8.82	16.6	48	0.58	4.8	0.33	0.22	13%	87%
	150	9.45	17.0	51	0.63	4.8	0.34	0.22	14%	86%
	160	10.08	17.4	55	0.67	4.8	0.35	0.23	15%	85%
	170	10.71	17.7	58	0.71	4.8	0.36	0.23	16%	84%
	180	11.34	18.1	62	0.75	4.8	0.36	0.24	18%	82%
	190	11.97	18.4	65	0.79	4.8	0.37	0.24	19%	81%
	200	12.60	18.7	68	0.84	4.8	0.38	0.24	20%	80%
	210	13.23	19.0	72	0.88	4.8	0.38	0.25	22%	78%
Kelt	650	40.94	25.9	222	1.00	4.8	0.52	0.34	34%	66%
	675	42.52	26.1	231	1.00	4.8	0.53	0.34	34%	66%
	700	44.09	26.3	239	1.00	4.8	0.53	0.34	34%	66%
	725	45.67	26.5	248	1.00	4.8	0.53	0.35	35%	65%
	750	47.24	26.7	257	1.00	4.8	0.54	0.35	35%	65%
	775	48.82	26.9	265	1.00	4.8	0.54	0.35	35%	65%
	800	50.39	27.1	274	1.00	4.8	0.55	0.35	35%	65%

Table D 187. Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 1; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.19	16.1	65	0.79	4.8	0.32	0.25	20%	80%
	140	8.82	16.6	70	0.86	4.8	0.33	0.26	22%	78%
	150	9.45	17.0	75	0.92	4.8	0.34	0.27	24%	76%
	160	10.08	17.4	80	0.98	4.8	0.35	0.27	27%	73%
	170	10.71	17.7	85	1.00	4.8	0.36	0.28	28%	72%
	180	11.34	18.1	90	1.00	4.8	0.36	0.28	28%	72%
	190	11.97	18.4	95	1.00	4.8	0.37	0.29	29%	71%
	200	12.60	18.7	100	1.00	4.8	0.38	0.29	29%	71%
	210	13.23	19.0	105	1.00	4.8	0.38	0.30	30%	70%
Kelt	650	40.94	25.9	325	1.00	4.8	0.52	0.41	41%	59%
	675	42.52	26.1	338	1.00	4.8	0.53	0.41	41%	59%
	700	44.09	26.3	350	1.00	4.8	0.53	0.41	41%	59%
	725	45.67	26.5	363	1.00	4.8	0.53	0.42	42%	58%
	750	47.24	26.7	375	1.00	4.8	0.54	0.42	42%	58%
	775	48.82	26.9	388	1.00	4.8	0.54	0.42	42%	58%
	800	50.39	27.1	400	1.00	4.8	0.55	0.43	43%	57%

Table D 188. Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 1; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.19	16.1	65	0.79	4.8	0.32	0.18	14%	86%
	140	8.82	16.6	70	0.86	4.8	0.33	0.18	15%	85%
	150	9.45	17.0	75	0.92	4.8	0.34	0.19	17%	83%
	160	10.08	17.4	80	0.98	4.8	0.35	0.19	19%	81%
	170	10.71	17.7	85	1.00	4.8	0.36	0.19	19%	81%
	180	11.34	18.1	90	1.00	4.8	0.36	0.20	20%	80%
	190	11.97	18.4	95	1.00	4.8	0.37	0.20	20%	80%
	200	12.60	18.7	100	1.00	4.8	0.38	0.20	20%	80%
	210	13.23	19.0	105	1.00	4.8	0.38	0.21	21%	79%
Kelt	650	40.94	25.9	325	1.00	4.8	0.52	0.28	28%	72%
	675	42.52	26.1	338	1.00	4.8	0.53	0.28	28%	72%
	700	44.09	26.3	350	1.00	4.8	0.53	0.29	29%	71%
	725	45.67	26.5	363	1.00	4.8	0.53	0.29	29%	71%
	750	47.24	26.7	375	1.00	4.8	0.54	0.29	29%	71%
	775	48.82	26.9	388	1.00	4.8	0.54	0.29	29%	71%
	800	50.39	27.1	400	1.00	4.8	0.55	0.30	30%	70%

Table D 189. Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 1; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.19	16.1	84	1.00	4.8	0.32	0.25	25%	75%
	140	8.82	16.6	90	1.00	4.8	0.33	0.26	26%	74%
	150	9.45	17.0	96	1.00	4.8	0.34	0.27	27%	73%
	160	10.08	17.4	103	1.00	4.8	0.35	0.27	27%	73%
	170	10.71	17.7	109	1.00	4.8	0.36	0.28	28%	72%
	180	11.34	18.1	116	1.00	4.8	0.36	0.28	28%	72%
	190	11.97	18.4	122	1.00	4.8	0.37	0.29	29%	71%
	200	12.60	18.7	129	1.00	4.8	0.38	0.29	29%	71%
	210	13.23	19.0	135	1.00	4.8	0.38	0.30	30%	70%
Kelt	650	40.94	25.9	418	1.00	4.8	0.52	0.41	41%	59%
	675	42.52	26.1	434	1.00	4.8	0.53	0.41	41%	59%
	700	44.09	26.3	450	1.00	4.8	0.53	0.41	41%	59%
	725	45.67	26.5	466	1.00	4.8	0.53	0.42	42%	58%
	750	47.24	26.7	482	1.00	4.8	0.54	0.42	42%	58%
	775	48.82	26.9	498	1.00	4.8	0.54	0.42	42%	58%
	800	50.39	27.1	514	1.00	4.8	0.55	0.43	43%	57%

Table D 190. Input parameters for the prediction of strike probability and mortality for Brown's Mill unit 1; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.19	16.1	44	0.54	4.8	0.32	0.18	10%	90%
	140	8.82	16.6	48	0.58	4.8	0.33	0.18	11%	89%
	150	9.45	17.0	51	0.63	4.8	0.34	0.19	12%	88%
	160	10.08	17.4	55	0.67	4.8	0.35	0.19	13%	87%
	170	10.71	17.7	58	0.71	4.8	0.36	0.19	14%	86%
	180	11.34	18.1	62	0.75	4.8	0.36	0.20	15%	85%
	190	11.97	18.4	65	0.79	4.8	0.37	0.20	16%	84%
	200	12.60	18.7	68	0.84	4.8	0.38	0.20	17%	83%
	210	13.23	19.0	72	0.88	4.8	0.38	0.21	18%	82%
Kelt	650	40.94	25.9	222	1.00	4.8	0.52	0.28	28%	72%
	675	42.52	26.1	231	1.00	4.8	0.53	0.28	28%	72%
	700	44.09	26.3	239	1.00	4.8	0.53	0.29	29%	71%
	725	45.67	26.5	248	1.00	4.8	0.53	0.29	29%	71%
	750	47.24	26.7	257	1.00	4.8	0.54	0.29	29%	71%
	775	48.82	26.9	265	1.00	4.8	0.54	0.29	29%	71%
	800	50.39	27.1	274	1.00	4.8	0.55	0.30	30%	70%

Table D 191. Input parameters for the prediction of strike probability and mortality for Lowell Tannery; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.39	15.5	70	0.40	4.8	0.38	0.25	10%	90%
	140	7.96	15.9	75	0.43	4.8	0.39	0.25	11%	89%
	150	8.53	16.4	81	0.46	4.8	0.40	0.26	12%	88%
	160	9.10	16.7	86	0.49	4.8	0.41	0.27	13%	87%
	170	9.67	17.1	91	0.52	4.8	0.42	0.27	14%	86%
	180	10.24	17.5	97	0.55	4.8	0.43	0.28	15%	85%
	190	10.81	17.8	102	0.58	4.8	0.43	0.28	16%	84%
	200	11.38	18.1	107	0.61	4.8	0.44	0.29	18%	82%
	210	11.95	18.4	113	0.65	4.8	0.45	0.29	19%	81%
Kelt	650	36.97	25.2	349	1.00	4.8	0.62	0.40	40%	60%
	675	38.40	25.5	362	1.00	4.8	0.62	0.40	40%	60%
	700	39.82	25.7	376	1.00	4.8	0.63	0.41	41%	59%
	725	41.24	25.9	389	1.00	4.8	0.63	0.41	41%	59%
	750	42.66	26.1	403	1.00	4.8	0.64	0.41	41%	59%
	775	44.08	26.3	416	1.00	4.8	0.64	0.42	42%	58%
	800	45.51	26.5	430	1.00	4.8	0.65	0.42	42%	58%

Table D 192. Input parameters for the prediction of strike probability and mortality for Lowell Tannery; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.39	15.5	88	0.50	4.8	0.38	0.25	12%	88%
	140	7.96	15.9	95	0.54	4.8	0.39	0.25	14%	86%
	150	8.53	16.4	101	0.58	4.8	0.40	0.26	15%	85%
	160	9.10	16.7	108	0.62	4.8	0.41	0.27	16%	84%
	170	9.67	17.1	115	0.66	4.8	0.42	0.27	18%	82%
	180	10.24	17.5	122	0.70	4.8	0.43	0.28	19%	81%
	190	10.81	17.8	128	0.73	4.8	0.43	0.28	21%	79%
	200	11.38	18.1	135	0.77	4.8	0.44	0.29	22%	78%
	210	11.95	18.4	142	0.81	4.8	0.45	0.29	24%	76%
Kelt	650	36.97	25.2	439	1.00	4.8	0.62	0.40	40%	60%
	675	38.40	25.5	456	1.00	4.8	0.62	0.40	40%	60%
	700	39.82	25.7	473	1.00	4.8	0.63	0.41	41%	59%
	725	41.24	25.9	490	1.00	4.8	0.63	0.41	41%	59%
	750	42.66	26.1	506	1.00	4.8	0.64	0.41	41%	59%
	775	44.08	26.3	523	1.00	4.8	0.64	0.42	42%	58%
	800	45.51	26.5	540	1.00	4.8	0.65	0.42	42%	58%

Table D 193. Input parameters for the prediction of strike probability and mortality for Lowell Tannery; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.39	15.5	50	0.28	4.8	0.38	0.25	7%	93%
	140	7.96	15.9	54	0.31	4.8	0.39	0.25	8%	92%
	150	8.53	16.4	57	0.33	4.8	0.40	0.26	9%	91%
	160	9.10	16.7	61	0.35	4.8	0.41	0.27	9%	91%
	170	9.67	17.1	65	0.37	4.8	0.42	0.27	10%	90%
	180	10.24	17.5	69	0.39	4.8	0.43	0.28	11%	89%
	190	10.81	17.8	73	0.42	4.8	0.43	0.28	12%	88%
	200	11.38	18.1	76	0.44	4.8	0.44	0.29	13%	87%
	210	11.95	18.4	80	0.46	4.8	0.45	0.29	13%	87%
Kelt	650	36.97	25.2	249	1.00	4.8	0.62	0.40	40%	60%
	675	38.40	25.5	258	1.00	4.8	0.62	0.40	40%	60%
	700	39.82	25.7	268	1.00	4.8	0.63	0.41	41%	59%
	725	41.24	25.9	277	1.00	4.8	0.63	0.41	41%	59%
	750	42.66	26.1	287	1.00	4.8	0.64	0.41	41%	59%
	775	44.08	26.3	296	1.00	4.8	0.64	0.42	42%	58%
	800	45.51	26.5	306	1.00	4.8	0.65	0.42	42%	58%

Table D 194. Input parameters for the prediction of strike probability and mortality for Lowell Tannery; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.39	15.5	70	0.40	4.8	0.38	0.30	12%	88%
	140	7.96	15.9	75	0.43	4.8	0.39	0.30	13%	87%
	150	8.53	16.4	81	0.46	4.8	0.40	0.31	14%	86%
	160	9.10	16.7	86	0.49	4.8	0.41	0.32	16%	84%
	170	9.67	17.1	91	0.52	4.8	0.42	0.33	17%	83%
	180	10.24	17.5	97	0.55	4.8	0.43	0.33	18%	82%
	190	10.81	17.8	102	0.58	4.8	0.43	0.34	20%	80%
	200	11.38	18.1	107	0.61	4.8	0.44	0.34	21%	79%
	210	11.95	18.4	113	0.65	4.8	0.45	0.35	23%	77%
Kelt	650	36.97	25.2	349	1.00	4.8	0.62	0.48	48%	52%
	675	38.40	25.5	362	1.00	4.8	0.62	0.49	49%	51%
	700	39.82	25.7	376	1.00	4.8	0.63	0.49	49%	51%
	725	41.24	25.9	389	1.00	4.8	0.63	0.49	49%	51%
	750	42.66	26.1	403	1.00	4.8	0.64	0.50	50%	50%
	775	44.08	26.3	416	1.00	4.8	0.64	0.50	50%	50%
	800	45.51	26.5	430	1.00	4.8	0.65	0.51	51%	49%

Table D 195. Input parameters for the prediction of strike probability and mortality for Lowell Tannery; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.39	15.5	70	0.40	4.8	0.38	0.21	8%	92%
	140	7.96	15.9	75	0.43	4.8	0.39	0.21	9%	91%
	150	8.53	16.4	81	0.46	4.8	0.40	0.22	10%	90%
	160	9.10	16.7	86	0.49	4.8	0.41	0.22	11%	89%
	170	9.67	17.1	91	0.52	4.8	0.42	0.23	12%	88%
	180	10.24	17.5	97	0.55	4.8	0.43	0.23	13%	87%
	190	10.81	17.8	102	0.58	4.8	0.43	0.24	14%	86%
	200	11.38	18.1	107	0.61	4.8	0.44	0.24	15%	85%
	210	11.95	18.4	113	0.65	4.8	0.45	0.24	16%	84%
Kelt	650	36.97	25.2	349	1.00	4.8	0.62	0.33	33%	67%
	675	38.40	25.5	362	1.00	4.8	0.62	0.34	34%	66%
	700	39.82	25.7	376	1.00	4.8	0.63	0.34	34%	66%
	725	41.24	25.9	389	1.00	4.8	0.63	0.34	34%	66%
	750	42.66	26.1	403	1.00	4.8	0.64	0.35	35%	65%
	775	44.08	26.3	416	1.00	4.8	0.64	0.35	35%	65%
	800	45.51	26.5	430	1.00	4.8	0.65	0.35	35%	65%

Table D 196. Input parameters for the prediction of strike probability and mortality for Lowell Tannery; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.39	15.5	88	0.50	4.8	0.38	0.30	15%	85%
	140	7.96	15.9	95	0.54	4.8	0.39	0.30	16%	84%
	150	8.53	16.4	101	0.58	4.8	0.40	0.31	18%	82%
	160	9.10	16.7	108	0.62	4.8	0.41	0.32	20%	80%
	170	9.67	17.1	115	0.66	4.8	0.42	0.33	21%	79%
	180	10.24	17.5	122	0.70	4.8	0.43	0.33	23%	77%
	190	10.81	17.8	128	0.73	4.8	0.43	0.34	25%	75%
	200	11.38	18.1	135	0.77	4.8	0.44	0.34	27%	73%
	210	11.95	18.4	142	0.81	4.8	0.45	0.35	28%	72%
Kelt	650	36.97	25.2	439	1.00	4.8	0.62	0.48	48%	52%
	675	38.40	25.5	456	1.00	4.8	0.62	0.49	49%	51%
	700	39.82	25.7	473	1.00	4.8	0.63	0.49	49%	51%
	725	41.24	25.9	490	1.00	4.8	0.63	0.49	49%	51%
	750	42.66	26.1	506	1.00	4.8	0.64	0.50	50%	50%
	775	44.08	26.3	523	1.00	4.8	0.64	0.50	50%	50%
	800	45.51	26.5	540	1.00	4.8	0.65	0.51	51%	49%

Table D 197. Input parameters for the prediction of strike probability and mortality for Lowell Tannery; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.39	15.5	50	0.28	4.8	0.38	0.21	6%	94%
	140	7.96	15.9	54	0.31	4.8	0.39	0.21	6%	94%
	150	8.53	16.4	57	0.33	4.8	0.40	0.22	7%	93%
	160	9.10	16.7	61	0.35	4.8	0.41	0.22	8%	92%
	170	9.67	17.1	65	0.37	4.8	0.42	0.23	8%	92%
	180	10.24	17.5	69	0.39	4.8	0.43	0.23	9%	91%
	190	10.81	17.8	73	0.42	4.8	0.43	0.24	10%	90%
	200	11.38	18.1	76	0.44	4.8	0.44	0.24	10%	90%
	210	11.95	18.4	80	0.46	4.8	0.45	0.24	11%	89%
Kelt	650	36.97	25.2	249	1.00	4.8	0.62	0.33	33%	67%
	675	38.40	25.5	258	1.00	4.8	0.62	0.34	34%	66%
	700	39.82	25.7	268	1.00	4.8	0.63	0.34	34%	66%
	725	41.24	25.9	277	1.00	4.8	0.63	0.34	34%	66%
	750	42.66	26.1	287	1.00	4.8	0.64	0.35	35%	65%
	775	44.08	26.3	296	1.00	4.8	0.64	0.35	35%	65%
	800	45.51	26.5	306	1.00	4.8	0.65	0.35	35%	65%

Table D 198. Input parameters for the prediction of strike probability and mortality for Moosehead unit 2; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	81	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	87	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	94	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	100	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	106	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	112	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	119	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	125	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	131	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	406	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	421	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	437	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	452	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	468	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	484	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	499	1.00	4.8	0.00	0.00	0%	100%

Table D 199. Input parameters for the prediction of strike probability and mortality for Moosehead unit 2; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	98	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	105	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	113	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	120	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	128	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	135	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	143	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	150	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	158	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	488	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	506	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	525	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	544	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	563	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	581	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	600	1.00	4.8	0.00	0.00	0%	100%

Table D 200. Input parameters for the prediction of strike probability and mortality for Moosehead unit 2; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	62	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	67	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	72	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	77	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	81	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	86	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	91	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	96	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	101	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	311	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	323	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	335	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	347	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	359	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	371	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	383	1.00	4.8	0.00	0.00	0%	100%

Table D 201. Input parameters for the prediction of strike probability and mortality for Moosehead unit 2; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	81	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	87	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	94	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	100	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	106	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	112	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	119	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	125	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	131	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	406	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	421	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	437	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	452	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	468	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	484	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	499	1.00	4.8	0.00	0.00	0%	100%

Table D 202. Input parameters for the prediction of strike probability and mortality for Moosehead unit 2; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	81	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	87	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	94	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	100	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	106	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	112	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	119	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	125	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	131	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	406	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	421	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	437	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	452	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	468	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	484	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	499	1.00	4.8	0.00	0.00	0%	100%

Table D 203. Input parameters for the prediction of strike probability and mortality for Moosehead unit 2; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	98	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	105	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	113	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	120	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	128	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	135	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	143	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	150	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	158	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	488	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	506	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	525	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	544	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	563	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	581	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	600	1.00	4.8	0.00	0.00	0%	100%

Table D 204. Input parameters for the prediction of strike probability and mortality for Moosehead unit 2; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	62	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	67	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	72	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	77	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	81	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	86	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	91	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	96	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	101	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	311	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	323	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	335	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	347	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	359	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	371	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	383	1.00	4.8	0.00	0.00	0%	100%

Table D 205. Input parameters for the prediction of strike probability and mortality for Moosehead unit 1; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	86	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	93	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	99	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	106	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	113	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	119	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	126	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	133	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	139	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	431	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	447	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	464	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	480	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	497	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	514	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	530	1.00	4.8	0.00	0.00	0%	100%

Table D 206 Input parameters for the prediction of strike probability and mortality for Moosehead unit 1; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	102	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	110	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	117	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	125	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	133	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	141	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	149	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	157	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	164	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	509	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	528	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	548	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	567	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	587	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	607	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	626	1.00	4.8	0.00	0.00	0%	100%

Table D 207 Input parameters for the prediction of strike probability and mortality for Moosehead unit 1; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	68	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	73	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	78	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	84	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	89	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	94	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	99	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	104	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	110	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	340	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	353	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	366	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	379	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	392	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	405	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	418	1.00	4.8	0.00	0.00	0%	100%

Table D 208 Input parameters for the prediction of strike probability and mortality for Moosehead unit 1; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	86	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	93	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	99	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	106	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	113	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	119	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	126	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	133	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	139	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	431	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	447	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	464	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	480	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	497	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	514	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	530	1.00	4.8	0.00	0.00	0%	100%

Table D 209. Input parameters for the prediction of strike probability and mortality for Moosehead unit 1; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	86	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	93	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	99	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	106	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	113	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	119	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	126	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	133	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	139	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	431	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	447	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	464	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	480	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	497	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	514	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	530	1.00	4.8	0.00	0.00	0%	100%

Table D 210. Input parameters for the prediction of strike probability and mortality for Moosehead unit 1; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	102	1.00	4.8	0.00	0.08	8%	92%
	140	27.56	23.5	110	1.00	4.8	0.00	0.08	8%	92%
	150	29.53	23.9	117	1.00	4.8	0.00	0.08	8%	92%
	160	31.50	24.3	125	1.00	4.8	0.00	0.08	8%	92%
	170	33.46	24.6	133	1.00	4.8	0.00	0.08	8%	92%
	180	35.43	25.0	141	1.00	4.8	0.00	0.08	8%	92%
	190	37.40	25.3	149	1.00	4.8	0.00	0.08	8%	92%
	200	39.37	25.6	157	1.00	4.8	0.00	0.08	8%	92%
	210	41.34	25.9	164	1.00	4.8	0.00	0.08	8%	92%
Kelt	650	127.95	32.8	509	1.00	4.8	0.00	0.08	8%	92%
	675	132.87	33.0	528	1.00	4.8	0.00	0.08	8%	92%
	700	137.80	33.2	548	1.00	4.8	0.00	0.08	8%	92%
	725	142.72	33.4	567	1.00	4.8	0.00	0.08	8%	92%
	750	147.64	33.6	587	1.00	4.8	0.00	0.08	8%	92%
	775	152.56	33.8	607	1.00	4.8	0.00	0.08	8%	92%
	800	157.48	34.0	626	1.00	4.8	0.00	0.08	8%	92%

Table D 211. Input parameters for the prediction of strike probability and mortality for Moosehead unit 1; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	25.59	23.0	68	1.00	4.8	0.00	0.00	0%	100%
	140	27.56	23.5	73	1.00	4.8	0.00	0.00	0%	100%
	150	29.53	23.9	78	1.00	4.8	0.00	0.00	0%	100%
	160	31.50	24.3	84	1.00	4.8	0.00	0.00	0%	100%
	170	33.46	24.6	89	1.00	4.8	0.00	0.00	0%	100%
	180	35.43	25.0	94	1.00	4.8	0.00	0.00	0%	100%
	190	37.40	25.3	99	1.00	4.8	0.00	0.00	0%	100%
	200	39.37	25.6	104	1.00	4.8	0.00	0.00	0%	100%
	210	41.34	25.9	110	1.00	4.8	0.00	0.00	0%	100%
Kelt	650	127.95	32.8	340	1.00	4.8	0.00	0.00	0%	100%
	675	132.87	33.0	353	1.00	4.8	0.00	0.00	0%	100%
	700	137.80	33.2	366	1.00	4.8	0.00	0.00	0%	100%
	725	142.72	33.4	379	1.00	4.8	0.00	0.00	0%	100%
	750	147.64	33.6	392	1.00	4.8	0.00	0.00	0%	100%
	775	152.56	33.8	405	1.00	4.8	0.00	0.00	0%	100%
	800	157.48	34.0	418	1.00	4.8	0.00	0.00	0%	100%

Table D 212 Input parameters for the prediction of strike probability and mortality for Milo unit 1; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.10	16.7	113	0.15	4.8	0.76	0.49	7%	93%
	140	9.80	17.2	122	0.16	4.8	0.78	0.51	8%	92%
	150	10.50	17.6	130	0.17	4.8	0.80	0.52	9%	91%
	160	11.20	18.0	139	0.18	4.8	0.81	0.53	10%	90%
	170	11.90	18.4	148	0.19	4.8	0.83	0.54	10%	90%
	180	12.60	18.7	156	0.20	4.8	0.85	0.55	11%	89%
	190	13.30	19.0	165	0.21	4.8	0.86	0.56	12%	88%
	200	14.00	19.4	174	0.23	4.8	0.88	0.57	13%	87%
	210	14.70	19.6	183	0.24	4.8	0.89	0.58	14%	86%
Kelt	650	45.49	26.5	565	0.73	4.8	1.00	0.65	48%	52%
	675	47.24	26.7	587	0.76	4.8	1.00	0.65	50%	50%
	700	48.99	26.9	609	0.79	4.8	1.00	0.65	51%	49%
	725	50.74	27.2	630	0.82	4.8	1.00	0.65	53%	47%
	750	52.49	27.4	652	0.85	4.8	1.00	0.65	55%	45%
	775	54.24	27.6	674	0.87	4.8	1.00	0.65	57%	43%
	800	55.99	27.8	695	0.90	4.8	1.00	0.65	59%	41%

Table D 213. Input parameters for the prediction of strike probability and mortality for Milo unit 1; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.10	16.7	122	0.16	4.8	0.76	0.49	8%	92%
	140	9.80	17.2	132	0.17	4.8	0.78	0.51	9%	91%
	150	10.50	17.6	141	0.18	4.8	0.80	0.52	10%	90%
	160	11.20	18.0	151	0.20	4.8	0.81	0.53	10%	90%
	170	11.90	18.4	160	0.21	4.8	0.83	0.54	11%	89%
	180	12.60	18.7	170	0.22	4.8	0.85	0.55	12%	88%
	190	13.30	19.0	179	0.23	4.8	0.86	0.56	13%	87%
	200	14.00	19.4	188	0.24	4.8	0.88	0.57	14%	86%
	210	14.70	19.6	198	0.26	4.8	0.89	0.58	15%	85%
Kelt	650	45.49	26.5	612	0.80	4.8	1.00	0.65	52%	48%
	675	47.24	26.7	636	0.83	4.8	1.00	0.65	54%	46%
	700	48.99	26.9	659	0.86	4.8	1.00	0.65	56%	44%
	725	50.74	27.2	683	0.89	4.8	1.00	0.65	58%	42%
	750	52.49	27.4	706	0.92	4.8	1.00	0.65	60%	40%
	775	54.24	27.6	730	0.95	4.8	1.00	0.65	62%	38%
	800	55.993	27.8	754	0.98	4.8	1.00	0.65	64%	36%

Table D 214 Input parameters for the prediction of strike probability and mortality for Milo unit 1; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.10	16.7	100	0.13	4.8	0.76	0.49	6%	94%
	140	9.80	17.2	108	0.14	4.8	0.78	0.51	7%	93%
	150	10.50	17.6	116	0.15	4.8	0.80	0.52	8%	92%
	160	11.20	18.0	123	0.16	4.8	0.81	0.53	8%	92%
	170	11.90	18.4	131	0.17	4.8	0.83	0.54	9%	91%
	180	12.60	18.7	139	0.18	4.8	0.85	0.55	10%	90%
	190	13.30	19.0	146	0.19	4.8	0.86	0.56	11%	89%
	200	14.00	19.4	154	0.20	4.8	0.88	0.57	11%	89%
	210	14.70	19.6	162	0.21	4.8	0.89	0.58	12%	88%
Kelt	650	45.49	26.5	501	0.65	4.8	1.00	0.65	42%	58%
	675	47.24	26.7	520	0.68	4.8	1.00	0.65	44%	56%
	700	48.99	26.9	539	0.70	4.8	1.00	0.65	46%	54%
	725	50.74	27.2	558	0.73	4.8	1.00	0.65	47%	53%
	750	52.49	27.4	578	0.75	4.8	1.00	0.65	49%	51%
	775	54.24	27.6	597	0.78	4.8	1.00	0.65	50%	50%
	800	55.99	27.8	616	0.80	4.8	1.00	0.65	52%	48%

Table D 215 Input parameters for the prediction of strike probability and mortality for Milo unit 1; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.10	16.7	113	0.15	4.8	0.76	0.59	9%	91%
	140	9.80	17.2	122	0.16	4.8	0.78	0.61	10%	90%
	150	10.50	17.6	130	0.17	4.8	0.80	0.62	11%	89%
	160	11.20	18.0	139	0.18	4.8	0.81	0.64	11%	89%
	170	11.90	18.4	148	0.19	4.8	0.83	0.65	12%	88%
	180	12.60	18.7	156	0.20	4.8	0.85	0.66	13%	87%
	190	13.30	19.0	165	0.21	4.8	0.86	0.67	14%	86%
	200	14.00	19.4	174	0.23	4.8	0.88	0.68	15%	85%
	210	14.70	19.6	183	0.24	4.8	0.89	0.69	16%	84%
Kelt	650	45.49	26.5	565	0.73	4.8	1.00	0.78	57%	43%
	675	47.24	26.7	587	0.76	4.8	1.00	0.78	59%	41%
	700	48.99	26.9	609	0.79	4.8	1.00	0.78	62%	38%
	725	50.74	27.2	630	0.82	4.8	1.00	0.78	64%	36%
	750	52.49	27.4	652	0.85	4.8	1.00	0.78	66%	34%
	775	54.24	27.6	674	0.87	4.8	1.00	0.78	68%	32%
	800	55.99	27.8	695	0.90	4.8	1.00	0.78	70%	30%

Table D 216 Input parameters for the prediction of strike probability and mortality for Milo unit 1; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.10	16.7	113	0.15	4.8	0.76	0.41	6%	94%
	140	9.80	17.2	122	0.16	4.8	0.78	0.42	7%	93%
	150	10.50	17.6	130	0.17	4.8	0.80	0.43	7%	93%
	160	11.20	18.0	139	0.18	4.8	0.81	0.44	8%	92%
	170	11.90	18.4	148	0.19	4.8	0.83	0.45	9%	91%
	180	12.60	18.7	156	0.20	4.8	0.85	0.46	9%	91%
	190	13.30	19.0	165	0.21	4.8	0.86	0.47	10%	90%
	200	14.00	19.4	174	0.23	4.8	0.88	0.47	11%	89%
	210	14.70	19.6	183	0.24	4.8	0.89	0.48	11%	89%
Kelt	650	45.49	26.5	565	0.73	4.8	1.00	0.54	40%	60%
	675	47.24	26.7	587	0.76	4.8	1.00	0.54	41%	59%
	700	48.99	26.9	609	0.79	4.8	1.00	0.54	43%	57%
	725	50.74	27.2	630	0.82	4.8	1.00	0.54	44%	56%
	750	52.49	27.4	652	0.85	4.8	1.00	0.54	46%	54%
	775	54.24	27.6	674	0.87	4.8	1.00	0.54	47%	53%
	800	55.99	27.8	695	0.90	4.8	1.00	0.54	49%	51%

Table D 217. nput parameters for the prediction of strike probability and mortality for Milo unit 1; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.10	16.7	122.45	0.16	4.8	0.76	0.59	9%	91%
	140	9.80	17.2	131.87	0.17	4.8	0.78	0.61	10%	90%
	150	10.50	17.6	141.29	0.18	4.8	0.80	0.62	11%	89%
	160	11.20	18.0	150.71	0.20	4.8	0.81	0.64	12%	88%
	170	11.90	18.4	160.13	0.21	4.8	0.83	0.65	13%	87%
	180	12.60	18.7	169.55	0.22	4.8	0.85	0.66	15%	85%
	190	13.30	19.0	178.97	0.23	4.8	0.86	0.67	16%	84%
	200	14.00	19.4	188.38	0.24	4.8	0.88	0.68	17%	83%
	210	14.70	19.6	197.80	0.26	4.8	0.89	0.69	18%	82%
Kelt	650	45.49	26.5	612.25	0.80	4.8	1.00	0.78	62%	38%
	675	47.24	26.7	635.80	0.83	4.8	1.00	0.78	64%	36%
	700	48.99	26.9	659.35	0.86	4.8	1.00	0.78	67%	33%
	725	50.74	27.2	682.90	0.89	4.8	1.00	0.78	69%	31%
	750	52.49	27.4	706.44	0.92	4.8	1.00	0.78	72%	28%
	775	54.24	27.6	729.99	0.95	4.8	1.00	0.78	74%	26%
	800	55.99	27.8	753.54	0.98	4.8	1.00	0.78	76%	24%

Table D 218. Input parameters for the prediction of strike probability and mortality for Milo unit 1; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.10	16.7	100	0.13	4.8	0.76	0.41	5%	95%
	140	9.80	17.2	108	0.14	4.8	0.78	0.42	6%	94%
	150	10.50	17.6	116	0.15	4.8	0.80	0.43	6%	94%
	160	11.20	18.0	123	0.16	4.8	0.81	0.44	7%	93%
	170	11.90	18.4	131	0.17	4.8	0.83	0.45	8%	92%
	180	12.60	18.7	139	0.18	4.8	0.85	0.46	8%	92%
	190	13.30	19.0	146	0.19	4.8	0.86	0.47	9%	91%
	200	14.00	19.4	154	0.20	4.8	0.88	0.47	9%	91%
	210	14.70	19.6	162	0.21	4.8	0.89	0.48	10%	90%
Kelt	650	45.49	26.5	501	0.65	4.8	1.00	0.54	35%	65%
	675	47.24	26.7	520	0.68	4.8	1.00	0.54	37%	63%
	700	48.99	26.9	539	0.70	4.8	1.00	0.54	38%	62%
	725	50.74	27.2	558	0.73	4.8	1.00	0.54	39%	61%
	750	52.49	27.4	578	0.75	4.8	1.00	0.54	41%	59%
	775	54.24	27.6	597	0.78	4.8	1.00	0.54	42%	58%
	800	55.99	27.8	616	0.80	4.8	1.00	0.54	43%	57%

Table D 219 Input parameters for the prediction of strike probability and mortality for Sebec H4; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.81	17.2	81	0.22	4.8	0.60	0.39	9%	91%
	140	10.57	17.6	87	0.24	4.8	0.62	0.40	9%	91%
	150	11.32	18.1	94	0.25	4.8	0.63	0.41	10%	90%
	160	12.07	18.5	100	0.27	4.8	0.65	0.42	11%	89%
	170	12.83	18.8	106	0.29	4.8	0.66	0.43	12%	88%
	180	13.58	19.2	112	0.30	4.8	0.67	0.44	13%	87%
	190	14.34	19.5	119	0.32	4.8	0.68	0.45	14%	86%
	200	15.09	19.8	125	0.34	4.8	0.70	0.45	15%	85%
	210	15.85	20.1	131	0.35	4.8	0.71	0.46	16%	84%
Kelt	650	49.05	27.0	406	1.00	4.8	0.95	0.62	62%	38%
	675	50.94	27.2	422	1.00	4.8	0.95	0.62	62%	38%
	700	52.83	27.4	437	1.00	4.8	0.96	0.63	63%	37%
	725	54.71	27.6	453	1.00	4.8	0.97	0.63	63%	37%
	750	56.60	27.8	468	1.00	4.8	0.98	0.64	64%	36%
	775	58.49	28.0	484	1.00	4.8	0.98	0.64	64%	36%
	800	60.37	28.2	500	1.00	4.8	0.99	0.64	64%	36%

Table D 220. Input parameters for the prediction of strike probability and mortality for Sebec H4; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.81	17.2	98	0.26	4.8	0.60	0.39	10%	90%
	140	10.57	17.6	105	0.28	4.8	0.62	0.40	11%	89%
	150	11.32	18.1	113	0.30	4.8	0.63	0.41	13%	87%
	160	12.07	18.5	120	0.32	4.8	0.65	0.42	14%	86%
	170	12.83	18.8	128	0.34	4.8	0.66	0.43	15%	85%
	180	13.58	19.2	135	0.36	4.8	0.67	0.44	16%	84%
	190	14.34	19.5	143	0.38	4.8	0.68	0.45	17%	83%
	200	15.09	19.8	150	0.40	4.8	0.70	0.45	18%	82%
	210	15.85	20.1	158	0.42	4.8	0.71	0.46	19%	81%
Kelt	650	49.05	27.0	488	1.00	4.8	0.95	0.62	62%	38%
	675	50.94	27.2	507	1.00	4.8	0.95	0.62	62%	38%
	700	52.83	27.4	525	1.00	4.8	0.96	0.63	63%	37%
	725	54.71	27.6	544	1.00	4.8	0.97	0.63	63%	37%
	750	56.60	27.8	563	1.00	4.8	0.98	0.64	64%	36%
	775	58.49	28.0	582	1.00	4.8	0.98	0.64	64%	36%
	800	60.3717	28.2	601	1.00	4.8	0.99	0.64	64%	36%

Table D 221. Input parameters for the prediction of strike probability and mortality for Sebec H4; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.81	17.2	62	0.17	4.8	0.60	0.39	7%	93%
	140	10.57	17.6	67	0.18	4.8	0.62	0.40	7%	93%
	150	11.32	18.1	72	0.19	4.8	0.63	0.41	8%	92%
	160	12.07	18.5	77	0.21	4.8	0.65	0.42	9%	91%
	170	12.83	18.8	81	0.22	4.8	0.66	0.43	9%	91%
	180	13.58	19.2	86	0.23	4.8	0.67	0.44	10%	90%
	190	14.34	19.5	91	0.25	4.8	0.68	0.45	11%	89%
	200	15.09	19.8	96	0.26	4.8	0.70	0.45	12%	88%
	210	15.85	20.1	101	0.27	4.8	0.71	0.46	12%	88%
Kelt	650	49.05	27.0	312	0.84	4.8	0.95	0.62	52%	48%
	675	50.94	27.2	324	0.87	4.8	0.95	0.62	54%	46%
	700	52.83	27.4	336	0.90	4.8	0.96	0.63	57%	43%
	725	54.71	27.6	348	0.94	4.8	0.97	0.63	59%	41%
	750	56.60	27.8	360	0.97	4.8	0.98	0.64	62%	38%
	775	58.49	28.0	372	1.00	4.8	0.98	0.64	64%	36%
	800	60.37	28.2	384	1.00	4.8	0.99	0.64	64%	36%

Table D 222. Input parameters for the prediction of strike probability and mortality for Sebec H4; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.81	17.2	81	0.22	4.8	0.60	0.47	10%	90%
	140	10.57	17.6	87	0.24	4.8	0.62	0.48	11%	89%
	150	11.32	18.1	94	0.25	4.8	0.63	0.49	12%	88%
	160	12.07	18.5	100	0.27	4.8	0.65	0.51	14%	86%
	170	12.83	18.8	106	0.29	4.8	0.66	0.52	15%	85%
	180	13.58	19.2	112	0.30	4.8	0.67	0.53	16%	84%
	190	14.34	19.5	119	0.32	4.8	0.68	0.53	17%	83%
	200	15.09	19.8	125	0.34	4.8	0.70	0.54	18%	82%
	210	15.85	20.1	131	0.35	4.8	0.71	0.55	19%	81%
Kelt	650	49.05	27.0	406	1.00	4.8	0.95	0.74	74%	26%
	675	50.94	27.2	422	1.00	4.8	0.95	0.74	74%	26%
	700	52.83	27.4	437	1.00	4.8	0.96	0.75	75%	25%
	725	54.71	27.6	453	1.00	4.8	0.97	0.76	76%	24%
	750	56.60	27.8	468	1.00	4.8	0.98	0.76	76%	24%
	775	58.49	28.0	484	1.00	4.8	0.98	0.77	77%	23%
	800	60.37	28.2	500	1.00	4.8	0.99	0.77	77%	23%

Table D 223. Input parameters for the prediction of strike probability and mortality for Sebec H4; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.81	17.2	81	0.22	4.8	0.60	0.33	7%	93%
	140	10.57	17.6	87	0.24	4.8	0.62	0.34	8%	92%
	150	11.32	18.1	94	0.25	4.8	0.63	0.34	9%	91%
	160	12.07	18.5	100	0.27	4.8	0.65	0.35	9%	91%
	170	12.83	18.8	106	0.29	4.8	0.66	0.36	10%	90%
	180	13.58	19.2	112	0.30	4.8	0.67	0.36	11%	89%
	190	14.34	19.5	119	0.32	4.8	0.68	0.37	12%	88%
	200	15.09	19.8	125	0.34	4.8	0.70	0.38	13%	87%
	210	15.85	20.1	131	0.35	4.8	0.71	0.38	14%	86%
Kelt	650	49.05	27.0	406	1.00	4.8	0.95	0.51	51%	49%
	675	50.94	27.2	422	1.00	4.8	0.95	0.52	52%	48%
	700	52.83	27.4	437	1.00	4.8	0.96	0.52	52%	48%
	725	54.71	27.6	453	1.00	4.8	0.97	0.53	53%	47%
	750	56.60	27.8	468	1.00	4.8	0.98	0.53	53%	47%
	775	58.49	28.0	484	1.00	4.8	0.98	0.53	53%	47%
	800	60.37	28.2	500	1.00	4.8	0.99	0.54	54%	46%

Table D 224 Input parameters for the prediction of strike probability and mortality for Sebec H4; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.81	17.2	98	0.26	4.8	0.60	0.47	12%	88%
	140	10.57	17.6	105	0.28	4.8	0.62	0.48	14%	86%
	150	11.32	18.1	113	0.30	4.8	0.63	0.49	15%	85%
	160	12.07	18.5	120	0.32	4.8	0.65	0.51	16%	84%
	170	12.83	18.8	128	0.34	4.8	0.66	0.52	18%	82%
	180	13.58	19.2	135	0.36	4.8	0.67	0.53	19%	81%
	190	14.34	19.5	143	0.38	4.8	0.68	0.53	21%	79%
	200	15.09	19.8	150	0.40	4.8	0.70	0.54	22%	78%
	210	15.85	20.1	158	0.42	4.8	0.71	0.55	23%	77%
Kelt	650	49.05	27.0	488	1.00	4.8	0.95	0.74	74%	26%
	675	50.94	27.2	507	1.00	4.8	0.95	0.74	74%	26%
	700	52.83	27.4	525	1.00	4.8	0.96	0.75	75%	25%
	725	54.71	27.6	544	1.00	4.8	0.97	0.76	76%	24%
	750	56.60	27.8	563	1.00	4.8	0.98	0.76	76%	24%
	775	58.49	28.0	582	1.00	4.8	0.98	0.77	77%	23%
	800	60.37	28.2	601	1.00	4.8	0.99	0.77	77%	23%

Table D 225. Input parameters for the prediction of strike probability and mortality for Sebec H4; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	9.81	17.2	62	0.17	4.8	0.60	0.33	5%	95%
	140	10.57	17.6	67	0.18	4.8	0.62	0.34	6%	94%
	150	11.32	18.1	72	0.19	4.8	0.63	0.34	7%	93%
	160	12.07	18.5	77	0.21	4.8	0.65	0.35	7%	93%
	170	12.83	18.8	81	0.22	4.8	0.66	0.36	8%	92%
	180	13.58	19.2	86	0.23	4.8	0.67	0.36	8%	92%
	190	14.34	19.5	91	0.25	4.8	0.68	0.37	9%	91%
	200	15.09	19.8	96	0.26	4.8	0.70	0.38	10%	90%
	210	15.85	20.1	101	0.27	4.8	0.71	0.38	10%	90%
Kelt	650	49.05	27.0	312	0.84	4.8	0.95	0.51	43%	57%
	675	50.94	27.2	324	0.87	4.8	0.95	0.52	45%	55%
	700	52.83	27.4	336	0.90	4.8	0.96	0.52	47%	53%
	725	54.71	27.6	348	0.94	4.8	0.97	0.53	49%	51%
	750	56.60	27.8	360	0.97	4.8	0.98	0.53	51%	49%
	775	58.49	28.0	372	1.00	4.8	0.98	0.53	53%	47%
	800	60.37	28.2	384	1.00	4.8	0.99	0.54	54%	46%

Table D 226. Input parameters for the prediction of strike probability and mortality for Sebec H6; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.43	16.3	77	0.19	4.8	0.76	0.50	9%	91%
	140	9.08	16.7	83	0.20	4.8	0.78	0.51	10%	90%
	150	9.73	17.1	89	0.22	4.8	0.80	0.52	11%	89%
	160	10.38	17.5	95	0.23	4.8	0.82	0.53	12%	88%
	170	11.03	17.9	101	0.25	4.8	0.84	0.54	13%	87%
	180	11.68	18.3	106	0.26	4.8	0.85	0.56	15%	85%
	190	12.33	18.6	112	0.28	4.8	0.87	0.57	16%	84%
	200	12.97	18.9	118	0.29	4.8	0.88	0.57	17%	83%
	210	13.62	19.2	124	0.31	4.8	0.90	0.58	18%	82%
Kelt	650	42.17	26.0	384	0.94	4.8	1.00	0.65	61%	39%
	675	43.79	26.3	399	0.98	4.8	1.00	0.65	64%	36%
	700	45.41	26.5	414	1.00	4.8	1.00	0.65	65%	35%
	725	47.03	26.7	429	1.00	4.8	1.00	0.65	65%	35%
	750	48.65	26.9	444	1.00	4.8	1.00	0.65	65%	35%
	775	50.27	27.1	458	1.00	4.8	1.00	0.65	65%	35%
	800	51.90	27.3	473	1.00	4.8	1.00	0.65	65%	35%

Table D 227. Input parameters for the prediction of strike probability and mortality for Sebec H6; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.43	16.3	94	0.23	4.8	0.76	0.50	11%	89%
	140	9.08	16.7	101	0.25	4.8	0.78	0.51	13%	87%
	150	9.73	17.1	108	0.27	4.8	0.80	0.52	14%	86%
	160	10.38	17.5	116	0.28	4.8	0.82	0.53	15%	85%
	170	11.03	17.9	123	0.30	4.8	0.84	0.54	16%	84%
	180	11.68	18.3	130	0.32	4.8	0.85	0.56	18%	82%
	190	12.33	18.6	137	0.34	4.8	0.87	0.57	19%	81%
	200	12.97	18.9	144	0.35	4.8	0.88	0.57	20%	80%
	210	13.62	19.2	152	0.37	4.8	0.90	0.58	22%	78%
Kelt	650	42.17	26.0	470	1.00	4.8	1.00	0.65	65%	35%
	675	43.79	26.3	488	1.00	4.8	1.00	0.65	65%	35%
	700	45.41	26.5	506	1.00	4.8	1.00	0.65	65%	35%
	725	47.03	26.7	524	1.00	4.8	1.00	0.65	65%	35%
	750	48.65	26.9	542	1.00	4.8	1.00	0.65	65%	35%
	775	50.27	27.1	560	1.00	4.8	1.00	0.65	65%	35%
	800	51.8954	27.3	578	1.00	4.8	1.00	0.65	65%	35%

Table D 228. Input parameters for the prediction of strike probability and mortality for Sebec H6; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.43	16.3	58	0.14	4.8	0.76	0.50	7%	93%
	140	9.08	16.7	62	0.15	4.8	0.78	0.51	8%	92%
	150	9.73	17.1	66	0.16	4.8	0.80	0.52	9%	91%
	160	10.38	17.5	71	0.17	4.8	0.82	0.53	9%	91%
	170	11.03	17.9	75	0.18	4.8	0.84	0.54	10%	90%
	180	11.68	18.3	80	0.20	4.8	0.85	0.56	11%	89%
	190	12.33	18.6	84	0.21	4.8	0.87	0.57	12%	88%
	200	12.97	18.9	88	0.22	4.8	0.88	0.57	12%	88%
	210	13.62	19.2	93	0.23	4.8	0.90	0.58	13%	87%
Kelt	650	42.17	26.0	288	0.71	4.8	1.00	0.65	46%	54%
	675	43.79	26.3	299	0.73	4.8	1.00	0.65	48%	52%
	700	45.41	26.5	310	0.76	4.8	1.00	0.65	49%	51%
	725	47.03	26.7	321	0.79	4.8	1.00	0.65	51%	49%
	750	48.65	26.9	332	0.81	4.8	1.00	0.65	53%	47%
	775	50.27	27.1	343	0.84	4.8	1.00	0.65	55%	45%
	800	51.90	27.3	354	0.87	4.8	1.00	0.65	56%	44%

Table D 229. Input parameters for the prediction of strike probability and mortality for Sebec H6; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.43	16.3	77	0.19	4.8	0.76	0.59	11%	89%
	140	9.08	16.7	83	0.20	4.8	0.78	0.61	12%	88%
	150	9.73	17.1	89	0.22	4.8	0.80	0.63	14%	86%
	160	10.38	17.5	95	0.23	4.8	0.82	0.64	15%	85%
	170	11.03	17.9	101	0.25	4.8	0.84	0.65	16%	84%
	180	11.68	18.3	106	0.26	4.8	0.85	0.67	17%	83%
	190	12.33	18.6	112	0.28	4.8	0.87	0.68	19%	81%
	200	12.97	18.9	118	0.29	4.8	0.88	0.69	20%	80%
	210	13.62	19.2	124	0.31	4.8	0.90	0.70	21%	79%
Kelt	650	42.17	26.0	384	0.94	4.8	1.00	0.78	74%	26%
	675	43.79	26.3	399	0.98	4.8	1.00	0.78	76%	24%
	700	45.41	26.5	414	1.00	4.8	1.00	0.78	78%	22%
	725	47.03	26.7	429	1.00	4.8	1.00	0.78	78%	22%
	750	48.65	26.9	444	1.00	4.8	1.00	0.78	78%	22%
	775	50.27	27.1	458	1.00	4.8	1.00	0.78	78%	22%
	800	51.90	27.3	473	1.00	4.8	1.00	0.78	78%	22%

Table D 230. Input parameters for the prediction of strike probability and mortality for Sebec H6; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.43	16.3	77	0.19	4.8	0.76	0.41	8%	92%
	140	9.08	16.7	83	0.20	4.8	0.78	0.42	9%	91%
	150	9.73	17.1	89	0.22	4.8	0.80	0.43	9%	91%
	160	10.38	17.5	95	0.23	4.8	0.82	0.44	10%	90%
	170	11.03	17.9	101	0.25	4.8	0.84	0.45	11%	89%
	180	11.68	18.3	106	0.26	4.8	0.85	0.46	12%	88%
	190	12.33	18.6	112	0.28	4.8	0.87	0.47	13%	87%
	200	12.97	18.9	118	0.29	4.8	0.88	0.48	14%	86%
	210	13.62	19.2	124	0.31	4.8	0.90	0.49	15%	85%
Kelt	650	42.17	26.0	384	0.94	4.8	1.00	0.54	51%	49%
	675	43.79	26.3	399	0.98	4.8	1.00	0.54	53%	47%
	700	45.41	26.5	414	1.00	4.8	1.00	0.54	54%	46%
	725	47.03	26.7	429	1.00	4.8	1.00	0.54	54%	46%
	750	48.65	26.9	444	1.00	4.8	1.00	0.54	54%	46%
	775	50.27	27.1	458	1.00	4.8	1.00	0.54	54%	46%
	800	51.90	27.3	473	1.00	4.8	1.00	0.54	54%	46%

Table D 231. Input parameters for the prediction of strike probability and mortality for Sebec H6; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.43	16.3	94	0.23	4.8	0.76	0.59	14%	86%
	140	9.08	16.7	101	0.25	4.8	0.78	0.61	15%	85%
	150	9.73	17.1	108	0.27	4.8	0.80	0.63	17%	83%
	160	10.38	17.5	116	0.28	4.8	0.82	0.64	18%	82%
	170	11.03	17.9	123	0.30	4.8	0.84	0.65	20%	80%
	180	11.68	18.3	130	0.32	4.8	0.85	0.67	21%	79%
	190	12.33	18.6	137	0.34	4.8	0.87	0.68	23%	77%
	200	12.97	18.9	144	0.35	4.8	0.88	0.69	24%	76%
	210	13.62	19.2	152	0.37	4.8	0.90	0.70	26%	74%
Kelt	650	42.17	26.0	470	1.00	4.8	1.00	0.78	78%	22%
	675	43.79	26.3	488	1.00	4.8	1.00	0.78	78%	22%
	700	45.41	26.5	506	1.00	4.8	1.00	0.78	78%	22%
	725	47.03	26.7	524	1.00	4.8	1.00	0.78	78%	22%
	750	48.65	26.9	542	1.00	4.8	1.00	0.78	78%	22%
	775	50.27	27.1	560	1.00	4.8	1.00	0.78	78%	22%
	800	51.90	27.3	578	1.00	4.8	1.00	0.78	78%	22%

Table D 232. Input parameters for the prediction of strike probability and mortality for Sebec H6; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	8.43	16.3	58	0.14	4.8	0.76	0.41	6%	94%
	140	9.08	16.7	62	0.15	4.8	0.78	0.42	6%	94%
	150	9.73	17.1	66	0.16	4.8	0.80	0.43	7%	93%
	160	10.38	17.5	71	0.17	4.8	0.82	0.44	8%	92%
	170	11.03	17.9	75	0.18	4.8	0.84	0.45	8%	92%
	180	11.68	18.3	80	0.20	4.8	0.85	0.46	9%	91%
	190	12.33	18.6	84	0.21	4.8	0.87	0.47	10%	90%
	200	12.97	18.9	88	0.22	4.8	0.88	0.48	10%	90%
	210	13.62	19.2	93	0.23	4.8	0.90	0.49	11%	89%
Kelt	650	42.17	26.0	288	0.71	4.8	1.00	0.54	38%	62%
	675	43.79	26.3	299	0.73	4.8	1.00	0.54	40%	60%
	700	45.41	26.5	310	0.76	4.8	1.00	0.54	41%	59%
	725	47.03	26.7	321	0.79	4.8	1.00	0.54	43%	57%
	750	48.65	26.9	332	0.81	4.8	1.00	0.54	44%	56%
	775	50.27	27.1	343	0.84	4.8	1.00	0.54	46%	54%
	800	51.90	27.3	354	0.87	4.8	1.00	0.54	47%	53%

Table D 233. Input parameters for the prediction of strike probability and mortality for Frankfort; baseline prediction.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.87	15.9	82	0.15	4.8	0.35	0.23	3%	97%
	140	8.48	16.3	88	0.16	4.8	0.36	0.24	4%	96%
	150	9.08	16.7	95	0.17	4.8	0.37	0.24	4%	96%
	160	9.69	17.1	101	0.18	4.8	0.38	0.25	5%	95%
	170	10.29	17.5	107	0.19	4.8	0.39	0.25	5%	95%
	180	10.90	17.8	113	0.20	4.8	0.40	0.26	5%	95%
	190	11.51	18.2	120	0.22	4.8	0.40	0.26	6%	94%
	200	12.11	18.5	126	0.23	4.8	0.41	0.27	6%	94%
	210	12.72	18.8	132	0.24	4.8	0.42	0.27	6%	94%
Kelt	650	39.36	25.6	410	0.74	4.8	0.57	0.37	27%	73%
	675	40.87	25.8	425	0.77	4.8	0.57	0.37	29%	71%
	700	42.39	26.1	441	0.80	4.8	0.58	0.38	30%	70%
	725	43.90	26.3	457	0.82	4.8	0.58	0.38	31%	69%
	750	45.41	26.5	473	0.85	4.8	0.59	0.38	33%	67%
	775	46.93	26.7	488	0.88	4.8	0.59	0.39	34%	66%
	800	48.44	26.9	504	0.91	4.8	0.60	0.39	35%	65%

Table D 234. Input parameters for the prediction of strike probability and mortality for Frankfort; fish angle +10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.87	15.9	98	0.18	4.8	0.35	0.23	4%	96%
	140	8.48	16.3	106	0.19	4.8	0.36	0.24	4%	96%
	150	9.08	16.7	113	0.20	4.8	0.37	0.24	5%	95%
	160	9.69	17.1	121	0.22	4.8	0.38	0.25	5%	95%
	170	10.29	17.5	128	0.23	4.8	0.39	0.25	6%	94%
	180	10.90	17.8	136	0.25	4.8	0.40	0.26	6%	94%
	190	11.51	18.2	144	0.26	4.8	0.40	0.26	7%	93%
	200	12.11	18.5	151	0.27	4.8	0.41	0.27	7%	93%
	210	12.72	18.8	159	0.29	4.8	0.42	0.27	8%	92%
Kelt	650	39.36	25.6	491	0.89	4.8	0.57	0.37	33%	67%
	675	40.87	25.8	510	0.92	4.8	0.57	0.37	34%	66%
	700	42.39	26.1	529	0.95	4.8	0.58	0.38	36%	64%
	725	43.90	26.3	548	0.99	4.8	0.58	0.38	38%	62%
	750	45.41	26.5	567	1.00	4.8	0.59	0.38	38%	62%
	775	46.93	26.7	586	1.00	4.8	0.59	0.39	39%	61%
	800	48.4424	26.9	604	1.00	4.8	0.60	0.39	39%	61%

Table D 235. Input parameters for the prediction of strike probability and mortality for Frankfort; fish angle -10 deg.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.87	15.9	63	0.11	4.8	0.35	0.23	3%	97%
	140	8.48	16.3	68	0.12	4.8	0.36	0.24	3%	97%
	150	9.08	16.7	73	0.13	4.8	0.37	0.24	3%	97%
	160	9.69	17.1	78	0.14	4.8	0.38	0.25	3%	97%
	170	10.29	17.5	83	0.15	4.8	0.39	0.25	4%	96%
	180	10.90	17.8	87	0.16	4.8	0.40	0.26	4%	96%
	190	11.51	18.2	92	0.17	4.8	0.40	0.26	4%	96%
	200	12.11	18.5	97	0.18	4.8	0.41	0.27	5%	95%
	210	12.72	18.8	102	0.18	4.8	0.42	0.27	5%	95%
Kelt	650	39.36	25.6	316	0.57	4.8	0.57	0.37	21%	79%
	675	40.87	25.8	328	0.59	4.8	0.57	0.37	22%	78%
	700	42.39	26.1	340	0.61	4.8	0.58	0.38	23%	77%
	725	43.90	26.3	352	0.64	4.8	0.58	0.38	24%	76%
	750	45.41	26.5	364	0.66	4.8	0.59	0.38	25%	75%
	775	46.93	26.7	377	0.68	4.8	0.59	0.39	26%	74%
	800	48.44	26.9	389	0.70	4.8	0.60	0.39	27%	73%

Table D 236. Input parameters for the prediction of strike probability and mortality for Frankfort; K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.87	15.9	82	0.15	4.8	0.35	0.28	4%	96%
	140	8.48	16.3	88	0.16	4.8	0.36	0.28	5%	95%
	150	9.08	16.7	95	0.17	4.8	0.37	0.29	5%	95%
	160	9.69	17.1	101	0.18	4.8	0.38	0.30	5%	95%
	170	10.29	17.5	107	0.19	4.8	0.39	0.30	6%	94%
	180	10.90	17.8	113	0.20	4.8	0.40	0.31	6%	94%
	190	11.51	18.2	120	0.22	4.8	0.40	0.32	7%	93%
	200	12.11	18.5	126	0.23	4.8	0.41	0.32	7%	93%
	210	12.72	18.8	132	0.24	4.8	0.42	0.33	8%	92%
Kelt	650	39.36	25.6	410	0.74	4.8	0.57	0.44	33%	67%
	675	40.87	25.8	425	0.77	4.8	0.57	0.45	34%	66%
	700	42.39	26.1	441	0.80	4.8	0.58	0.45	36%	64%
	725	43.90	26.3	457	0.82	4.8	0.58	0.46	38%	62%
	750	45.41	26.5	473	0.85	4.8	0.59	0.46	39%	61%
	775	46.93	26.7	488	0.88	4.8	0.59	0.46	41%	59%
	800	48.44	26.9	504	0.91	4.8	0.60	0.47	42%	58%

Table D 237. Input parameters for the prediction of strike probability and mortality for Frankfort; K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.87	15.9	82	0.15	4.8	0.35	0.19	3%	97%
	140	8.48	16.3	88	0.16	4.8	0.36	0.20	3%	97%
	150	9.08	16.7	95	0.17	4.8	0.37	0.20	3%	97%
	160	9.69	17.1	101	0.18	4.8	0.38	0.21	4%	96%
	170	10.29	17.5	107	0.19	4.8	0.39	0.21	4%	96%
	180	10.90	17.8	113	0.20	4.8	0.40	0.21	4%	96%
	190	11.51	18.2	120	0.22	4.8	0.40	0.22	5%	95%
	200	12.11	18.5	126	0.23	4.8	0.41	0.22	5%	95%
	210	12.72	18.8	132	0.24	4.8	0.42	0.23	5%	95%
Kelt	650	39.36	25.6	410	0.74	4.8	0.57	0.31	23%	77%
	675	40.87	25.8	425	0.77	4.8	0.57	0.31	24%	76%
	700	42.39	26.1	441	0.80	4.8	0.58	0.31	25%	75%
	725	43.90	26.3	457	0.82	4.8	0.58	0.32	26%	74%
	750	45.41	26.5	473	0.85	4.8	0.59	0.32	27%	73%
	775	46.93	26.7	488	0.88	4.8	0.59	0.32	28%	72%
	800	48.44	26.9	504	0.91	4.8	0.60	0.32	29%	71%

Table D 238. Input parameters for the prediction of strike probability and mortality for Frankfort; compounded fish angle +10 deg. & K +20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.87	15.9	98.21	0.18	4.8	0.35	0.28	5%	95%
	140	8.48	16.3	105.77	0.19	4.8	0.36	0.28	5%	95%
	150	9.08	16.7	113.32	0.20	4.8	0.37	0.29	6%	94%
	160	9.69	17.1	120.88	0.22	4.8	0.38	0.30	6%	94%
	170	10.29	17.5	128.43	0.23	4.8	0.39	0.30	7%	93%
	180	10.90	17.8	135.99	0.25	4.8	0.40	0.31	8%	92%
	190	11.51	18.2	143.54	0.26	4.8	0.40	0.32	8%	92%
	200	12.11	18.5	151.10	0.27	4.8	0.41	0.32	9%	91%
	210	12.72	18.8	158.65	0.29	4.8	0.42	0.33	9%	91%
Kelt	650	39.36	25.6	491.07	0.89	4.8	0.57	0.44	39%	61%
	675	40.87	25.8	509.96	0.92	4.8	0.57	0.45	41%	59%
	700	42.39	26.1	528.85	0.95	4.8	0.58	0.45	43%	57%
	725	43.90	26.3	547.73	0.99	4.8	0.58	0.46	45%	55%
	750	45.41	26.5	566.62	1.00	4.8	0.59	0.46	46%	54%
	775	46.93	26.7	585.51	1.00	4.8	0.59	0.46	46%	54%
	800	48.44	26.9	604.40	1.00	4.8	0.60	0.47	47%	53%

Table D 239. Input parameters for the prediction of strike probability and mortality for Frankfort; compounded fish angle -10 deg. & K -20%.

Life Stage	Fish Length, L (mm)	Fish Length to Blade Thickness Ratio (L/t)	Predicted Slope (m) for L/t vs Strike Velocity	L sin θ	Blade Strike Probability	Max Strike Velocity for 100% Survival, V100 (m/s)	Mortality Coefficient, K	Adjusted Mortality Coefficient, 0.65K	Mortality Probability	Survival Probability
Smolt	130	7.87	15.9	63	0.11	4.8	0.35	0.19	2%	98%
	140	8.48	16.3	68	0.12	4.8	0.36	0.20	2%	98%
	150	9.08	16.7	73	0.13	4.8	0.37	0.20	3%	97%
	160	9.69	17.1	78	0.14	4.8	0.38	0.21	3%	97%
	170	10.29	17.5	83	0.15	4.8	0.39	0.21	3%	97%
	180	10.90	17.8	87	0.16	4.8	0.40	0.21	3%	97%
	190	11.51	18.2	92	0.17	4.8	0.40	0.22	4%	96%
	200	12.11	18.5	97	0.18	4.8	0.41	0.22	4%	96%
	210	12.72	18.8	102	0.18	4.8	0.42	0.23	4%	96%
Kelt	650	39.36	25.6	316	0.57	4.8	0.57	0.31	18%	82%
	675	40.87	25.8	328	0.59	4.8	0.57	0.31	18%	82%
	700	42.39	26.1	340	0.61	4.8	0.58	0.31	19%	81%
	725	43.90	26.3	352	0.64	4.8	0.58	0.32	20%	80%
	750	45.41	26.5	364	0.66	4.8	0.59	0.32	21%	79%
	775	46.93	26.7	377	0.68	4.8	0.59	0.32	22%	78%
	800	48.44	26.9	389	0.70	4.8	0.60	0.32	23%	77%

Atlantic Salmon Fate and Straying at Upstream Fish Passage Facilities on the Penobscot River

Date: February 16, 2011

On December 8, 2010, NOAA's National Marine Fisheries Service (NMFS) convened a panel of experts in Atlantic salmon (*Salmo salar*) biology and behavior to develop the best available scientific information concerning the fate of Atlantic salmon that are unable to pass certain upstream fishways in the Penobscot River watershed. The purpose of this paper is to document the decisions of the expert panel that were made in relationship to data inputs for the Penobscot River dam impact analysis modeling effort. This report is a work in progress and should not be considered an official policy paper issued by the National Marine Fisheries Service. Any comments and questions regarding any of the information in this draft are welcomed and should be directed to Jeff Murphy at 207-866-7379.

Summary: Few, if any, upstream fishways provide 100% safe, timely, and effective passage for migratory fish including Atlantic salmon. Although multiple studies have been conducted in the Penobscot River to measure the effectiveness of fishways at various hydroelectric facilities, very little data is available concerning the fate of adult Atlantic salmon that are unsuccessful in locating or negotiating upstream fishways at dams.

In order to carry out its responsibilities for recovering the Gulf of Maine (GOM) Distinct Population Segment (DPS) of endangered Atlantic salmon, NMFS is constructing a life history model of Atlantic salmon populations in the Penobscot River that will be used to explore a variety of survival scenarios and to help define levels of take that the GOM DPS could accommodate without appreciably reducing survival and recovery. The model will be used to establish survival performance standards at hydroelectric projects on the Penobscot River for use in upcoming section 7 consultations for Federal Energy Regulatory Agency (FERC) licensed hydroelectric projects. Pursuant to section 7 of the Endangered Species Act (ESA), the FERC cannot issue a license for a hydroelectric project that jeopardizes the continued existence of the species. Explanations of the process of determining jeopardy and destruction or adverse modification of critical habitat are set forth in section 7(a)(2) of the ESA and as defined by 50 CFR §402.02 (the consultation regulations).

To develop the Penobscot River model, it is necessary to define the fate of adult salmon that are unsuccessful in passing individual fishways in the Penobscot River watershed. In the absence of site specific data, NMFS determined that an expert panel could be convened to provide the best available scientific information regarding this subject.

The expert panel was represented by state, federal, and private sector biologists and engineers with expertise in Atlantic salmon biology and behavior at fishways. The expert panel consisted of the following participants: Alex Haro (U.S. Geological Survey), Joe Zydlewski (U.S. Geological Survey), Randy Spencer (Maine Department of Marine Resources), Norm Dube (Maine Department of Marine Resources), Scott Hall (Black Bear Hydro), Kevin Bernier(Brookfield Power), Steve Gephard (Connecticut Department of Environmental Protection) Ross Jones (Fisheries and Oceans Canada), Steve Sheppard (Aquatic Science Associates), Jeff Murphy (NMFS), Tim Sheehan (NMFS), Don Dow (NMFS), and Tara Trinko

Lake (NMFS).

Issue:
Do Atlantic salmon that are unsuccessful in locating and negotiating upstream fishways at FERC-licensed hydroelectric projects in the Penobscot River: a) die; b) return to the ocean un-spawned; or c) stray and spawn in downstream reaches.

Decision:
Through best professional judgment, the expert panel reached consensus regarding the fate of adult Atlantic salmon that are unsuccessful at locating and negotiating upstream fishways at FERC-licensed hydroelectric projects in the Penobscot River watershed (Table 1). Note that hydroelectric projects upstream of the first impassable dam were not were not evaluated by the group (e.g., dams upstream of the Medway Project on the West Branch of the Penobscot River). Regarding straying and fitness of adults spawning in non-natal productivity units, the panel was unable to reach consensus. Instead, the panel suggested: 1) a general straying rate for each production unit could not be developed; 2) a graduated rate for straying to higher quality habitat higher in the system should be considered; 3) straying into Production Unit #2 (East Branch Penobscot drainage) is probably at the highest level for the drainage and straying into Production Unit #3 (Mattawamkeag drainage) is probably at the next highest level and so on down river; 4) generally, fish will tend to stray within a HUC8 watershed (i.e. fish in the Piscataquis drainage tend to stay within the Piscataquis (Production units 4-8)); 5) Atlantic salmon stocked low in the Penobscot River are probably not straying to production units high up in the system. The group committed to working on this issue in the near future to reach some resolve.

Rationale:
The Penobscot Watershed was separated into 15 discrete production units for analysis. The geographic extent of each production units was based on locations of hydroelectric projects in the watershed as such (see Figure 1):

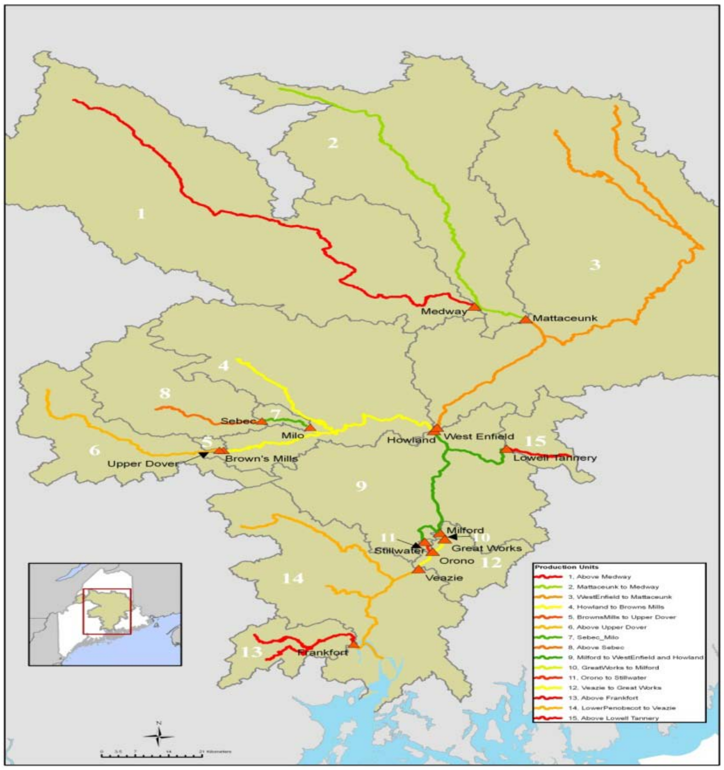
The expert panel addressed two topics including: 1) defining the fate of adult Atlantic salmon unsuccessfully passing upstream fishways in the Penobscot River; and 2) the effect of upstream straying. Notes from the workshop are provided in Attachment A.

For each topic, NMFS provided simple worksheets in which the expert panel was requested to populate (Attachment B). For each worksheet NMFS provided a listing and definition of the fields. The first row of each worksheet was populated with dummy values (*in gray/italics font*) for demonstration purposes.

Based upon best professional judgment, the expert group modified the worksheet #1 to reflect a baseline proportion of adult salmon mortality expected due if a fish was unable to locate and negotiate an upstream fishway (1%) and an additional proportion of mortality (1-2%) at fishways due to site specific factors (e.g., poaching, lack of thermal refugia, etc.). A baseline mortality was not established for those dams currently operating without upstream fishways. Following this analysis, the expert panel estimated the proportion of unsuccessfully passed fish that were likely to return to the ocean un-spawned or stray to other production units. The expert panel was able to populate all the attributes of the modified worksheet #2.

After much discussion, the expert panel could not populate the worksheet #2.

Figure 1. Location of production units within the Penobscot River watershed.



Production Unit Definitions - Downstream to Upstream boundaries

1. Medway to the West Branch headwaters
2. Mattaceunk to Medway-East Branch headwaters
3. West Enfield to Mattaceunk-Mattawamkeag River headwaters
4. Howland to Brown's Mills-Milo-Pleasant River headwaters
5. Brown's Mills to the Dover Upper Dam
6. Dover Upper Dam to the Piscataquis River headwaters
7. Milo to Sebec
8. Sebec to the Sebec River headwaters
9. Stillwater-Milford to Lowell-Howland-West Enfield
10. Great Works to Milford
11. Orono to Stillwater
12. Veazie to Orono-Great Works
13. Frankfort to the Marsh Stream headwaters
14. Verona Island to Frankfort-Veazie
15. Lowell to the Passadumkeag Headwaters

Table 1. Summary of upstream passage inefficiency and straying decisions made by expert panel.

Dam	Baseline Proportion Dead (%)	Additional Percentage Dead (%)	Total Proportion Dead (%)	Proportion out to Sea (%)	Reasons for fallback to Ocean	Proportion to Stray (%)	Destination of straying fish (fish that fail to pass fishway) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Medway	0	0	0	0	.	100	-	100	-	-	-	-	-	-	-	-	-	-	-	-	-
Mattaceunk	1	0	1	0	.	99	-	-	100	-	-	-	-	-	-	-	-	-	-	-	-
West Enfield	1	1[a]	2	0	.	98	-	-	-	60[e]	-	-	-	-	40	-	-	-	-	-	-
Dover Upper Dam	1	1[b]	2	0	.	98	-	-	-	100	-	-	-	-	-	-	-	-	-	-	-
Brown's Mills	1	1[c]	2	0	.	98	-	-	-	100	-	-	-	-	-	-	-	-	-	-	-
Sebec	0	0	0	0	.	100	-	-	-	10	-	-	90	-	-	-	-	-	-	-	-
Milo	0	0	0	0	.	100	-	-	-	100	-	-	-	-	-	-	-	-	-	-	-
Howland	1	1[a]	2	0	.	98	-	-	40[e]	-	-	-	-	-	60	-	-	-	-	-	-
Lowell Tannery	1	0	1	0	.	99	-	-	1	1	-	-	-	-	98	-	-	-	-	-	-
Stillwater	0	0	0	0	.	100	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-
Milford	1	0	1	0	.	99	-	-	-	-	-	-	-	-	-	-	-	80	-	20	-
Great Works	1	1[c]	2	10	.	88	-	-	-	-	-	-	-	-	-	-	-	80	-	20	-
Orono	0	0	0	0	.	100	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-
Veazie	1	2[d]	3	15	proximity to ocean + handling	82	-	-	-	-	-	-	-	-	-	-	-	-	10	90	-
Frankfort	1	1[d]	2	10	proximity to ocean	88	-	-	-	-	-	-	-	-	-	-	-	10	-	90	-

[a] high percentage of fall back

[b] poaching

[c] lack of thermal refugia

[d] seal predation and/or handling

[e] confirm with Gorsky report

Attachment A
Expert Panel Workshop Notes
December 8, 2010

Adult Atlantic salmon Upstream Passage Workshop-
December 8, 2010 Maine Field Station

Participants
Alex Haro (USGS), Joe Zydlewski (USGS, UMaine), Randy Spencer (MDMR), Norm Dube (MDMR), Scott Hall (Black Bear Hydro), Kevin Bernier(Brookfield Power), Steve Gephard (Connecticut DEP) Ross Jones (DFO), Don Dow (NOAA), Steve Sheppard (Aquatic Science Associates), Jeff Murphy (NOAA), Tim Sheehan (NOAA), Tara Trinko Lake (NOAA)
Introduction /Overview–Jeff Murphy
Model Overview- Jeopardy Analysis Model (JAM) run through- Tim Sheehan
Questions about the JAM

- Why is Sebec included when W. Branch is not, will they be removed from future versions?
    - Both Sebec and the West Branch are included within the current version of the model. It is being developed to have the capacity to model the entire drainage, regardless of it there is passage at any one facility. This may allow for future scenarios to be model where passage may be created where it previously didn't exist.
- Where do upstream/downstream passage numbers come from?
    - They are from Penobscot Multi Species Management Plan- Greg Mackey (compiled from Holbrook studies, studies referenced in Holbrook's thesis and best professional judgment)
- Does the broodstock take account for hatchery fish being preferentially taken and wild adults are released?
    - Currently, no. We will need to discuss if this detail needs to be incorporated into the model.
- Does this scheme account for actual stocking practices today? (Kevin B.)
    - Yes, we can change the input values based on what is happening with stocking regimes.
- Are we going to assume that all fish spawn?
    - Yes
- Will there be a 50/50 sex ratio?
    - There can be any sex ration that we desire. We will determine the appropriate sex ratio to use base on the best available information from the ME DMR and USFWS.
- Upstream passage
    - Several studies have been conducted in the Penobscot River watershed which assess upstream passage effectiveness at various dams. The plan is to use existing data to develop upstream effectiveness ranges at dams where robust data exist. Absent robust data, NFMS will use best professional judgment to assign upstream

effectiveness. It should be noted that, in general, upstream effectiveness is less affected by river flows than downstream effectiveness, and therefore passage across dams within a year will not be correlated.

  -

- Is there a need to model flow data for parts of the catchment where we don't have stream gages?
  - We are going to correlate flow amongst production units,
  - USGS uses Stream Stats to calculate flow based on any area in the basin (Alex)
- What numbers are you using for average number of eggs per female? (Steve G.)
  - Legualt PVA
  - Norm suggested that we take this number from Craig Brook fish
- Where does the marine survival estimate come from?
  - Current version is from the Salmon PVA
  - Will likely use more recent estimates with Penobscot and Narraguagus numbers
- Why 2000 initial adults? And why were they assigned to specific production units
  - We can initiate the model with any number of adults, 2,000 was just what we used for this run. We set 2000 fish as the interim recovery criteria.
  - We assigned them to the production units based on the proportion of habitat.
- One option to determine the distribution of adults throughout the Production Units is to run model for 50yrs and then start the model with the final numbers to make sure that it is realistic. (Joe Z.)
  - We can consider doing this but we would need to modify our input values substantially as stocking plans currently the determining factor as to where fish originate from. Also, we would need to artificially increase our survival estimates to make sure our population is sustain 50 years into the future. We aren't set on the "proportional" approach listed above and will consider alternatives as appropriate. (Tim S.)
- What is the end product from the modeling exercise?
  - Timeline is to finalize the model by spring 2011, develop a Northeast Fisheries Science Center Lab Reference Document by late spring/early summer and pursue a peer reviewed journal publication after.

Round Table Discussion on Upstream Passage Behavior

- Alex H.
  - No one documents what happens to fish that fail, we ignore those fish, Jim McCleave impressed this point on Alex, the fish that fail have value, the failure is difficult to document
  - Sometimes downstream passage studies note fish that were tossed out of dataset
  - Passage is not absolute, fish stop and spawn before they get to the next dam, often times this is not documented, if fish didn't nose into fishway they weren't documented, studies not properly set up to study this
  - There are various levels of passage such as: made it halfway to fishway; made it up, but fell back; could not find fishway.
  - There was a pre-dam condition, most dams were built on falls or existing cascades, hard to document, often times passage was not absolute, this is a source of contention with negotiations

- Joe Z.
  - Provided an overview of previous studies investigating issues related to this but did not provide any general insights into the question.
- Randy S.
  - Doesn't think that generalization is possible given location specific factor - estimates will need to be determined on a site-specific basis
  - Also stressed that the estimates will need to be determined based on any and all available information and our best guesses
- Norm D.
  - Telemetry studies have used fish of unknown stocking locations, how do you understand where fish decide to move?
  - Depending on hydro situation fish may spend weeks below the dam, what happens to those fish?
- Kevin B.
  - Three years of telemetry work below Mattaceunk Dam
    - Stomach tags, release 60 fish .25 miles below dam, used any fish that they could, not only origin from above dam
    - Adults do use smaller streams to spawn
    - 1984,1985, all fish stayed in production unit, 1986 some fish dropped down,
    - Feels that fish will stay in production unit if they don't pass fishway
- Steve G.
  - 10% of all adults that return to Holyoke are released upriver – all from fry stocking - don't know where these fish came from (however, with new genetic marking program, they will begin to be able to answer those questions)
    - Migratory rates between the dams are consistent, slowest right after Holyoke, after that they move from 1 dam to the next in less than one day
    - Very few seem to wander, migration is fast, directed and unequivocal
    - Some exceptions, in the middle river some fish will sample different streams but stay in the same general area
    - If a fish that has passed one fishway does not pass the next, it is located within the lower production unit
  - Fish stocked in tributary rivers were more often captured at Holyoke
  - Net enclosure, fish would spawn in terrible habitat because they were raised there, imprinting is very important
    - Some evidence showed that for smolts held in a tide water area, they came back, didn't go up river (some did) and spawned in the crappy area around the tide water. When they stopped holding fish in the tide water area, the subsequent spawning there stopped.
  - We can't assume that hatchery fish will imprint where we stock them. Where do the fish truly imprint?
  - Doesn't think that upstream migration results in large amount of mortality

        - However, wandering fish are moving downstream, and mortality is introduced here
    - Upstream migration motivation relies heavily upon instream flows, some variability is to be expected, however impounding dams decrease flow
    - Mortality on adult returns is likely very low – however downstream movements of adults may have a significant mortality factor
- Ross J.
    - Salmon in the St. John River, low discharge river, tagged wild salmon at the Mactaquac dam, fish showed up at a counting fence on tributary at a lower trib.
        - Highlights wandering and straying
        - Acoustic tagging of fish on Big salmon pool, lots of downstream/upstream movement, exploring and looking for tribs
    - Highlighted mortality at upstream fishways, basket fishway resulted in mortality because fish become stranded behind the basket.
    - Mentioned a St. John acoustic study where hatchery fish were less likely to use fishways or find fishways.
- Don D.
    - Encountered problems with interpreting previous studies. It was hard for him to pinpoint the exact number of fish that actually try to use fishway in the studies.
        - Most studies didn't follow all fish to all destinations, so not passing doesn't mean that a fish tried (it possibly spawned elsewhere) – Dimitry's study came close as he reported the number of fish that nosed into a fishway, however he didn't report how many came up to the dam but didn't find the tailrace.
        - Mattaceunk (from Kevin) if fish found the tailrace, they used the fishway
        - Hard to interpret the fall back issue from the completed studies.
- Steve S.
    - Reiterated homing issue, radio tagged 150 fish, didn't always have ability to select fish with upstream origin, comprised the study and migratory behavior
    - Imprinting occurs as early as fall when fish is a parr, so hatchery fish may have already imprinted.
    - Hatchery fish probably didn't move as fast as wild fish, or seek out a particular area
    - What happens to fish that don't pass and remain in mainstem
        - Mainstem is fairly poor habitat, there is some good tributary habitat, but not much for adult spawning
        - Assign some portion of non-passage to tributary habitat and account for quality and quantity in those tribs
        - Fish that remained in mainstem died
    - Penobscot system is artificially regulated
- Jeff M.

    - Are there generalities for ATS that don't reach natal area? Do they have general behavior (always spawn, always head out to ocean, etc)

Table 1 (see also Table 1 Excel sheet)

- ***General Discussion***
  - May consider incorporating flow as an informative variable in determining straying, path choice… In the absence of detailed flow data could use a proxy such as river depth and bank full width for the areas of interest (Joe Z.)
  - We need to know what the current stocking regime is in order to identify where straying fish are going. (Steve G.)
    - No necessarily the case as this exercise assumes that fish are stocked into each Production Unit and we are evaluating the eventual fate these fish for each Unit independently of any other.
  - Could consider incorporating a penalty for non-passage based on habitat above vs. habitat below instead of fecundity? (Joe Z.)
  - What about death due to seal predation?
    - This can be incorporated into the proportion dead column
  - For one trap on the St John's, estimate dead is 1-5% annually (Ross J.)
  - Dead fish at Veazie is mostly due to weather events, hot weather
  - Holbrook data for Milford called into question by Steve Sheppard (n=3)
  - Brown's Mills doesn't have proximate thermal refugia
    - waste treatment facility is nearest refugia
  - Note of Guilford Dam due to its impacts on high quality and quantity of spawning and rearing habitat (Norm D. and Randy S.)
    - Tim explained that we aren't explicitly including it, but that other dams (culverts, etc.) are all part of the environmental baseline
- ***Decisions for Total Proportion Dead***
  - *Group decided that 1% would be the standard proportion dead*
  - *An additional 1% will be added on a site-specific bases according for the following reasons:*
    - *Seals – increased likelihood of seal predation*
      - *Frankfort and Veazie due to location in the drainage*
    - *Handling – increased mortality due to handling*
      - *Veazie*
    - *Stalling and lack of thermal refugia – increased stalling due to poor attraction couple with a lack of appropriate thermal refugia*
      - *Great Works and Brown's Mills (**???**)*
    - *High percentage of fall back – increased likelihood of fall back behavior*
      - *Howland and West Enfield due to location in the drainage*
    - *Poaching – increased likelihood of poaching*
      - *Dover Upper Dam (**???**)*
- ***Decisions for Proportion out to Sea***
  - If above Great Works, fallback likelihood to Ocean is 0%,
  - *Assume 10% for fish at Great Works*
    - Joe Z. observed up to 50% leaving out to sea

        - Steve G. countered that these fish have been handled and cannot be equated
    - Assumed 15% for Veazie
        - Due to proximity to the ocean and increased fall back due to handling
            - Is this our fault or the dam owner's fault?
            - Is it appropriate to included this if it is due to science?
    - Assumed 10% for Frankfort
        - Due to proximity to the ocean
- ***Decisions for Destination of straying***
    - Completed via group discussion
    - Need to verify assignments for West Enfield and Howland based on Dimitry's data
- ***Decisions for discounting fish that are forced into a downstream production unit due to failure to pass dam/fishway***
    - Should we discount fish that are not able to make it to their natal spawning habitat?
    - *Folks considered it important to consider a discount*
        - *If we don't we are suggesting that when fish aren't allowed to pass and spawn elsewhere that all is good with the world.*
    - *Difficult to assess and even more difficult to estimate a discount*
        - *Hard to come up with reproductive costs for not passing*
        - *Could also suffer reproductive costs from passing a long fishway*
    - *Option 1* - *Literature search on effects on fitness for unsuccessful passage?*
        - *Might be some evidence from West Coast Chinook, possibly from Scotland*
        - *However, the affect might be so minimal it wouldn't be worth incorporating*
    - *Option 2* - *Could add in a straw man and then do sensitivity analysis to evaluate the effect (and need)*
    - *Option 3* - *Incorporate the habitat quality either in terms of Production cap – higher cap for higher quality habitat*
        - Possibly incorporate a penalty based on habitat potential immediately above and immediately below the dam
    - *Option 4* - *Some sort of discount based on the ratio of where you started from to where you ended up (via the habitat quality scores)*

Table 2. Discussion

- ***General Discussion***
    - River reared fish generally have high fidelity - >90%
    - Dimitry's thesis/database contains raw data homing percentage
    - In 1986, ~440 out of 476 adults captured at Weldon were no from the East Branch as identified by lack of fin clip. (Kevin B.)
        - Could be that they were from fry stocking or wild spawners, but these #ers are assumed to be low.
        - There were a lot of deformed dorsal fins.
        - The majority of these fish are assumed to be smolt stocked strays
    - In 2009, there were 300+ fish through Weldon but there were only 87 wild fish captured at Veazie. (Kevin B.)
        - There wasn't any smolt stocking up above Weldon for those cohorts of returns

        - Straying occurs, greater for wild fish than hatchery fish (Steve S.)
        - Straying is production unit specific (Randy S.)
        - Homing numbers in literature available for fry, smolts are difficult (Joe Z.)
        - One rate for the whole river is not palatable, perhaps a graduated rate for the production units (Tim S.)
        - Data may be available for the St. John River at the Mactaquac (Ross J.)
        - Data may be available for the East Branch - to tell East Branch vs. non East Branch fish, can't be more specific (Steve S.)
        - East Branch examples identified above have data that can be provided (Kevin B.)
            - DMR trucked adults up river, even to the East Branch, this may confound straying information (Norm D.)

- ***Decisions***
    - Suggestion of using some combination of guesses, but also using some rules as defined by strength of homing and attraction strength based on flow (depth and full bank width) plus using any available data to estimates numbers where we can
    - General consensus was that specific straying # was hard to come up with and group was hesitant to put forward any #s.
        - A general straying % for each production unit is not acceptable as we do not think it reflects reality (Tim S.)
    - Group agreed to the following general tendencies to help guide our efforts in populating Table 2
        - Group agreed to use a graduated rate for straying to higher quality habitat higher in the system
            - Straying into Production Unit #2 is probably at the highest level for the drainage and straying into 3 is probably the next highest level and so on down river
                - More fish will stray to these high quality areas
                - Kevin B.'s data may help inform rates to apply in this part of the drainage (Units 2 and 3)
        - Group decided that there was some fidelity, such as within each HUC8.
            - For example, fish in Piscataquis tend to stay in Piscataquis
            - Fish that make it to the Piscataquis or come from there probably stray at a lower rate
        - Fish stocked low in the river, say below Veazie, are probably not straying up to Production Units high up in the system (i.e. PU 2)

Miscellaneous Notes

- West Enfield is a vertical slot
- Moosehead Dam – in between Dover upper and Brown's Mills – need to footnote it in the report and consider adding in some sort of discount for this segment
- Joe suggested creating a schematic of the model in Stella to be a separate, for public use, version of the model to help people see the flow of it and be able on click on it and see the calculations behind it
- We will need to consider the possibility of keeping hatchery origin fish separate from wild origin fish within the model due to the effects of straying and poor homing for the two different origins.

- This may cause a problem in terms of CPUE power and limits of Excel.
    - Could possibly keep track within the current model, run two separate models, wild and hatchery, and add the outputs together at the end…
- Will need to evaluate the need for this in regards to the task at hand the final products needed for the analyses.
    - We may not need to incorporate this as the current state of affairs includes very little wild inputs and the restored population may have very little hatchery input
    - More discussion is needed within NOAA

Attachment B
Expert Panel Worksheets

Worksheet #1. Upstream passage inefficiency worksheet used during expert panel.

Dam	Proportion unsuccessful*	Proportion dead	Proportion out to sea	Proportion to stray and spawn downstream	Final destination (according to Productivity Units and the proportion to each unit)				
West Enfield	*20%*	*2%*	*2%*	*16%*	*PU 9 (85%)*	*PU 15 (15%)*			
Medway									
Mattaceunk									
West Enfield									
Dover Upper Dam									
Brown's Mills									
Sebec	**100%**								
Milo	**100%**								
Howland									
Lowell Tannery									
Stillwater									
Milford									
Great Works									
Orono									
Veazie									
Frankfort									

*Based upon best available data from existing fish passage studies

Worksheet #1 Fields

- Dam
    - Identifies the dam in question
- Proportion unsuccessful
    - What proportion of fish will not successfully pass this dam, will not spawn in Productivity Unit directly above that dam and instead will be forced into an alternate fate?
    - This number will equal (1 minus "the upstream efficiency").
- Proportion dead
    - Of the 'Proportion unsuccessful', what proportion of them will die prior to spawning and therefore will not contribute any eggs to the next generation?

- Proportion out to sea
  - Of the 'Proportion unsuccessful', what proportion of them will migrate downstream to the ocean, not spawn in the Penobscot River (they may spawn in a different river system, but that is not being considered within our modeling efforts) and therefore will not contribute any eggs to the next generation?
- Proportion to stray and spawn downstream
  - Of the 'Proportion unsuccessful', what proportion of them will spawn in a lower reach (Productivity Unit)?
  - NOTE – the 'Proportion dead', 'Proportion out to sea' and 'Proportion to stray and spawn downstream' will add up to the 'Proportion unsuccessful' for each row.
- Final destination (according to Productivity Units AND the proportion to each unit)
  - Of the 'Proportion to stray and spawn downstream', where will they end up downstream and in what proportions?
  - NOTE – The 'Final destination (according to Productivity Units AND the proportion to each unit)" will add up to 100% for each row. In the example provided, 85% of the 16% that stray will migrate to PU 9 and the remaining 15% will migrate to PU 15.

Worksheet #2. Upstream straying worksheet used during the expert panel.

Productivity Unit	Proportion straying upstream	Final destination (according to Productivity Units and the proportion to each unit)				
4	*20%*	*PU 6 (70%)*	*PU 7 (10%)*	*PU 8 (20%)*		
1						
2						
3						
4						
5						
6						
7	**0%**	-	-	-		
8	**0%**	-	-	-		
9						
10						
11						
12						
13						
14						
15						

Worksheet #2 Fields

- Productivity Unit
  - Natal river reach of interest.
  - The table just lists the Productivity Units by numbers. Feel free to modify these labels/names if desired.
- Proportion straying upstream
  - What proportion of the fish from a particular Productivity Unit will stray to an upriver Productivity Unit?
- Final destination (according to Productivity Units AND the proportion to each unit)
  - Of the fish that stray upstream, where will they end up and in what proportions?
  - NOTE – The 'Final destination (according to Productivity Units AND the proportion to each unit)' will add up to 100% for each row. In the example provided, 70% of the 20% that stray will end up migrating to PU6, 10% will migrate to PU 7 and 20% will migrate to PU 8.

APPENDIX C

NMFS Dam Impact Analysis Model

Table of Contents

1 Introduction

The Gulf of Maine Distinct Population Segment (GOM DPS) of Atlantic salmon was listed as endangered under the U.S. Endangered Species Act (74 Federal Register 29344, June 19, 2009). Dams have been identified as a major contributor to the historic decline and current low abundance of salmon in the GOM DPS (NRC 2004; Fay *et al.* 2006). To better understand the impacts of dams on the production potential of Atlantic salmon, we developed a tool to simulate the interactions of Atlantic salmon and dams, particularly hydroelectric dams in the Penobscot River watershed. The Penobscot River watershed was chosen as the area of study for several reasons. In recent years, approximately 75% of all U.S. Atlantic salmon returns have come from the Penobscot River (USASAC 2011). Also, multiple hydroelectric dams, which reduce migration success for downstream migrating smolts and upstream migrating adults, are located on both mainstem and major tributary reaches.

Predicting the future of an endangered or threatened species is a vital part of planning management and recovery actions (NRC 1995) and population models are important tools for assessing management strategies and evaluating risks to these species (Morris and Doak 2002; McGowan and Ryan 2009; McGowan and Ryan 2010). A life history modeling approach was undertaken because a large amount of life-stage-specific information is available for Atlantic salmon. Life history models can provide biological realism but may require many assumptions regarding the various inputs. Population viability analysis (PVA) is a stochastic life history-type model used for predicting changes in population abundance given uncertain biological parameters (Beissinger 2002). PVA models are species-specific, and, therefore, each PVA is unique.

A simple PVA quantitatively estimates information related to population growth and extinction probabilities for a single population (Dennis *et al.* 1991). A simple PVA is a stochastic exponential growth model of population size, which is equivalent to a stochastic Leslie-matrix projection with no density dependence. More complex PVA approaches have been developed, whereby life history characteristics are accounted for within the model, such as the age distribution within the abundance measure. In addition, a more complex PVA could include different life history processes, which would be compartmentalized within the model, and allow for the incorporation of such things as juvenile survival rates, adult survival rates, habitat limitations/degradation, age-specific fecundity, and migration rates (Beissinger 2002). One such life-cycle model, SalmonPVA, was developed for the GOM DPS (Legault 2004). The SalmonPVA is a state-space model structured to represent GOM DPS Atlantic salmon life history characteristics. The results generated from these more complex PVA models, such as the SalmonPVA, can be used to explore the potential effects of management actions in light of unknown future conditions, the variability surrounding input data and assumptions made when designing the model (Legault 2005). The fine-filter approach, such as was applied within the SalmonPVA, may provide information to decision makers related to an array of management measures available (Samson 2002).

We developed the Dam Impact Analysis Model (DIA Model), a state-space model that is similar in structure to the SalmonPVA but representative of Penobscot River Atlantic salmon life history characteristics. The DIA Model can project changes in future abundance and can provide information about model inputs that can help inform recovery efforts for the modeled population. Specifically, the

DIA Model was developed to assess the relative impacts of hydroelectric facility operations within the Penobscot River watershed on the production potential of the Penobscot River Atlantic salmon population. The DIA Model simulations are not meant to predict absolute abundance, but rather are meant to project the relative change in abundance under different modeling scenarios.

This document describes the DIA Model developed for Atlantic salmon in the Penobscot River watershed. A full description of the chronology of the model development (**Table 1.1**) and modeling approach is presented and all input values, distributions, and assumptions are outlined.

2 Model Overview

An overview of the DIA Model is provided below. A schematic outlining the life stages modeled, additions and subtractions to the population and other metrics effecting the population was developed (**Figure 2.1**). A full description of all model inputs is provided in **Section 3**.

In generation one (i.e. year 1), the DIA Model was seeded with the mean annual number of two sea-winter (2SW) female returns captured at the trap above Veazie Dam during 2002–2011, which equaled 587 fish. These fish were binomially assigned among the production units (PUs) according to the production potential of each PU (**see Section 3.1**). Production potential was zero in PUs that could not be accessed due to lack of upstream dam passage, and, therefore, no adults were seeded into these PUs. For all subsequent calculations, the numbers of Atlantic salmon were rounded, rather than binomially assigned, to maintain whole numbers of fish and to minimize computational time.

For each DIA Model iteration, the 2SW females in year 1 were multiplied by the fecundity rate to estimate the number of eggs produced in that same year (**see Section 3.2**). The number of eggs was then multiplied by the egg to smolt survival rate to estimate the number of two-year old smolts produced in year 4 (**see Section 3.3**). If the number of smolts in a PU exceeded the production potential cap, then the number of smolts was reduced to the maximum allowed for that PU. Smolts surviving from the egg stage were considered wild-origin fish. Additionally, there is the option to have hatchery-origin smolts 'stocked' into each PU (**see Section 3.4**). All smolts (hatchery- and wild-origin) then migrated downstream from their initial PU, through subsequent downstream PUs and over dams, to Verona Island. As fish migrated through PUs, they experienced in-river mortality (i.e., freshwater natural mortality; **see Section 3.5**). To account for this, the number of smolts in a PU was multiplied by the in-river survival rate (i.e., 1 – in-river mortality rate) raised to the distance traveled. In their initial PU, smolts were assumed to travel only half the length of the PU because fish could start their migration from a variety of locations within the PU (e.g., the furthest point upstream, the furthest point downstream). As smolts migrated downstream through subsequent PUs, they traveled the distance from the point of entry to the point of exit (e.g., fish from PU 7 would travel the distance from Milo Dam to Howland Dam in PU 4). The in-river mortality rate was applied to each PU-specific group of smolts as they migrated downstream through each subsequent PU, until reaching the northern tip of Verona Island.

Smolts exiting a PU had to traverse a dam to enter into a downstream PU. To account for dam-related mortality, the number of smolts above each dam was multiplied by the correlated draws from the dam-specific cumulative probability functions of total project survival to estimate the number of smolts remaining after passing each dam (**see Sections 3.6.1 and 3.6.2**). Smolts that started their migration in PU 9, or further upstream, could travel through the Mainstem or Stillwater Branch of the Penobscot River (**see Section 3.6.3**). The number of smolts reaching PU 9 was multiplied by the Stillwater Branch path choice to estimate the number of smolts that migrated through that branch. The remaining smolts migrated through the mainstem. Smolts continued to migrate downstream through subsequent PUs, encountering in-river and dam-related mortality, until the survivors reached Verona Island.

At Verona Island, there is an option to apply a latent mortality rate to account for the negative effects on survival from passing multiple dams (**see Section 3.7**). A latent mortality rate could have been calculated for smolts originating in each PU, based on the number of dams that fish from each PU passed. However, in these DIA Model simulations, a latent mortality rate of 0% per dam was applied, which effectively removed the latent mortality effect. This was done because accurately quantifying latent mortality has not been possible, mainly due to the difficulties associated with measuring mortality after fish have left the river system. Although wild- and hatchery-origin smolts were treated the same during downstream migration (i.e. subjected to the same in-river mortality rates, smolt survival probabilities at dams, and latent mortality rates), hatchery-origin smolts typically experience lower survival than wild-origin smolts (**see Section 3.8**). Hence, a discount was applied to hatchery-origin smolts to estimate the total number of wild-equivalents before they migrated out to sea. The remaining number of wild-equivalent smolts was halved to convert the number to wild-equivalent female smolts, which was needed to estimate the number of adult female returns. These wild-equivalent female smolts were considered post-smolts as they migrated beyond Verona Island, and the total number of female post-smolts in year 4 was multiplied by the marine survival rate to estimate the number of 2SW females that returned in year 6 (**see Section 3.9**).

The proportion of 2SW females that attempted to migrate upstream to each PU equaled the proportion of wild-equivalent female smolts that originated from each PU. Within the Penobscot River watershed, homing is less than 100%, so a proportion of adults strayed from their natal PU to other PUs (**see Section 3.10**). Adults then migrated upstream from Verona Island and encountered dams as they attempted to migrate to their targeted PU (**see Section 3.11**). Upstream dam passage rates dictated the proportion of adults that were able to pass each dam. 2SW females that were unable to pass a dam died, returned to sea or migrated to a different, down river PU to spawn (**see Section 3.12**). Adults that successfully passed dams continued to migrate upstream through all upriver PUs, until they reached their desired PU. There is no in-river mortality factor applied as freshwater mortality in free flowing stretches of river is assumed to be low for adult Atlantic salmon. In years when hatchery-reared smolts were stocked, 150 2SW females were removed from the migrating population just after passing the Veazie Dam for hatchery broodstock purposes (**see Section 3.4**). Hatchery broodstock were removed in a way that each PU contributed adult spawners in proportion to their adult returns. The number of 2SW females that reached their desired PU spawned and produced eggs in that same year (i.e., year 6). This entire process was then repeated for nine more generations (one generation equals 5 years).

All fish were tracked according to their PU of origin. The adult portion of the Atlantic salmon life cycle focused on 2SW females because the vast majority of females return as 2SW fish and egg production is one of the limiting factors for this population (USASAC 2011). The smolt life stage focused on age-2 fish because the majority (>85%) of naturally-reared Atlantic salmon smolts from Maine, and specifically the Penobscot River, migrate to the ocean as age-2 fish, with smaller proportions of both age-1 and age-3 juveniles present (USASAC 2011). Although kelts can play an important role in the life history of Atlantic salmon, this life stage was not included in the DIA Model due to limited quantitative information for model inputs and the limited number of kelts present.

A cohort of fish and its descendants were tracked through the life stages. Inputs were year- and iteration-specific random draws from distributions to incorporate stochastic variation into the model. All DIA Model iterations were run for 50 years, which equaled ten plus generations of fish, and 5,000 iterations were run for each simulation. All model iterations were run with @Risk.

3 Inputs for DIA Model

3.1 Production Units

The DIA Model was built for the Penobscot River watershed. The watershed was divided into 15 sections, referred to hereafter as Production Units (PUs; **Table 3.1.1**; **Figure 3.1.1**). The upstream boundary of each PU was either the headwaters of a tributary or a hydroelectric dam. The downstream boundary of each PU was a hydroelectric dam, except in PU 14, where the downstream boundary was the northern tip of Verona Island. Using dams as PU endpoints meant that Atlantic salmon could not enter or exit a PU without attempting to pass a dam, with the exception of PU 14. This scheme helped further delineate the salmon-dam interactions in the model.

Total network length, longest segment length, and partial segment length were distances calculated to describe each PU (**Table 3.1.1**). Total network length represents the sum of all stream kilometers within a particular PU. Longest segment length represents the longest straight path distance that a fish could swim within a PU. Partial segment length represents the distance that a fish would swim in when traversing from one PU to another (e.g., fish from PU 2 would travel the distance from Mattaceunk Dam to West Enfield Dam in PU 3). PUs can have no partial segment length (e.g., PU 15), one partial segment length (e.g., PU 2), or two partial segment lengths (e.g., PU 4). The longest segment lengths and partial segment lengths were also used to calculate in-river mortality (**see Section 3.5**).

Each PU has the potential to support a different number of fish based on available habitat. Our measurement unit for Atlantic salmon is a habitat unit (HU) equal to 100 m^2. The number of Atlantic salmon HUs was calculated for each PU using a model which estimated spawning and rearing habitat (**Table 3.1.2;** Wright *et al.* 2008). The number of Atlantic salmon HUs was used as a measure of production potential (i.e., the number of Atlantic salmon each PU could produce), and the proportional production potential (i.e., proportion of HUs in a PU compared the total habitat units for the drainage) was used to seed adults as well as to limit the number of smolts in each PU.

The model was seeded with 2SW females that were binomially assigned among the PUs according to the proportion of HU is each PU (**Table 3.1.2**). PUs 1, 7, 8, and 11 were not allotted any HUS because adults were unable to access them due to lack of upstream dam passage. Therefore, no 2SW females were allocated to these PUs.

The number of smolts in each PU was limited with a production potential cap, which was the maximum number of smolts allowed per HU (i.e., 10 smolts per 100 m^2; **Table 3.1.2**). Three smolts per 100 m^2 is a commonly accepted production potential in the Penobscot River (Meister 1962). Thus we set the maximum to 10 smolts per 100 m^2 to prevent biologically unrealistic outputs being from produced via stochastic sampling.

PU 1, which is the West Branch of the Penobscot River above Medway, is different than the other PUs. Medway does not have upstream or downstream passage, so no fish are able to access this PU. Also, no anadromous Atlantic salmon are stocked in PU 1, so no juveniles are produced and no smolts migrate through it en route to PU 2 (**Figure 3.1.1**). Although PU 1 was built into the DIA Model, it did not contribute to the Atlantic salmon population. PU 1 was included in the model because the West Branch was historically important Atlantic salmon habitat and could be recognized as a potential component of Atlantic salmon recovery efforts in the Penobscot River in the future.

3.2 Eggs per Female

Adult female Atlantic salmon spawn at various ages, and typically older females produce more eggs. In the DIA Model, a fecundity rate was applied to the number of 2SW females in a year to estimate the number of eggs that would be produced the same year.

The number of eggs produced per female Atlantic salmon was estimated using fecundity data for Penobscot River sea-run female Atlantic salmon, spawned at Craig Brook National Fish Hatchery during 1997–2010 (Denise Buckley, U.S. Fish and Wildlife Service, personal communication). The data were derived primarily from 2SW females, but a small number of older females were also spawned each year. @Risk was used to fit a distribution to the average number of eggs per female in each year, and the data were best described by a normal distribution with μ = 8,304 and σ = 821 (**Figure 3.2.1**). Year- and iteration-specific values were drawn from this distribution for base case fecundity values in all DIA Model simulations.

3.3 Egg to Smolt Survival

Atlantic salmon spend the first years of their lives in rivers, from the time they are eggs until they migrate to the ocean as smolts. Atlantic salmon go through several life stages during this time: egg, fry, parr, and smolt. The DIA Model did not calculate the number of fish at all of these life stages. Instead, an egg to smolt survival rate was applied to the number of eggs in a year to estimate the number of smolts that would survive three years later and be available to initiate a downstream migration to the ocean.

The egg to smolt survival rate was calculated based on the methods of Legault (2004). Egg to fry, fry to parr0+, parr0+ to parr1+, and parr1+ to smolt survival rates were obtained from the literature and were combined using a method that would account for uncertainty in each study. In order to be combined, studies for a particular life stage were standardized to the same time interval. The standardized mean, minimum, and maximum values were used to generate a triangular distribution for each study. The triangles were added together to form a new survival rate distribution for that life stage. This probability distribution function was converted to a cumulative distribution function, and the 10th and 90th percentiles were used as the limits of a uniform distribution. The uniform distribution was used to describe the uncertainty in survival for each life stage.

Studies which could be used to generate the uniform distributions were included or excluded with some subjectivity. The selections made for studies in Legault (2004) were not reassessed, and studies that were included in Legault (2004) also contributed to the distributions for this model. Additional studies that were published post-Legault (2004) were also considered, and the decisions to include or exclude them are described below.

The egg to fry survival rate came directly from a study of GOM DPS Atlantic salmon (Jordan and Beland 1981) instead of using the objective process described above. The uniform distribution for survival of 15 to 35%, covered most other estimates of survival in the literature (see Table 2 in Legault 2004), and was thought to best represent egg to fry survival of Atlantic salmon in Maine (Legault 2004). Two additional studies were excluded because they were not considered representative of Atlantic salmon survival in Maine (**Table 3.3.1**; Dumas and Marty 2006; Flanagan *et al.* 2008).

The fry to parr0+ survival rate was derived using the objective process described above, with the standard time period of two months. Seven studies were included, resulting in a uniform distribution ranging from 31 to 60% (**Table 3.3.2**; see Table 3 in Legault 2004; **Figure 3.3.1**). Other studies were excluded because they were not considered representative of Atlantic salmon survival in Maine for various reasons. One study had extremely low survival (Coghlan and Ringler 2004). Another study had a wide range of survival, including low survival rates, and did not report a mean survival rate (Coghlan *et al.* 2007). The duration of one study could not be determined (Raffenberg and Parrish 2003). Two studies (Aprahamian *et al.* 2004; Millard 2005) had multiple survival rate estimates, and these estimates were averaged for each study after standardizing the time period so that neither study would have too much influence on the overall calculation of survival for this life stage. The seven studies which were included had mean standardized survival rates ranging from 40.3 to 59.2% (Egglishaw and Shackley 1973; Egglishaw and Shackley 1980; Gardiner and Shackley 1991; Orciari *et al.* 1994; McMenemy 1995; Aprahamian *et al.* 2004; Millard 2005).

The parr0+ to parr1+ survival rate was derived using the objective process described above, with the standard time period of twelve months. Eight studies were included, resulting in a uniform distribution of survival ranging from 13 to 56% (**Table 3.3.3**; see Table 4 in Legault 2004; **Figure 3.3.2**). One study was excluded because survival was parsed out by season (Letcher *et al.* 2002). The eight studies which were included had mean standardized survival rates ranging from 11.3 to 51.0% (Meister 1962; Egglishaw and Shackley 1980; Kennedy and Strange 1980; Kennedy and Strange 1986; Gardiner and Shackley 1991; Orciari *et al.* 1994; Cunjak *et al.* 1998; Aprahamian *et al.* 2004)

The parr1+ to smolt survival rate was derived using the objective process described above, with the standard time period of nine months. Five studies were included, resulting in a uniform distribution ranging from 17 to 50% (**Table 3.3.4**; see Table 5 in Legault 2004; **Figure 3.3.3**). One study was excluded because the life stage of the fish was unclear (Letcher *et al.* 2002). The five studies which were included had mean standardized survival rates ranging from 16.8 to 45.8% (Meister 1962; Myers 1984; Orciari *et* *al.* 1994; Cunjak *et al.* 1998; John F. Kocik, NOAA's National Marine Fisheries Service, personal communication).

Combining the minimum and maximum values across these life stages produced a possible range from 0.10 to 5.88% for the egg to smolt survival rate, with a mean of 1.31% (**Table 3.3.5**). The egg to fry, fry to parr0+, parr0+ to parr1+, and parr1+ to smolt distributions were each sampled 10,000 times, and the life stage survival values from each iteration were multiplied together to calculate an egg to smolt survival rate. The sum of random values from the egg to fry, fry to parr0+, parr0+ to parr1+, and parr1+ to smolt distributions was approximately normal by the central limit theorem, and egg to smolt survival could be expressed as the sum of the natural logs of each survival rate (Hilborn and Walters 1992; Legault 2004). This meant that the distribution of egg to smolt survival approximated a lognormal distribution (**Figures 3.3.4**). These data were fitted with a lognormal distribution with μ = 1.31%, minimum = 0.10%, and maximum = 5.88% for the base case egg to smolt survival distribution (**Figure 3.3.5**). The 90% confidence interval encompasses survival values between 0.5 and 2.4%, which coincides with the general perception that egg to smolt survival should be around 1 – 2% (Legault 2004). Year- and iteration-specific values were sampled with the @Risk add-on for all DIA Model simulations.

3.4 Hatchery Stocking

Hatchery-origin fry, parr, and smolts are stocked annually into the Penobscot River to supplement wild production with the goal of recovery of the Atlantic salmon population in the Penobscot Bay Salmon Habitat Recover Unit (SHRU). The DIA Model allowed for smolt-stocking, as more than 90% adult returns to the Penobscot River have originated from smolt stocking (USASAC 2011). Within the DIA Model, hatchery smolts were stocked and proceeded through the downstream migration and ocean migration with their wild conspecifics.

Smolt stocking could be turned on or off on a yearly basis in the DIA Model. When smolt stocking was turned on, a total of 550,000 smolts were stocked, to mimic the approximate number stocked annually. Smolts were distributed throughout the watershed according to the mean proportion stocked in each PU during 2003–2012 (**Table 3.4.1**; USASAC 2011, Justin Stevens, NOAA's National Marine Fisheries Service, personal communication). In years when stocking was turned on, 150 2SW females were removed above Veazie Dam from the upstream migrating population of adults to fulfill the broodstock requirements. If 150 or fewer 2SW females were present above Veazie Dam, all of the fish were removed for hatchery broodstock. A total of 550,000 smolts were stocked annually regardless of the number of 2SW females removed for broodstock as broodstock shortages were assumed to be made up from backup broodstock sources. If smolt stocking was turned off, no broodstock were collected, and all 2SW females that successfully ascended the Veazie Dam fishway proceeded upriver.

3.5 In-river Mortality

Emigrating smolts are subjected to varying levels of in-river natural mortality as they migrate from their rearing habitat to the ocean. To incorporate this dynamic into the DIA Model, a distribution of mortality estimates per km was generated from telemetry studies conducted within the Penobscot River.

A network array of telemetry receivers was deployed throughout the Penobscot River, and groups of both wild- and hatchery-origin smolts were tagged and released at various locations throughout the drainage in 2005 and 2006 (Holbrook *et al.* 2011) and again in 2009 and 2010 (Joseph Zydlewski, U.S. Geological Survey, Maine Cooperative Fish and Wildlife Research Unit, personal communication). Estimates of mortality per km between successive telemetry unit/array pairs for each year- and origin-specific release group were derived from mark–recapture model outputs performed in Program MARK (White and Burnham 1999). Only fish that survived to the first receiver/array were included to remove potential bias associated with tagging-related mortality. Mortality estimates for successive telemetry unit/array pairs that spanned a hydroelectric facility were also excluded because dam-related mortality was accounted for in **Section 3.6.1**. A total of 64 estimates of mortality per km were available. Eleven of these estimates were removed from the analysis due to concerns that they were biased by tagging-release effects, the river segment being too small (<1 km long), or the river segment being flanked by two dams. The resulting dataset included estimates ranging from 0.0 to 2.8% loss per km migrated. These estimates were calculated from river segments that were between one and 20 km long. A cumulative frequency distribution was created from the data (**Figure 3.5.1**), and 34.6% of the distribution represented a 0.0% mortality per km.

The DIA Model applied year- and iteration-specific values from the in-river mortality distribution, which meant the same mortality per km value was used for all PUs in a year. To avoid the unlikely scenario of 35% of the iterations having 0% mortality per km, a new in-river mortality distribution was developed for use in the DIA Model. This new in-river mortality distribution was created using a sub-model developed with @Risk. A total of 500,000 smolts were proportionally distributed across all PUs, according to the production potential of each PU. No smolts were stocked into PU 1, as this PU was excluded from the DIA Model due to the lack of upstream access into this system. Smolts were not stocked into PU 11 (Stillwater Branch) to simplify the simulation by not requiring an input variable for path choice between the Mainstem and Stillwater branches. PU-specific in-river mortality values were based on random draws from the cumulative distribution in-river mortality estimates described above. To calculate the number of surviving smolts entering each downriver PU, the PU-specific in-river mortalities were subtracted from one and raised to the distance travelled within a PU for each group of smolts (**Table 3.1.1)**. Smolts in the sub-model were stocked in the middle of a PU, and the number of smolts surviving from the PU in which they were stocked was based on half the longest segment length of that PU. Smolts were assumed to have traveled the entire length of subsequent PUs (i.e., partial segment length). The survivors after PU 14 were summed, and an estimated mortality rate per km was calculated as the proportion of smolts that survived divided by the total distance smolts migrated. A total of 10,000 iterations were performed and the resulting mortality per km distribution was best described by a beta distribution with shape parameters α_1 = 11.245 and α_2 = 9.8007, minimum = zero, and maximum = 0.00038077 (**Figure 3.5.2**). Year- and iteration-specific values were sampled from this new distribution for base case in-river mortality rates in all DIA Model simulations.

3.6 Downstream Dam Passage Survival Rates

3.6.1 Desktop Survival Analysis

The Penobscot River Basin has been extensively developed for hydroelectric power generation. Approximately 116 dams are located in the Penobscot River watershed, and 24 of these dams operate under a FERC hydropower license or exemption (Fay *et al.* 2006). However, the DIA Model focused only on 15 FERC licensed dams within designated Atlantic salmon critical habitat (74 Federal Register 39003, August 10, 2009).

Hydroelectric dams are known to impact Atlantic salmon through various mechanisms, such as habitat alteration, fish passage delays, and entrainment and impingement. Very few studies have been conducted in Maine to directly assess fish entrainment and mortality on Atlantic salmon at hydroelectric facilities. As the DIA Model was designed to understand the impacts of these FERC regulated dams on the productivity of the Penobscot River Atlantic salmon population, an accurate description of the total mortality associated with each of these facilities was required. Given the paucity of field data to describe these effects, Alden Research Laboratory, Inc. (hereafter referred to as Alden) was contracted to estimate current smolt survival rates at 15 dams on the Penobscot River, based on estimates of turbine entrainment and mortality, spillway use and mortality, bypass efficiency and mortality, indirect mortality and latent mortality.

The route that a salmon smolt takes when passing a dam is a major factor in its likelihood of survival. Fish that pass through a properly designed downstream bypass have a better chance of survival than a fish that goes over a spillway, which, in turn, has a better chance of survival than a fish swimming through the turbines. Facility-specific characteristics were obtained and used by Alden to estimate flow-specific total project mortality estimates based on flow-specific turbine, spillway, and bypass mortality estimates with an additional indirect mortality rate applied (i.e., mortality due primarily to predation and sublethal injuries during passage). The probability of all possible flow conditions at all modeled facilities in five cubic feet per second (cfs) was also estimated. The flow-specific total project survival estimates and the flow probabilities were combined into project-specific cumulative distributions for each modeled facility (**Figure 3.6.1.1**), resulting in smolt survival estimates weighted against the likelihood of occurrence. Random draws were taken from these cumulative distributions and used for the facility-specific inputs of total project smolt survival for each year and iteration of the DIA Model, as described in **Section 3.6.2**. A full description of the Alden procedures can be found in Appendix A.

An exception to the above outlined procedures was for the Upper Dover Dam. The total project survival for this facility was set to 92.15% for each year and iteration of the DIA Model. There is no turbine entrainment at this facility as the project is not presently operating. There is also no downstream bypass for smolts to utilize. As such, all migrating smolts must pass the facility via the spillway, which has a set 97% survival rate. In addition, there is an estimated 5% indirect mortality rate (i.e. 95% survival) for all smolts migrating pass any facility due to sub-lethal injuries, increased stress and/or disorientation (Appendix A). The total project survival of 92.15% for the Upper Dover Dam was determined from the product of the spillway and the indirect survival rates.

3.6.2 Downstream Passage Correlation

Survival of smolts migrating past hydroelectric facilities is generally positively correlated with river flow. Downstream migrating smolts typically have two or three routes by which they can transverse a hydroelectric facility: a downstream bypass (if available), over the spillway, or through the turbines. Under low flow conditions, more flow is proportioned to the turbines and less flow is proportioned to the downstream bypass and the spillway, thereby increasing the proportion of smolts passing through the turbines. Passing through the turbines generally results in increased mortality and injury rates compared to passing via a downstream bypass or the spillway. Conversely, under high flow conditions, a greater proportion of the flow, and, therefore, downstream migrating smolts, passes through the downstream bypass and spillway where smolt survival is typically higher.

Alden estimated probability of flow and total project survival for all possible flow conditions in five cfs increments for 15 FERC regulated hydroelectric facilities on the Penobscot River (**see Section 3.6.1**). Year-specific random draws from the survival estimates provided by Alden were weighted according to the likelihood of flow and used as the total project survival input in the DIA Model. These estimates were then used to calculate the number of smolts that survive at each facility as they migrate downstream to the ocean. Within the Penobscot River, if one facility is experiencing high flows and consequentially high smolt survival, all facilities are likely experiencing relatively high flows and high smolt survival. A mechanism was needed to correlate random draws of total project survival across all facilities within each year which would incorporate the variation in flow documented within the drainage.

Flow data from 24 current and historic monitoring sites within the Penobscot River watershed were accessed through the USGS National Water Information System (http://waterdata.usgs.gov/nwis). Available flow data spanned from the lower reaches of the system to the headwater, including all major tributaries. Careful review of the available data resulted in 19 sites being removed from the analysis because of a lack of contemporary data, the location within the drainage was not applicable to the DIA Model, or the time series was short. Continuous flow data were available for the remaining five sites (USGS gauge 1029500 – East Branch Penobscot River at Grindstone, USGS gauge 1030500 – Mattawamkeag River near Mattawamkeag, USGS gauge 1034000 - Piscataquis River at Medford, USGS gauge 1031500 – Piscataquis River near Dover-Foxcroft, and USGS gauge 1034500 – Penobscot River at West Enfield) for the period 1935–2010. The smolt migration occurs within the months of April through June, so a correlation analysis was run on the mean April–June flow for each facility (**Table 3.6.2.1**). The minimum correlation coefficient (r) = 0.831, maximum = 0.981, and μ = 0.901, suggest that flow within the Penobscot drainage was highly correlated and, therefore, high flow and high smolt survival at one facility corresponded with high flow and high smolt survival at all facilities within the drainage.

To correlate the random draws from the Alden smolt survival distributions to the level of correlation demonstrated for flow within the drainage, cumulative distributions of total project smolt survival were developed with @Risk for each modeled facility (**Figure 3.6.1.1**). A random number was generated for each year and matched to the cumulative distribution for each modeled facility to select the corresponding flow and smolt survival values. As the correlation analysis demonstrated that flow within the Penobscot drainage was highly correlated but not identical, a small amount of variation was added to the year-specific random numbers. The variation came in the form of year- and facility-specific values sampled from a uniform distribution with μ = 0 and limits = ± 0.1695. The selection of ± 0.1695 was a result of simulation tests calculating the correlation of the random numbers under different uniform distributions. A distribution of ± 0.1695 resulted in a mean correlation of 0.901 and thereby approximated the level of correlation demonstrated within the flow data. The year-specific random number with added variation for each facility was matched to the facility-specific cumulative distributions of smolt survival to select the corresponding total project smolt survival value. The smolt survival values were weighted against the likelihood of the corresponding flow condition occurring via the cumulative distribution. In a few instances, the distance between neighboring hydroelectric facilities was small enough that flow conditions at the up-river dam were likely identical to the lower dam. In these cases, the same value was used for both dams to match to the cumulative distribution. This occurred with four pairs of facilities: Great Works and Milford, Orono and Stillwater, Brown's Mills and Dover Upper, and Milo and Sebec. Year- and iteration-specific smolt survival estimates were selected in this manner for all DIA Model simulations.

3.6.3 Downstream Path Choice

A unique feature of the Penobscot River is the Stillwater Branch (i.e., Stillwater River). The Stillwater Branch is an approximately 17-km long side channel of the Penobscot River that begins at river km 47 (measured from the top of Verona Island), runs along the north and western sides of Orson and Marsh Islands, and rejoins the mainstem at river km 58.5, upriver of Veazie Dam (**Figure 3.1.1**). Smolts originating upriver of the Stillwater Branch have the option of migrating via the Stillwater Branch or the mainstem. Differential survival is likely experienced by smolts migrating through these two routes due to differences in local environs and the presence of multiple hydroelectric facilities. Smolts that migrate via the mainstem encounter 2 dams: Milford and Great Works. Smolts that migrate via the Stillwater Branch encounter 3 dams: Gilman Falls, Stillwater and Orono. Gilman Falls serves to control Stillwater head pond height and was not included within the DIA Model as it is assumed to have a minor negative effect on downstream migrating smolts due to the presence of a natural bypass channel adjacent to the dam and the lack of hydroelectric production capacity. However, Milford, Great Works, Stillwater, and Orono dams do have the potential to significantly affect downstream migrating smolts and have been shown to have varying cumulative probabilities of calculated total project smolt survival (**Figure 3.6.1.1**). Additionally, previous telemetry investigations have shown that the proportion of the smolts accessing the Stillwater Branch varies annually (Holbrook *et al.* 2011). To accurately assess the impacts that hydroelectric facilities may have on migrating smolts in the Penobscot River, the option of migrating down the Stillwater Branch or mainstem was incorporated into the DIA Model.

As previously mentioned, a network array of telemetry receivers was deployed throughout the Penobscot River and groups of both wild- and hatchery-origin smolts were tagged and released at various locations throughout the drainage in 2005 and 2006 and again in 2009 and 2010. Release group-specific (2005 and 2006) and origin-specific (2009 and 2010) estimates of Stillwater Branch use were calculated (Holbrook *et al.* 2011; Joseph Zydlewski U.S. Geological Survey, Maine Cooperative Fish and Wildlife Research Unit, personal communication). Stillwater Branch use estimates (n = 6) were fitted to a triangular distribution with a minimum value = 4.4%, a most likely value = 25.9%, and a maximum value = 25.9% with @Risk (**Figure 3.6.3.1**). A cumulative frequency distribution was developed from 5,000 random draws from the triangular distribution (**Figure 3.6.3.2**). The proportion of smolts that accessed the Stillwater Branch during their migration was determined via a random draw from the cumulative frequency distribution. Smolts that migrated through the Stillwater Branch were subjected to in-river mortality and mortality associated with the Stillwater and Orono dams. All remaining smolts migrated via the mainstem and were subjected to in-river mortality and mortality associated with the Milford and Great Works dams. Random draws were correlated the total project survival estimates according to the methods detailed in **Section 3.6.2**. Year- and iteration-specific Stillwater Branch use estimates were selected in this manner for all base case DIA Model simulations.

3.7 Latent Mortality

In addition to experiencing direct mortality at hydroelectric dams, Atlantic salmon also experience mortality that is related to passing multiple dams, which is hereafter referred to as latent mortality. This mortality is due to cumulative effects of stress and injury over the course of passing multiple dams and usually occurs in the estuary or ocean (Budy *et al.* 2002; Schaller and Petrosky 2007; Haeseker *et al.* 2012). The DIA Model contained an option to apply a latent mortality rate at Verona Island. This rate was calculated for smolts originating in each PU and was based on the number of dams that fish passed.

Effectively quantifying latent mortality, including in the Penobscot River, has not been possible, mainly because of difficulties directly measuring mortality after fish have left the river system. Therefore, a latent mortality rate of 0% per dam was applied for these DIA Model simulations, effectively removing the latent mortality effect. Although no latent mortality was included in these simulations, even a small latent mortality rate could have a large effect on the number of smolts (and consequently 2SW females) in the Penobscot River population considering the number of hydroelectric dams that are currently in the watershed.

3.8 Hatchery Discount

Although hatchery- and wild-origin smolts experience the same kinds of mortality, hatchery-origin smolts typically experience lower survival than wild-origin smolts, and so a discount was applied to hatchery-origin smolts to estimate the number of wild-equivalents before they migrated out to sea.

To estimate a hatchery discount, survival rates of wild- and hatchery-origin fish were obtained from the literature. Studies were included or excluded from the hatchery discount calculation with some subjectivity, and the decisions to include or exclude them are described below (**Table 3.8.1**).

Studies of wild- and hatchery-origin Atlantic salmon were used to estimate survival from smolt to adult life stages. Studies were excluded because they were not considered representative of Atlantic salmon in the Penobscot River watershed for various reasons. Studies were excluded if survival rates were not given (De Leaniz *et al.* 1989; Fleming *et al.* 1997; Einum and Fleming 2001; Salminen *et al.* 2007). Other studies were excluded because their study design made the survival rates inapplicable for the hatchery discount (Jonsson *et al.* 1991; Jonsson and Fleming 1993; Jonsson 1997; Jonsson *et al.* 2003; Jokikokko *et al.* 2006; Peyronnet *et al.* 2008; Kallio-Nyberg *et al.* 2011). The data points that were included (n = 17) had wild to hatchery survival ratios ranging from 1.18 to 8.20% (Jonsson *et al.* 1991; Crozier and

Kennedy 1993; Jonsson and Fleming 1993; Jokikokko *et al.* 2006; Jonsson *et al.* 2003; Jutila *et al.* 2003; Kallio-Nyberg *et al.* 2004; Saloniemi *et al.* 2004; Peyronnet *et al.* 2008; Kallio-Nyberg *et al.* 2011).

@Risk was used to fit a distribution to the included wild versus hatchery survival ratios, and the data were best described by a log logistic distribution, with γ = 1, β = 1.4271, α = 1.9922, and maximum = 12 (**Figure 3.8.1**). Year- and iteration-specific values were drawn from this distribution for base case hatchery discount values in all DIA Model simulations. The proportion of hatchery smolts at Verona Island (after the latent mortality rate was applied) was divided by the year- and iteration-specific hatchery discount to estimate the number of wild-equivalent smolts.

3.9 Marine Survival

U.S. Atlantic salmon spend approximately one half of their life cycle in the marine environment. To account for this, the DIA Model estimated the number of female post-smolts that successfully emigrated to Verona Island at the upper-most reaches of Penobscot Bay, and a marine survival distribution was applied to this population to estimate the number of 2SW female returns that would successfully migrate to Greenland and back to Verona Island over the course of the following two years. These 2SW females would then be available to migrate upstream en route to their natal spawning grounds.

Although the marine survival phase has received increased attention in recent times, an accurate assessment of marine survival for the Penobscot River salmon population is not available. Counts of adult returns divided by the total number of smolts stocked into the Penobscot River can be used as a surrogate for the marine survival rate, and these data are available from 1969 through the present. However, these are not accurate estimates of marine survival because they incorporate mortality of smolts in freshwater (i.e., stocking, in-river, and dam-related mortality). Marine survival estimates do exist for the Narraguagus River, a small coastal Gulf of Maine river located approximately 105 km northeast of Penobscot Bay, but the estimates are from a shorter time series (1997–present) and are for naturally-reared individuals. The documented difference in survival between smolt-stocked individuals and naturally-reared individuals makes this data series unrepresentative of the Penobscot population. Finally, the DIA Model focused on 2SW female returns, and none of the existing datasets provide sex-specific estimates of marine survival. As such, a new 2SW female-specific marine survival distribution was generated from available data from the Penobscot River, which aimed to remove the freshwater mortality factors.

To estimate a 2SW female marine survival distribution, the number of female smolts at Verona Island had to be estimated first. Year-specific estimates of the number of smolts stocked into the Penobscot River during 1969–2008 (USASAC 2011) were halved to approximate the number of stocked female smolts and then multiplied by the proportion of smolts that survived to Verona Island to adjust for mortality during the freshwater portion of the migration. Smolt survival to Verona Island was estimated from five years (2005, 2006, 2009, 2010, and 2011) of telemetry studies conducted within the Penobscot River (Joseph Zydlewski, U.S. Geological Survey, Maine Cooperative Fish and Wildlife Research Unit, personal communication). Seventeen estimates were obtained from hatchery- and wild-origin groups released at six different locations, and the means were fitted to a beta distribution with shape parameters α_1 = 4.1923 and α_2 = 1.8648, minimum = zero, and maximum = one with @Risk (**Figure 3.9.1**). Year-specific values were sampled from this distribution to estimate the number of female smolts that would survive from stocking to Verona Island.

Estimates of 2SW adults returning to the Penobscot River were obtained for return years 1971–2010 (USASAC 2011). These estimates represented all 2SW returns and, as the DIA Model focused on 2SW female returns, needed to be discounted accordingly. Sex statistics were available for the Penobscot River from 1978 to 2011 (**Figure 3.9.2**; Maine Department of Marine Resources fishway trap database, 2010 version). During 1978–1999, sex statistics were based on field determinations made at the adult trap. Starting in 2000, fish collected for broodstock were individually tagged in the field and brought to the hatchery, where their sex could accurately be determined during spawning. The 2000–2011 data are considered more accurate because sex determinations made in the field early in the season, prior to sexual dimorphism, are difficult. When converting the 2SW adult returns to female 2SW returns, the year-specific sex ratio estimates were used for 2000–2010, and the 2000–2010 mean ratio was used for all years prior.

Year-specific 2SW female marine survival rates were calculated by dividing the estimated number of 2SW female returns by the estimated number of female smolts at Verona Island. A total of 10,000 iterations were run, where the number of female smolts that would survive from stocking to Verona Island was a stochastic process (as described above). The iterations also had a maximum survival of 25%, which was exceeded in less than 0.05% of the iterations. The resulting 1971–2010 median values were fitted to an inverse gaussian distribution with μ = 0.006265, shape parameter λ = 0.0068723, and a shift of 0.00000813424 with @Risk (**Figure 3.9.3**). Year- and iteration-specific values were sampled from this distribution for base case marine survival rates in all DIA Model simulations.

3.10 Straying

Adult Maine Atlantic salmon have been shown to have a high degree of river of origin homing with rates of 98–99% in hatchery-release studies (Baum 1997). However the in-river migration behavior and how it may affect reach-level productivity is poorly understood. Within-river homing behavior and its effect on distribution of spawning adults is postulated as being driven by habitat (i.e., temperature, flow, and substrate) (Kocik and Ferreri 1998), the presence of conspecifics (i.e., pheromone cues), and environmental cues (Fleming 1996). Atlantic salmon have a strong tendency to return to river reaches where they have been reared. Saunders (1967) estimated a homing rate of 70% for naturally-reared smolts in the upper Miramichi, NB, Canada. Similarly, Heggberget *et al.* (1988) showed adult Atlantic salmon returned with very high affinity (μ = 87%) to areas they had selected as spawning grounds when artificially displaced. Evolutionarily, in-river homing is logical as the success of an individual's rearing would provide selection for the local habitat characteristics, and returning adults provide this selective advantage to future progeny. However, limited levels of straying also benefits salmon populations by allowing for plasticity in habitat use in response to varying population levels (i.e., balancing density dependent effects) and the opportunity to colonize new habitat as well as the prevention of genetic bottlenecking (Heggberget *et al.* 1988).

Estimated in-river homing rates and straying patterns were developed to more accurately model the spatial distribution of Atlantic salmon production in the Penobscot River watershed. PU-specific homing rates and straying patterns were developed through an assessment of all available pertinent data and information including various Atlantic salmon behavioral studies conducted within the Penobscot (Power and McCleave 1980; Shepard 1995; Gorsky 2005; Gorsky *et al.* 2009; Holbrook *et al.* 2009; Douglas B. Sigourney, U.S. Geological Survey, Maine Cooperative Fish and Wildlife Research Unit, personal communication), fishway trap data from throughout the drainage (Maine Department of Marine Resources fishway trap database, 2010 version), and Expert Panel recommendations made on the topic (Appendix B: Atlantic Salmon Fate and Straying at Upstream Fish Passage Facilities on the Penobscot River).

Estimates of PU-specific homing rates and straying patterns could not be developed based on the behavioral studies and fishway trap data for two primary reasons. First, the available data were not representative of the entire drainage as some PUs had no information from which to draw conclusions. Second, the patterns observed within the various datasets could not be delineated into behavioral effects versus effects confounded by upstream passage issues. Estimates of PU-specific homing rates and straying patterns should be based on behavioral patterns only and need to be free from influences of upstream passage issues as these affects are included within the Upstream Dam Passage Inefficiency dynamics (**Section 3.12**).

A set of logical rules was developed to assist with estimating PU-specific homing rates and straying patterns by using the specific study results combined with the Expert Panel opinions and local knowledge (**Table 3.10.1**). The logical rules are as follows:

- PUs 1, 2, 3, 4, 5, 6, 7, 8, 13, and 15 were defined as headwater areas.
- Headwater homing rates were set at 90%.
- PUs 9, 10, 11, 12, and 14 were defined as mainstem.
- Mainstem homing rates were set at 70%.
- Straying was proportionally divided according to 90% upriver and 10% downriver.
- Upstream straying was assigned equally to adjacent PUs.
- Downstream straying was assigned to the downstream PU.

Exceptions to these logical rules are as follows:

- PUs 1 and 2 - These PUs are in the upper drainage and straying fish would likely stop in multiple lower PUs (i.e., all straying fish were not confined to straying into the immediate downstream PU).
- PUs 4, 5, and 6 - It was believed some fish would stray into PUs 7 and 8 (i.e., lateral straying).
- PUs 7 and 8 – Similar to the rationale for PUs 1 and 2, straying fish would likely stop in multiple lower PUs (i.e., all straying fish were not confined to straying into the immediate downstream PU).

- PUs 9, 10, 11, and 12 - These PUs contain lower quality spawning habitat compared to adjacent PUs. Therefore, a higher rate of straying into adjacent PUs containing higher quality spawning habitat was assumed (i.e., lateral straying).
- PU 13 - This lower river drainage is unique in that it is a fairly large, self-contained drainage, and all straying was assumed to be upstream due to a lack of suitable habitat downstream.
- PU 14 - This lower river drainage is unique in that it is mostly large mainstem habitat with only a small amount of suitable habitat that is tributaries. All straying was assumed to be upstream due to a lack of suitable habitat downstream.
- PU 15 – Similar to PU 13, this lower river drainage is unique in that it is a fairly large, self-contained drainage. Straying was assumed to be primarily downstream, with a small amount of straying upstream.

The actual rates of homing and straying for returning Penobscot Atlantic salmon are likely determined by a combination of biotic and abiotic factors, but a dataset of homing rates and straying patterns with dam passage factors removed was needed for the DIA Model. A dataset of this sort was not available, so rather than using solely biased observational data, rates based on logical concepts, field data, expert opinions, and biological theory were developed for the population model. The PU-specific homing rates and straying patterns described above were the best available information for use in the DIA Model.

3.11 Upstream Dam Passage Survival Rates

3.11.1 Veazie, Great Works, Milford, and All Other Dams

After spending several years feeding in the ocean, adult Atlantic salmon return to rivers to spawn. As stated in **Section 3.6.1**, a large number of dams are located within the Penobscot River watershed, and Atlantic salmon must attempt to pass these dams on their upstream migration to their spawning grounds. The DIA Model also addressed upstream passage dynamics at 15 of those dams. The calculation of upstream dam passage was dependent upon each dam.

Numerous telemetry studies have been conducted within the Penobscot River that focused on evaluating upstream passage of adult Atlantic salmon. These studies were conducted in 1987–1990, 1992, and 2002–2006 and have provided estimates of upstream passage at Veazie, Great Works, and Milford dams (Holbrook *et al.* 2009). Veazie estimates ranged from 0.4210 to 0.9840, with μ = 0.6485 and σ = 0.1907, Great Works estimates ranged from 0.1190 to 0.9440, with μ = 0.6730 and σ = 0.2783 and Milford estimates ranged from 0.6670 to 1.0000, with μ = 0.8993 and σ = 0.0958. These data were used to generate cumulative frequency distributions with @Risk (**Figures 3.11.1.1, 3.11.1.2, and 3.11.1.3**). To avoid using outliers from these datasets, minimums and maximums were placed on each of the cumulative distributions, using $\mu \pm \sigma$ to calculate the limits (**Table 3.11.1.1**). Year- and iteration-specific values were randomly drawn from these cumulative distributions for base case upstream dam passage rates in all DIA Model simulations.

Four dams (i.e., Medway, Milo, Sebec, and Orono) did not have any upstream passage, meaning adults were not able to access the PUs above these dams (i.e., PUs 1, 7, 8, and 11), and so upstream passage was set to zero (**Table 3.11.1.1**). No adults were seeded in these PUs (because of the lack of upstream access). Subsequently, no smolts originated in them, and no 2SW females would home to them. However, a small proportion of adults were allowed to attempt to stray to these PUs (**see Section 3.10**) although their attempts would be unsuccessful due to the lack of passage at the facilities at the lower boundary of the PU.

Upstream passage estimated for the eight remaining modeled dams (i.e., Mattaceunk, West Enfield, Dover Upper, Brown's Mills, Howland, Lowell, Stillwater, and Frankfort) were not available. Generalized estimates were used in previous modeling efforts (USFWS 1988) and were adopted here. A uniform distribution was developed for the eight remaining dams using $\mu \pm \sigma$ (i.e., 0.92 ± 0.0325) as the upper and lower limits of the distributions (**Table 3.11.1.1**). Year- and iteration-specific values were sampled from the uniform distributions with @Risk for the base case upstream dam passage rates in all DIA Model simulations. Adults that were not able to pass a dam died, returned to sea, or went to another PU (**see Section 3.12**).

3.11.2 Upstream Path Choice

As stated in **Section 3.6.3**, the Stillwater Branch presents a unique situation in the Penobscot River. Fish have the option to migrate through the Stillwater Branch or the mainstem. Whereas smolts were able to migrate downstream through either the Stillwater Branch or the Mainstem in the DIA Model, all adult spawners that attempted to migrate upstream of PU 12 were forced to migrate through the mainstem. This was because Orono Dam, which was the downstream endpoint of PU 11 and the Stillwater Branch, had no upstream fish passage.

No adults were seeded in PU 11 (because of the lack of upstream access). Subsequently, no smolts originated in PU 11, and no 2SW females would home to PU 11. A small proportion of adults attempted to stray to PU 11 (**Section 3.10**). However, given the lack of upstream passage, all adults were diverted to the mainstem.

3.12 Upstream Dam Passage Inefficiency

Few, if any, upstream fishways provide safe, timely, and effective passage for 100% of migratory fish, including Atlantic salmon. Although multiple studies have been conducted in the Penobscot River to measure the effectiveness of fishways at various hydroelectric facilities, very little data are available concerning the fate of adult Atlantic salmon that are unsuccessful in locating or negotiating upstream fishways at dams.

Within the DIA Model, the fate of adult salmon that were unsuccessful in passing an individual dam needed to be defined to more accurately model the spatial distribution of Atlantic salmon production in the Penobscot River watershed. In the absence of site-specific data, NMFS convened an expert panel, consisting of state, federal, and private sector biologists and engineers with expertise in Atlantic salmon biology and behavior at fishways, to address the issue. Specifically, the Expert Panel was asked if Atlantic salmon that are unsuccessful in locating and negotiating upstream fishways at the 15 hydroelectric projects modeled in the DIA Model die, return to the ocean un-spawned, or stray and spawn in downstream reaches. Through best professional judgment, the Expert Panel reached consensus regarding the fate of adult Atlantic salmon that are unsuccessful at locating and negotiating upstream fishways at the 15 hydroelectric projects modeled in the DIA Model (**Table 3.12.1**). It should be noted that hydroelectric projects upstream of the first impassable dam on the West Branch of the Penobscot River were not evaluated by the group (e.g., dams upstream of Medway). A full description of the discussions and decisions reached are detailed in Appendix B: Atlantic Salmon Fate and Straying at Upstream Fish Passage Facilities on the Penobscot River.

The Expert Panel recognized that no upstream fishway is 100% effective and concluded that a baseline 1% mortality is likely at all fishways for fish that do not successfully pass (**Table 3.12.2**). Mortality estimates were increased for specific facilities due to a variety of reasons such as there being a high percentage of fallback and, therefore, a high percentage of re-ascent and failure, a possibility of poaching-related mortality caused by migration delays, mortality due to a lack a thermal refuge for delayed adults, and a possibility of predation, mainly by seals, at the lower river dams. The logic behind assigning specific proportions of fish to return to the ocean un-spawned were related to proximity of the facility to the ocean and increased handling at the fishway trapping facility at Veazie Dam. The proportions of fish that were determined to be confined within the various downstream PUs after not successfully ascending a particular fishway were determined by consensus within the Expert Panel, based on the knowledge and expertise contained within the group.

Within the DIA Model, adult returns must pass at least one dam en route to their spawning grounds, with the exception of fish destined for PU 14. Some percentage of these fish will not successfully pass each facility according to the upstream dam passage survival rates (**see Section 3.11**). These unsuccessful fish will die, return to the sea un-spawned, or be redirected to a downstream PU according to the proportion detailed in **Table 3.12.1**.

4 DIA Model Results in Support of the NMFS Biological Opinion

The DIA Model was used to run several scenarios in support of the NMFS biological opinion, which is based on the Biological Assessment and Species Protection Plan in response to the Black Bear Hydro Partners, LLC (hereafter referred to as Black Bear) amendment applications for the Stillwater and Orono projects. The following sections (**Sections 4.1, 4.2, and 4.3**) describe each scenario evaluated and the corresponding results.

The reported results include estimated total adult abundance (**Sections 4.1, 4.2, and 4.3**), distribution of adults (**Sections 4.1, 4.2, and 4.3**), total number and proportion of smolts killed by dams (**Sections 4.1 and 4.2**), and total number of smolts killed by latent mortality (**Section 4.3**). Total adult abundance was recorded as the median number of 2SW females across all PUs. For each of three areas of the Penobscot River watershed, the distribution of adults was recorded as the proportion of iterations when at least one 2SW female was present. The three areas of the Penobscot River watershed (**Figure 3.1.1**) were: (1) above West Enfield Dam (i.e., PUs 1–3), (2) in the Piscataquis River watershed (i.e., PUs 4–8), and (3) below West Enfield Dam (i.e., PUs 9–15). Total number of smolts killed by dams was recorded as the median number of smolts killed during downstream dam passage across all 15 hydroelectric dams. Total proportion of smolts killed by dams was recorded as the median proportion of smolts killed during downstream dam passage across all 15 hydroelectric dams. Total number of smolts killed by latent mortality was recorded as the median number of smolts killed by latent mortality across all PUs and the 15 hydroelectric dams. Total proportion of smolts killed by latent mortality was recorded as the median proportion of smolts killed by latent mortality across all PUs and the 15 hydroelectric dams.

4.1 Base Case, Future Federal Actions, and Proposed Actions

The base case scenario inputs were the same as described in **Section 3**. The base case scenario provides a standard for comparison of the effects of future Federal actions and the proposed Species Protection Plan on Atlantic salmon productivity within the Penobscot River.

The future Federal actions scenario incorporated the proposed changes to the Penobscot River watershed that are included in the Penobscot River Restoration Project (PRRP). These changes include removing Veazie and Great Works dams and building a bypass around Howland Dam. The future Federal actions scenario was represented in the DIA model as the base case scenario with the exception of downstream and upstream passage rates at Veazie, Great Works and Howland Dams being set to one (i.e., all successfully smolts and adults pass).

The proposed actions scenario incorporated changes to Black Bear hydroelectric projects as outlined within their Species Protection Plan. These changes include downstream passage rates of 0.96 at Orono, Stillwater, Milford, and West Enfield dams, and upstream passage rates of 0.95 at Milford and West Enfield dams. The proposed actions scenario was represented in the DIA model as the future Federal actions scenario with downstream and upstream passage rates at the aforementioned hydroelectric dams set to 0.96 and 0.95, respectively.

The DIA Model was seeded with 587 2SW females for all three scenarios (**Table 4.1.1; Figure 4.1.1**). In the base case scenario, the median number of 2SW females declined from 587 in generation 1 to 225 in generation 2, and varied without trend in subsequent generations. Adult abundance followed the same pattern in the future Federal actions and proposed actions scenarios. Adult abundance for generations 2–10 was lowest in the base case scenario and highest in the proposed actions scenario.

The proportion of iterations when at least one 2SW female was located in each Penobscot River watershed area equaled one in generation 1 for all three areas in the base case, future Federal actions, and proposed actions scenarios (**Table 4.1.2; Figure 4.1.2**). The proportion of iterations remained at one for the area below West Enfield Dam in generations 2–10 for all three scenarios. The proportion of iterations for the area above West Enfield Dam was similar to the proportion of iterations for the area of the Piscataquis River watershed. The proportion of iterations in these two areas declined in generation 2 and varied without trend in subsequent generations for all three scenarios. The proportion of iterations when at least one 2SW female was located in each Penobscot River watershed area was lowest in the base case scenario and highest in the proposed actions scenario.

The total number of smolts killed by dams during downstream passage was the highest in generation 1, declined from generation 1 to generation 2, and varied without trend in generations 2–10 for the base case, future Federal actions, and proposed actions scenarios (**Table 4.1.3; Figure 4.1.3**). The number of smolts killed was highest in the base case scenario and lowest in the proposed actions scenario.

The total proportion of smolts killed by dams during downstream passage varied without trend in generations 1–10 for the base case, future Federal actions, and proposed actions scenarios (**Table 4.1.4; Figure 4.1.3**). The proportion of smolts killed was highest in the base case scenario and lowest in the proposed actions scenario.

4.2 Recovery Analysis

The DIA Model was used to evaluate the effects of hydroelectric facilities on Atlantic salmon production within the Penobscot River under a recovery scenario where freshwater and marine survival rates were increased to a level where a self sustaining population could be expected. The scenarios outlined in **Section 4.1** were run with a two times increase in freshwater survival (i.e., egg to smolt survival), a four times increase in marine survival, and the hatchery component of the model turned off. Two sets of starting values of adults were also tested: the mean annual number of 2SW female returns captured at the trap above Veazie Dam during 2002–2011 (i.e., 587 2SW females), and the number of 2SW females needed for a recovered population (i.e., 1,000 2SW females). The inputs of each run are detailed below.

Recovery "1" runs were the base case scenario with a two times increase in freshwater survival, a four times increase in marine survival, and the hatchery component of the model turned off. Recovery "2" runs were the future Federal actions scenario (i.e., base case scenario with downstream and upstream passage rates at Veazie, Great Works, and Howland dams set to one), with a two times increase in freshwater survival, a four times increase in marine survival, and the hatchery component of the model turned off. Recovery "3" runs were the proposed action scenario (i.e., future Federal actions scenario with downstream passage rates at Orono, Stillwater, Milford, and West Enfield dams set to 0.96 and upstream passage rates at Milford and West Enfield dams set to 0.95), with a two times increase in freshwater survival, a four times increase in marine survival, and the hatchery component of the model turned off. Recovery "4" runs were the base case scenario with all Black Bear hydroelectric facilities (except Medway Dam) removed (i.e., downstream and upstream passage at Orono, Stillwater, Milford, and West Enfield dams set to one), with a two times increase in freshwater survival, a four times increase in marine survival, and the hatchery component of the model turned off. These four scenarios were run twice. Recovery "a" model runs seeded the DIA Model with the mean annual number of 2SW female returns captured at the trap above Veazie Dam during 2002–2011 (i.e., 587 2SW females) and recovery "b" model runs seeded the DIA Model with the number of 2SW females needed for a recovered population (i.e., 1,000 2SW females).

Recovery "a" runs were seeded with 587 2SW females, and all four runs generally increased over ten generations (**Table 4.2.1; Figure 4.2.1**). Recovery run 1a increased the least and recovery run 4a increased the most.

The proportion of iterations when at least one 2SW female was located in each Penobscot River watershed area equaled one or was close to one in generations 1–10, for all three areas, in recovery runs 1a, 2a, 3a, and 4a (**Table 4.2.2; Figure 4.2.2**). The proportion of iterations was just below one in recovery run 1a for generations 4–10 in the areas above West Enfield Dam and of the Piscataquis River watershed. The proportion of iterations equaled one in all other generations and areas for recovery runs 1a, 2a, 3a, and 4a.

The trend in total number of smolts killed by dams during downstream passage differed in the recovery “a” runs (**Table 4.2.3; Figure 4.2.3**). In recovery run 1a, the total number of smolts killed declined from generation 1 to generation 4 and then increased to generation 10. In recovery run 2a, the total number of smolts killed declined from generation 1 to generation 2 and then increased to generation 10. In recovery runs 3a and 4a, the total number of smolts killed increased from generation 1 to generation 10.

The total proportion of smolts killed by dams during downstream passage decreased during generations 1–10 for recovery runs 1a, 2a, 3a, and 4a (**Table 4.2.4; Figure 4.2.3**). The proportion of smolts killed was highest in recovery run 1a and lowest in recovery run 4a.

Recovery “b” runs were seeded with 1,000 2SW females, and all four runs generally increased over ten generations (**Table 4.2.5; Figure 4.2.4**). Recovery run 1b increased the least and recovery run 4b increased the most.

The proportion of iterations when at least one 2SW female was located in each Penobscot River watershed area equaled one or was close to one in generations 1–10, for all three areas, in recovery runs 1b, 2b, 3b, and 4b (**Table 4.2.6; Figure 4.2.5**). The proportion of iterations was just below one in recovery run 1b for generations 4–10 in the area above West Enfield Dam, in recovery run 1b for generations 5–10 in the area of the Piscataquis River watershed, and in recovery run 2b for generation 10 in the area above West Enfield Dam. The proportion of iterations equaled one in all other generations and areas for recovery runs 1b, 2b, 3b, and 4b.

The trend in total number of smolts killed by dams during downstream passage differed in the recovery “b” runs (**Table 4.2.7; Figure 4.2.6**). In recovery run 1b, the total number of smolts killed declined from generation 1 to generation 5 and then increased to generation 10. In recovery run 2b, the total number of smolts killed declined from generation 1 to generation 2 and then increased to generation 10. In recovery runs 3b and 4b, the total number of smolts killed increased from generation 1 to generation 10.

The total proportion of smolts killed by dams during downstream passage decreased during generations 1–10 for recovery runs 1b, 2b, 3b, and 4b (**Table 4.2.8; Figure 4.2.6**). The proportion of smolts killed was highest in recovery run 1b and lowest in recovery run 4b.

4.3 Latent Mortality Effects

Although latent mortality was set to zero in the base case DIA Model (**Section 3.7**), several scenarios that incorporated different levels of latent mortality were run. The base case scenario was altered to test scenarios with 1, 5, and 10% mortality rates per dam passed.

The DIA model was seeded with 587 2SW females for latent mortality 1, 5, and 10% scenarios (**Table 4.3.1; Figure 4.3.1**). In all three scenarios, the median number of 2SW females declined from generation

1 to generation 2, and varied without trend in subsequent generations. Adult abundance for generations 2–10 was lowest in the latent mortality 10% scenario and highest in the latent mortality 1% scenario.

The proportion of iterations when at least one 2SW female was located in each Penobscot River watershed area equaled one in generation 1 for all three areas and in the latent mortality 1, 5, and 10% scenarios (**Table 4.3.2; Figure 4.3.2**). The proportion of iterations remained at one for the area below West Enfield Dam in generations 2–10 for all three scenarios. The proportion of iterations for the area above West Enfield Dam was similar to the proportion of iterations for the area of the Piscataquis River watershed. The proportion of iterations in these two areas declined from generation 1 to generation 3 and varied without trend in subsequent generations for all three scenarios. The proportion of iterations when at least one 2SW female was located in each Penobscot River watershed area was lowest in the latent mortality 10% scenario and highest in the latent mortality 1% scenario.

The total number of smolts killed by dams due to latent mortality was the highest in generation 1, declined from generation 1 to generation 2, and varied without trend in generations 2–10 for the latent mortality 1, 5, and 10% scenarios (**Table 4.3.3; Figure 4.3.3**). The number of smolts killed was highest in the latent mortality 10% scenario and lowest in the latent mortality 1% scenario.

5 Tables

Table 1.1. Chronology of Penobscot Dam Impact Analysis (DIA) Model.

Date	Meeting Content
September 2009	Kick-off meeting with NEFSC and NERO staff in Woods Hole, MA.
November 2009	Workgroup meeting in Orono, ME to discuss development of DIA Model.
December 2009	Workgroup meeting in Woods Hole, MA to discuss development of DIA Model.
December 2009	Workgroup conference call.
January 2010	Workgroup conference call.
February 2010	Workgroup meeting in Portland, ME to discuss DIA Model development.
March 2010	Workgroup conference call.
March 2010	Development of Survival Distribution Statement of Work.
April 2010	Workgroup conference call.
April 2010	Survival Distribution Request for Proposals issued by NERO.
July 2010	Workgroup meeting in Woods Hole, MA to review Survival Distribution proposals.
September 2010	Survival Distribution project awarded to Alden Research Laboratory, Inc.
October 2010	Workgroup meeting in Woods Hole, MA.
October 2010	Kick-off meeting with Alden Research Laboratory, Inc. in Woods Hole, MA.
October 2010	Workgroup conference call.
December 2010	Phase I check in conference call with Alden Research Laboratory, Inc.
December 2010	Expert Panel meeting in Orono, ME.
December 2010	Workgroup conference call.
January 2011	Model introduction meeting with U.S. Fish and Wildlife Service in Orono, ME.
January 2011	Phase I meeting with Alden Research Laboratory, Inc. in Orono, ME.
February 2011	Alden Research Laboratory, Inc. submits draft Phase I report.
February 2011	Conference call with Alden Research Laboratory, Inc.
March 2011	Workgroup conference call.
April 2011	Workgroup conference call.
May 2011	Workgroup conference call.
June 2011	Work group meeting in Gloucester, MA.
June 2011	Phase II meeting in Gloucester, MA with Alden Research Laboratory, Inc.
July 2011	Workgroup conference call.
August 2011	Workgroup conference call.
September 2011	Alden Research Laboratory, Inc. submits draft Phase II report.
September 2011	Workgroup conference call.
November 2011	Workgroup conference call.
December 2011	Progress meeting in Orono, ME with Alden Research Laboratory, Inc.
February 2012	Workgroup conference call.
March 2012	Workgroup conference call.
April 2012	Workgroup conference call.
May 2012	Workgroup conference call.
May 2012	Workgroup meeting in Orono, ME.

Date	Meeting Content
June 2012	Northeast Fisheries Science Center produces final model outputs.
June 2012	Workgroup conference call.
July 2012	Workgroup conference call.
August 2012	Workgroup conference call.

Table 3.1.1. Descriptions of production unit (PU) boundaries in the Penobscot River watershed with corresponding metrics of total network length, longest segment length, and partial segment length used within the DIA Model. Total network length represents the sum of all stream kilometers within a particular PU. Longest segment length represents the longest straight path distance that a fish could swim in a given PU. All smolts were subjected to natural mortality for half the distance of the longest segment length when migrating through their natal PU. Partial segment length corresponds to the distance that smolts would be subjected to natural mortality when traversing from one PU to another (i.e., not starting from their natal PU). Partial segment lengths in parentheses indicate situations where smolts can enter a PU from two different locations and, therefore, could be subjected to different levels of natural mortality based on different distances travelled.

PU	Downstream Boundaries	Upstream Boundaries	Total Network Length (km)	Longest Segment Length (km)	Partial Segment Length (km)
1	Medway	West Branch headwaters	4,358	309	NA
2	Mattaceunk	East Branch headwaters, Medway	1,842	139	13
3	West Enfield	Mattawamkeag River headwaters, Mattaceunk	3,068	208	50
4	Howland	Pleasant River headwaters, Milo, Brown's Mills	873	125	42 (65)
5	Brown's Mills	Dover Upper	25	10	10
6	Dover Upper	Piscataquis River headwaters	906	78	NA
7	Milo	Sebec	46	12	12
8	Sebec	Sebec River headwaters	675	59	NA
9	Stillwater, Milford	Howland Dam, West Enfield Dam, Lowell Dam	1,147	65	54
10	Great Works	Milford	2	2	2
11	Orono	Stillwater	7	4	4
12	Veazie	Great Works, Orono	156	49	7
13	Frankfort	Marsh Stream headwaters	437	54	NA
14	Verona Island	Kenduskeag Stream headwaters, Frankfort, Veazie	2,575	121	10 (41)
15	Lowell	Passadumkeag River headwaters	207	49	NA

Table 3.1.2. Number of Atlantic salmon habitat units available within the Penobscot River, the number of habitat units accessible to Atlantic salmon and used within the DIA Model, the proportional production potential (i.e., proportion of the total habitat units used) used for seeding adults into the model, and the production potential cap (i.e., habitat units used multiplied by ten) used for limiting the number of smolts produced to a maximum projected productivity level for each production unit (PU).

PU	Habitat Units Available (in 100 m^2)	Habitat Units Used (in 100 m^2)	Proportional Production Potential	Production Potential Cap
1	84,287	0	0	0
2	44,250	44,250	0.2053	442,505
3	56,450	56,450	0.2619	564,495
4	42,849	42,849	0.1988	428,486
5	284	284	0.0013	2,839
6	21,782	21,782	0.1011	217,819
7	1,733	0	0	0
8	13,922	0	0	0
9	17,860	17,860	0.0829	178,599
10	4	4	0.0001	40
11	940	0	0	0
12	5,925	5,925	0.0275	59,247
13	4,801	4,801	0.0223	48,013
14	17,727	17,727	0.0822	177,271
15	3,601	3,601	0.0167	36,010

Table 3.3.1. Egg to fry survival values from the literature (post-Legault 2004), assuming 8 months for standardization of survival rates. None of these entries were used to further describe egg to fry survival. See Legault (2004) for additional references considered.

			# Years	Duration	Reported Percent Survival			Converted Percent Survival		
Author	Region	Origin	of Data	(months)	Mean	Lower	Upper	Mean	Lower	Upper
Dumas & Marty 2006	France	hatchery	1	3	32.30	NA	NA	4.91	NA	NA
Dumas & Marty 2006	France	hatchery	1	3	83.60	NA	NA	62.02	NA	NA
Dumas & Marty 2006	France	hatchery	1	3	73.90	NA	NA	44.64	NA	NA
Dumas & Marty 2006	France	hatchery	1	3				37.19	4.91	62.02
Flanagan et al. 2008	New Brunswick	hatchery	2	7	1.33	0.00	4.00	0.72	0.00	2.53
Flanagan et al. 2008	New Brunswick	hatchery	2	7	12.50	3.00	48.00	9.29	1.82	43.22

Table 3.3.2. Fry to parr0+ survival values from the literature (post-Legault 2004), assuming 2 months for standardization of survival rates. Highlighted entries were used to describe fry to parr0+ survival. See Legault (2004) for additional references considered.

					Reported Percent Survival			Converted Percent Survival		
Author	**Region**	**Origin**	**# Years of Data**	**Duration (months)**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**
Aprahamian et al. 2004	England	hatchery		3.5	23.42	7.80	41.30	43.63	23.28	60.33
Aprahamian et al. 2004	England	hatchery	1	3.5	22.50	NA	NA	42.64	NA	NA
Aprahamian et al. 2004	England	hatchery		3.5	14.62	1.20	26.20	33.33	7.99	46.52
Aprahamian et al. 2004	England	hatchery	2	3.5	30.15	27.40	32.90	50.40	47.72	52.98
Aprahamian et al. 2004, ave.	England	hatchery	3	3.5	20.54	1.20	41.30	40.48	7.99	60.33
Coghlan & Ringler 2004	New York	hatchery	1	1	7.00	NA	NA	0.49	NA	NA
Coghlan & Ringler 2004	New York	hatchery	1	2	2.00	NA	8.00	2.00	NA	8.00
Coghlan et al. 2007	New York	hatchery	1	2	NA	1.00	66.00	NA	1.00	66.00
Raffenberg & Parrish 2003	Vermont	hatchery	unk	unk	NA	2.00	50.00	NA	2.00	50.00
Millard 2005	New York	hatchery	1	3.5	24.00	4.00	38.00	44.24	15.89	57.53
Millard 2005	New York	hatchery	1	3.5	6.00	1.00	22.00	20.04	7.20	42.10
Millard 2005	New York	hatchery	1	3.5	37.00	28.00	63.00	56.66	48.32	76.80
Millard 2005, average	New York	hatchery	1	3.5				40.31	7.20	76.80

Table 3.3.3. Parr0+ to parr1+ survival values from the literature (post-Legault 2004), assuming 12 months for standardization of survival rates. Highlighted entries were used to describe parr0+ to parr1+ survival. See Legault (2004) for additional references considered.

			# Years	Duration	Reported Percent Survival			Converted Percent Survival		
Author	Region	Origin	of Data	(months)	Mean	Lower	Upper	Mean	Lower	Upper
Letcher et al. 2002	Massachusetts	hatchery	1	8	0.56	NA	NA	0.04	NA	NA
Letcher et al. 2002	Massachusetts	hatchery	1	5	0.71	NA	NA	0.00	NA	NA
Aprahamian et al. 2004	England	hatchery	2	12.67	26.32	19.90	34.10	28.25	21.67	36.10

Table 3.3.4. Parr1+ to smolt survival values from the literature (post-Legault 2004), assuming 9 months for standardization of survival rates. This entry was not used to further describe parr1+ to smolt survival. See Legault (2004) for additional references considered.

			# Years	Duration	Reported Percent Survival			Converted Percent Survival		
Author	Region	Origin	of Data	(months)	Mean	Lower	Upper	Mean	Lower	Upper
Letcher et al. 2002	Massachusetts	hatchery	2		0.34	0.21	0.46	0.10	NA	NA

Table 3.3.5. Summary of life stage survival rates used to develop the egg to smolt survival distribution.

Life Stage		Survival (%)		
Begin	**End**	**Min**	**Max**	**Mean**
Egg	Fry	15	35	25.0
Fry	Parr 0+	31	60	45.5
Parr 0+	Parr 1+	13	56	34.5
Parr 1+	Smolt	17	50	33.5
Egg	Smolt	0.10	5.88	1.31

Table 3.4.1. Mean percentage and number of hatchery-reared smolts stocked into each production unit (PU) from 2003-2012.

PU	Smolts Stocked (%)	Number of Smolts Stocked
1	0	0
2	0	0
3	17.2	94,628
4	34.6	190,076
5	0	0
6	0	0
7	0	0
8	0	0
9	31.7	174,495
10	0	0
11	0	0
12	14.2	78,109
13	0	0
14	2.3	12,692
15	0	0
Total	100	550,000

Table 3.6.2.1. Correlation Analysis results on annual mean 1935 – 2010 April through June flow data at five monitoring sites (identified by their seven digit US geological Survey gauge number) within the Penobscot River drainage.

	1029500	1030500	1031500	1034500	1034000
1029500	1.000	0.918	0.831	0.959	0.882
1030500	0.918	1.000	0.834	0.931	0.869
1031500	0.831	0.834	1.000	0.888	0.981
1034500	0.959	0.931	0.888	1.000	0.922
1034000	0.882	0.869	0.981	0.922	1.000

Table 3.8.1. Survival rates of wild- and hatchery-origin fish and the ratio of wild versus hatchery survival from the literature. Highlighted entries were used to describe the hatchery discount. Multiple survival rates for one study indicate results from different parts of study design (e.g., multiple rivers or ages, different recapture location).

Author	Region	Start	End	Wild Survival Rate	Hatchery Survival Rate	Wild:Hatchery Survival Ratio
Crozier and Kennedy 1993	Northern Ireland	1973	1990	0.0820	0.0100	8.2
Crozier and Kennedy 1993	Northern Ireland	1973	1990	0.0820	0.0230	3.6
Crozier and Kennedy 1993*	Northern Ireland	1973	1990	0.0110	0.0010	7.3
Crozier and Kennedy 1993	Northern Ireland	1983	1990	0.3250	0.0720	4.5
Crozier and Kennedy 1993	Northern Ireland	1983	1990	0.3250	0.1280	2.5
De Leaniz et al. 1989	Spain	1985	1988	NA	NA	NA
De Leaniz et al. 1989	Spain	1985	1988	NA	NA	NA
Einum & Fleming 2001	Multiple	NA	NA	NA	NA	NA
Fleming et al. 1997	Norway	NA	NA	NA	NA	NA
Jokikokko et al. 2006	Finland	1986	1992	0.0843	0.0580	1.5
Jokikokko et al. 2006	Finland	1986	1992	0.0843	0.0375	2.2
Jokikokko et al. 2006	Finland	1986	1992	NA	NA	1.0
Jokikokko et al. 2006	Finland	1986	1992	NA	NA	2.1
Jokikokko et al. 2006	Finland	1986	1992	NA	NA	2.1
Jokikokko et al. 2006	Finland	1986	1992	NA	NA	1.0
Jokikokko et al. 2006	Finland	1986	1992	NA	NA	3.5
Jokikokko et al. 2006	Finland	1986	1992	NA	NA	3.4
Jonsson 1997	Multiple	NA	NA	NA	NA	2.0
Jonsson & Fleming 1993	Multiple	NA	NA	0.0690	0.0280	2.5
Jonsson & Fleming 1993	Multiple	NA	NA	0.0690	0.0070	9.9
Jonsson & Fleming 1993	Multiple	NA	NA	0.0690	0.0320	2.2
Jonsson et al. 1991	Norway	1975	1989	0.0580	0.0320	1.8
Jonsson et al. 1991	Norway	1975	1989	0.0290	0.0120	2.4

Author	Region	Start	End	Wild Survival Rate	Hatchery Survival Rate	Wild:Hatchery Survival Ratio
Jonsson et al. 1991	Norway	1975	1989	0.0020	0.0020	1.0
Jonsson et al. 2003	Norway	1981	1999	0.0710	0.0290	2.4
Jonsson et al. 2003	Norway	1981	1999	0.0710	0.0270	2.6
Jonsson et al. 2003	Norway	1981	1999	0.0180	0.0040	4.5
Jonsson et al. 2003	Norway	1981	1999	0.0180	0.0020	9.0
Jonsson et al. 2003	Norway	1981	1999	0.0890	0.0330	2.7
Jonsson et al. 2003	Norway	1981	1999	0.0890	0.0290	3.1
Jutila et al. 2003	Finland	1991	1993	0.1043	0.0713	1.5
Kallio-Nyberg et al. 2004	Finland	1972	1998	0.3300	0.2600	1.3
Kallio-Nyberg et al. 2011	Finland	1986	2007	0.0379	0.0208	1.8
Kallio-Nyberg et al. 2011	Finland	1986	2007	0.0379	0.0182	2.1
Peyronnet et al. 2008	Ireland	1980	2000	0.1598	0.0569	2.8
Peyronnet et al. 2008	Ireland	1980	2000	0.2089	0.0989	2.1
Peyronnet et al. 2008	Ireland	1980	2000	0.1107	0.0434	2.6
Salminen et al. 2007	Finland	1988	1999	NA	NA	NA
Saloniemi et al. 2004	Finland	1991	1993	0.1290	0.1095	1.2

*Reported wild:hatchery survival ratio was different than calculated value from wild and hatchery survival rates. Reported ratio was used instead of calculated value.

Table 3.10.1. Homing rates and straying patterns by production unit (PU) for the DIA Model, based on an assessment of previous behavioral studies, fishway trap data, Expert Panel recommendations, and local knowledge. The Natal PU (rows) identifies where a fish was reared and the Final Destination PU (columns) identifies where a fish will attempt to migrate. Homing rates are bolded and listed in the diagonal row. Grey cells indicate no straying from that Natal PU into the Final Destination PU.

	Final Destination PU														
Natal PU	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**0.900**	0.080	0.009	0.005	0	0	0	0	0.005	0	0	0	0	0	0.001
2	0.070	**0.900**	0.009	0.010	0	0	0	0	0.010	0	0	0	0	0	0.001
3	0	0.010	**0.900**	0.050	0.010	0.010	0	0	0.010	0	0	0	0	0	0.010
4	0	0	0.010	**0.900**	0.001	0.049	0.020	0.020	0	0	0	0	0	0	0
5	0	0	0	0.010	**0.900**	0.080	0.004	0.004	0.002	0	0	0	0	0	0
6	0	0	0	0.080	0.01	**0.900**	0.005	0.005	0	0	0	0	0	0	0
7	0	0	0	0.020	0	0	**0.900**	0.080	0	0	0	0	0	0	0
8	0	0	0	0.020	0	0	0.080	**0.900**	0	0	0	0	0	0	0
9	0	0.010	0.040	0.080	0	0	0	0	**0.700**	0.050	0.010	0.010	0	0	0.100
10	0.020	0.020	0.060	0.060	0	0	0	0	0.100	**0.700**	0.010	0.010	0.010	0	0.010
11	0.010	0.020	0.040	0.020	0	0	0	0	0.100	0.050	**0.700**	0.020	0.020	0.010	0.010
12	0	0	0.020	0.020	0	0	0	0	0.200	0.020	0.020	**0.700**	0.010	0.010	0
13	0	0	0.040	0.020	0	0	0	0	0.030	0	0	0	**0.900**	0.010	0
14	0	0	0.030	0.060	0	0	0	0	0.080	0.020	0.010	0.100	0	**0.700**	0
15	0	0.010	0.010	0	0	0	0	0	0.060	0.010	0.010	0	0	0	**0.900**

Table 3.11.1.1. Upstream passage for 15 hydroelectric dams included in the DIA Model, including the mean, standard deviation, minimum, and maximum values.

Hydroelectric Dam	Mean	Standard Deviation	Minimum	Maximum
Medway	0	0	0	0
Mattaceunk	0.9200	0.0325	0.8875	0.9525
West Enfield	0.9200	0.0325	0.8875	0.9525
Dover Upper	0.9200	0.0325	0.8875	0.9525
Brown's Mills	0.9200	0.0325	0.8875	0.9525
Sebec	0	0	0	0
Milo	0	0	0	0
Howland	0.9200	0.0325	0.8875	0.9525
Lowell	0.9200	0.0325	0.8875	0.9525
Milford	0.8993	0.0958	0.6670	1.0000
Stillwater	0.9200	0.0325	0.8875	0.9525
Great Works	0.6730	0.2783	0.1190	0.9440
Orono	0	0	0	0
Veazie	0.6485	0.1907	0.4210	0.9840
Frankfort	0.9200	0.0325	0.8875	0.9525

Table 3.12.1. Details regarding the fate of adult spawners that do not successful migrate above each of the 15 hydroelectric facilities modeled within the DIA Model. Unsuccessful fish will: 1) die, 2) return to the sea and not spawn or 3) will be redirected to a downstream PU according to the proportions detailed under the Destination PU.

				Destination PU														
Dam Failed to Pass	Proportion that Die	Proportion Returning to Sea	Proportion Remaining Downstream	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Medway	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Mattaceunk	0.01	0	0.99	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
West Enfield	0.02	0	0.98	0	0	0	0.6	0	0	0	0	0.4	0	0	0	0	0	0
Dover Upper	0.02	0	0.98	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Brown's Mills	0.02	0	0.98	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Sebec	0	0	1	0	0	0	0.1	0	0	0.9	0	0	0	0	0	0	0	0
Milo	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Howland	0.02	0	0.98	0	0	0.4	0	0	0	0	0	0.6	0	0	0	0	0	0
Lowell	0.01	0	0.99	0	0	0.01	0.01	0	0	0	0	0.98	0	0	0	0	0	0
Milford	0.01	0	0.99	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0.2	0
Stillwater	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Great Works	0.02	0.10	0.88	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0.2	0
Orono	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Veazie	0.03	0.15	0.82	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.9	0
Frankfort	0.02	0.10	0.88	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0.9	0

Table 3.12.2. Justification used for determining the percentages of Atlantic salmon adult spawners that die or return to sea and do not spawn for each of the 15 hydroelectric facilities modeled within the DIA Model. The percentages are applied to fish that do not successfully pass each facility. The remaining fish are redirected to a downstream PU to spawn.

Dam	Total Dead (%)	Justification	Total out to Sea (%)	Justification
Medway	0	no passage	0	
Mattaceunk	1	baseline	0	
West Enfield	2	baseline, high percentage of fall back	0	
Dover Upper	2	baseline, poaching	0	
Brown's Mills	2	baseline, stalling, and lack of thermal refugia	0	
Sebec	0	no passage	0	
Milo	0	no passage	0	
Howland	2	baseline, high percentage of fall back	0	
Lowell	1	baseline	0	
Stillwater	0	no passage	0	
Milford	1	baseline	0	
Great Works	2	baseline, stalling, and lack of thermal refugia	10	proximity to ocean
Orono	0	no passage	0	
Veazie	3	baseline, seal predation, handling	15	proximity to ocean, handling
Frankfort	2	baseline, seal predation	10	proximity to ocean

Table 4.1.1. Twenty-fifth percentile, median, and seventy-fifth percentile of the number of 2SW females across all PUs in generations 1–10 for the base case, future Federal actions, and proposed actions scenarios.

	Base Case			Future Federal Actions			Proposed Actions		
	25%	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**
generation 1	587	587	587	587	587	587	587	587	587
generation 2	82	225	553	134	373	816	145	402	887
generation 3	82	218	540	122	363	839	144	408	913
generation 4	83	218	555	128	370	841	142	408	936
generation 5	83	219	543	122	375	865	145	409	931
generation 6	82	219	544	122	386	830	143	413	942
generation 7	80	218	566	122	371	858	147	407	934
generation 8	84	214	545	126	378	843	143	418	932
generation 9	84	214	542	124	371	843	145	409	926
generation 10	83	207	556	123	371	854	148	411	910

Table 4.1.2. Proportion of iterations when at least one 2SW female was present in three areas of the Penobscot River watershed: above West Enfield Dam (i.e., PUs 1–3), in the Piscataquis River watershed (i.e., PUs 4–8), and below West Enfield Dam (i.e., PUs 9–15). Values are listed for generations 1–10 for the base case, future Federal actions, and proposed actions scenarios.

	Base Case			Future Federal Actions			Proposed Actions		
	above W. Enfield	Piscataquis	below W. Enfield	above W. Enfield	Piscataquis	below W. Enfield	above W. Enfield	Piscataquis	below W. Enfield
generation 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 2	0.68	0.68	1.00	0.91	0.91	1.00	0.92	0.92	1.00
generation 3	0.64	0.65	1.00	0.90	0.90	1.00	0.92	0.92	1.00
generation 4	0.64	0.65	1.00	0.90	0.91	1.00	0.92	0.92	1.00
generation 5	0.63	0.64	1.00	0.90	0.90	1.00	0.92	0.92	1.00
generation 6	0.64	0.65	1.00	0.90	0.90	1.00	0.92	0.92	1.00
generation 7	0.64	0.64	1.00	0.91	0.91	1.00	0.92	0.92	1.00
generation 8	0.63	0.64	1.00	0.90	0.91	1.00	0.92	0.92	1.00
generation 9	0.64	0.65	1.00	0.91	0.91	1.00	0.92	0.92	1.00
generation 10	0.64	0.64	1.00	0.90	0.90	1.00	0.92	0.92	1.00

Table 4.1.3. Twenty-fifth percentile, median, and seventy-fifth percentile of the number of smolts killed during downstream dam passage across all 15 hydroelectric dam. Values are listed for generations 1–10 for the base case, future Federal actions, and proposed actions scenarios.

	Base Case			Future Federal Actions			Proposed Actions		
	25%	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**
generation 1	165,316	178,595	195,776	58,673	61,347	64,821	29,359	31,036	33,129
generation 2	152,262	164,152	181,001	53,106	55,425	60,460	25,581	26,925	29,710
generation 3	151,714	163,093	179,958	53,009	55,282	60,366	25,525	26,733	29,168
generation 4	152,297	163,764	179,605	53,013	55,247	60,216	25,440	26,690	29,297
generation 5	151,054	162,613	178,929	53,015	55,302	60,312	25,431	26,712	29,249
generation 6	152,037	163,105	180,543	52,983	55,313	60,232	25,489	26,756	29,238
generation 7	151,824	163,277	179,110	53,040	55,209	60,111	25,460	26,735	29,288
generation 8	152,027	163,276	180,214	53,027	55,260	60,126	25,446	26,758	29,253
generation 9	151,997	163,599	180,527	53,022	55,303	60,141	25,477	26,768	29,301
generation 10	152,151	163,643	179,710	52,989	55,328	60,381	25,466	26,720	29,166

Table 4.1.4. Twenty-fifth percentile, median, and seventy-fifth percentile of the proportion of smolts killed during downstream dam passage across all 15 hydroelectric dams. Values are listed for generations 1–10 for the base case, future Federal actions, and proposed actions scenarios.

	Base Case			Future Federal Actions			Proposed Actions		
	25%	median	75%	25%	median	75%	25%	median	75%
generation 1	0.10	0.11	0.12	0.03	0.03	0.04	0.02	0.02	0.02
generation 2	0.10	0.11	0.12	0.03	0.03	0.03	0.01	0.02	0.02
generation 3	0.10	0.11	0.12	0.03	0.03	0.03	0.01	0.02	0.02
generation 4	0.10	0.11	0.12	0.03	0.03	0.03	0.01	0.02	0.02
generation 5	0.10	0.10	0.12	0.03	0.03	0.03	0.01	0.02	0.02
generation 6	0.10	0.11	0.12	0.03	0.03	0.03	0.01	0.02	0.02
generation 7	0.10	0.11	0.12	0.03	0.03	0.03	0.01	0.02	0.02
generation 8	0.10	0.11	0.12	0.03	0.03	0.03	0.01	0.02	0.02
generation 9	0.10	0.11	0.12	0.03	0.03	0.03	0.01	0.02	0.02
generation 10	0.10	0.11	0.12	0.03	0.03	0.03	0.01	0.02	0.02

Table 4.2.1. Twenty-fifth percentile, median, and seventy-fifth percentile of the number of 2SW females across all PUs in generations 1–10 for recovery runs 1a, 2a, 3a, and 4a.

	Recovery - Run 1a			Recovery - Run 2a			Recovery - Run 3a			Recovery - Run 4a		
	25%	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**
generation 1	587	587	587	587	587	587	587	587	587	587	587	587
generation 2	277	517	996	377	710	1,349	407	766	1,467	435	807	1,567
generation 3	269	645	1,479	378	930	2,249	412	1,045	2,594	484	1,120	2,798
generation 4	295	814	2,025	421	1,195	3,472	489	1,414	4,327	576	1,613	4,907
generation 5	334	980	2,396	464	1,597	4,709	561	1,908	6,157	695	2,396	7,134
generation 6	390	1,144	2,668	554	1,953	5,952	698	2,569	7,777	862	3,239	9,735
generation 7	427	1,253	2,836	623	2,338	7,174	837	3,256	9,485	1,078	4,230	11,605
generation 8	472	1,303	3,028	735	2,651	7,798	1,015	3,929	10,396	1,335	5,076	12,905
generation 9	508	1,360	3,017	812	3,079	8,376	1,228	4,280	11,356	1,608	5,796	14,323
generation 10	529	1,378	3,089	906	3,373	9,126	1,353	4,755	12,083	1,905	6,425	14,986

Table 4.2.2. Proportion of iterations when at least one 2SW female was present in three areas of the Penobscot River watershed: above West Enfield Dam (i.e., PUs 1–3), in the Piscataquis River watershed (i.e., PUs 4–8), and below West Enfield Dam (i.e., PUs 9–15). Values are listed for generations 1–10 for recovery runs 1a, 2a, 3a, and 4a.

	Recovery - Run 1a			Recovery - Run 2a			Recovery - Run 3a			Recovery - Run 4a		
	above W. Enfield	Piscat-aquis	below W. Enfield	above W. Enfield	Piscat-aquis	below W. Enfield	above W. Enfield	Piscat-aquis	below W. Enfield	above W. Enfield	Piscat-aquis	below W. Enfield
generation 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 4	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 5	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 6	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 7	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 8	0.97	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 9	0.97	0.98	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 10	0.97	0.98	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4.2.3. Twenty-fifth percentile, median, and seventy-fifth percentile of the number of smolts killed during downstream dam passage across all 15 hydroelectric dams. Values are listed for generations 1–10 for recovery runs 1a, 2a, 3a, and 4a.

	Recovery - Run 1a			Recovery - Run 2a			Recovery - Run 3a			Recovery - Run 4a		
	25%	median	75%	25%	median	75%	25%	median	75%	25%	median	75%
generation 1	26,450	36,204	48,728	13,571	18,496	24,703	9,125	12,402	16,545	4,876	6,737	9,396
generation 2	6,758	13,975	28,088	8,785	17,751	36,256	6,499	13,389	26,609	3,697	7,451	15,343
generation 3	3,590	9,438	22,000	7,330	18,630	49,288	6,072	15,218	38,978	3,441	8,618	22,495
generation 4	3,145	8,977	22,274	7,026	21,603	66,333	5,900	18,004	56,325	3,510	10,537	33,202
generation 5	3,219	9,884	24,488	7,142	26,058	88,432	6,469	22,448	76,779	3,950	13,341	42,457
generation 6	3,525	11,328	26,505	8,017	30,490	106,304	7,477	29,721	88,949	4,351	16,319	54,931
generation 7	3,949	12,360	27,841	8,859	35,895	120,405	8,718	36,140	104,739	5,217	20,778	66,681
generation 8	4,199	13,057	28,393	10,029	41,821	126,303	10,164	42,408	115,771	6,137	25,572	77,117
generation 9	4,578	13,733	29,412	11,070	50,408	132,049	11,883	48,984	121,289	7,178	29,031	86,019
generation 10	4,742	13,780	30,659	12,432	54,640	141,321	13,881	54,903	131,241	8,459	33,562	89,608

Table 4.2.4. Twenty-fifth percentile, median, and seventy-fifth percentile of the proportion of smolts killed during downstream dam passage across all 15 hydroelectric dams. Values are listed for generations 1–10 for recovery runs 1a, 2a, 3a, and 4a.

	Recovery - Run 1a			Recovery - Run 2a			Recovery - Run 3a			Recovery - Run 4a		
	25%	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**
generation 1	0.10	0.11	0.12	0.05	0.05	0.06	0.03	0.04	0.04	0.02	0.02	0.02
generation 2	0.10	0.11	0.12	0.04	0.05	0.05	0.03	0.03	0.03	0.01	0.02	0.02
generation 3	0.10	0.10	0.11	0.04	0.04	0.04	0.03	0.03	0.03	0.01	0.01	0.01
generation 4	0.10	0.10	0.11	0.04	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.01
generation 5	0.10	0.10	0.11	0.04	0.04	0.04	0.02	0.02	0.02	0.01	0.01	0.01
generation 6	0.10	0.10	0.11	0.03	0.04	0.04	0.02	0.02	0.02	0.01	0.01	0.01
generation 7	0.10	0.10	0.11	0.03	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.01
generation 8	0.09	0.10	0.11	0.03	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.01
generation 9	0.09	0.10	0.11	0.03	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.01
generation 10	0.09	0.10	0.11	0.03	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.01

Table 4.2.5. Twenty-fifth percentile, median, and seventy-fifth percentile of the number of 2SW females across all PUs in generations 1–10 for recovery runs 1b, 2b, 3b, and 4b.

	Recovery - Run 1b			Recovery - Run 2b			Recovery - Run 3b			Recovery - Run 4b		
	25%	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**
generation 1	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
generation 2	470	890	1,685	642	1,240	2,347	706	1,318	2,462	733	1,415	2,645
generation 3	442	1,055	2,366	644	1,586	3,858	709	1,748	4,451	826	2,007	4,810
generation 4	497	1,245	2,777	705	2,015	5,516	826	2,402	6,577	950	2,833	7,868
generation 5	533	1,372	2,999	766	2,496	7,048	995	3,164	8,789	1,177	4,008	10,592
generation 6	570	1,404	3,109	885	2,799	8,069	1,148	3,912	10,391	1,473	4,950	12,924
generation 7	594	1,474	3,151	1,016	3,329	8,556	1,325	4,527	11,380	1,796	5,697	14,024
generation 8	609	1,499	3,224	1,098	3,597	9,411	1,506	5,076	12,378	2,071	6,402	14,750
generation 9	615	1,520	3,310	1,236	3,922	9,516	1,652	5,460	12,997	2,441	7,060	16,058
generation 10	631	1,556	3,262	1,296	4,071	9,811	1,817	5,645	13,391	2,694	7,265	16,663

Table 4.2.6. Proportion of iterations when at least one 2SW female was present in three areas of the Penobscot River watershed: above West Enfield Dam (i.e., PUs 1–3), in the Piscataquis River watershed (i.e., PUs 4–8), and below West Enfield Dam (i.e., PUs 9–15). Values are listed for generations 1–10 for recovery runs 1b, 2b, 3b, and 4b.

	Recovery - Run 1b			Recovery - Run 2b			Recovery - Run 3b			Recovery - Run 4b		
	above W. Enfield	Piscat-aquis	below W. Enfield	above W. Enfield	Piscat-aquis	below W. Enfield	above W. Enfield	Piscat-aquis	below W. Enfield	above W. Enfield	Piscat-aquis	below W. Enfield
generation 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 4	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 5	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 6	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 7	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 8	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 9	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 10	0.98	0.99	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 4.2.7. Twenty-fifth percentile, median, and seventy-fifth percentile of the number of smolts killed during downstream dam passage across all 15 hydroelectric dams. Values are listed for generations 1–10 for recovery runs 1b, 2b, 3b, and 4b.

	Recovery - Run 1b			Recovery - Run 2b			Recovery - Run 3b			Recovery - Run 4b		
	25%	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**
generation 1	45,064	61,398	82,288	22,995	31,306	42,029	15,652	21,245	28,443	8,271	11,589	15,963
generation 2	11,126	23,289	48,014	14,803	30,789	62,784	11,262	22,178	45,844	6,219	12,900	25,844
generation 3	6,022	14,740	34,547	12,653	32,337	84,804	10,248	25,546	65,851	5,943	14,959	38,663
generation 4	5,132	13,723	29,857	11,636	37,421	106,981	10,165	30,396	89,123	5,835	18,557	50,948
generation 5	4,982	13,698	29,875	12,026	42,248	130,797	11,218	37,393	107,332	6,683	22,581	65,274
generation 6	5,166	13,989	30,841	12,758	47,729	139,079	12,162	45,276	120,987	7,506	25,873	79,210
generation 7	5,442	14,804	30,867	14,580	54,005	141,667	13,523	52,438	128,283	8,437	29,596	87,513
generation 8	5,604	14,845	32,014	15,987	58,515	148,278	15,757	58,184	137,598	10,032	34,137	92,475
generation 9	5,672	15,394	32,192	17,403	64,974	154,271	16,772	62,107	143,457	11,025	37,795	95,348
generation 10	5,984	15,550	32,307	18,976	67,420	155,787	19,346	64,722	145,808	12,576	39,620	99,028

Table 4.2.8. Twenty-fifth percentile, median, and seventy-fifth percentile of the proportion of smolts killed during downstream dam passage across all 15 hydroelectric dams. Values are listed for generations 1–10 for recovery runs 1b, 2b, 3b, and 4b.

	Recovery - Run 1b			Recovery - Run 2b			Recovery - Run 3b			Recovery - Run 4b		
	25%	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**
generation 1	0.10	0.11	0.12	0.05	0.05	0.06	0.03	0.04	0.04	0.02	0.02	0.02
generation 2	0.10	0.11	0.12	0.05	0.05	0.05	0.03	0.03	0.03	0.01	0.02	0.02
generation 3	0.10	0.10	0.11	0.04	0.04	0.04	0.03	0.03	0.03	0.01	0.01	0.01
generation 4	0.10	0.10	0.11	0.04	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.01
generation 5	0.10	0.10	0.11	0.04	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.01
generation 6	0.10	0.10	0.11	0.04	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.01
generation 7	0.10	0.10	0.11	0.03	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.01
generation 8	0.10	0.10	0.11	0.03	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.01
generation 9	0.10	0.10	0.11	0.03	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.02
generation 10	0.10	0.10	0.11	0.03	0.04	0.04	0.02	0.02	0.03	0.01	0.01	0.02

Table 4.3.1. Twenty-fifth percentile, median, and seventy-fifth percentile of the number of 2SW females across all PUs in generations 1–10 for the latent mortality 1, 5, and 10% scenarios.

	Latent Mortality - 0.01			Latent Mortality - 0.05			Latent Mortality - 0.1		
	25%	median	75%	25%	median	75%	25%	median	75%
generation 1	587	587	587	587	587	587	587	587	587
generation 2	79	212	536	64	166	441	51	124	341
generation 3	79	201	524	64	165	438	50	120	330
generation 4	78	211	524	66	167	438	51	120	325
generation 5	77	210	526	65	165	443	52	120	331
generation 6	78	211	526	66	166	437	50	119	324
generation 7	79	204	525	64	168	434	50	121	324
generation 8	82	208	520	66	162	428	50	119	329
generation 9	80	208	519	64	165	437	51	122	339
generation 10	77	207	528	66	165	433	51	119	341

Table 4.3.2. Proportion of iterations when at least one 2SW female was present in three areas of the Penobscot River watershed: above West Enfield Dam (i.e., PUs 1–3), in the Piscataquis River watershed (i.e., PUs 4–8), and below West Enfield Dam (i.e., PUs 9–15). Values are listed for generations 1–10 for the latent mortality 1, 5, and 10% scenarios.

	Latent Mortality - 0.01			Latent Mortality - 0.05			Latent Mortality - 0.1		
	above W. Enfield	Piscataquis	below W. Enfield	above W. Enfield	Piscataquis	below W. Enfield	above W. Enfield	Piscataquis	below W. Enfield
generation 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
generation 2	0.66	0.67	1.00	0.60	0.61	1.00	0.51	0.52	1.00
generation 3	0.62	0.63	1.00	0.57	0.57	1.00	0.48	0.49	1.00
generation 4	0.63	0.63	1.00	0.57	0.58	1.00	0.48	0.49	1.00
generation 5	0.63	0.64	1.00	0.56	0.57	1.00	0.47	0.48	1.00
generation 6	0.63	0.64	1.00	0.57	0.58	1.00	0.48	0.49	1.00
generation 7	0.62	0.63	1.00	0.57	0.58	1.00	0.48	0.49	1.00
generation 8	0.63	0.63	1.00	0.57	0.58	1.00	0.48	0.48	1.00
generation 9	0.62	0.63	1.00	0.57	0.58	1.00	0.48	0.49	1.00
generation 10	0.62	0.63	1.00	0.57	0.58	1.00	0.48	0.49	1.00

Table 4.3.3. Twenty-fifth percentile, median, and seventy-fifth percentile of the number of smolts killed by dams due to latent mortality across all 15 hydroelectric dams. Values are listed for generations 1–10 for the latent mortality 1, 5, and 10% scenarios.

	Latent Mortality - 0.01			Latent Mortality - 0.05			Latent Mortality - 0.1		
	25%	**median**	**75%**	**25%**	**median**	**75%**	**25%**	**median**	**75%**
generation 1	11,776	12,413	12,964	58,707	61,842	64,668	117,584	123,688	129,302
generation 2	10,936	11,471	11,909	54,379	57,182	59,303	108,508	113,744	117,855
generation 3	10,916	11,467	11,886	54,496	57,061	59,254	108,475	113,748	117,892
generation 4	10,931	11,469	11,884	54,391	57,099	59,188	108,507	113,947	117,821
generation 5	10,905	11,446	11,864	54,439	57,116	59,208	108,169	113,778	117,768
generation 6	10,927	11,464	11,899	54,286	57,051	59,094	108,830	113,981	117,817
generation 7	10,907	11,446	11,887	54,285	57,066	59,099	108,179	113,632	117,622
generation 8	10,933	11,461	11,895	54,279	57,054	59,108	108,596	113,821	117,681
generation 9	10,907	11,447	11,873	54,448	57,057	59,093	108,733	113,982	117,947
generation 10	10,943	11,470	11,899	54,399	57,097	59,195	108,290	113,775	117,698

6 Figures

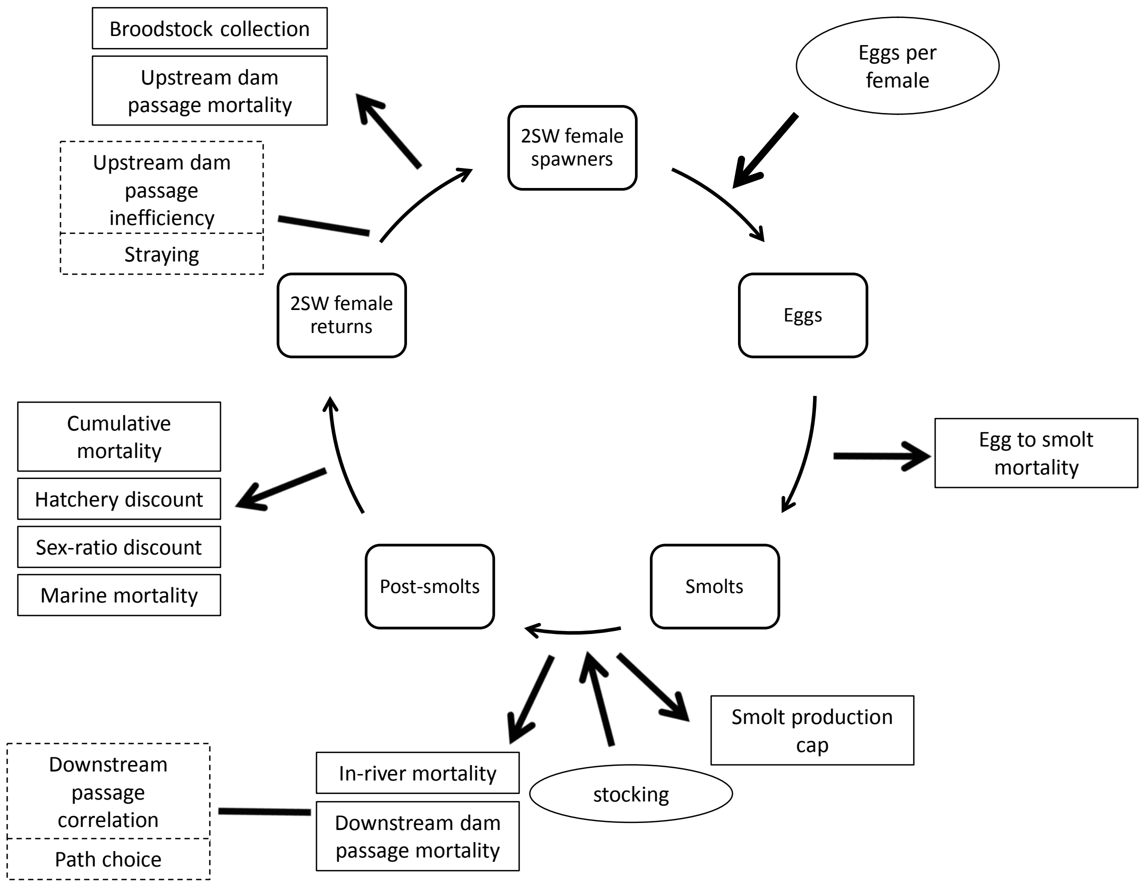


Figure 2.1. Schematic of the processes detailed within the DIA Model. Rounded rectangles indicate life cycle stages, ovals indicate additions to the population, and rectangles indicate subtractions from the population. Dashed rectangles are neither additions to nor subtractions to the population, but represent dynamics incorporated into the model. All model runs simulated ten five-year generations (50 years) and consisted of 5,000 iterations.

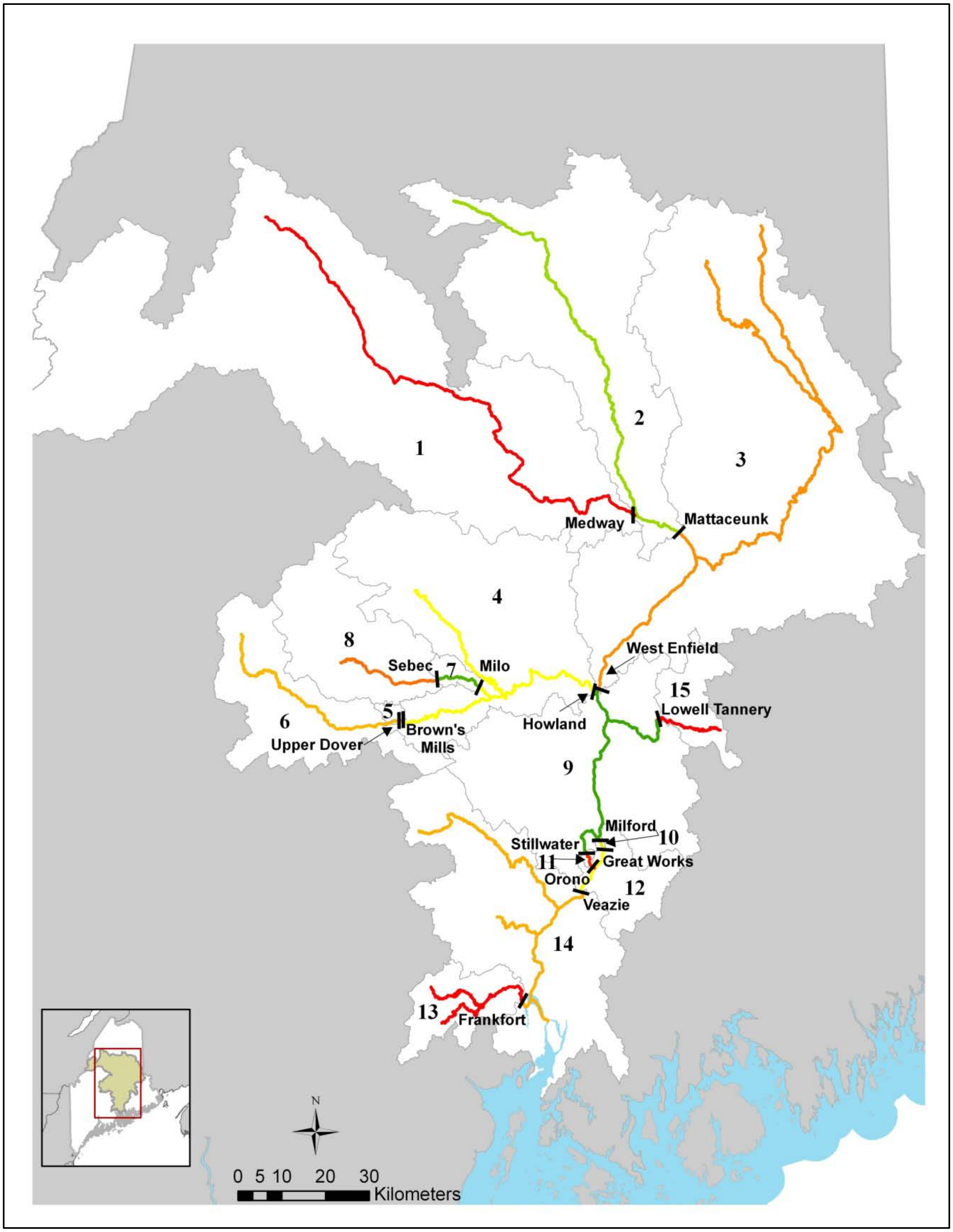


Figure 3.1.1. The Penobscot River watershed and major tributaries divided into 15 Production Units (PUs). Locations of the 15 hydroelectric dams included in the DIA Model are denoted by dashes and the name of each dam. The map inset is the Penobscot River watershed within the state of Maine.

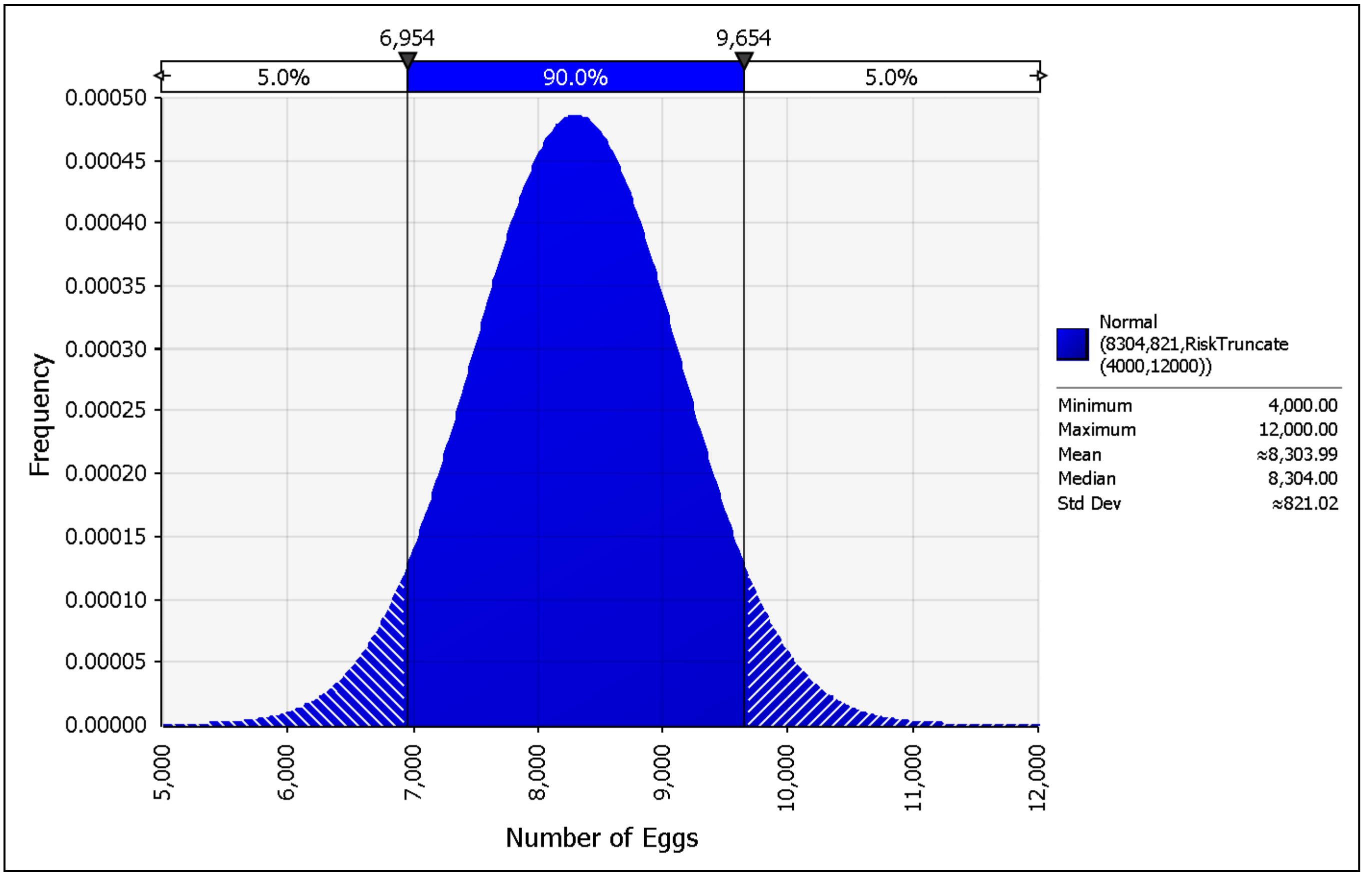


Figure 3.2.1. Simulated distribution of eggs produced per adult female Atlantic salmon generated from mean annual fecundity estimates for Penobscot River sea-run female Atlantic salmon spawned at Craig Brook National Fish Hatchery during 1997–2010.

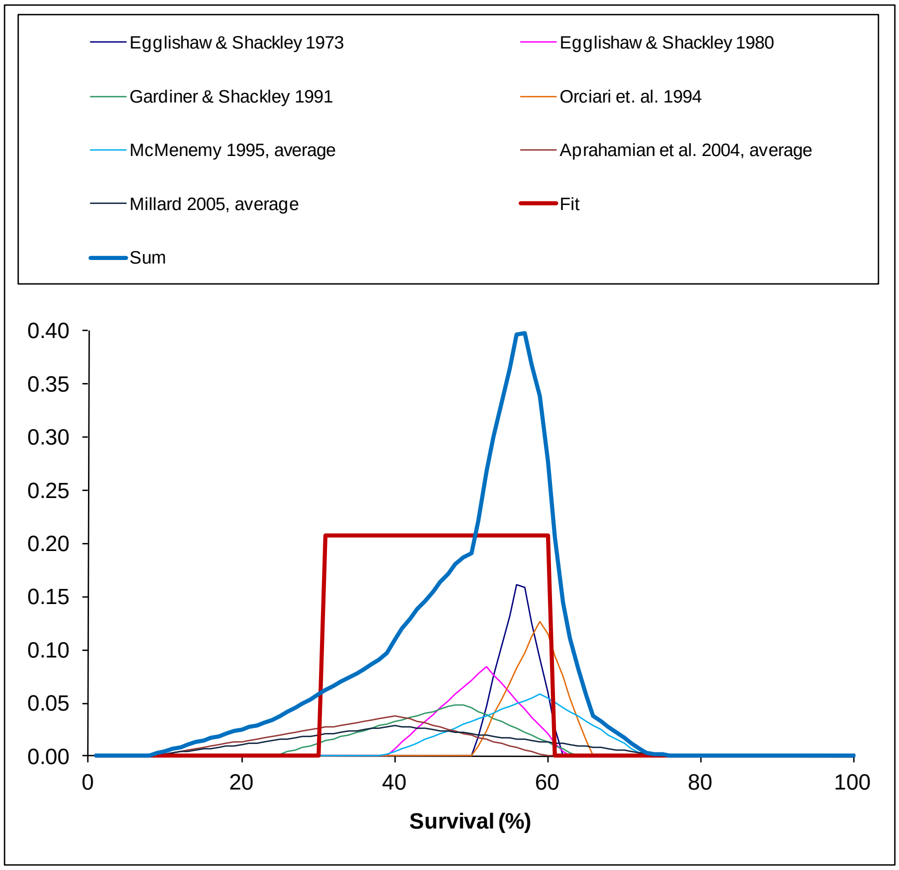


Figure 3.3.1. Fry to parr0+ survival estimates from seven studies, the calculated sum of these values, and the resulting uniform distribution (denoted Fit).

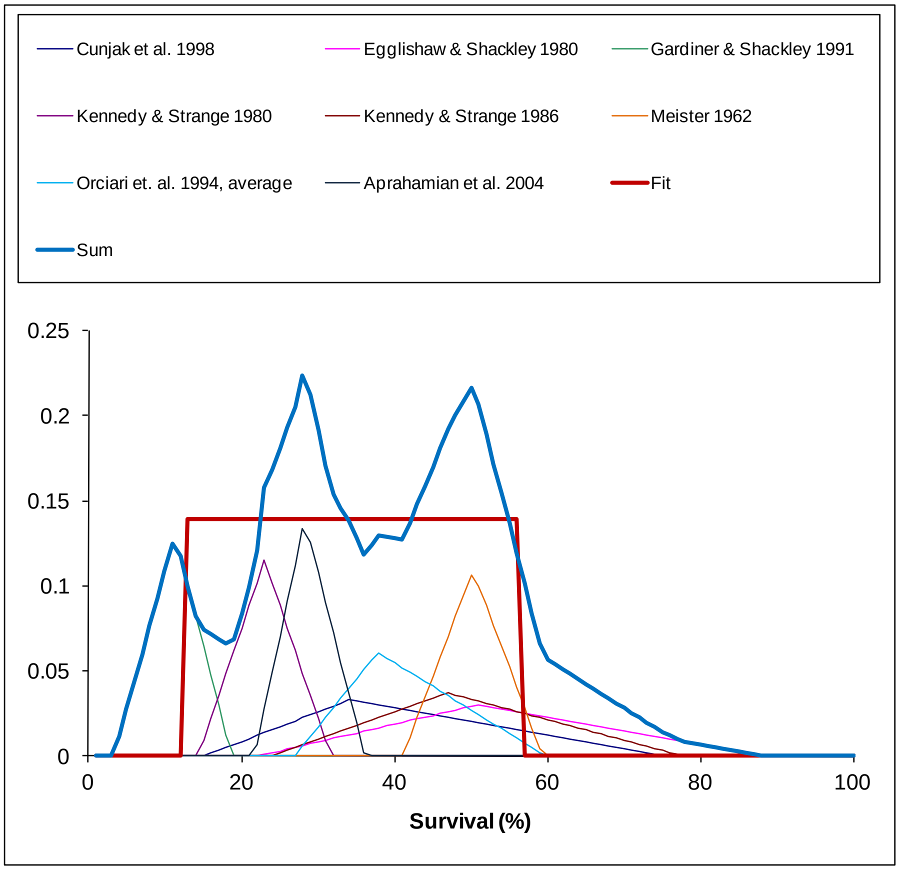


Figure 3.3.2. Parr0+ to parr1+ survival estimates from eight studies, the calculated sum of these values, and the resulting uniform distribution (denoted Fit).

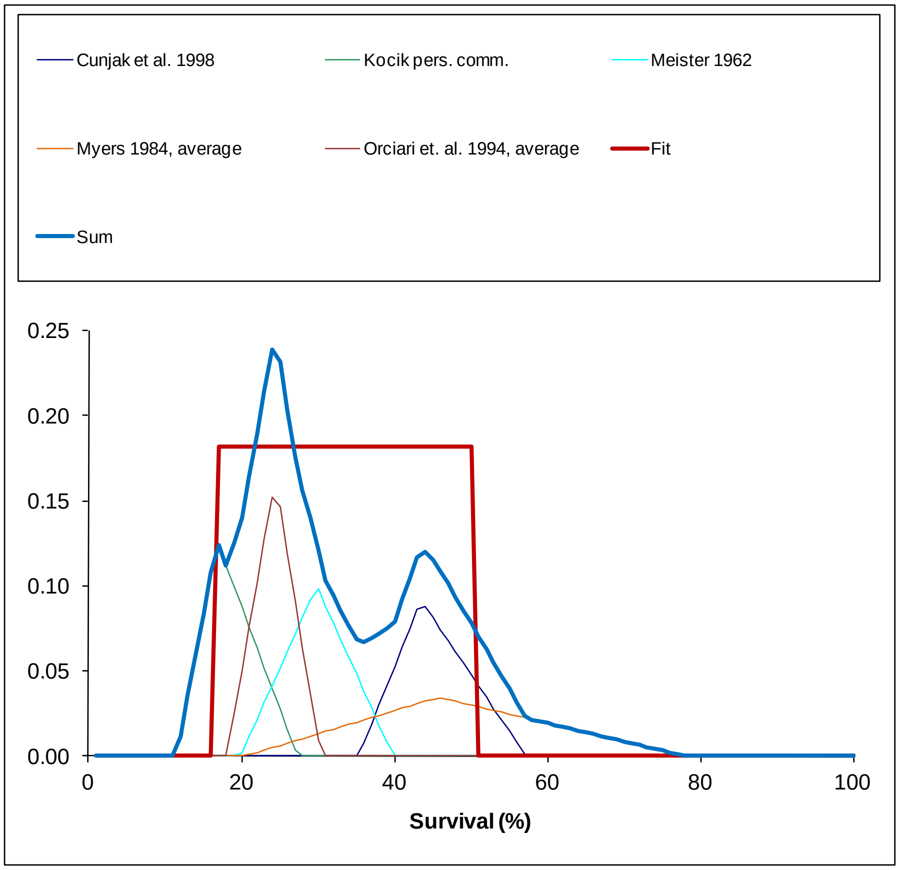


Figure 3.3.3. Parr1+ to smolt survival estimates from five studies, the calculated sum of these values, and the resulting uniform distribution (denoted Fit).

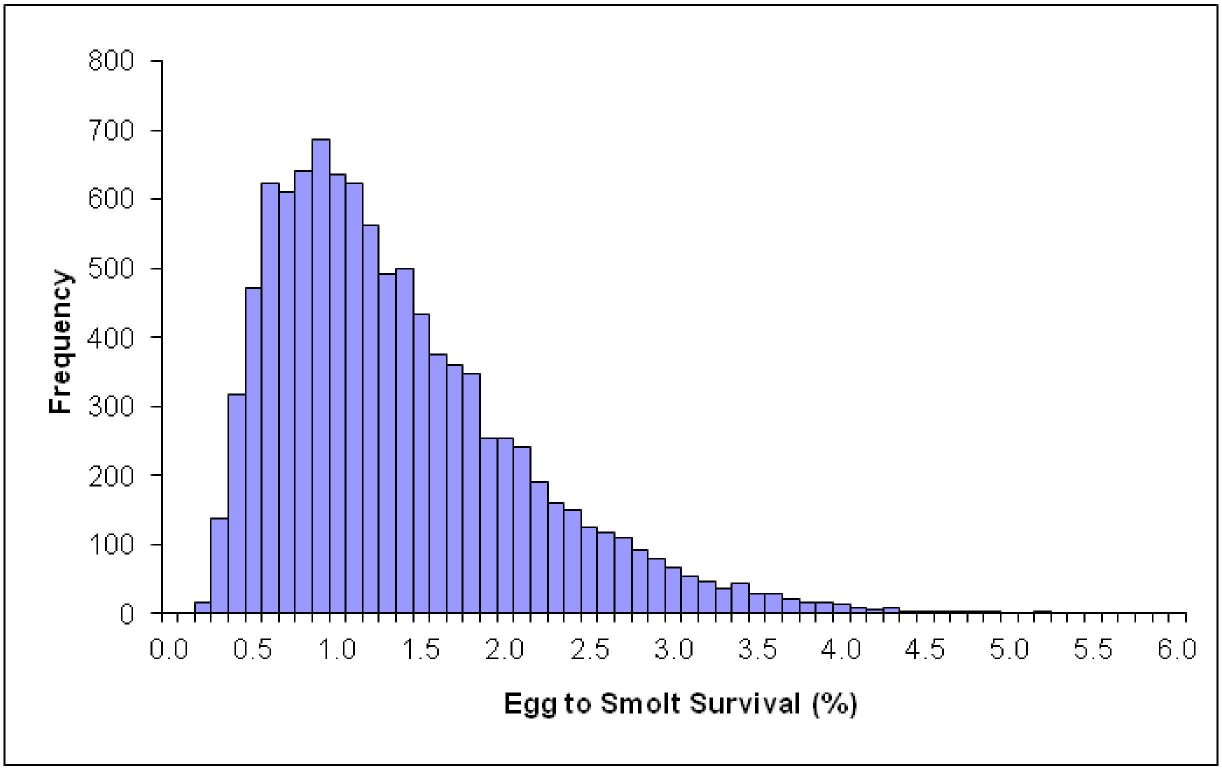


Figure 3.3.4. Histogram of 10,000 egg to smolt survival rates calculated by randomly selecting a survival value from each of the uniform distributions associated with the four juvenile life stage transitions.

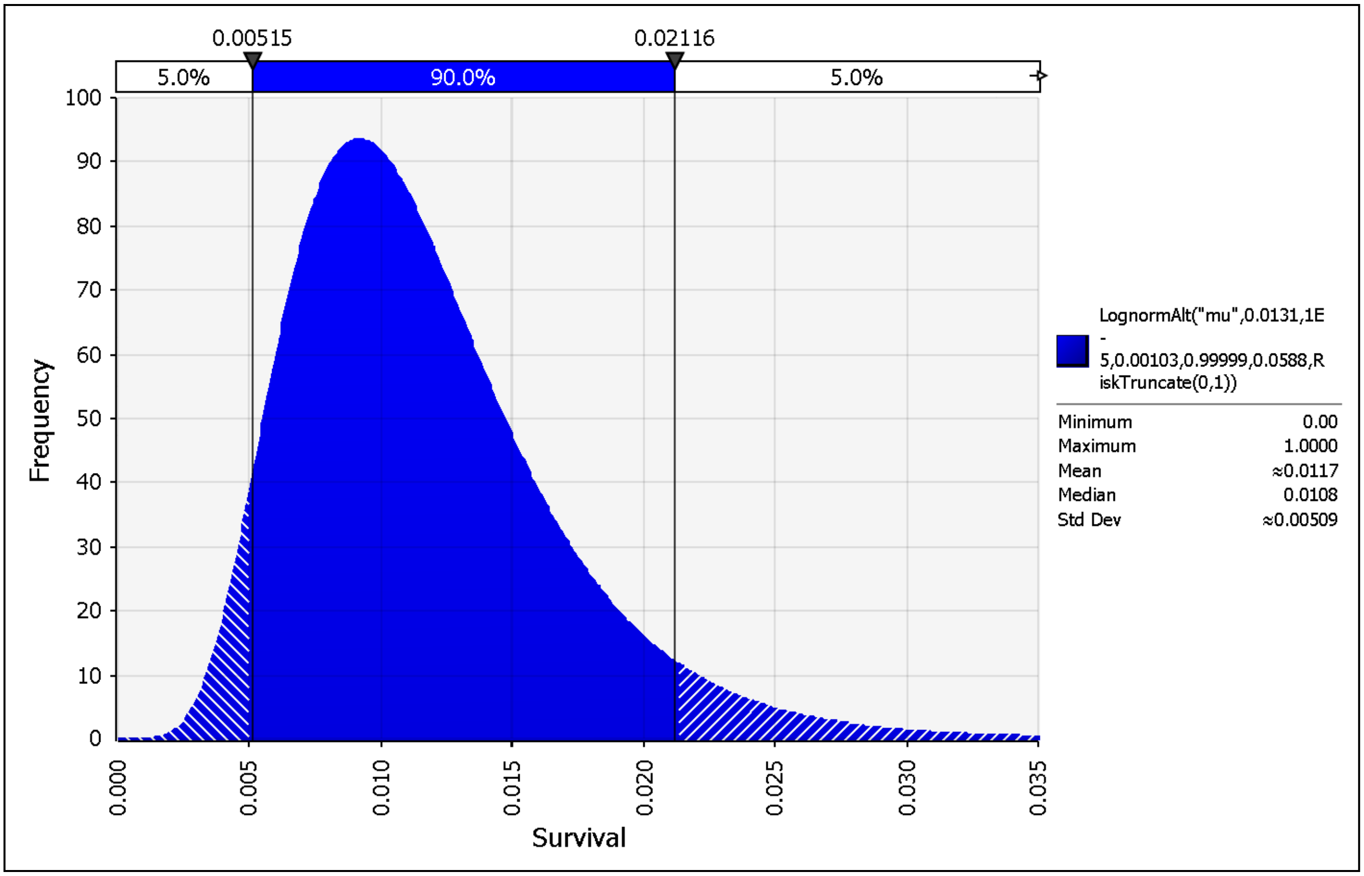


Figure 3.3.5. Fitted distribution of egg to smolt survival used in all DIA Model simulations.

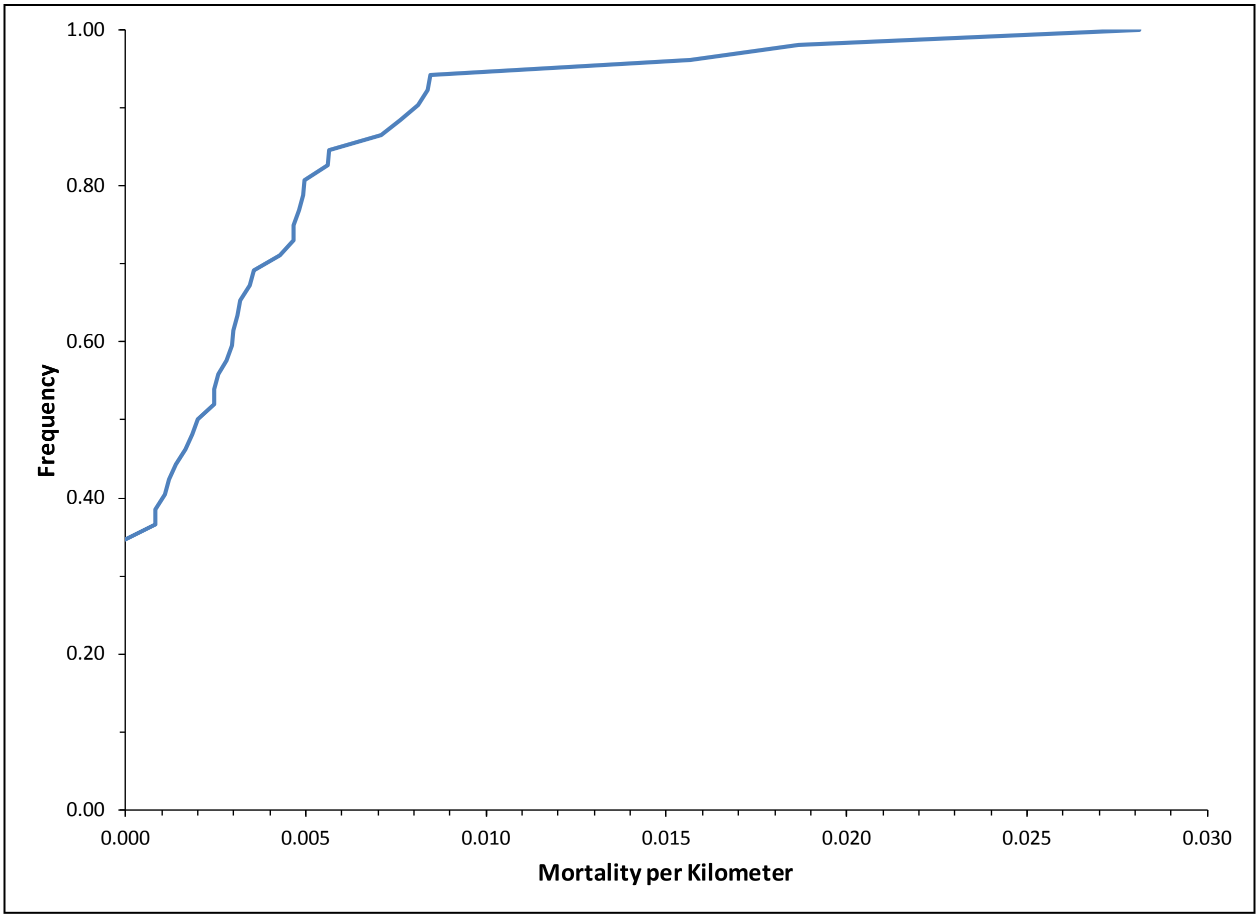


Figure 3.5.1. Cumulative frequency distribution of mortality per km for smolts migrating through the Penobscot River, generated from 53 estimates over four years of study (2005, 2006, 2009, and 2010) in the Penobscot River.

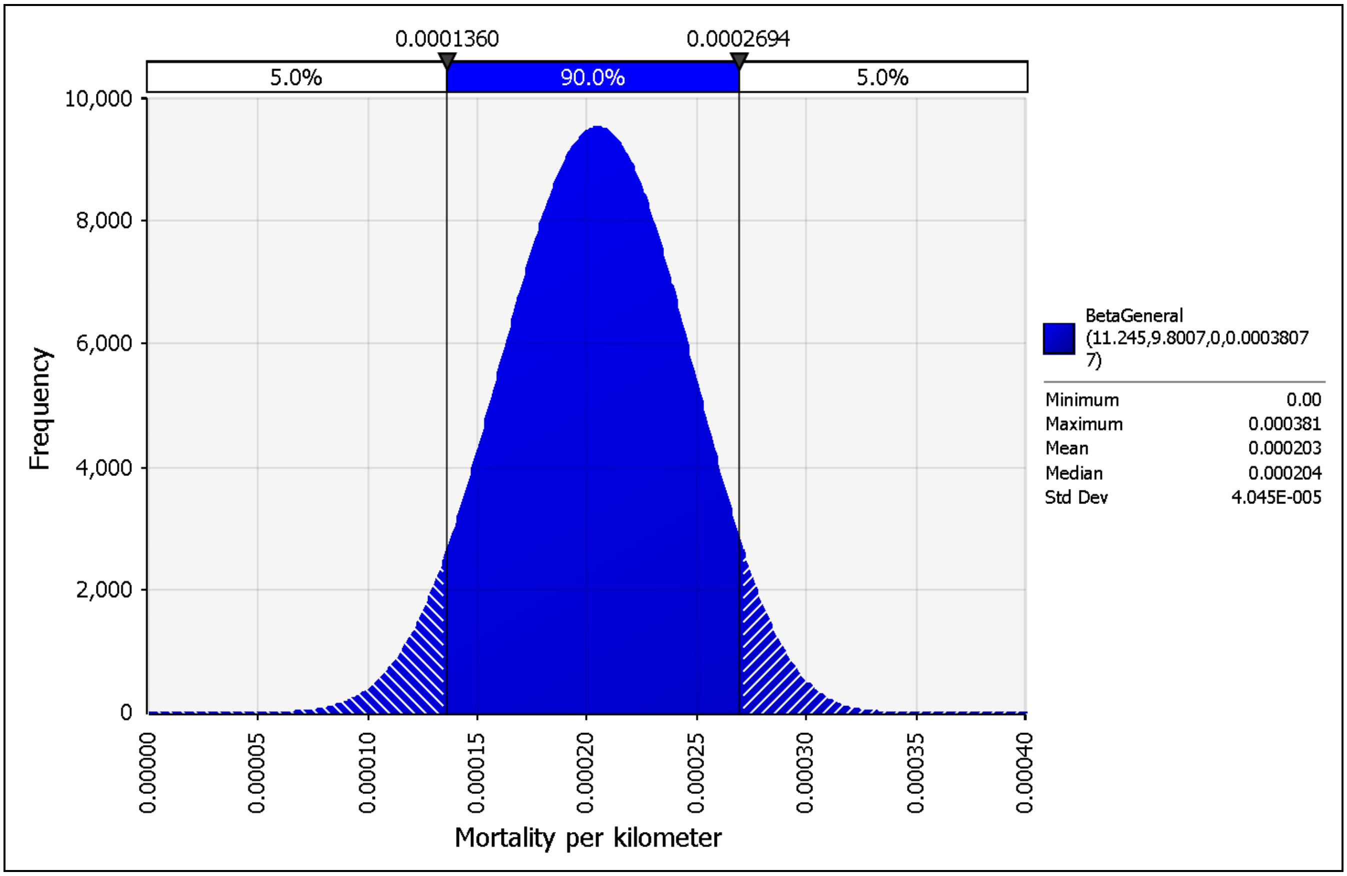


Figure 3.5.2. Simulated distribution of mortality per km for Penobscot River smolts migrating from their rearing habitat to the ocean. Mortality estimates did not include dam-related mortality and were generated through a sub-model which used random draws from a cumulative distribution made from field data gathered during telemetry studies on the Penobscot River. Estimates from the random draws were applied on a production unit- and iteration-specific level to estimate the number of smolts that would reach the ocean and to calculate an overall mortality per km estimate.

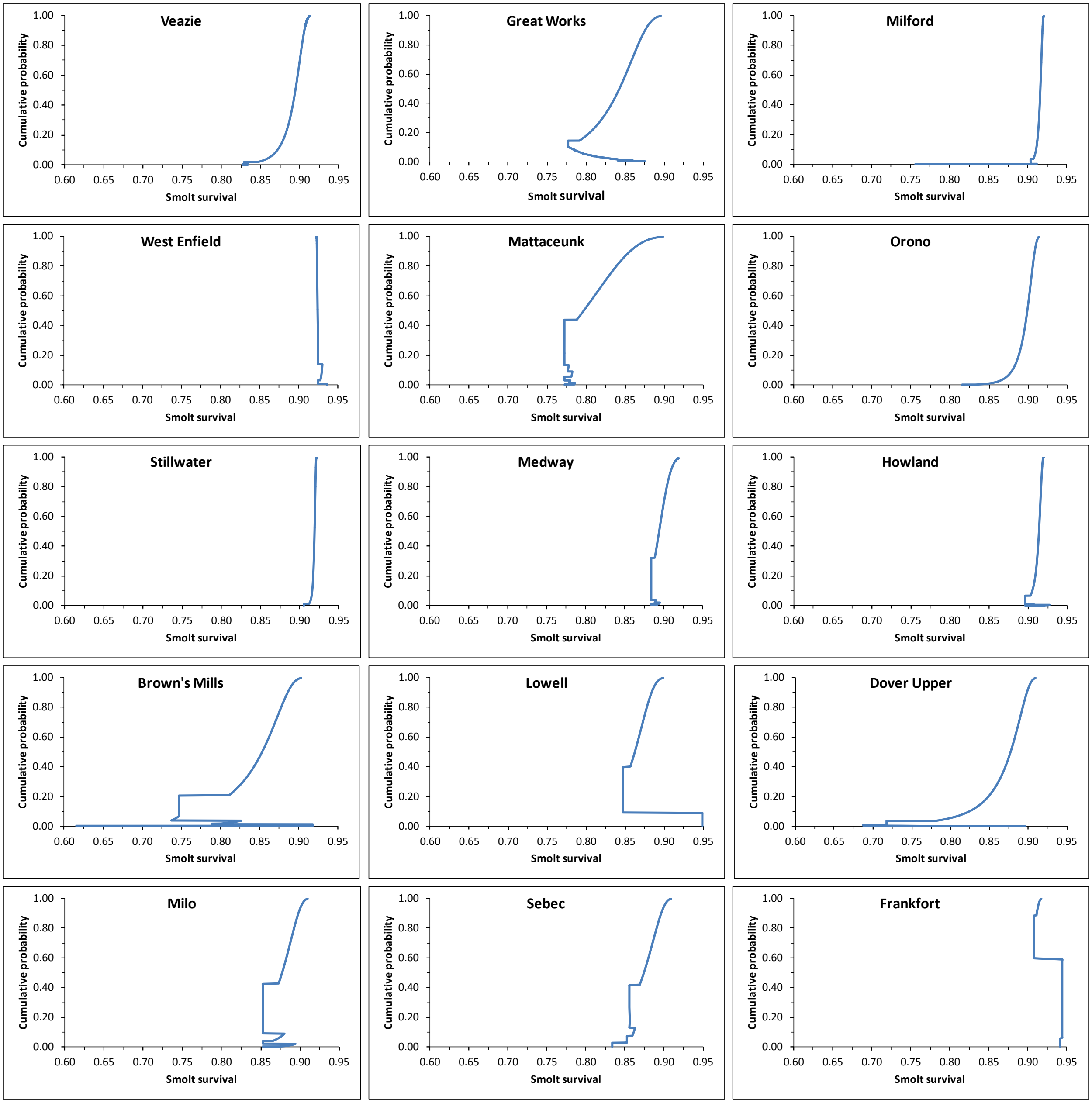


Figure 3.6.1.1. Cumulative probability of calculated total project smolt survival based on calculated smolt survival and probability of flow at five cubic feet per second (cfs) increments as provided by Alden Research Laboratory, Inc. Survival at low flows is typically variable as operational changes with increasing flows (e.g., engaging additional turbines) alter the proportion of flow passing via the turbines versus the spillway and downstream bypass and, therefore, alter the proportion of smolts passing via the turbine, where mortality and injury rates are often higher than alternative passage routes. Note the common x-axis for all graphs.

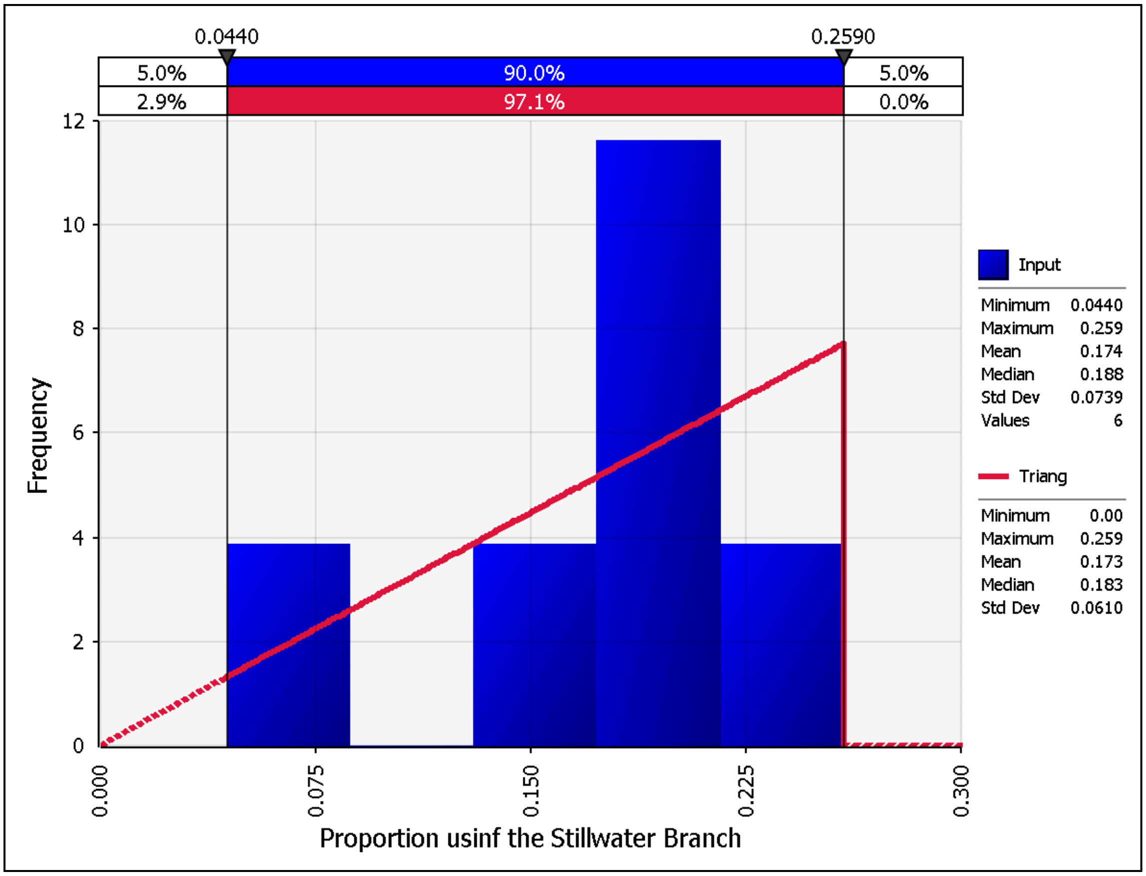


Figure 3.6.3.1. Estimates of Stillwater Branch use based on four years of telemetry studies (2005, 2006, 2009, and 2010) within the Penobscot River and the corresponding triangular distribution used to partition downstream migrating smolts according to downstream migrating path.

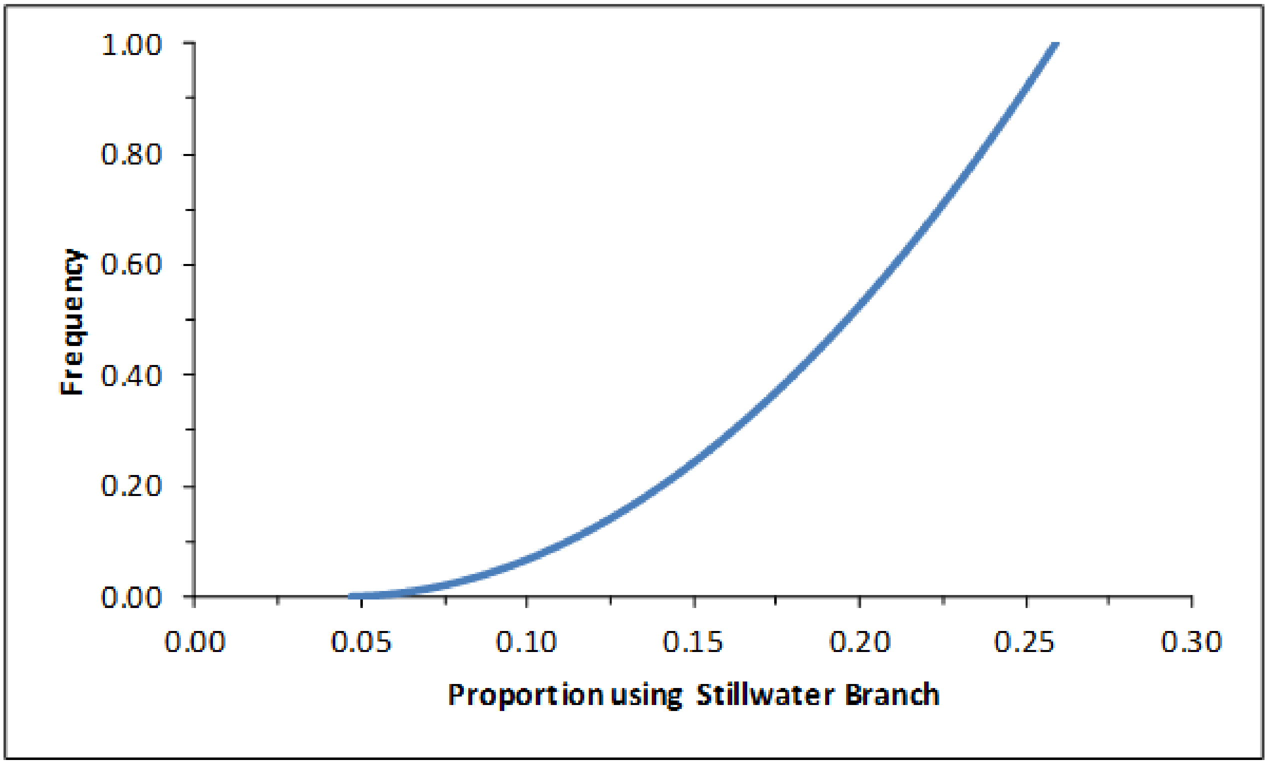


Figure 3.6.3.2. Cumulative frequency distribution of Stillwater Branch use based on 5,000 random draws from the triangular distribution developed from four years of telemetry studies within the Penobscot River.

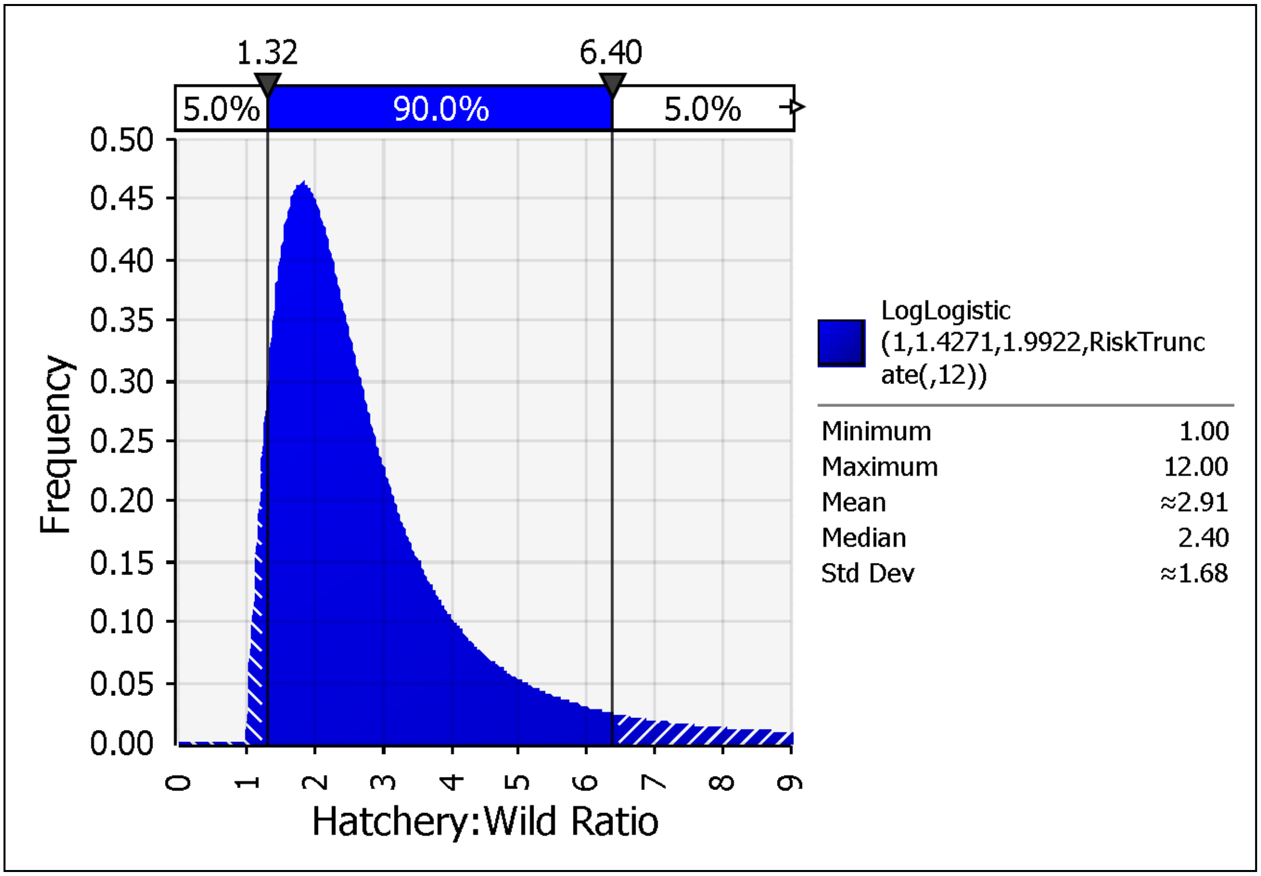


Figure 3.8.1. Fitted distribution of hatchery discount values. A total of 17 data points were obtained from the literature, describing Atlantic salmon smolt to adult survival rates for both hatchery- and wild-origin Atlantic salmon. Year- and iteration-specific draws from this distribution were made and the hatchery discount values were applied to the hatchery smolts at Verona to estimate the number of wild-equivalent smolts.

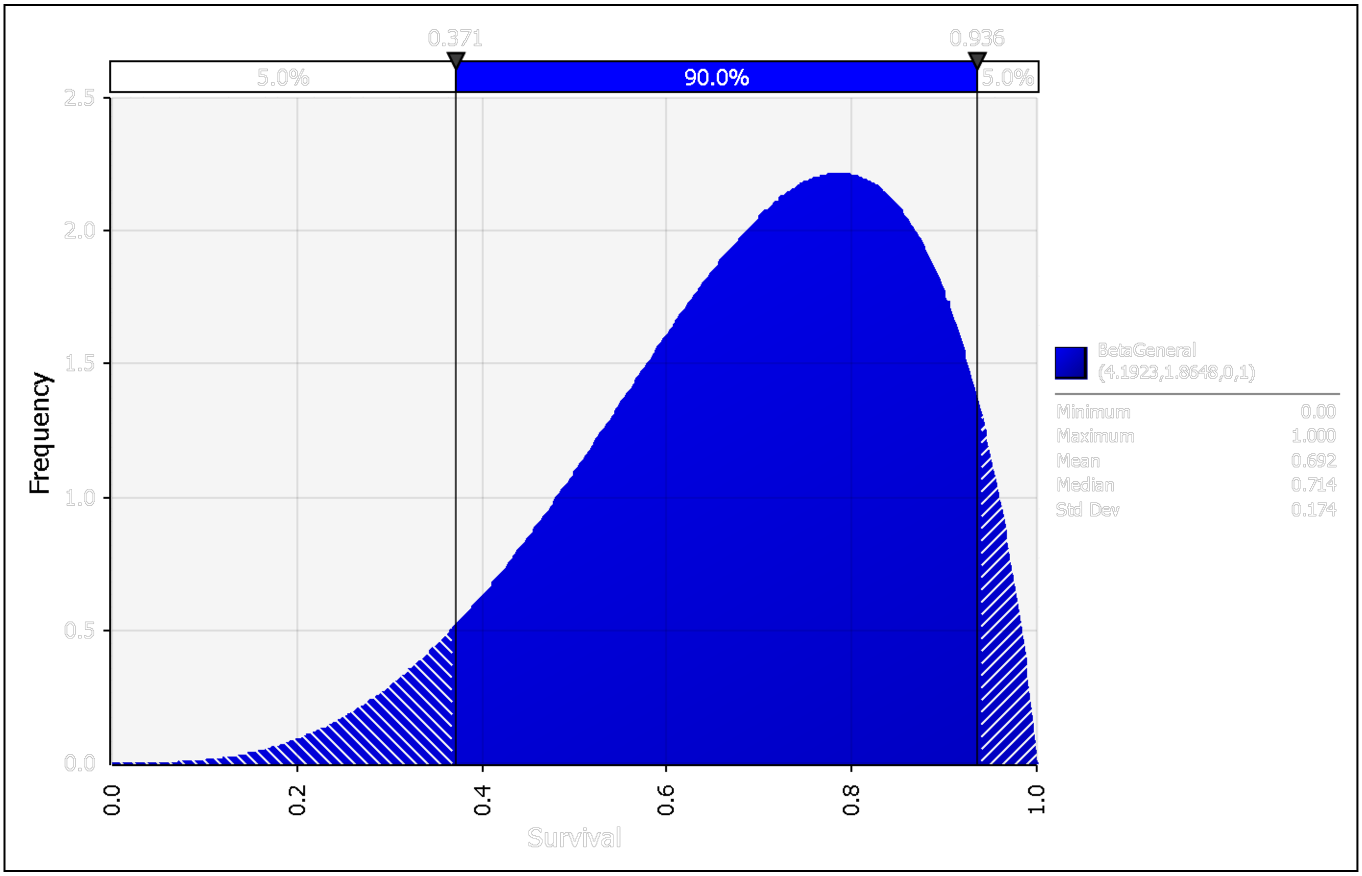


Figure 3.9.1. Fitted distribution of freshwater survival (stocking to Verona Island) generated from 17 data points from five years (2005, 2006, 2009, 2010 and 2011) of telemetry studies on hatchery and wild fish released at six sites in the Penobscot River.

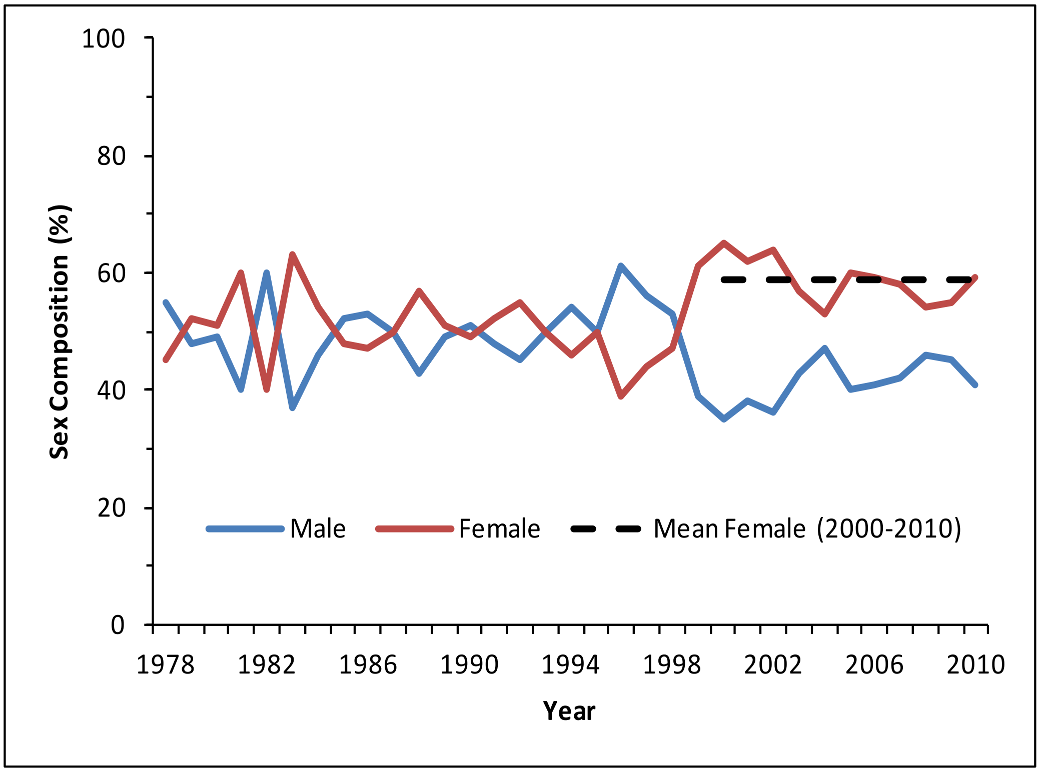


Figure 3.9.2. Sex composition of Penobscot River 2SW adult returns during 1978–2010. The 1978–1999 data represented determinations made in the field throughout the migratory season, whereas 2000–2010 data were corrected at the hatchery prior to spawning.

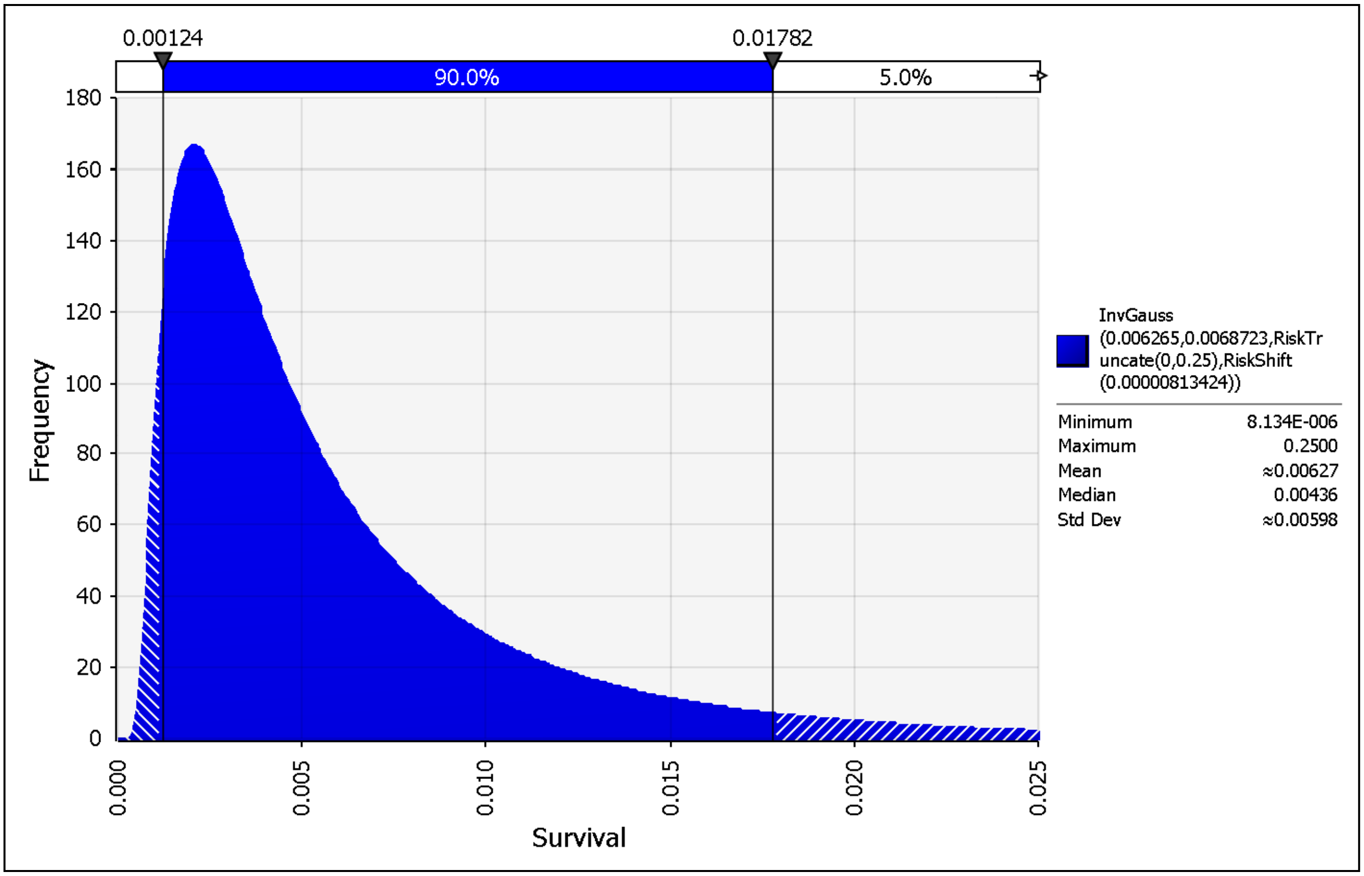


Figure 3.9.3. Fitted 2SW female marine survival distribution generated by dividing the number of 2SW adult returns (1971–2010), adjusted for the proportion female, by the number of stocked smolts (1969–2008) contributing to those returns, adjusted for the number of females stocked and freshwater mortality.

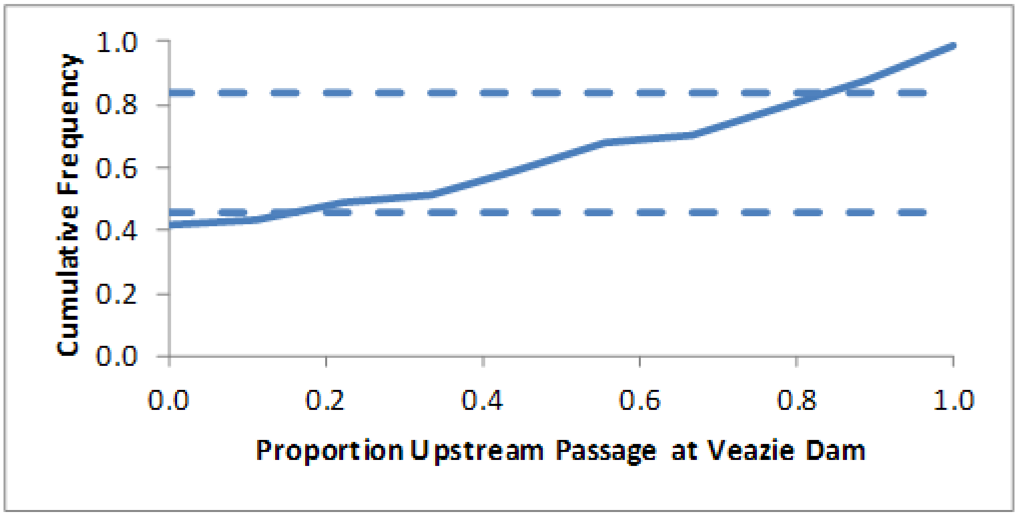


Figure 3.11.1.1. Cumulative distribution of upstream dam passage (with $\mu \pm \sigma$ minimum and maximum values indicated by the dashed lines) for Veazie.

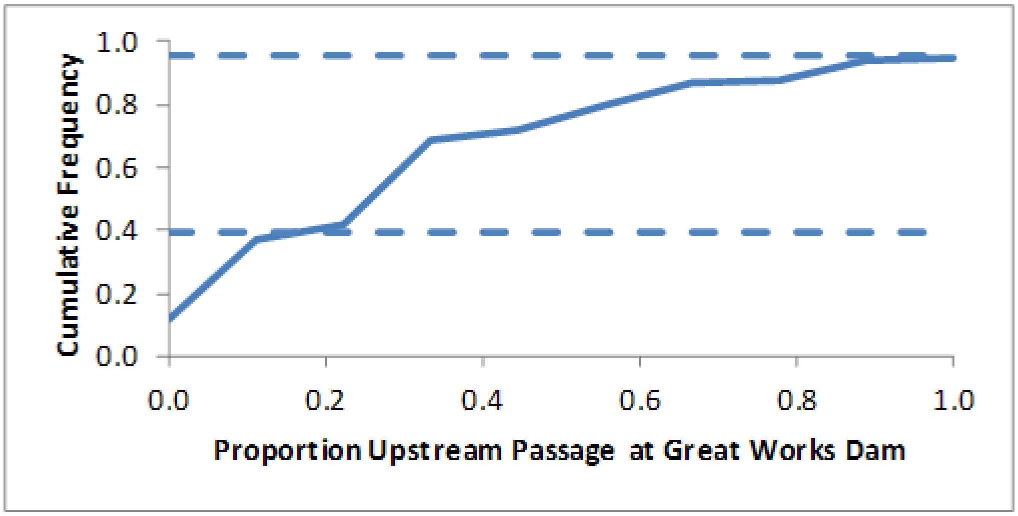


Figure 3.11.1.2. Cumulative distribution of upstream dam passage (with $\mu \pm \sigma$ minimum and maximum values indicated by the dashed lines) for Great Works.

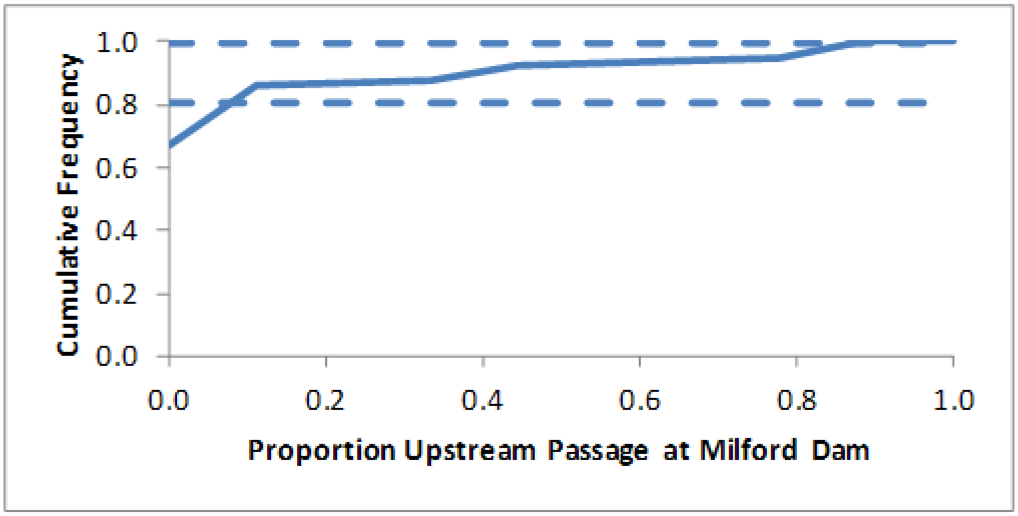


Figure 3.11.1.3. Cumulative distribution of upstream dam passage (with $\mu \pm \sigma$ minimum and maximum values indicated by the dashed lines) for Milford.

Results Figures

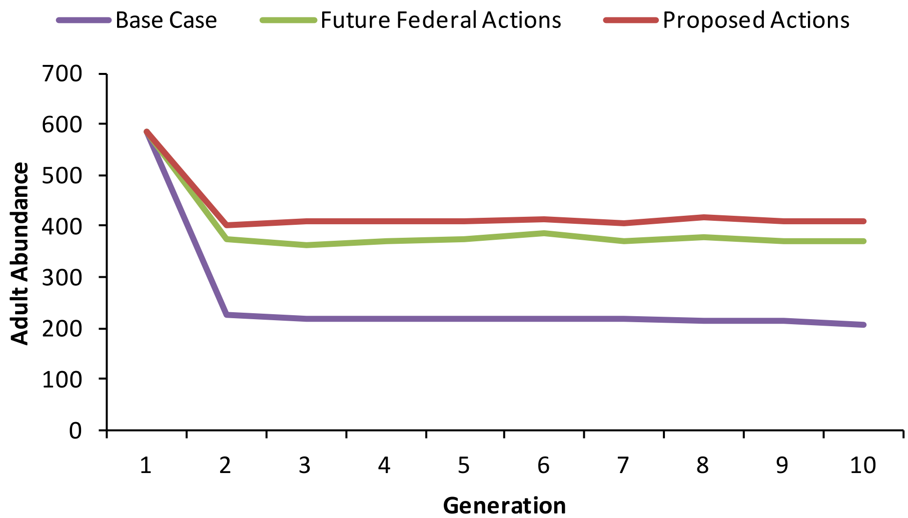


Figure 4.1.1. Median number of 2SW females across all PUs in generations 1–10 for the base case, future Federal actions, and proposed actions scenarios.

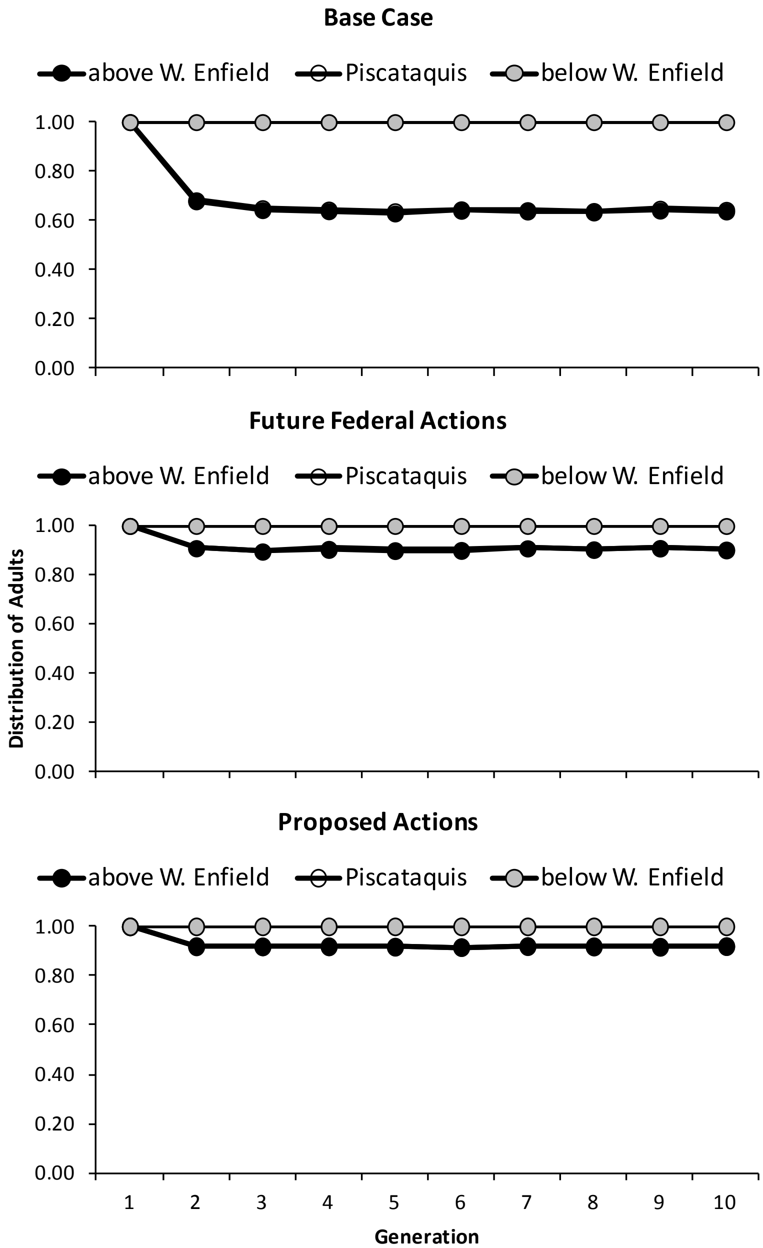


Figure 4.1.2. Proportion of iterations when at least one 2SW female was present in generations 1–10 in three areas of the Penobscot River watershed: above West Enfield Dam (i.e., PUs 1–3), in the Piscataquis River watershed (i.e., PUs 4–8), and below West Enfield Dam (i.e., PUs 9–15). The top panel is the base case scenario, the middle panel is the future Federal actions scenario, and the bottom panel is the proposed actions scenario.

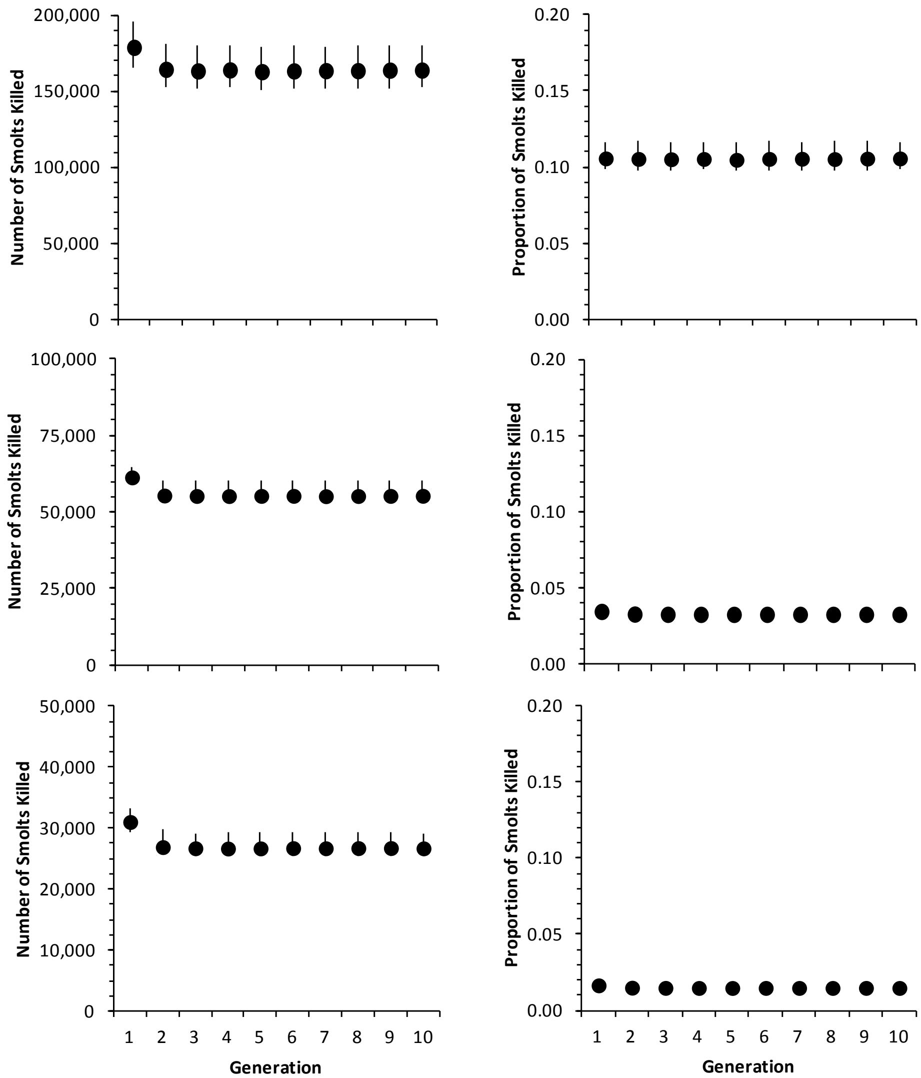


Figure 4.1.3. Median number (panels on the left) and median proportion (panels on the right) of smolts killed during downstream dam passage across all 15 hydroelectric dams. Values are shown for generations 1–10. The circles represent the median values, and the lines represent the twenty-fifth to the seventy-fifth percentiles. Panels in the top row are for the base case scenario, panels in the middle row are for the future Federal actions scenario, and panels in the bottom row are for the proposed actions scenario.

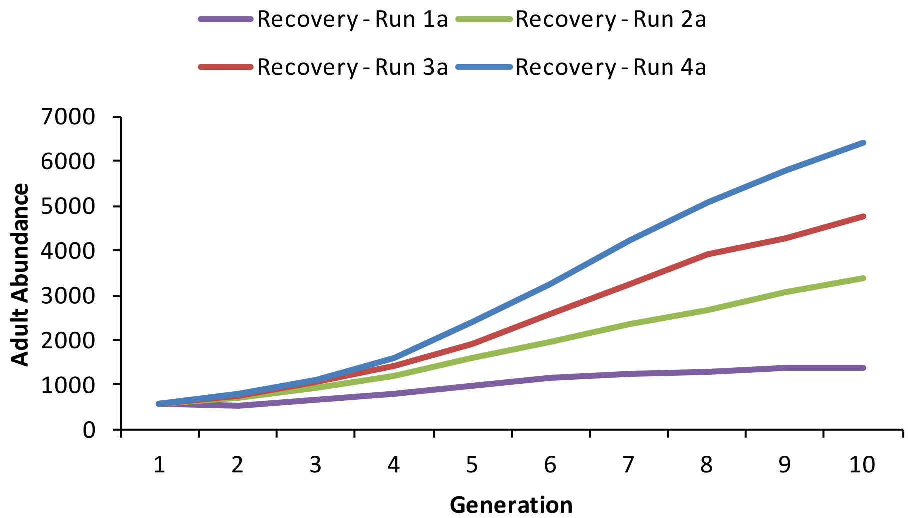


Figure 4.2.1. Median number of 2SW females across all PUs in generations 1–10 for recovery runs 1a, 2a, 3a, and 4a.

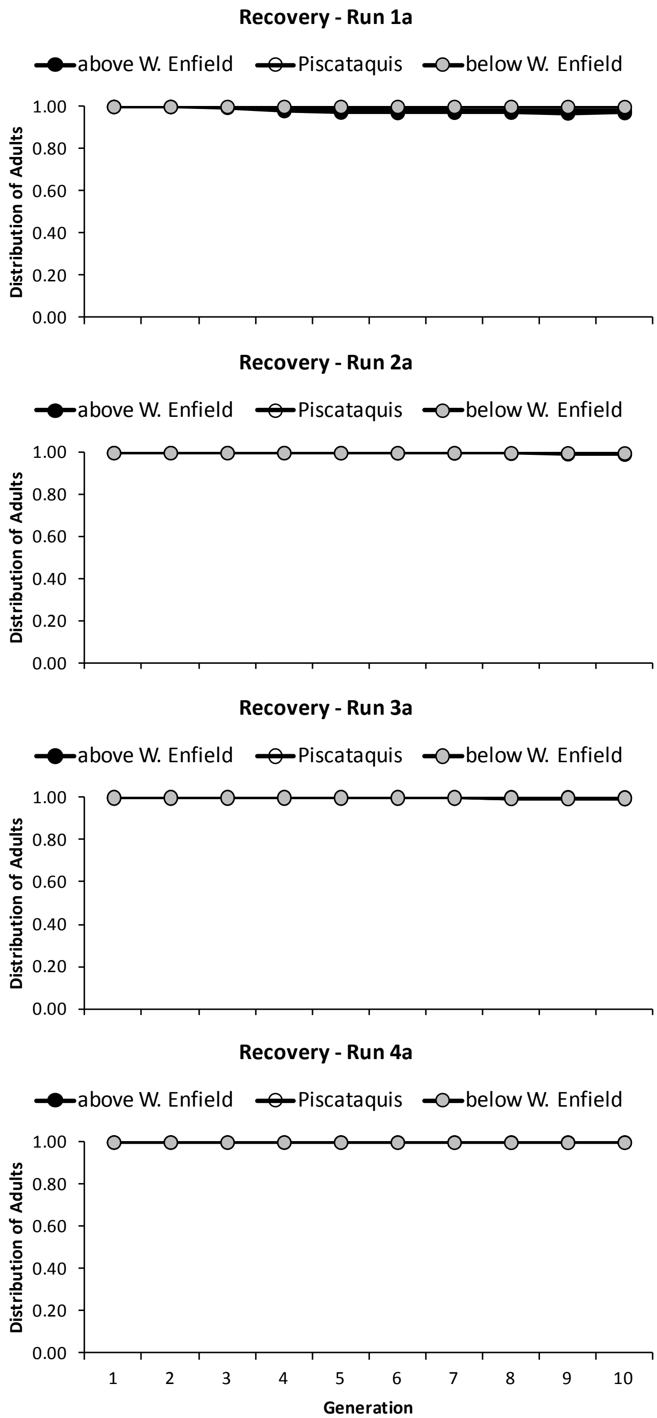


Figure 4.2.2. Proportion of iterations when at least one 2SW female was present in generations 1–10 in three areas of the Penobscot River watershed: above West Enfield Dam (i.e., PUs 1–3), in the Piscataquis River watershed (i.e., PUs 4–8), and below West Enfield Dam (i.e., PUs 9–15). The top panel is recovery run 1a, the second panel from the top is recovery run 2a, the third panel from the top is recovery run 3a, and the bottom panel is recovery run 4a.

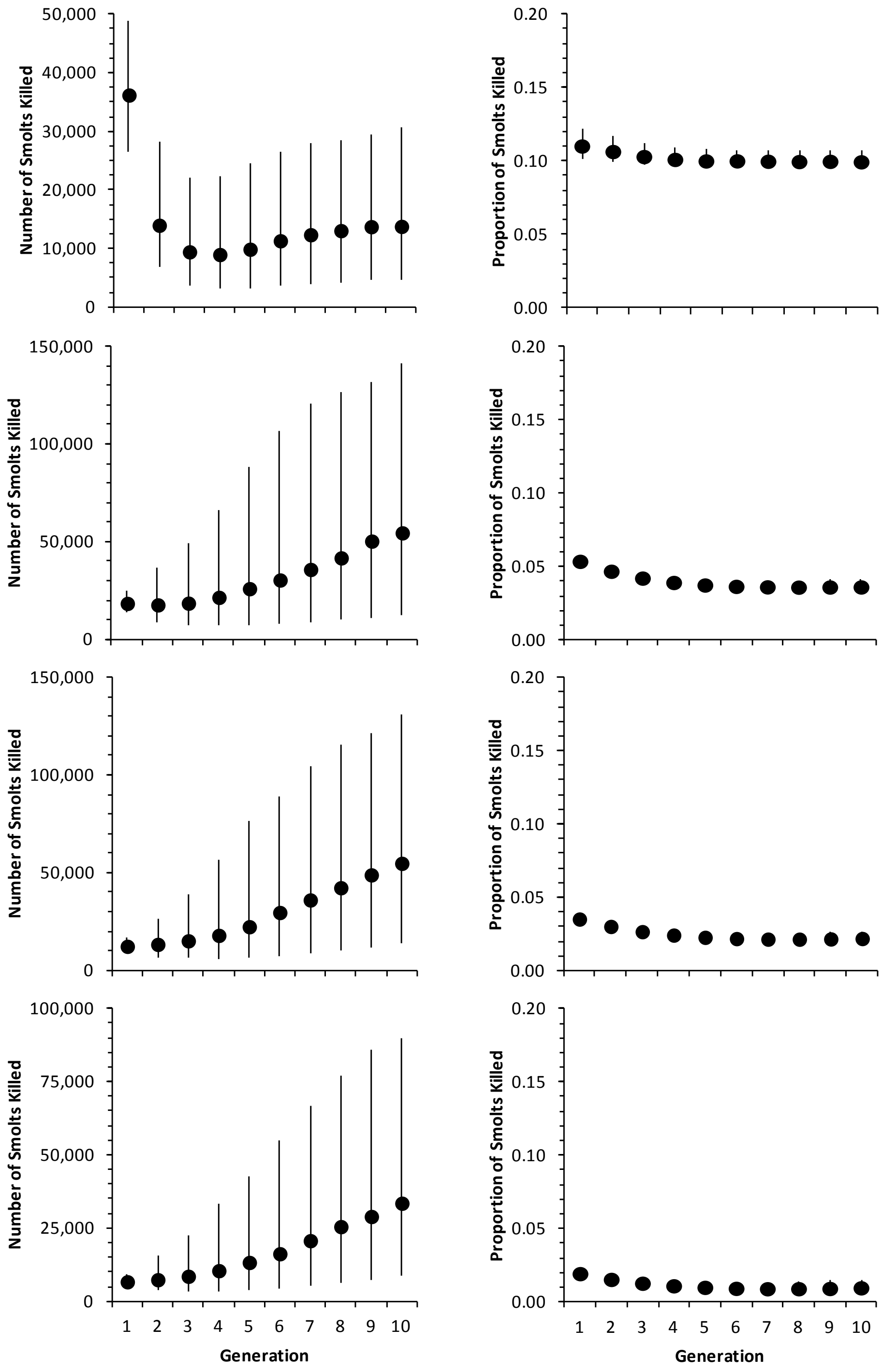


Figure 4.2.3. Median number (panels on the left) and median proportion (panels on the right) of smolts killed during downstream dam passage across all 15 hydroelectric dams. Values are shown for generations 1–10. The circles represent the median values, and the lines represent the twenty-fifth to the seventy-fifth percentiles. Panels in the top row are for recovery run 1a, panels in the second row from the top are for recovery run 2a, panels in the third row from the top are recovery run 3a, and panels in the bottom row are for recovery run 4a.

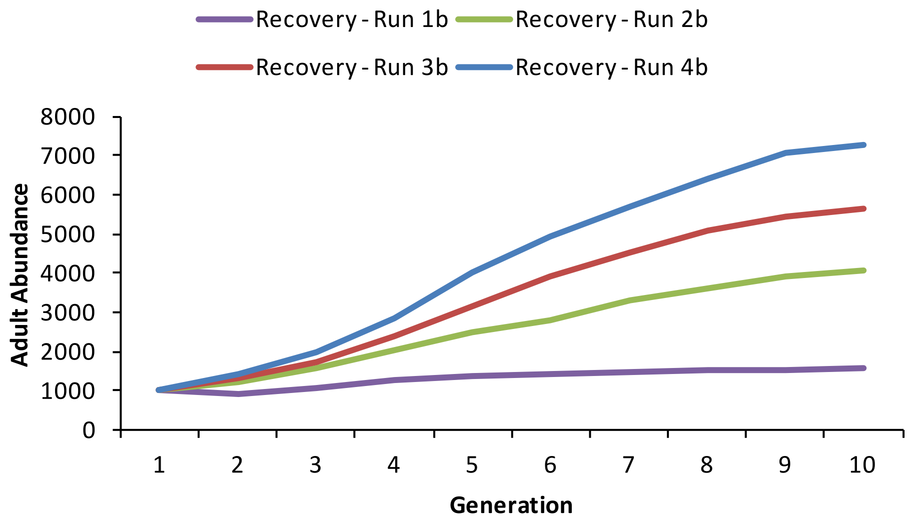


Figure 4.2.4. Median number of 2SW females across all PUs in generations 1–10 for recovery runs 1b, 2b, 3b, and 4b.

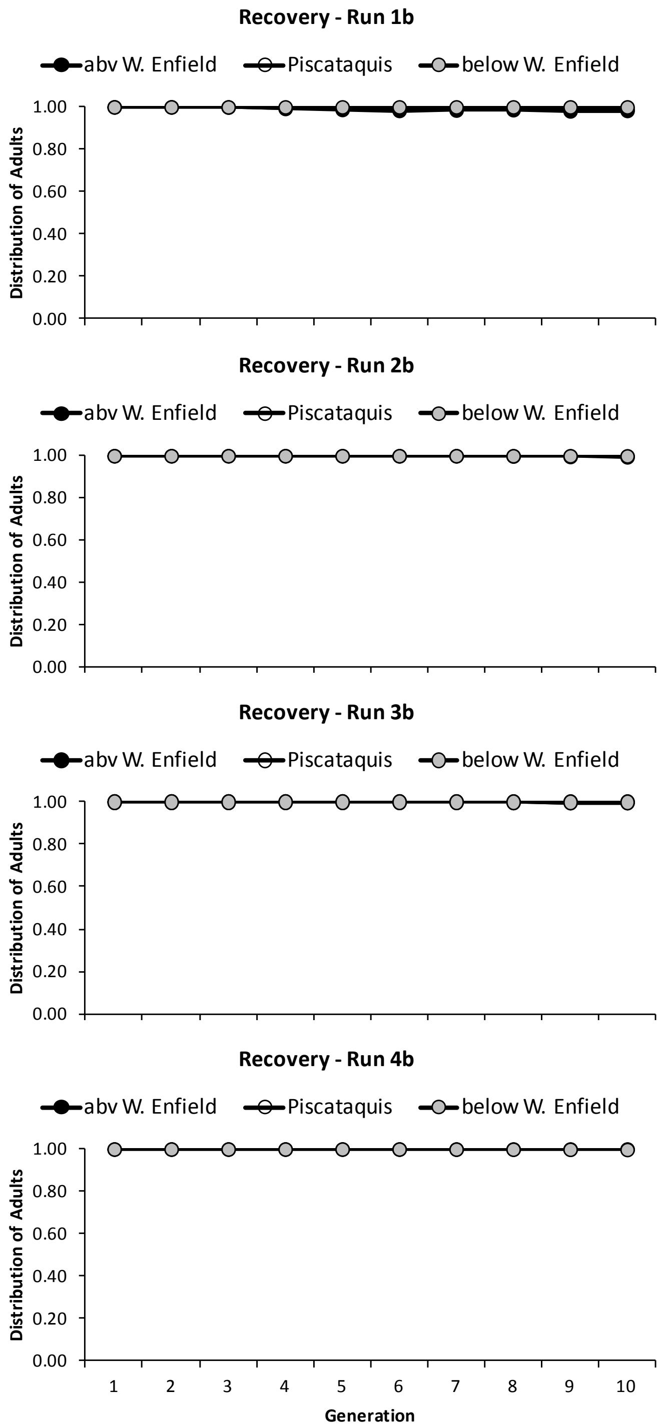


Figure 4.2.5. Proportion of iterations when at least one 2SW female was present in generations 1–10 in three areas of the Penobscot River watershed: above West Enfield Dam (i.e., PUs 1–3), in the Piscataquis River watershed (i.e., PUs 4–8), and below West Enfield Dam (i.e., PUs 9–15). The top panel is recovery run 1b, the second panel from the top is recovery run 2b, the third panel from the top is recovery run 3b, and the bottom panel is recovery run 4b.

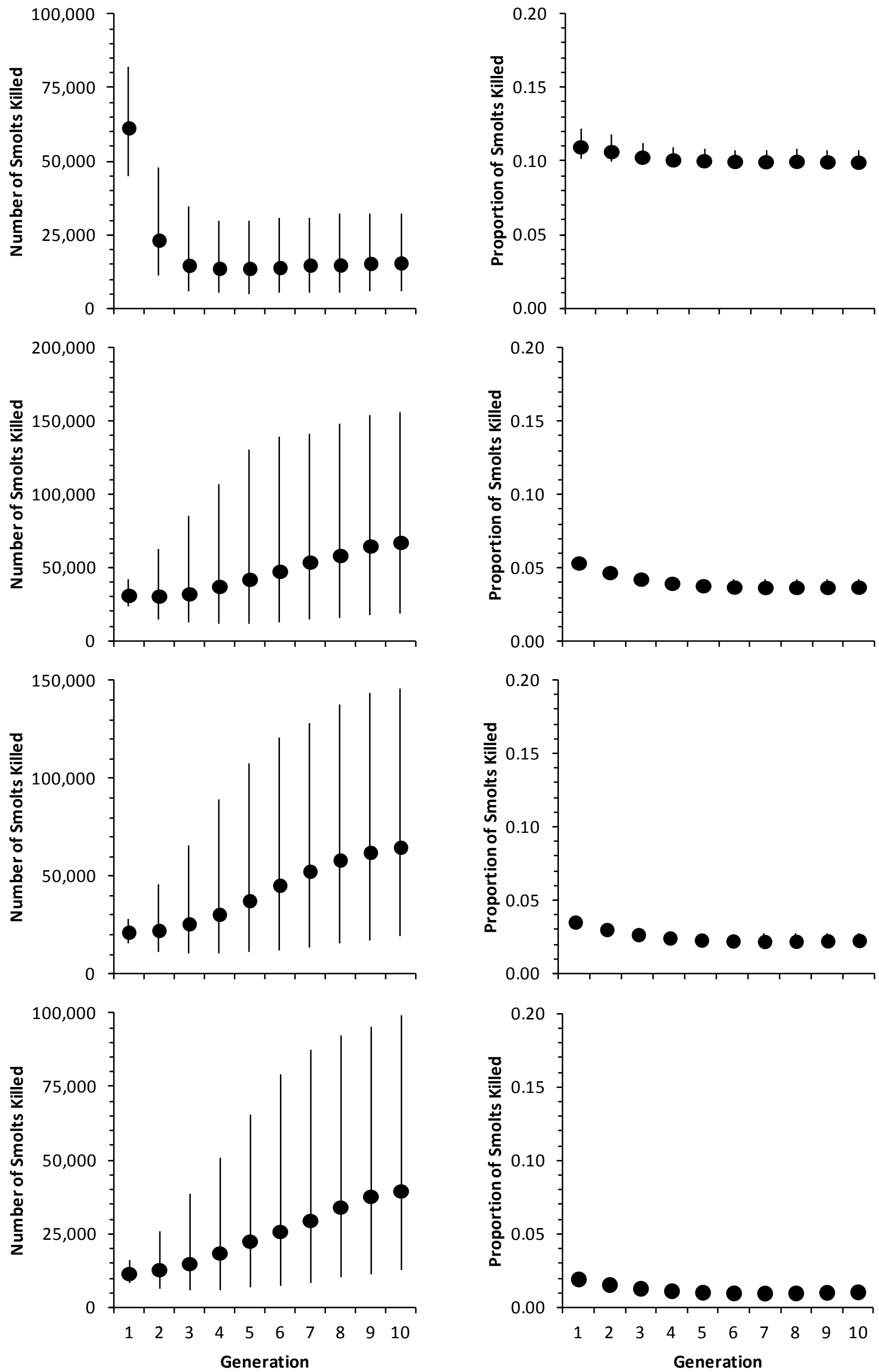


Figure 4.2.6. Median number (panels on the left) and median proportion (panels on the right) of smolts killed during downstream dam passage across all 15 hydroelectric dams. Values are shown for generations 1–10. The circles represent the median values, and the lines represent the twenty-fifth to the seventy-fifth percentiles. Panels in the top row are for recovery run 1b, panels in the second row from the top are for recovery run 2b, panels in the third row from the top are recovery run 3b, and panels in the bottom row are for recovery run 4b.

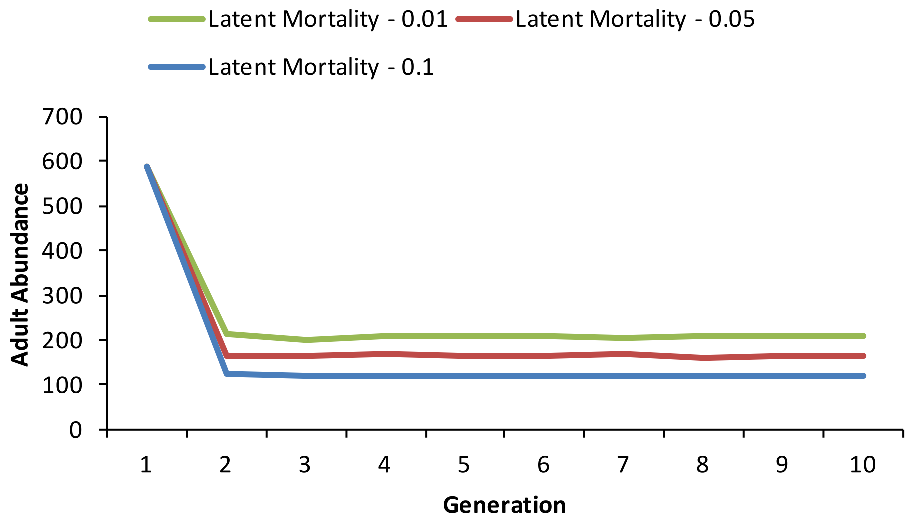


Figure 4.3.1. Median number of 2SW females across all PUs in generations 1–10 for the latent mortality 1, 5, and 10% scenarios.

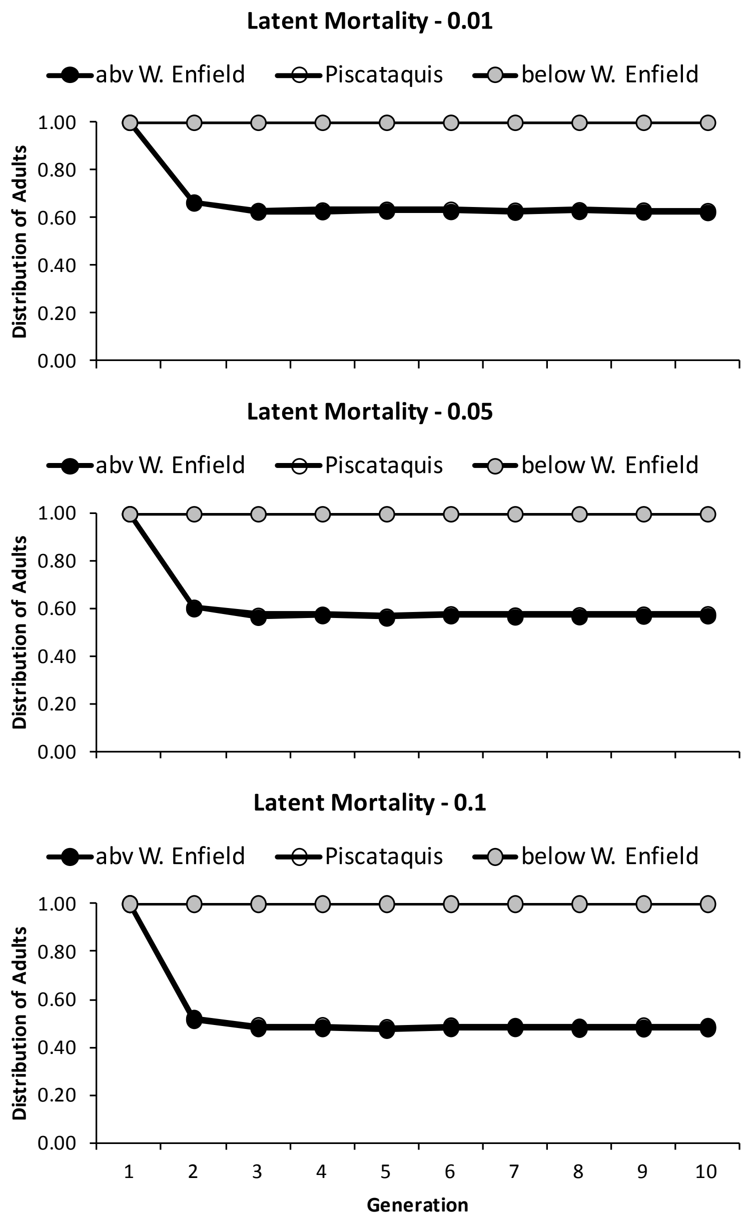


Figure 4.3.2. Proportion of iterations when at least one 2SW female was present in generations 1–10 in three areas of the Penobscot River watershed: above West Enfield Dam (i.e., PUs 1–3), in the Piscataquis River watershed (i.e., PUs 4–8), and below West Enfield Dam (i.e., PUs 9–15). The top panel is the latent mortality 1% scenario, the middle panel is the latent mortality 5% scenario, and the bottom panel is the latent mortality 10% scenario.

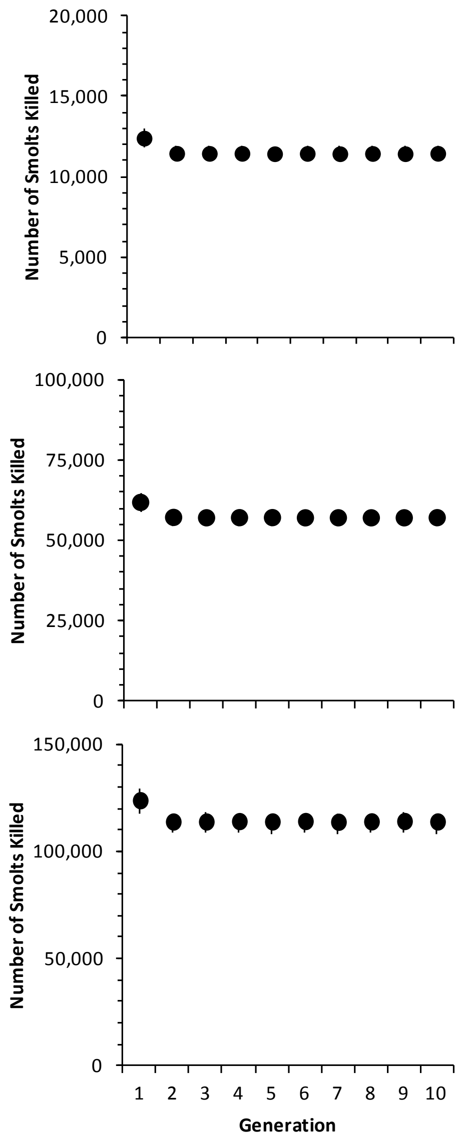


Figure 4.3.3. Median number of smolts killed by dams due to latent mortality across all 15 hydroelectric dams. Values are shown for generations 1–10. The circles represent the median values, and the lines represent the twenty-fifth to the seventy-fifth percentiles. The panel in the top row is for the latent mortality 1% scenario, the panel in the middle row is for the latent mortality 5% scenario, and the panel in the bottom row is for the latent mortality 10% scenario.

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Final: 06-28-12

Technical Memorandum

Assumptions Used and Verification Process for the Development
of the Black Bear Hydro Species Projection Plan

1.0 Background

NOAA's National Marine Fisheries Service (the "NMFS") and the U.S. Fish and Wildlife Service (the "FWS") jointly (the "Services") administer the Endangered Species Act (the "Act" or "ESA") with regards to the federal listing of the Gulf of Maine Distinct Population Segment of Atlantic salmon ("Atlantic salmon" or the "GOM DPS"). Atlantic salmon was first listed in 2000, which included a limited portion of its range in coastal Maine watersheds from Cobscook Bay to Merrymeeting Bay but did not include much, if any, of the Androscoggin, Kennebec and Penobscot Rivers (65 FR 69469, November 17, 2000). These three major rivers were included in an expanded listing of Atlantic salmon in 2009 (74 FR 29344, June 19, 2009) and the designation of critical habitat in the same year (74 FR 29300, June 19, 2009). In these rules, the Services identified dams as one of the greatest impediments to self-sustaining populations of Atlantic salmon in Maine. As a result of the expanded listing, hydroelectric projects licensed by the Federal Energy Regulatory Commission (the "FERC") are now required to address take of Atlantic salmon and many Licensees are undergoing planning processes to obtain an incidental take permits from the Services.

A Species Protection Plan (a "SPP") is one such planning approach ensuring that take of the listed salmon will be avoided or minimized by: (1) setting upstream and downstream fish passage performance standards; (2) developing an adaptive management framework for implementing measures (and monitoring their effectiveness) to meet the performance standards; (3) filing the plan as an amendment of the FERC license for the hydroelectric project; (4) requesting that FERC consult with the Services; and (5) obtaining an incidental take statement through section 7(a)(2) of the Act, if appropriate. The Services provide technical assistance to the Licensee in developing the Species Project Plan that is filed with FERC.

To ensure that the administration record is transparent, by this memorandum we are documenting the informal process that we participated in with the Licensee to develop the plan and confirm that the plan's approach is based on the best available science. The Black Bear Hydro SPP will also be independently assessed in a Biological Opinion (the "BO") on the effects of the FERC licensing and operation of the subject hydroelectric projects on listed species including whether the proposed action is likely to jeopardize listed species or destroy or adversely modify designated critical habitat (50 C.F.R. § 402.02). This technical memorandum was prepared by FWS and provides only the FWS confirmation of the validity of the Black Bear SPP. It is meant to document the informal consultation that occurred in the development of the SPP between the Service and the Licensee. At this point in time, it is unclear whether it will be adopted by NMFS in their independent analysis as lead agency in the preparation of the BO.

2.0 The Action – Black Bear Species Protection Plan

Black Bear Hydro Partners, LLC ("Black Bear") owns and operates hydroelectric projects in the Penobscot River watershed pursuant to licenses issued by the FERC. These projects are the Orono Project No. 2710, Stillwater Project No. 2712, Milford Project No. 2534, West Enfield Project No. 2600 (licensed to Bangor Pacific Hydro

Associates [BPHA[1]]), and Medway Project No. 2666. Black Bear filed applications at FERC on May 18, 2011, to amend its licenses for the Orono and Stillwater Projects to allow for the construction of a new powerhouse at each project. Before FERC amends the licenses for the Orono and Stillwater Projects, Black Bear is filing a Species Protection Plan and associated biological assessment with FERC to amend the licenses of the five projects so that FERC can initiate section 7(a)(2) consultation with NMFS (the lead Service agency in the consultation). The consultation will result in a BO that determines whether the revised operation of Black Bear's hydroelectric projects in the Penobscot River watershed will jeopardize the continued existence of Atlantic salmon (*Salmo salar*, endangered); shortnose sturgeon (*Acipenser brevirostrum*, endangered); or Atlantic sturgeon (*A. oxyrinchus oxyrinchus*, threatened) or result in the destruction or adverse modification of any designated critical habitat for those species. The hydroelectric projects owned by Black Bear are part of the Lower Penobscot River Multiparty Settlement Agreement[2] (the "MPA") and also represent a significant portion of the projects on the mainstem rivers above the Town of Veazie (Penobscot, Piscataquis, Mattawamkeag, Passadumkeag, and East Branch Rivers) in the Penobscot River watershed regulated by FERC and within Atlantic salmon designated critical habitat (Figure 1). Consequently, the SPP has the potential to significantly affect the survival and recovery of salmon.

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[1] Bangor Pacific Hydro Associates, which is wholly owned by Black Bear affiliates, owns and operates the West Enfield Project.

[2] In order to implement the MPA, in consultation with the signatories and NMFS, Black Bear developed specific license articles for each hydroelectric project, consistent with Attachment A of the MPA and the accompanying Federal Power Act Section 18 fish passage prescriptions from USFWS and NMFS, that have been incorporated into the existing project licenses.

The purpose of the SPP is to identify enhancements to avoid or minimize impacts related to the operation of Black Bear's hydroelectric facilities and protect Atlantic salmon, shortnose sturgeon, and Atlantic sturgeon. The scope of this technical memorandum is limited to Atlantic salmon as the other species are regulated under the ESA solely by NMFS. The Black Bear SPP contributes to the protection of Atlantic salmon through a combination of improving upstream and downstream passage; avoiding or minimizing delay and injury; and protecting habitat in the project areas. Briefly, these measures include: (1) implementing fishway improvements under the MPA; (2) setting performance standards of 96 percent for downstream fish passage for the kelt and smolt phases and 95 percent for upstream fish passage for the adult phase; (3) conducting studies to determine whether the performance standards are met and continue to be met in the future; (4) developing an adaptive management framework that includes a progression of steps that are implemented until the performance standards are met (e.g., the last step for downstream migration being partial day-time and total night-time shutdown of the hydroelectric facility); and (5) addressing upstream fish passage at the Orono Project if salmon encounter significant delay. For a more complete account of the SPP refer to the MPA[3] and the SPP and biological assessment (Black Bear Hydro Partners 2012).

[3] The Lower Penobscot River Multiparty Settlement Agreement (MPA) was filed with FERC on June 2004 and signed by PPL Maine LLC, the U.S. Department of Interior (acting through its Fish and Wildlife Service, Bureau of Indian Affairs, and the National Park Service), four State of Maine natural resource agencies (the Maine State Planning Office, Department of Marine Resources, Department of Inland Fisheries and Wildlife, and the Atlantic Salmon Commission), the Penobscot Indian Nation, American Rivers, Atlantic Salmon Federation, Maine Audubon, Natural Resources Council of Maine, Trout Unlimited, and the Penobscot River Restoration Trust. The Nature Conservancy joined the Trust after the MPA was filed with FERC.

3.0 Analytical Approach

Three methods were used to confirm the reasonableness of SPP. First, a life history model was constructed using matrix population modeling techniques (Caswell 2001), including the use of Life Table Response Experiments ("LTRE"), to compare the existing baseline to the condition that would occur under the SPP and MPA (the "Action"). The life history model was constructed to predict effects of changes to the three stages that are either influenced by the hydroelectric projects or are relevant to the baseline: the smolt, marine, and in-river returning adult survival stages. Four alternatives were evaluated to better understand the relative and incremental effect of the SPP: (1) the "Baseline" or pre-action condition; (2) the "MPA Only" or dam decommissioning under the MPA in which the Veazie and Great Works Projects are removed and a bypass channel is constructed around the Howland Project; (3) the "SPP (and MPA)" or alternative that includes the dam decommissioning in the "MPA Only" alternative along with achieving the performance measures identified in the SPP (96 percent survival for smolts and kelts and 95 percent passage efficiency for adults); and (4) the "Unimpounded" or alternative without dams based on smolt survival estimates from unimpounded, demographically stable rivers in Canada. Second, the results of in-river smolt survival studies were compiled for unimpounded sections of rivers with dams and for rivers without dams to predict the range of in-river survival that could be expected under those conditions. These data were used to understand the effect of naturogenic influences on smolt survival that occur in rivers or river segments without significant impoundment influences or hydroelectric projects. And third, a model was developed to predict the effectiveness of concentrating and increasing the amount of spill on smolt survival to predict whether spill or reduced turbine operation, a fundamental assumption in the SPP, can be used to meet the downstream performance standard for smolts of 96 percent survival.

In this memorandum, the survival from one stage to the next is often cited. For example, when we refer to the smolt survival we mean the percentage of smolts that survive to enter the next life history stage (a post-smolt or smolt that enters the estuary or marine environment). We express survival as a decimal equivalent so 96 percent is expressed as 0.9600.

3.1 Life History Model

An existing life history model was adopted that was developed for predicting the influence of different management actions on Atlantic salmon in the Penobscot River (Robertson 2005) and later used by Sweka et al. (2008) in a method to prioritize management activities in Maine and by the Maine Department of Marine Resources to examine the viability of sub-populations of salmon in the Penobscot River watershed for planning purposes (MDMR and MDIFW 2009). The model is based on matrix population modeling techniques, which have been used widely for decades in studies of demography, ecology, evolution, wildlife management, and endangered species assessment (Caswell 2001). Generally, a matrix population model is constructed by first graphing the life cycle to describe the life history stages of the species (e.g., the egg, fry, parr, smolt, post-smolt, adult marine, adult freshwater and kelt stages for salmon); determining a time interval for each stage; determining survival from one stage to the next, the transition survival; constructing the Leslie matrix; and implementing it through commercial software, such as Microsoft Excel. The Leslie matrix is a discrete, age-structured model of population growth developed in the 1950's and is used widely in population ecology (Caswell 2001). It is one of the most often applied methods to describe the population growth where the population is closed to migration and where only one sex, usually the female, is considered.

Robertson's (2005) modeling approach was adopted because it was designed for the GOM DPS; it was easily reproducible and understandable; it was accessible to anyone through widely available commercial software (Microsoft Excel and PopTools, a free Excel add-in available at www.poptools.org); it was used by others to address resource management questions; it was able to calculate lambda (the population growth rate, λ), an easily calculated and interpretable measure of population viability (a $\lambda < 1$ means that the population is declining, a $\lambda = 1$ means that the population is stable, and a $\lambda > 1$ means that the population is increasing); and it was based on the demographics of wild and not hatchery salmon. Details on how the model was constructed, its assumptions and Atlantic salmon life history can be found in Robertson (2005) and we focus here on: (1) the changes made to the model to make it more relevant to the analysis, (2) how the model was checked after it was changed, (3) the method used to develop the baseline and action condition, (4) the use of Life Table Response Experiments to compare the baseline to the action condition, and (5) the performance of the SPP relative to the existing baseline.

3.1.1 Changes to the Model

Robertson (2005) developed two versions of the model: a deterministic and a stochastic model. The deterministic model (the “general model”) represents the average or general case and it uses average values for the transition survival estimates from one stage to the next. A stochastic model estimates a mean, variance, and probability distribution of potential outcomes by selecting values of the survival parameters for each stage randomly from the range of the survival estimates measured in field studies for many cases or simulations. The general model is often used to check the reasonableness of a model against field studies and it allows one to easily modify the parameters to predict how they may influence the outcome. The stochastic version is used to understand and calculate the probability of a certain outcome. We made three changes that affect each model version by: (1) incorporating the smolt stage as a model component; (2) modifying the smolt to returning adult survival; and (3) assuming a normal rather than triangular distribution for most of the survival estimates. Each is discussed below.

Incorporating the Smolt Stage

Robertson used a 12-month time interval for the model, which works well with most of the salmon life history stages. The 12-month period that includes the smolt stage also includes portions of the parr (1+ and 2+ parr stages depending upon when smoltification occurs) and the post-smolt (the early estuarine and marine period) stages. Roberson combined the smolt stage and the pre-smolt parr stage into a single 6.5-month stage. We changed the model to include a smolt stage of 1.5 months thereby reducing the parr period from 6.5 month to 5 months. This change allowed the model to include changes in smolt survival, one of three parameters varied in the LTREs.

Smolt to Returning Adult Survival

Robertson used a mean, minimum, and maximum overall survival of smolt to returning adult of 0.011, 0.005 and 0.04, respectively. These values are higher than the wild return rate that has been measured on the Narraguagus River, a mean return rate of 0.007 (Table 1). The large number of hatchery smolts stocked in the Penobscot River and the lack of estimates for the number of wild smolts makes it difficult to measure the wild smolt to returning adult survival for the watershed so we use the smolt to adult return rate for the Narraguagus River to represent the expected range for wild fish in the Penobscot River.

Narraguagus River data represent wild fish because hatchery supplementation has focused on the use of fry and not smolts. As stocked fry, the salmon are present for two years in freshwater and are assumed to be better adapted to river conditions and more like wild fish than if stocked at a later stage. Both watersheds also include an estuary or sheltered marine portion that smolts must migrate through before they enter the open water within the Gulf of Maine, and thus are comparable. Therefore, we replaced the values Robertson assigned for the overall survival for smolt to returning adult with those measured for the Narraguagus River. In doing so, we also needed to re-calculate the values that Robertson used for the high marine survival condition using his method (Robertson 2005: 68-69). This recalculation results in pre-regime shift marine survival values for the mean, minimum and maximum of 0.0304, 0.009 and 0.0519, respectively.

We use the terms “pre-regime shift” and “regime shift” in marine survival to refer to a decline of between 50 and 70 percent in the marine survival of many salmon populations in the North Atlantic between the mid-1980s and the early 1990s. The exact cause of this decline is unknown but it corresponds with a general cooling of the North Atlantic. The “pre-regime shift” refers to the higher marine survival that occurred prior to the regime shift and the “regime shift” refers to the lower marine survival that occurred afterwards and is the current condition.

Past reported pre-regime shift marine survival estimates are often confounded by the lack of correction for commercial and recreational exploitation rates. However, the recalculated marine survival estimates appear to be reasonable based on past estimates. Friedland and Reddin (1993: the return rates were scaled off of Figure 6.2) reported a Penobscot River return rate of about 0.0061, a minimum of 0.0028 and a maximum of 0.0122 for hatchery fish and without correction for exploitation. Chadwick (1993) suggests doubling the marine survival rates of hatchery fish to obtain an estimate for wild fish, which would put the Penobscot River smolt to adult return rate at between 0.006 and 0.0244 after exploitation based on Friedland and Reddin’s rates. Chadwick also reported mean total survival of 1SW (“one sea-winter”) fish for Canada of between 0.01 and 0.07 after exploitation (between 0.005 and 0.035 for 2SW (“two sea-winter”) fish if one assumes a similar monthly survival rate). The recalculated marine survival rates used in the model (a mean of 0.0304, a minimum of 0.009, and a maximum of 0.0519) appear to be within the range of past estimates especially when one considers that the model does not assume any exploitation. The past reported survival rate would be higher if corrected for past exploitation, which ranged between 5 and 25 percent, depending upon the fishery (Robertson 2005: Figure 3-2).

Assuming a Normal rather than Triangular Distribution

The stochastic version of the Robertson's model drew randomly from a triangular distribution that uses minimum, mean or likely, and maximum values, which produces values that tend to the mean but allow extremely high and low values. This distribution is often used in applications with subjective descriptions where the range or magnitude is known, such as the high and low values, but when little is known about the mean requiring an "inspired guess." We believe that more is known about the survival estimates than is reflected by the assumptions of the triangular distribution. Many of the estimates were from field studies using standard methods and assuming a normal distribution. We explored the use of a normal distribution by approximating a standard deviation from Robertson's reported minimum, maximum, and mean for each survival estimate by dividing the range by four (Mendenhall 1979); drawing 500 samples randomly from a normal distribution between probabilities of 0.025 and. 0.975; and checking the simulated minimum and maximum against those used by Robertson (Table 2). The minimum, maximum, range, and mean were similar to those used by Robertson except for the smolt to adult return survival (Robertson's S_sr parameter) where the normal distribution resulted in a negative minimum value and an underestimated maximum value. Given the closeness of our simulated values to Robertson's, we assumed a normal distribution for all the estimates except the smolt to adult return survival, which was estimated with a triangular distribution.

A normal distribution provides several advantages over the triangular distribution: it is consistent with the distribution used in the field studies that underlay the estimate; it is not as uniform as the triangular distribution so the probability of drawing a minimum or maximum is less likely; and it provides a greater variance from the mean than one would expect from the triangular distribution so it better represents biological data; and it is easy to incorporate in a model making it simpler to understand and apply.

3.1.2 Checking the Model

A model is intended to be a simplification of ecological processes so it will always be imperfect. However, models are useful to structure our reasoning and decision-making processes, organize and synthesize field studies, test our understanding, and make and communicate predictions (Starfield and Bleloch 1991). A matrix population model is described explicitly from its mathematically structure using linear algebra so its components are transparent. This transparency leads to posing questions, like: Is the life history accurately described? Are the survival and fecundity estimates reasonable? Is the method used to introduce stochasticity appropriate? These structural questions to test the model were addressed in Robertson (2005). Our approach to checking the model is to determine if the general model provides a reasonable prediction of λ, certain survival estimates, and age distribution based on empirical data or through other independent estimates of λ.

The model was first checked by comparing λ calculated by the general model with three independent estimates. First, λ was estimated from empirical data by exponential regression from 1993 to 2010 for the Narraguagus River (Table 3). The period from 1993 to 2010 was used to calculate λ from empirical data because it reflects contemporary conditions, namely a lower marine survival for Atlantic salmon caused by a regime shift in marine conditions. This period also corresponds with the cessation of significant commercial and recreational exploitation for salmon. Lambda was approximated by exponential regression as 0.893. The general model was adjusted with a mean monthly smolt survival value of 0.882 from Kocik et al. (2009) (the mean river survival was normalized to monthly survival to be consistent with the model and it was calculated by $0.828^{(1/1.5)}$) and a mean smolt to adult return rate of 0.007 based on empirical data from the Narraguagus River (see Section 4.1.1.) The general model predicts λ as 0.873, which is very close (within two percent) to the empirical approximation of 0.893.

Second, λ from the general model was compared to the λ estimated by Legault (2005) for the Narraguagus River by a diffusion approximation population viability analysis (PVA). Legault used this method to verify a PVA created for Atlantic salmon that covered the geographic area of the 2004 listing. The diffusion approximation PVA estimated λ as 0.889, which is similar (also within two percent) to the general model prediction of 0.873 for the Narraguagus River.

Third, we completed an exponential regression for the Penobscot River, but it was a poor fit because of the high variability of wild returns likely due to inconsistent management activities that would result in either smaller or larger year classes of wild fish (number of broodstock relative to return, quantity and locations of parr and fry stocking). However, Sweka and Bartron (unpublished data) completed a PVA for the

Penobscot River by applying an improved diffusion approximation method to estimate wild growth rate corrected for hatchery supplementation. They estimated a mean λ of 0.613 for the period from 1990 to 2010 without hatchery supplementation and a λ of 0.577 assuming that 25 percent of naturally reared returns were from stocked hatchery fry. The general model was adjusted with a mean monthly smolt survival value of 0.6429 (the mean river survival normalized to monthly survival to be consistent with the model and estimated by $0.5155^{(1/1.5)}$) at Fort Point reported by Holbrook et al. (2011); a mean smolt to adult return rate of 0.007 from empirical data (see Section 4.1.1.); and a mean upstream cumulative survival of 0.7238 estimated for the baseline condition using Monte Carlo analysis, which is described below. The general model predicts λ for the Penobscot River as 0.652, which is close to (within 6 percent) the λ for wild fish of 0.613 estimated by Sweka and Bartron. Based on these three independent sources, the prediction of λ by the general model appears to be within the range approximated by either empirical data or other analytical methods using model parameters based on contemporary conditions (Table 4).

The general model includes some survival estimates that are calculated indirectly from empirical data. For example, the survival of kelts was calculated from empirically measured adult survival in freshwater and in the marine environment. Some of the model indirect survival estimates have been measured empirically and can be used to get a sense of the internal consistency in the model. Kocik et al. (2009) estimated post-smolt survival in the Narraguagus River using an acoustic array for six years from 1997 to 2004. They found that the first month mortality for smolt emigrating to offshore waters ranged from 53 to 64 percent (equating to survival ranging from 0.36 to 0.47). The stochastic model was used to estimate the estuarine and marine post-smolt survival via a Monte Carlo analysis (a statistical method described in Section 4.1.3) to develop a range of estimates for the model's survival parameter for estuarine smolt to the beginning of the first sea-winter phase (Robertson's S_psm parameter) through a 1.5 month period, the approximate length of Kocik et al.'s study. The S_psm parameter is one of several model parameters that is indirectly calculated (not a parameter that is estimated directly from empirical studies) so it is a good test of the internal consistency of the model. The stochastic model used a mean and standard deviation of in-river smolt survival of 0.8809 and 0.0038, respectively. These values were estimated through a Monte Carlo analysis of the in-river smolt survival estimates from Kocik et al. A mean smolt to adult return rate of 0.007 was also used in the analysis from empirical data (see Section 4.1.1.). The model estimates correspond closely with the empirical study. The stochastic model predicts a range of post-smolt survival from 0.33 to 0.47 whereas Kocik et al. found a range from 0.36 to 0.47 (Table 5). Robertson (2005) also reported a similar result when he compared his modeled results with preliminary results from Kocik's et al. study.

The general model provides the age distribution of the population, which can be compared to empirical data. As a Leslie matrix, the general model considers only females so the single sex limits the analysis that can be used because 1SW ("one sea-winter") adult salmon or grilse are nearly all male. The low return rate for 3SW ("three sea-winter") and MSW ("multisea-winter") adult salmon also makes it difficult to use those age classes because of the small sample size for wild fish.

Therefore, we compared the modeled and observed proportions of 2SW ("two sea-winter") adult salmon to check the model results. Table 6 presents the age distribution for adult returns to both rivers based on empirical (trap counts) and model proportions for 2SW fish. The general model predicts that 2SW fish would account for 85.5 and 83.7 percent of the proportion of 2SW, 3SW and MSW fish for the Penobscot and Narraguagus Rivers, respectively. The empirical data from 1993 to 2010 averages 96.5 and 92.5 percent for 2SW fish from the Penobscot and Narraguagus Rivers, respectively. The empirical data indicates that the model underestimates the proportion of 2SW fish by 9.5 to 11.4 percent, which appears to be reasonable considering the small number of wild origin fish and the recent changes that have affected the population due to the regime shift in marine conditions, hatchery practices, and declining populations. It is unlikely that the populations have had sufficient time or have achieved significant numbers of wild fish to attain a stable age distribution.

Non-equilibrium populations may show different response to perturbations than are predicted by the model, especially if the analysis focuses on elasticity or proportional response to a proportional perturbation in the matrix (Robertson 2005). Elasticity is often used to predict the relative influence of each life stage to λ or some other demographic measure. Our analysis is not using the model in this manner so the lack of a stable age structure may be less influential on the results. However, the lack of a stable age structure would be an issue with most modeling approaches and how it would affect the calculation of λ is unknown. A comparative analysis of alternatives where the change of λ is being measured, such as a LTRE, makes it more likely that the effect of an unstable age distribution would be similar under each alternative and therefore will have little influence on the outcome.

3.1.3 Method Used to Develop Alternatives

In order to construct the scenarios to compare baseline condition with the SPP or other alternatives, one must identify the life history stages that will be influenced by alternatives and then develop a method to determine the transition survival for those stages under each alternative. These transition survivals are then used in the LTRE to compare alternatives. Two statistical techniques, Monte Carlo Simulation and the Delta Method, were used to construct the transition survivals for the alternatives. Monte Carlo Simulation is a computer simulation that relies on repeated random sampling from a specified distribution to estimate a mean, variance and probability for a parameter. This method is often used when it is infeasible or sufficient data are lacking to compute an exact result. This technique generally requires one to define the range of possible values, generate a large number of values randomly from a probability distribution, aggregate the results and develop the estimate statistics. We largely use this approach to construct the smolt and adult transition survival estimates and to estimate λ from the stochastic model by: (1) assuming a normal distribution; (2) drawing from a domain of that distribution between the 5th and 95th percentiles (we excluded the extreme values represented in the tails of the distribution); (3) computing estimates from 10,000 random samples; and then (4) aggregating the data to estimate the mean, variance, and the primary percentiles. The Delta Method is a method for approximating the variance from arithmetic operations (division, multiplication) with means that uses the Taylor Series expansion. This technique is useful in developing a mean and variance of a parameter that was not measured but can be estimated using arithmetic operations from other measured parameters. We use this approach to estimate the other (or "natural") mortality - mortality that is not accounted for by the hydroelectric projects. Cumulative other or natural mortality was not measured as part of the available empirical studies so it must be calculated using the Delta Method.

Three life history stages are important to consider when evaluating the SPP relative to the baseline condition: smolt to adult survival (Robertson's S_sr parameter), smolt survival (Robertson's S_smolt), and adult in-river survival (Robertson's S_rm). Smolt to adult survival is used to calculate the marine survival stages in the model so it can be used to reflect the current regime shift in marine conditions and a change assuming that more favorable marine conditions occur in the future. The location of most hydroelectric projects on the Penobscot River in mainstem rivers limits their interaction with salmon to the migratory stages, namely the smolt stage during downstream passage and the adult in-river stages through both upstream passage (as fish entering the river to spawn) and downstream passage (as kelts or post-spawned fish leaving the river to enter the ocean). Our analysis assumes that the cumulative upstream passage efficiency at each dam is a proxy for survival because the empirical studies on the Penobscot River have focused on passage efficiency and not survival. We believe that this assumption is appropriate because: (1) salmon that spawn in the mainstem (the portion of fish that do not pass the dam) will experience lower reproductive success due to environmental conditions, such as elevated temperature, than fish that migrate higher in the watershed, (2) an assumption of no reproductive success (lower survival) leads to a more conservative analysis, and (3) the general model was validated using this approach and it predicted λ within the range of an independent estimate for the Penobscot River (J. Sweka and M. Bartron, unpublished data).

The three stages were varied to develop the Life Table Response Experiment (LTRE) scenarios for four alternatives: (1) the "Baseline" or pre-action condition; (2) the "MPA Only" or dam decommissioning under the MPA; (3) the "SPP (and MPA)" or alternative that includes the dam decommissioning in the "MPA Only" alternative along with the performance measures identified in the SPP; and (4) the "Unimpounded" or alternative without dams based on smolt survival estimates from unimpounded, demographically stable rivers in Canada (Table 7). The alternatives were used to assess the benefit of the "MPA Only" and the "SPP (and MPA)" alternatives relative to the baseline. The "Unimpounded" alternative was included only to understand how λ would respond if the smolt and adult in-river survival was comparable to unimpounded Canadian rivers that have stable populations of Altantic salmon (Restigouche and Miramichi Rivers). By including this alternative, we are not suggesting to remove additional dams; rather we want to better understand how sensitive λ may be to smolt and adult in-river survival within the range of survival that would be expected to occur in an unimpounded watershed with a stable population.

The LTRE also assesses conditions based on low (regime shift) and high (pre-regime shift) marine survival to evaluate what change in λ may result if marine survival improves to levels similar to what occurred before the regime shift. The low marine survival uses the empirical value for the smolt to adult return from the Narraguagus River (see Section 4.1.1). The high marine survival adopts those used by Robertson (2005) for pre-regime shift period from 1970 to 1984. We examine a low and high marine survival condition to understand if a positive population growth rate ($\lambda > 1$) can be achieved with the implementation of the SPP under each marine survival (low and high) condition. This is an important consideration in determining whether the SPP will result in a trend towards recovery and whether positive population growth is possible under pre-regime shift marine conditions. The LTRE smolt and adult in-river survival values in Table 7 were constructed accordingly:

Smolt Survival

1. Baseline

   "Baseline" smolt survival was approximated by using cumulative downstream survival estimates from Holbrook et al. (2011) during 2005 and 2006 and from upstream release sites on the Piscataquis and Penobscot River located above the hydroelectric project included in the SPP to Fort Point, Maine (Table 8). Monte Carlo methods were used to randomly draw 10,000 samples from Holbrook et al.'s six estimates to develop a mean survival and variance. Each Monte Carlo draw randomly selected one of six estimates and then randomly drew a value from a normal distribution constructed by the estimate's mean and standard deviation between the 5^{th} and 95^{th} percentile. The survival estimate was then normalized to the model by calculating monthly survival, assuming the survival in Holbrook (2011) represented the total survival of the model's smolt stage (1.5 months).

2. MPA Only

   The "MPA Only" smolt survival was approximated by two steps. First, Monte Carlo methods were used to determine the cumulative survival at the remaining hydroelectric projects assuming the decommissioning of three hydroelectric projects (the Veazie, Great Works and Howland Projects). Second, the survival estimate for other (or "natural") survival was multiplied by the cumulative hydroelectric project survival to arrive at a cumulative downstream survival and a variance using the Delta Method. For the first step, mean survival estimates for each hydroelectric project from Holbrook et al. (2011) were used except for the Mattaceunk Project, which was not included in their study. Therefore, the survival estimates for the West Enfield Project were used as a surrogate for the Mattaceunk Project. Monte Carlo methods were used to randomly draw 10,000 samples of cumulative hydroelectric project survival. Each Monte Carlo draw randomly selected a mean estimate for each hydroelectric project (each project had up to four mean estimates); randomly drew a value from a normal distribution constructed by each estimate's mean and standard deviation between the 5^{th} and 95^{th} percentile; randomly selected upstream starting points at either the Howland or Mattaceunk Projects; randomly selected a passage through either the Stillwater Branch (at a probability of 20 percent) or the Penobscot River (80 percent probability); and then multiplied each survival drawn for each project together to construct a cumulative hydroelectric project survival. This process was completed for 10,000 iterations to develop a mean cumulative hydroelectric project survival estimate and variance.

Currently, a small number of adult salmon return to areas of the Passadumkeag River upstream of the Lowell Tannery dam and to areas of the Piscataquis River upstream of the Brown's Mill, Moosehead Manufacturing, or Guilford dams so the hydroelectric projects associated with those dams were not included in estimating smolt survival (N. Dube, Maine Department of Marine Resources, 2012, personal communication). The SPP does not apply to those other project so their effect, if any, would also be consistent among the alternatives evaluated in the LTRE.

For the second step, it was necessary to approximate other or "natural" smolt survival – the cumulative survival in reaches that are not influenced by the hydroelectric projects, which was calculated using a simple arithmetic operation and the Delta Method ($S_{\text{other or "natural"}} = S_{\text{cumulative downstream}}/S_{\text{baseline cumulative hydroelectric}}$). The baseline cumulative hydroelectric project survival was estimated using the above method in step one by substituting Holbrook et al.'s survival estimates for the Veazie, Great Works and Howland Projects as opposed to those used assuming that the projects were decommissioned (Table 11). The cumulative downstream survival in the equation was calculated earlier (Table 8). The survival estimate for other (or "natural") survival was then multiplied with the cumulative hydroelectric project survival calculated in step one to arrive at the "MPA only" cumulative downstream survival and a variance using the Delta Method. This survival estimate was then normalized to the model by calculating monthly survival, assuming the survival in Holbrook (2011) represented the total survival of the model's smolt stage (1.5 months).

3. SPP (and MPA)

The "SPP (and MPA)" smolt survival was approximated by the same two step method that was used for the "MPA Only" alternative. First, Monte Carlo methods were used to determine the cumulative survival for the hydroelectric projects assuming the decommissioning of three hydroelectric projects (the Veazie, Great

Works and Howland Projects) and the implementation of the SPP downstream performance standard of 96 percent survival at the Orono, Stillwater, Milford and West Enfield Projects. Holbrook et al. (2011) did not include the Mattaceunk Project in their study so we use the smolt survival estimates at the West Enfield Project as a surrogate in the Monte Carlo simulation. Second, the survival estimate for other (or "natural") survival was multiplied with the cumulative hydroelectric project survival to arrive at a cumulative downstream survival and a variance using the Delta Method. The resulting "SPP (and MPA)" cumulative downstream survival and the values used in its construction are shown in Table 10.

4. Unimpounded

The "Unimpounded" smolt survival was approximated by using freshwater smolt survival estimates from the Miramichi (2003 to 2011) and Restigouche (2004 to 2011) Rivers in Canada (J. Carr, Atlantic Salmon Federation, 2011, personal communication) (Table 12). These data represent an unimpounded or unaltered condition that is similar to the Penobscot River: the Atlantic salmon populations are classified as stable (Parrish et al. 1998); the survival estimates were measured over river distances of 115.3 km (Restigouche) and 127.5 km (Miramichi), which approximates the distance to or above the most upstream major hydroelectric projects on the Penobscot and Piscataquis Rivers; the physiographic provinces and glacial history of the watersheds are similar; the study fish were of wild origin; and the data represent a relatively long record for survival estimates compared to other studies. The survival estimate was normalized to the model by calculating mean monthly survival, assuming that Carr's survival estimates represented the total survival of the model's smolt stage (1.5 months).

Adult In-River Survival

5. Baseline

"Baseline" cumulative adult in-river survival was approximated by using upstream fishway efficiency estimates from Holbrook et al. (2009) and from USFWS (1988) based on several studies completed for the hydroelectric projects between 1997 and 2006 (Table 13). Monte Carlo methods were used to randomly draw 10,000 samples of cumulative hydroelectric project survival. Each Monte Carlo simulation randomly drew a value from a normal distribution constructed by each project's upstream adult survival mean and standard deviation between the 5th and 95th percentile, randomly selected passage through either the Howland (Piscataquis River) or Great Works (Penobscot River) Projects at a probability of 50 percent, and then multiplied each survival drawn for each project together to construct a cumulative hydroelectric project survival. This process was completed for 10,000 iterations to develop a mean cumulative hydroelectric project survival estimate and variance. The survival estimate was then normalized to the model by calculating monthly survival, assuming the total survival of the model's upstream adult in-river stage (3.5 months).

6. MPA Only

The "MPA Only" cumulative adult in-river survival was approximated by using upstream fishway efficiency estimates from Holbrook et al. (2009) and from USFWS (1988) based on several studies completed for the hydroelectric projects between 1997 and 2006. It also assumes the decommissioning of the Veazie, Howland and

Great Works Hydroelectric Projects and an adult upstream survival of 1.00 or no mortality at those projects (Table 14). The same Monte Carlo methods that were used for the "Baseline" alterative were also used to develop a "MPA Only" mean cumulative hydroelectric project survival estimate and variance.

7. SPP (and MPA)

The "SPP (and MPA)" cumulative adult in-river survival was approximated by using upstream fishway efficiency estimates from USFWS (1988) developed for the Mattaceunk Project; it assumes the decommissioning of the Veazie, Howland and Great Works Hydroelectric Projects and an adult upstream survival of 1.00 or no mortality at those projects; and it assumes an upstream adult survival of 0.95 based on the performance standards at the Milford and West Enfield Projects (Table 15). The same Monte Carlo methods that were used for the "Baseline" alterative were also used to develop a "SPP (and MPA)" mean cumulative hydroelectric project survival estimate and variance.

8. Unimpounded

The "Unimpounded" upstream adult survival used the estimate in the general model developed by Robertson's (2005) of a mean of 0.9700 and a standard deviation 0.0001.

3.1.4 Results of the Life Table Response Experiments

Life Table Response Experiments were used to compare the four alternatives discussed above: "Baseline" – the baseline or pre-action condition; "MPA Only" – the project decommissions identified under the MPA; "SPP (and MPA)" – the action alternative that includes the SPP (and the elements in the MPA); and "Unimpounded" – a condition without dams using smolt survival estimates from unimpounded, demographically stable rivers in Canada. In the LTRE, we varied the vital rates (survival and fecundity) and the range of survivals that could be expected in the smolt to adult return, smolt and in-river returning adult stages for each alternative and for a low and high marine survival condition. Lambda was used as the comparative measure. Table 7 includes the eight LTRE scenarios and the transition survival used for each stage to construct the scenarios for the alternatives. The general and stochastic models were used to evaluate each scenario and the results are included in Table 16 and Figure 2. Lambda estimates are shown for both models. The "general model" represents the average or general case and it uses average values for the transition survival estimates from one stage to the next. The "stochastic model" selects the survival parameters for each stage randomly from the range of the survival estimates measured in field studies and used in the LTRE to estimate a mean, variance and probability distributions of potential outcomes based on 10,000 iterations. Table 16 includes the percentiles for λ as P1, P5, P20…P90, P95 and P99. These percentiles can be interpreted as the probability of meeting that value of lambda. We also follow Robertson's (2005) convention of constructing an 80 percent confidence (80% CI) interval for each mean value by using the interval between the P10 (the 10^{th} percentile) and P90 (the 90^{th} percentile) from the simulated results. Robertson chose the 80% CI to reflect a confidence interval that reduced the likelihood of the more extreme (and less probable) combinations of very poor survival occurring in several life history stages. This analysis and the LTREs should be used for comparative purposes only, how one scenario performs against another, since projected values of λ by a matrix model can overestimate empirical measured values because: (1) the model assumes that the population is at an equilibrium age-structure and it is unlikely that this condition occurs, (2) LTREs tend to overestimate λ in stochastic approaches, (3) the survival estimates and their probability density functions are difficult to measure and construct empirically (Robertson 2005, Caswell 2001).

The following results can be drawn from Table 16 and Figure 2:

1. The current low marine survival from the regime shift in marine condition significantly depresses the potential for population growth. None of the alternatives evaluated results in a $\lambda > 1$ under low marine survival within a reasonable probability;
2. The "Baseline" condition does not result in a $\lambda > 1$ under either low or high marine survival within a reasonable probability;
3. The "MPA Only" and "SPP (and MPA)" alternatives improve conditions over baseline by increasing the expected value of λ by 26.2 and 30.0 percent, respectively, under low marine survival and by 25.9 and 29.4 percent, respectively, under high marine survival;
4. The 80% CI shown in Figure 2 indicates that λ is highly variable large due to the wide range in the distributions of the survival estimates for each stage. This variability is relatively consistent among LTRE scenarios because: (1) only three out of the ten model stages were varied in analysis and (2) the distribution of the stages that were varied in the LTRE (the smolt to adult return, smolt, and in-river returning adult stages) were similar;

5. The “MPA Only” and “SPP (and MPA)” alternatives result in 50 percent or higher probability of $\lambda > 1$ for high marine survival scenario; and
6. The “SPP (and MPA)” alternative performs slightly worse than the “Unimpounded” alternative under both low and high marine survival. The “Unimpounded” alternative assumes smolt and adult in-river survivals that are comparable to Canadian rivers that have stable populations of Atlantic salmon.

3.2 Empirical Approach

The second method used to verify the reasonableness of SPP performance standard for smolt survival was an empirical approach. The results of in-river smolt survival studies were compiled for unimpounded sections of rivers with dams and for rivers without dams to understand the range of survival that could be expected under those conditions. These data are used to understand the range of smolt survival under naturogenic influences that occurs in rivers or river segments without significant impoundment influences or hydroelectric projects (Table 17).

We used smolt survival data for rivers in which Atlantic salmon populations were classified as stable by Parrish et al. (1998) and contain only wild fish. Only the rivers in New Brunswick and Quebec, Canada met these requirements, specifically the Cascapedia, Miramichi, Restigouche, St. Jean, and York Rivers. We standardized survival by calculating an instantaneous survival rate per kilometer (S/km). The stable populations had a mean survival rate of 0.9923 S/km, a minimum of 0.9662 S/km and a maximum of 0.9993 S/km (Table 18). The survival rates for the “Baseline” condition (mean survival of 0.5194 to Fort Point) and the SPP (mean survival of 0.7102) from the total reach length (123 km) in Holbrook et al. (2011) are 0.9957 and 0.9972 S/km, respectively. Using this measure, the SPP is above the median for stable rivers (53rd percentile) and the "Baseline" is below the median (41st percentile) (Table 18).

These results indicate that the SPP is comparable to stable rivers for smolt survival, which is consistent with the results from the life history model where the SPP performed slightly less than the "Unimpounded" alternative.

3.3 Spill Response Model

The third method used to verify the reasonableness of SPP performance standards for smolt survival was the development of a Spill Response Model. The model evaluates the effectiveness of concentrating and increasing the amount of spill on smolt survival to predict whether spill or reduced turbine operation, a fundamental assumption in the SPP, can be used to meet the performance standard. This model was used to assess whether the SPP and the use of spill is practicable and is able to meet the 96 percent survival standard for downstream fish passage.

The model was constructed with widely available commercial software (Microsoft Excel) and provided a method to compare scenarios by predicting the number of smolts that would survive at a hydroelectric project if spill is provided as a conservation measure. Although the original purpose of the model was to facilitate group discussion of the benefit of different operational changes, it also helped to verify that the SPP performance standards could be met using spill. The model scenarios are constructed by entering assumed values for turbine entrainment survival, the day the spill starts, the percent of fish that would migrate at night, the efficiency of the downstrean fish passage facility, and the amount of spill as a percentage of the river flow. The model results provide the total smolt survival and the proportion that use the spillway. It assumes that smolts will first choose the spillway; then the downstream bypass, and finally the turbines to pass by the project. The number of smolts passing each route is determined by the number of smolts that remain to pass and the efficiency of the passage route. For example, if 100 smolts are moving downstream and the passage efficiency is 50 percent for each routes then 50 fish would pass via the spillway (100*0.50); 25 fish would pass via the downstream bypass (50*0.50) and 13 fish would passage via turbine passage (25*0.50). The overall survival for this example would be 0.88 (calculated as (50+25+13)/100)).

There are two fundamental elements in the model: (1) a probability distribution that describes the downstream smolt migration timing and abundance and (2) a relation between the spill passage route and the amount of spill measured as a percent of total river flow. The probability distribution was developed from daily catch data collected below the Veazie Project from screw traps between 2000 and 2005 (C. Lipsky, National Marine Fisheries Service, 2011, personal communication). A Cauchy probability density function was developed from the data to estimate smolt abundance based on calendar day (Table 19). The relation between the spill passage route and the amount of spill was developed by Shepard (1991). Shepard studied the passage route selection using radio telemetry at the Veazie, Orono, and West Enfield Projects on the Penobscot River. During Shepard's studies, the percent river flow, percent spill relative to total river flow, and the percent spillway smolt passage were measured at each project. A linear regression was developed between percent spillway passage of fish and percent spill relative to total river flow (Table 20; [percent spillway passage] = 1.15*[% spill], r^2 = 0.934). The model calculates a range of survival rates based on the confidence bands of the regression analysis. The minimum is the lower bound of the 95% confidence band, the mean is the predicted regression line, and the maximum is the upper bound of the 95% confidence band. The relation between the spill passage route and the amount of spill is used to predict how many fish will use the spillway for downstream passage, and the Cauchy probability density function is used to estimate the number or portion of fish that are affected by the number of days that spill is provided at the project.

In order to evaluate the SPP, the assumed values for turbine entrainment survival, the day the spill starts, the percent of fish that would migrate at night, and the efficiency of the downstream fish passage facility must be specified. We used the values reported in the literature for most of these parameters (Table 24). The starting day was set as May 1 when the run typically starts in earnest (> 5 percent, Table 19); turbine entrainment survival was taken from a recent study by NMFS (Table 21); the proportion of nocturnal migration was taken from field or experimental studies of smolt movement (Table 22); and the range of efficiency for downstream fish passage facilities was compiled from fishway efficiency studios at hydroelectric projects (Table 23). We evaluated the most restrictive step in the SPP adaptive management framework, specifically: "Two weeks of 100% spill of river flow at night (except for one unit, which will be operated at its lowest possible setting as required for powerhouse startup), followed by two weeks of spill at 25% of river flow during day and night."

The scenarios evaluated for the SPP ranged from "not likely" to "likely." That is, the "not likely" scenario used minimum values for the turbine entrainment, percent nocturnal migration, and downstream fish passage efficiency parameters; the "less likely" scenario used the 25th and 75th percentile values for the parameters and the "most likely" scenario used the 50th percentile value for the parameters (Table 24). The results are included in Table 25. All of the scenarios met the downstream performance standard except for the "not likely" scenario, which had a range for survival of 0.9196 to 0.9235. These results appear to suggest that the SPP should have a high likelihood of meeting the performance standard under all but the most conservative of assumptions (the use of the minimum values for the parameters).

4.0 Summary

Our analytical approach used three methods to confirm the reasonableness of the SPP: (1) a life history model was constructed using matrix population modeling techniques to compare the existing baseline to the condition that would occur through the implementation of the SPP; (2) in-river smolt survival studies were compiled to understand the range of survival that could be expected under naturogenic influences that occur in rivers or river segments without significant impoundment influences or hydroelectric projects; and (3) a spill response model was constructed to predict the likelihood of meeting the 96 percent downstream performance standard for smolts through the implementation of the SPP. Based on the results of these analyses, it is our opinion that implementing the SPP together with the MPA will significantly improve the baseline condition and that the measures in the SPP are likely to meet the performance standards. The most relevant conclusions are:

1. None of the alternatives evaluated results in a $\lambda > 1$ under current low marine survival within a reasonable probability;
2. The "Baseline" condition does not result in a $\lambda > 1$ under either low or high marine survival within a reasonable probability;
3. Implementation of the SPP together with the MPA significantly improves conditions over the baseline by increasing λ by 30.0 percent under low marine survival and 29.4 percent under high marine survival;
4. Implementation of the SPP together with the MPA results in a $\lambda > 1$ during high marine survival with a high degrees of certainty – a 75 percent probability;
5. The smolt survival under the SPP together with the MPA is within the range of survival comparable to Canadian rivers that have stable populations of Atlantic salmon;
6. Implementation of the SPP together with the MPA has a high likelihood of meeting the smolt performance standard. It also has a high likelihood of meeting the adult performance standard given that three of six projects covered in the SPP will be providing volitional passage (dam removal or bypass channel); two of the projects are not located in the primary upstream migratory route (Stillwater and Orono Project); and the remaining two either have or will soon have state-of-the-art fishways and/or have demonstrated relative high fish passage efficiency (Milford and West Enfield Projects).

Implementation of the SPP together with the MPA should meaningfully improve conditions for Atlantic salmon on the Penobscot River. It should appreciably improve the conservation status of the species by increasing λ over that of the baseline. It should result in a "trending towards recovery" by improving the baseline condition and by moving the species closer to recovery. It should not deepen the current low population viability largely caused by low marine survival resulting from the regime shift in marine conditions. And its implementation will likely result in a positive growth rate if marine conditions improve to levels that approach pre-regime shift conditions. The implementation of the SPP together with the MPA may therefore have a beneficial effect to the conservation of the species.

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Figure 1. Penobscot River watershed showing hydroelectric projects and major dams.

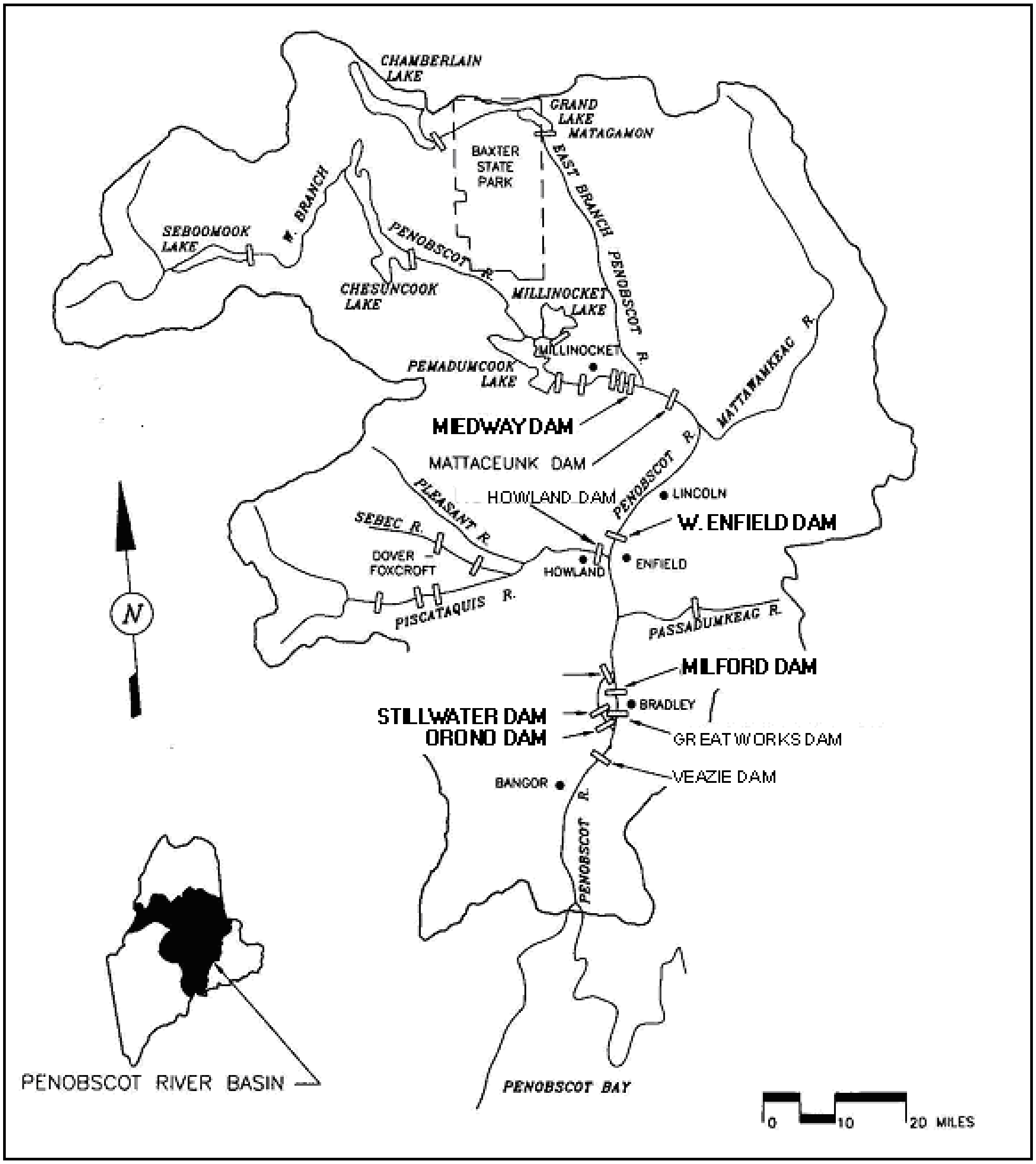

Table 1. Overall survival from smolt to adult return for the Narraguagus River

Year	Number of Smolts	Number of Adult Returns	Return Rate
1997	2898	24	0.00828
1998	2866	16	0.00558
1999	4346	35	0.00805
2000	2094	8	0.00382
2001	2621	25	0.00954
2002	1800	10	0.00556
2003	1368	13	0.00950
2004	1344	13	0.00967
2005	1298	12	0.00924
2006	2612	2	0.00077
		Mean	0.0070
		Std. Dev.	0.0030

Table 2. Comparison of the minimum and maximum used by Robertson (2005) with those drawn from a normal distribution between probabilities of 0.025 and 0.975.

	Robertson (2005)			Simulated			
Model Parameter[4]	Mean	Min	Max	Approx. Std Dev	Mean	Min	Max
S_e	0.1650	0.0800	0.3500	0.0675	0.1631	0.0338	0.2973
S_fp	0.3250	0.2100	0.4800	0.0675	0.3260	0.1938	0.4562
S_ps	0.3350	0.0500	0.5500	0.1250	0.3426	0.0900	0.5779
S_p	0.9458	0.8672	0.9695	0.0256	0.9463	0.8957	0.9959
S_sr[5]	0.0110	0.0050	0.0400	0.0088	0.0109	-0.0060	0.0280
R_2SW	0.9500	0.9100	0.9900	0.0200	0.9497	0.9111	0.9873
S_kr	0.1000	0.0100	0.1500	0.0350	0.1032	0.0314	0.1686
F_2SW	3780	2732	5659	732	3794	2393	5202
F_3SW	5100	5009	5844	209	5106	4691	5493
F_MSW	5675	5285	10382	1274	5673	3220	8172

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[4] Model parameter and explanation from Robertson (2005)

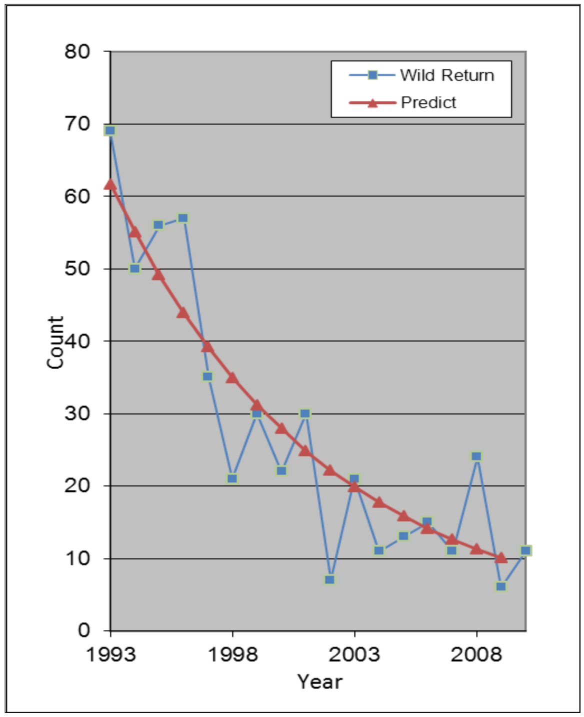
Model Parameter	Explanation
S_e	Overall survival from egg to fry, including egg, eyed egg and alevin (sac-fry) phases (1 November to mid-May; 6.5 months).
S_fp	Overall survival from fry to 1 parr, including fry and 0+ parr phases (mid-May to 31 December; 7.5 months).
S_ps	Overall survival from 1 parr to end of freshwater smolt phase, including 1 parr, 1+ parr, 2 parr, freshwater smolt, and sometimes 2+ parr and 3 parr phases (1 January of 1st year after hatch to mid-May of 2+ or 3+ year; 16.5 or 28.5 months).
S_p	Monthly survival during parr and freshwater smolt phases.
S_sr	Overall survival from estuarine smolt to return as 2SW or 3SW spawner, including the estuarine smolt, post-smolt, 1SW, 2SW and sometimes 3SW phases (mid-May of smolt year to mid-July after 2 or 3 winters at sea; 26 or 38 months)
R_2SW	The proportions of females exiting the 2SWreturn and 3SW-return life histories, as measured by the run-composition at time of return (mid-July).
S_kr	Overall survival from maiden spawn (1 November of 2SW or 3SW return year) to mid-July return after two winters at sea, including kelt, post-kelt and MSW salmon phases (20.5 months).
F_2SW	Fecundity (number of female eggs) per 2SW spawner.
F_3SW	Fecundity (number of female eggs) per 3SW spawner.
F_MSW	Fecundity (number of female eggs) per MSW (repeat) spawner.

[5] The simulated results for S_sr indicated a negative minimum value suggesting that a triangular distribution was more suitable for that analysis than a normal distribution.

Table 3. Calculation of λ for wild origin Atlantic salmon from the Narraguagus River 1993 to 2010

Narraguagus River Wild Origin Atlantic Salmon

Year	1SW	2SW	3SW	Repeat	Total Return
1993	6	61	0	2	69
1994	4	42	0	4	50
1995	0	51	0	5	56
1996	9	43	0	5	57
1997	1	30	0	4	35
1998	1	18	0	2	21
1999	6	23	0	1	30
2000	13	8	0	1	22
2001	5	22	2	1	30
2002	4	3	0	0	7
2003	0	21	0	0	21
2004	1	8	1	1	11
2005	1	12	0	0	13
2006	3	12	0	0	15
2007	2	9	0	0	11
2008	4	18	1	1	24
2009	1	5	0	0	6
2010	3	6	0	2	11



Exponential Regression

Parameter	Est value	St dev
b0	229.704	38.158
b1	-0.113	0.019
λ	0.893	

Residual St dev	0.419636
R2	0.68798
R2(adj)	0.668479
F	35.2788
Prob(>F)	2.08E-05

Table 4. Comparison of λ for Atlantic salmon predicted by the general model with either empirical data or other independent sources.

Source	Method	λ	General Model, λ
Empirical	Exponential regression of Narraguagus River Wild Returns 1993 to 2010	0.893	0.873
Legault (2005)	Diffusion approximation for Narraguagus River	0.889	0.873
Sweka and Bartron (unpublished data)	Improved diffusion approximation for Penobscot River (wild only) 1990 to 2010	0.613	0.652

Table 5. Stochastic model results from marine post-smolt survival for the Narraguagus River based on a Monte Carlo analysis of 10,000 iterations

Statistic	Model Survival Estimate	Kocik et al. (2009)
Min	0.3314	0.36
p1	0.3495	
p5	0.3695	
p10	0.3829	
p20	0.3968	
p25	0.4024	
p50	0.4212	
p75	0.4372	
p80	0.4409	
p90	0.4499	
p95	0.4558	
p99	0.4634	
Max	0.4720	0.47
Mean	0.4182	
Variance	0.0007	

Table 6. Age distribution for adult returns to the Penobscot and Narraguagus Rivers based on trap counts and proportion of 2SW from empirical and modeled results.

Narraguagus River Wild Origin

Year	1SW	2SW	3SW	Repeat	Total	% 2SW
1993	6	61	0	2	63	96.8
1994	4	42	0	4	46	91.3
1995	0	51	0	5	56	91.1
1996	9	43	0	5	48	89.6
1997	1	30	0	4	34	88.2
1998	1	18	0	2	20	90.0
1999	6	23	0	1	24	95.8
2000	13	8	0	1	9	88.9
2001	5	22	2	1	25	88.0
2002	4	3	0	0	3	100.0
2003	0	21	0	0	21	100.0
2004	1	8	1	1	10	80.0
2005	1	12	0	0	12	100.0
2006	3	12	0	0	12	100.0
2007	2	9	0	0	9	100.0
2008	4	18	1	1	20	90.0
2009	1	5	0	0	5	100.0
2010	3	6	0	2	8	75.0
Mean						92.5

% 2SW

River	General Model	Mean Estimate[6]
Narraguagus	83.7	92.5
Penobscot	85.5	95.5

Penobscot River Wild Origin

Year	1SW	2SW	3SW	Repeat	Total	% 2SW
1993	22	92	1	6	99	92.9
1994	48	93	0	6	99	93.9
1995	6	84	0	1	85	98.8
1996	13	335	3	5	343	97.7
1997	6	174	2	1	177	98.3
1998	29	130	1	4	135	96.3
1999	46	110	0	10	120	91.7
2000	17	70	0	2	72	97.2
2001	24	98	2	0	100	98.0
2002	14	41	1	2	44	93.2
2003	6	56	0	2	58	96.6
2004	5	59	3	2	64	92.2
2005	6	22	0	2	24	91.7
2006	15	33	0	0	33	100.0
2007	35	88	0	0	88	100.0
2008	23	80	0	0	80	100.0
2009	12	74	1	0	75	98.7
2010	23	53	0	0	53	100.0
Mean						96.5

[6] The mean calculated for the proportion of 2SW from the empirical data assumes a 1:1 male:female ratio for all years.

Table 7. Life Table Response Experiment (LTRE) scenarios and transition survival used for the smolt to adult return, smolt and adult in-river stages for four alternatives: (1) the "Baseline" or pre-action condition; (2) the "MPA Only" or dam decommissioning under the MPA; (3) the "SPP (and MPA)" or alternative that includes the performance measures and elements of the MPA; and (4) the "Unimpounded" or alternative without dams based on smolt survival estimates from unimpounded, demographically stable rivers in Canada. Robertson's (2005) model variable names are indicated parenthetically.

	Smolt to Adult Return (S_sr)				Smolt (S_smolt)		Adult In-river (S_rm)	
LTRE Scenario	Mean	Std. Dev.	Min.	Max	Mean	Std. Dev.	Mean	Std. Dev.
Baseline / Low Marine Survival	0.0070	0.0024	0.0021	0.0119	0.6429	0.0995	0.7238	0.0904
Baseline / High Marine Survival	0.0304	0.0104	0.0090	0.0519	0.6429	0.0995	0.7238	0.0904
MPA Only / Low Marine Survival	0.0070	0.0024	0.0021	0.0119	0.7387	0.1685	0.9460	0.0322
MPA Only / High Marine Survival	0.0304	0.0104	0.0090	0.0519	0.7387	0.1685	0.9460	0.0322
SPP (and MPA) / Low Marine Survival	0.0070	0.0024	0.0021	0.0119	0.7914	0.1604	0.9669	0.0201
SPP (and MPA) / High Marine Survival	0.0304	0.0104	0.0090	0.0519	0.7914	0.1604	0.9669	0.0201
Unimpounded / Low Marine Survival	0.0070	0.0024	0.0021	0.0119	0.8458	0.0912	0.9700	0.0001
Unimpounded / High Marine Survival	0.0304	0.0104	0.0090	0.0519	0.8458	0.0912	0.9700	0.0001

Table 8. Cumulative smolt survival from upstream release sites on the Penobscot and Piscataquis River to Fort Point, Maine from Holbrook et al. (2011)

Release Site	Year	Type	Mean	Std. Dev.
Piscataquis River	2005	Hatchery	0.5990	0.0570
Piscataquis River	2006	Hatchery	0.4540	0.0480
Penobscot River	2006	Hatchery	0.5300	0.0430
Penobscot River	2005	Wild	0.6840	0.0820
Penobscot River	2005	Hatchery	0.3930	0.1340
Penobscot River	2006	Wild	0.4580	0.1020

Monte Carlo Simulation

	Mean	Variance	Std. Dev.	Iterations
Cumulative Downstream Survival	0.5194	0.0137	0.1172	10,000
Cumulative Monthly Downstream Survival	0.6429	0.0099	0.0995	10,000

Table 9. Smolt survival for hydroelectric projects on the Penobscot River from Holbrook et al. (2011) for the "MPA only" alternative[7]

Hydroelectric Project	Year	Type	Mean	Std. Dev.
West Enfield	2005	Wild	0.9050	0.0680
West Enfield	2006	Hatchery	0.8200	0.0420
West Enfield	2006	Wild	0.8700	0.0700
Howland			1.0000	0.0001
Milford	2005	Hatchery	0.9160	0.0430
Milford	2005	Wild	0.9410	0.0880
Milford	2006	Hatchery	0.8150	0.0370
Milford	2006	Wild	0.8460	0.1000
Great Works			1.0000	0.0001
Sillwater	2005	Hatchery	1.0000	0.0001
Stillwater	2005	Wild	0.8460	0.1410
Stillwater	2006	Hatchery	1.0000	0.0001
Orono[8]	2005	Hatchery	1.0000	0.0001
Orono[5]	2005	Wild	1.0000	0.0001
Orono[5]	2006	Hatchery	1.0000	0.0001
Orono[5]	2006	Wild	1.0000	0.0001
Veazie			1.0000	0.0001

Monte Carlo Simulation

	Mean	Variance	Std. Dev.	Iterations
Cumulative Hydroelectric Proj. Survival	0.7861	0.0220	0.1484	10,000
Cumulative Monthly Hydro. Proj. Survival	0.8485	0.0117	0.1083	10,000
Other or Natural Survival	0.8706	0.0271	0.1646	
Cumulative Total Monthly Survival	0.7389	0.0284	0.1685	Delta Method

[7] The "MPA only" alterative assumes the decommissioning of the Veazie, Howland and Great Works Hydroelectric Projects. For this alternative, the smolt survival was assumed to be 1.00 or no mortality.

[8] Holbrook et al. (2011) studied smolt survival 2005 and 2006 when the Orono Project was not operating because of a penstock failure. The survival estimates for the Stillwater Project were used in the analysis to represent the likely range of survival for the Orono Project if it was operating.

Table 10. Smolt survival for hydroelectric projects on the Penobscot River from Holbrook et al. (2011) for the "SPP (and MPA)" alternative[9]

Hydroelectric Project	Year	Type	Mean	Std. Dev.
Mattaceunk[10]	2005	Wild	0.9050	0.0680
Mattaceunk	2006	Hatchery	0.8200	0.0420
Mattaceunk	2006	Wild	0.8700	0.0700
West Enfield		Perf. Std.	0.9600	0.0430
Howland		Decommission	1.0000	0.0001
Milford		Perf. Std.	0.9600	0.0430
Great Works		Decommission	1.0000	0.0001
Sillwater		Perf. Std.	0.9600	0.0245
Orono		Perf. Std.	0.9600	0.0245
Veazie		Decommission	1.0000	0.0001

Monte Carlo Simulation

	Mean	Variance	Std. Dev.	Iterations
Cumulative Hydro. Proj. Survival	0.8703	0.0087	0.0935	10,000
Cumulative Monthly Hydro. Proj. Survival	0.9091	0.0044	0.0661	10,000
Other or Natural Survival	0.8706	0.0271	0.1646	
Cumulative Total Monthly Survival	0.7914	0.0257	0.1604	Delta Method

[9] The "SPP and MPA" alterative assumes the decommissioning of the Veazie, Howland and Great Works Hydroelectric Projects and a smolt survival of 1.00 or no mortality at those projects. It also assumes a smolt survival of 0.96 with a three percent standard deviation (0.0245) based on the performance standards at the Orono, Stillwater, Milford and West Enfield Projects.

[10] Holbrook et al. (2011) did not include the Mattaceunk Project in their study. This analysis uses their smolt survival estimates at the West Enfield Project as a surrogate.

Table 11. Smolt survival for hydroelectric projects on the Penobscot River from Holbrook et al. (2011) used to calculate other or "natural" survival[11]

Hydroelectric Project	Year	Type	Mean	Std. Dev.
West Enfield	2005	Wild	0.9050	0.0680
West Enfield	2006	Hatchery	0.8200	0.0420
West Enfield	2006	Wild	0.8700	0.0700
Howland	2005	Hatchery	0.7920	0.0640
Howland	2006	Hatchery	0.7110	0.0570
Milford	2005	Hatchery	0.9160	0.0430
Milford	2005	Wild	0.9410	0.0880
Milford	2006	Hatchery	0.8150	0.0370
Milford	2006	Wild	0.8460	0.1000
Great Works	2005	Hatchery	0.9540	0.0370
Great Works	2005	Wild	1.0000	0.0001
Great Works	2006	Hatchery	0.9880	0.0120
Great Works	2006	Wild	0.9090	0.0870
Sillwater	2005	Hatchery	1.0000	0.0001
Stillwater	2005	Wild	0.8460	0.1410
Stillwater	2006	Hatchery	1.0000	0.0001
Orono[12]	2005	Hatchery	1.0000	0.0001
Orono[9]	2005	Wild	1.0000	0.0001
Orono[9]	2006	Hatchery	1.0000	0.0001
Orono[9]	2006	Wild	1.0000	0.0001
Veazie	2005	Hatchery	1.0000	0.0001
Veazie	2005	Wild	1.0000	0.0001
Veazie	2006	Hatchery	0.9670	0.0190
Veazie	2006	Wild	1.0000	0.0001

	Mean	Variance	Std. Dev.	
Cumulative Monthly Hydro. Proj. Survival	0.7384	0.0064	0.0803	
Cumulative Monthly Downstream Survival	0.6429	0.0099	0.0995	See Table 8
Cumulative Monthly Other or "Natural" Survival	0.8706	0.0271	0.1646	Delta Method

[11] Other or "natural" smolt survival is the cumulative survival in reaches that are not influenced by the hydroelectric projects.
[12] Holbrook et al. (2011) studied smolt survival 2005 and 2006 when the Orono Project was not operating because of a penstock failure. The survival estimates for the Stillwater Project were used in the analysis to represent the likely range of survival for the Orono Project if it was operating.

Table 12. Freshwater smolt survival from the Miramichi (2003 to 2011) and Restigouche (2004 to 2011) Rivers in Canada using acoustic telemetry methods (J. Carr, Atlantic Salmon Federation, 2011, personal communication)

Province	River	Type	Release Distance (km)	Year	Survival	Monthly Survival
New Brunswick	Miramichi	Wild	127.5	2003	0.91	0.939
New Brunswick	Miramichi	Wild	127.5	2004	0.81	0.869
New Brunswick	Miramichi	Wild	127.5	2005	0.90	0.932
New Brunswick	Miramichi	Wild	127.5	2006	0.85	0.897
New Brunswick	Miramichi	Wild	127.5	2007	0.91	0.939
New Brunswick	Miramichi	Wild	127.5	2008	0.88	0.918
New Brunswick	Miramichi	Wild	127.5	2009	0.63	0.735
New Brunswick	Miramichi	Wild	127.5	2010	0.81	0.869
New Brunswick	Miramichi	Wild	127.5	2011	0.83	0.883
New Brunswick	Restigouche	Wild	115.3	2004	0.61	0.719
New Brunswick	Restigouche	Wild	115.3	2005	0.78	0.847
New Brunswick	Restigouche	Wild	115.3	2006	0.80	0.862
New Brunswick	Restigouche	Wild	115.3	2007	0.82	0.876
New Brunswick	Restigouche	Wild	115.3	2008	0.74	0.818
New Brunswick	Restigouche	Wild	115.3	2009	0.75	0.826
New Brunswick	Restigouche	Wild	115.3	2010	0.80	0.862
New Brunswick	Restigouche	Wild	115.3	2011	0.45	0.587
Mean					0.78	0.846
Std. Dev.					0.12	0.091

Table 13. Upstream adult survival for hydroelectric projects on the Penobscot River from Holbrook et al. (2009)[13] and USFWS (1988)[14] used to calculate cumulative upstream passage efficiency for the "Baseline" alternative.

Hydroelectric Project	Source	N	Mean	Std. Dev.
Veazie	Holbrook et al. (2009)	10	0.6485	0.1907
Great Works	Holbrook et al. (2009)	10	0.6730	0.2783
Milford	Holbrook et al. (2009)	10	0.8993	0.0958
Howland	USFWS (1988)		0.9200	0.0325
West Enfield	USFWS (1988)		0.9200	0.0325
Mattaceunk	USFWS (1988)		0.9200	0.0325

Monte Carlo Simulation

	Mean	Variance	Std. Dev.	Iterations
Cumulative Monthly Hydro.Proj. Survival	0.7238	0.0082	0.0904	10,000

[13] Holbrook et al. (2009) reported annual estimates for a 10-year period from 1987-1982, 1990, 1992 and 2002-2006.

[14] USFWS (1988) upstream passage efficiency estimates from the ASAL model were used for the Howland, West Enfield and Mattaceunk Projects because little empirical data was available for these projects. The ASAL model used an expert panel to approximate the upstream passage efficiencies at each project using a median of 0.92, a minimum of 0.85 and a maximum of 0.98. The standard deviation was estimated as 0.0325 by dividing the range by four. The ASAL model estimates are consistent with the limited fishway efficiency studies that have been completed at these projects. Shepard (1995) and Shepard and Hall (1991) estimated a mean upstream efficiency for the West Enfield/Howland Projects of 0.917 based on three years of study in 1989, 1990 and 1992 (fishway efficiency estimates of 0.90, 1.00 and 0.85, respectively). Bernier (1986) estimated a mean of 0.833 based on one year of study in 1986 (three replicates of 0.89, 0.90 and 0.71). Both studies identified the difficulty in using hatchery fish because of their reduced homing tendency that may have resulted in less purposeful upstream migration characteristic of wild fish.

Table 14. Upstream adult survival for hydroelectric projects on the Penobscot River from Holbrook et al. (2009)[15] and USFWS (1988)[16] used to calculate cumulative upstream passage efficiency for the "MPA Only" alternative[17].

Hydroelectric Project	Source	N	Mean	Std. Dev.
Veazie	Decommission		1.000	0.0001
Great Works	Decommission		1.000	0.001
Milford	Holbrook et al. (2009)	10	0.8993	0.0958
Howland	Decommission		1.000	0.0001
West Enfield	USFWS (1988)		0.9200	0.0325
Mattaceunk	USFWS (1988)		0.9200	0.0325

Monte Carlo Simulation

	Mean	Variance	Std. Dev.	Iterations
Cumulative Monthly Hydro. Proj. Survival	0.9460	0.0010	0.0322	10,000

[15] Holbrook et al. (2009) reported annual estimates for a 10-year period from 1987-1982, 1990, 1992 and 2002-2006.

[16] USFWS (1988) upstream passage efficiency estimates from the ASAL model were used for the Howland, West Enfield and Mattaceunk Projects because little empirical data was available for these projects. The ASAL model used an expert panel to approximate the upstream passage efficiencies at each project using a median of 0.92, a minimum of 0.85 and a maximum of 0.98. The standard deviation was estimated as 0.0325 by dividing the range by four. The ASAL model estimates are consistent with the limited fishway efficiency studies that have been completed at these projects. Shepard (1995) and Shepard and Hall (1991) estimated a mean upstream efficiency for the West Enfield/Howland Projects of 0.917 based on three years of study in 1989, 1990 and 1992 (fishway efficiency estimates of 0.90, 1.00 and 0.85, respectively). Bernier (1986) estimated a mean of 0.833 based on one year of study in 1986 (three replicates of 0.89, 0.90 and 0.71). Both studies identified the difficulty in using hatchery fish because of their reduced homing tendency that may have resulted in less purposeful upstream migration characteristic of wild fish.

[17] The "MPA only" alterative assumes the decommissioning of the Veazie, Howland and Great Works Hydroelectric Projects and an adult upstream survival of 1.00 or no mortality at those projects.

Table 15. Upstream adult survival for hydroelectric projects on the Penobscot River from USFWS (1988)[18] used to calculate cumulative upstream passage efficiency for the "SPP (and MPA)" alternative[19].

Hydroelectric Project	Source	Mean	Std. Dev.
Veazie	Decommission	1.000	0.0001
Great Works	Decommission	1.000	0.0001
Milford	SPP	0.9500	0.0201
Howland	Decommission	1.000	0.0001
West Enfield	SPP	0.9500	0.0201
Mattaceunk	USFWS (1988)	0.9200	0.0325

Monte Carlo Simulation

	Mean	Variance	Std. Dev.	Iterations
Cumulative Monthly Hydro. Proj. Survival	0.9669	0.0004	0.0201	10,000

[18] USFWS (1988) upstream passage efficiency estimates from the ASAL model were used for the Howland, West Enfield and Mattaceunk Projects because little empirical data was available for these projects. The ASAL model used an expert panel to approximate the upstream passage efficiencies at each project using a median of 0.92, a minimum of 0.85 and a maximum of 0.98. The standard deviation was estimated as 0.0325 by dividing the range by four.

[19] The "SPP (and MPA)" alterative assumes the decommissioning of the Veazie, Howland and Great Works Hydroelectric Projects and an upstream adult survival of 1.00 or no mortality at those projects. It also assumes an upstream adult survival of 0.95 with a three percent standard deviation (0.0201) based on the performance standards at the Milford and West Enfield Projects.

Table 16. Life Table Response Experiment (LTRE) results. The table includes model predictions of λ for each LTRE scenario ("Baseline", "MPA Only", "SPP (and MPA)", and "Unimpounded" alternatives) under a low and high marine survival condition. Lambda estimates are shown for both the general and stochastic models. The "general model" represents the average or general case and it uses average values for the transition survival estimates from one stage to the next. The "stochastic model" randomly selects the survival parameters for each stage from the range of the survival estimates measured in field studies and used in the LTRE (Table 7) to estimate a mean, variance and probability distributions of potential outcomes based on 10,000 iterations.

	General Model	Stochastic Model (λ)														
LTRE Scenario	λ	Mean	Var.	Min.	P1	P5	P10	P20	P25	P50	P75	P80	P90	P95	P99	Max.
Baseline / Low Marine Survival	0.65	0.64	0.01	0.35	0.45	0.50	0.53	0.56	0.58	0.64	0.70	0.72	0.76	0.79	0.86	1.03
Baseline / High Marine Survival	0.85	0.84	0.01	0.47	0.58	0.65	0.68	0.73	0.75	0.83	0.91	0.94	0.99	1.04	1.14	1.34
MPA Only / Low Marine Survival	0.82	0.80	0.01	0.44	0.59	0.64	0.68	0.72	0.73	0.80	0.87	0.89	0.94	0.98	1.05	1.23
MPA Only / High Marine Survival	1.07	1.05	0.02	0.61	0.76	0.83	0.87	0.93	0.95	1.04	1.14	1.16	1.22	1.28	1.38	1.55
SPP (and MPA) / Low Marine Survival	0.85	0.83	0.01	0.51	0.62	0.67	0.70	0.74	0.76	0.83	0.90	0.92	0.97	1.01	1.08	1.22
SPP (and MPA) / High Marine Survival	1.10	1.08	0.02	0.66	0.78	0.86	0.91	0.96	0.99	1.08	1.18	1.20	1.26	1.32	1.42	1.62
Unimpounded / Low Marine Survival	0.86	0.85	0.01	0.53	0.64	0.69	0.72	0.77	0.78	0.85	0.92	0.94	0.98	1.02	1.09	1.20
Unimpounded / High Marine Survival	1.14	1.11	0.02	0.66	0.82	0.90	0.94	1.00	1.02	1.10	1.20	1.22	1.28	1.33	1.42	1.54

Figure 2. Life Table Response Experiment (LTRE) results. The figure is based on results presented in Table 16. It includes model predictions of λ for each LTRE scenario ("Baseline", "MPA Only", "SPP (and MPA)", and "Unimpounded" alternatives) under a low and high marine survival condition. Lambda estimates are shown for the "stochastic model", which randomly selects the survival parameters for each stage from the range of the survival estimates measured in field studies and used in the LTRE (Table 7) to estimate a mean and the probability distributions of potential outcomes based on 10,000 iterations. The confidence interval (80% CI) shown is the interval for each mean between the P10 (the 10th percentile) and P90 (the 90th percentile) from the simulated results.

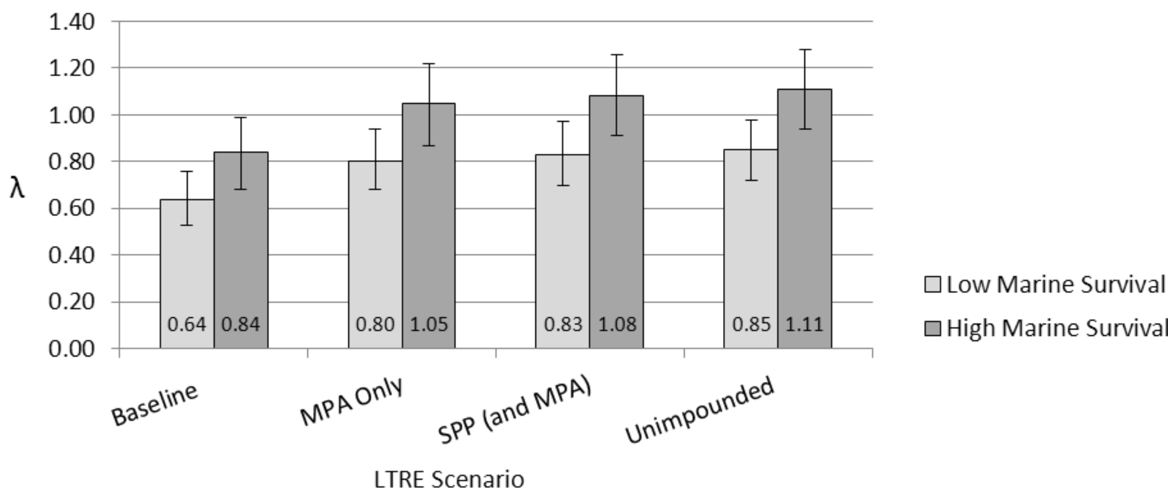


Table 17. Compilation of empirical results for published and unpublished smolt survival studies in the United States, Canada and Europe.

Country	Locality	River	Status [20]	Type[21]	Smolt	Dist. (km)	Telemetry Method	Year	Survival	N	Inst. S rate/km[22]	Source
Canada	Quebec	Cascapedia	Stable	Unaltered	Wild	8.1	Acoustic	2005	0.757		0.9662	C. Carr, pers. comm. 2011
Canada	Quebec	Cascapedia	Stable	Unaltered	Wild	8.1	Acoustic	2006	0.944		0.9929	C. Carr, pers. comm. 2011
Canada	Quebec	Cascapedia	Stable	Unaltered	Wild	8.1	Acoustic	2007	0.757		0.9662	C. Carr, pers. comm. 2011
Canada	Quebec	Cascapedia	Stable	Unaltered	Wild	8.1	Acoustic	2008	0.953		0.9941	C. Carr, pers. comm. 2011
Canada	Quebec	Cascapedia	Stable	Unaltered	Wild	8.1	Acoustic	2009	0.851		0.9802	C. Carr, pers. comm. 2011
Canada	Quebec	Cascapedia	Stable	Unaltered	Wild	8.1	Acoustic	2010	0.981	40	0.9977	C. Carr, pers. comm. 2011
Canada	New Brunswick	Miramichi	Stable	Unaltered	Wild	127.5	Acoustic	2003	0.910		0.9993	C. Carr, pers. comm. 2011
Canada	New Brunswick	Miramichi	Stable	Unaltered	Wild	127.5	Acoustic	2004	0.810		0.9983	C. Carr, pers. comm. 2011
Canada	New Brunswick	Miramichi	Stable	Unaltered	Wild	127.5	Acoustic	2005	0.900	25	0.9992	C. Carr, pers. comm. 2011
Canada	New Brunswick	Miramichi	Stable	Unaltered	Wild	127.5	Acoustic	2006	0.850	27	0.9987	C. Carr, pers. comm. 2011
Canada	New Brunswick	Miramichi	Stable	Unaltered	Wild	127.5	Acoustic	2007	0.910	40	0.9993	C. Carr, pers. comm. 2011
Canada	New Brunswick	Miramichi	Stable	Unaltered	Wild	127.5	Acoustic	2008	0.880	40	0.9990	C. Carr, pers. comm. 2011
Canada	New Brunswick	Miramichi	Stable	Unaltered	Wild	127.5	Acoustic	2009	0.630	80	0.9964	C. Carr, pers. comm. 2011
Canada	New Brunswick	Miramichi	Stable	Unaltered	Wild	127.5	Acoustic	2010	0.810	80	0.9983	C. Carr, pers. comm. 2011
Canada	New Brunswick	Miramichi	Stable	Unaltered	Wild	127.5	Acoustic	2011	0.830	80	0.9985	C. Carr, pers. comm. 2011
Canada	New Brunswick	Restigouche	Stable	Unaltered	Wild	115.3	Acoustic	2004	0.610		0.9957	C. Carr, pers. comm. 2011
Canada	New Brunswick	Restigouche	Stable	Unaltered	Wild	115.3	Acoustic	2005	0.780	55	0.9978	C. Carr, pers. comm. 2011
Canada	New Brunswick	Restigouche	Stable	Unaltered	Wild	115.3	Acoustic	2006	0.800	70	0.9981	C. Carr, pers. comm. 2011
Canada	New Brunswick	Restigouche	Stable	Unaltered	Wild	115.3	Acoustic	2007	0.820	100	0.9983	C. Carr, pers. comm. 2011
Canada	New Brunswick	Restigouche	Stable	Unaltered	Wild	115.3	Acoustic	2008	0.740	45	0.9974	C. Carr, pers. comm. 2011
Canada	New Brunswick	Restigouche	Stable	Unaltered	Wild	115.3	Acoustic	2009	0.750	81	0.9975	C. Carr, pers. comm. 2011
Canada	New Brunswick	Restigouche	Stable	Unaltered	Wild	115.3	Acoustic	2010	0.800	80	0.9981	C. Carr, pers. comm. 2011
Canada	New Brunswick	Restigouche	Stable	Unaltered	Wild	115.3	Acoustic	2011	0.450	98	0.9931	C. Carr, pers. comm. 2011
Canada	Quebec	St. Jean	Stable	Unaltered	Wild	20.0	Acoustic	2005	0.794		0.9886	C. Carr, pers. comm. 2011

[20] Status as defined by Parrish et al. (1998)
[21] Type is based on whether the river is significantly impounded (“altered”) or not (“unaltered”). For the unaltered type, the smolt survival results are only reported for the free-flowing sections of the river.
[22] Instantaneous survival rate per kilometer

Canada	Quebec	St. Jean	Stable	Unaltered	Wild	20.0	Acoustic	2006	0.935		0.9966	C. Carr, pers. comm. 2011
Canada	Quebec	St. Jean	Stable	Unaltered	Wild	20.0	Acoustic	2007	0.645		0.9783	C. Carr, pers. comm. 2011
Canada	Quebec	St. Jean	Stable	Unaltered	Wild	20.0	Acoustic	2008	0.673		0.9804	C. Carr, pers. comm. 2011
Canada	Quebec	St. Jean	Stable	Unaltered	Wild	20.0	Acoustic	2009	0.673		0.9804	C. Carr, pers. comm. 2011
Canada	Quebec	St. Jean	Stable	Unaltered	Wild	20.0	Acoustic	2010	0.860	49	0.9925	C. Carr, pers. comm. 2011
Canada	Quebec	York	Stable	Unaltered	Wild	16.0	Acoustic	2005	0.833	24	0.9887	Koed et al. (2006)
Canada	Quebec	York	Stable	Unaltered	Wild	16.0	Acoustic	2006	0.933	30	0.9957	Martin et al. (2009)
Denmark	Midtyjlland	Skjern	Restoration	Unaltered	Wild	23.0	Radio	2000	0.923	26	0.9965	Koed et al. (2006)
Denmark	Midtyjlland	Skjern	Restoration	Unaltered	Wild	20.5	Radio	2002	0.784	51	0.9882	Koed et al. (2006)
Norway	Hedmark	Eira	Declining	Altered	Hatchery	9.0	Acoustic	2009	0.850	20	0.9821	Thorstad et al. (2011)
Sweden	Gavleborgs	Testebo	Declining	Altered	Hatchery	1.7	Both	2006	0.968	45	0.9808	Serrano et al. (2009)
Sweden	Gavleborgs	Testebo	Declining	Altered	Hatchery	1.7	Both	2007	0.981	55	0.9888	Serrano et al. (2009)
U.K.	Wales	Conwy	Declining	Unaltered	Wild	6.4	Acoustic	1992	1.000	5	1.0000	Moore et al. (1995)
U.K.	Wales	Conwy	Declining	Unaltered	Wild	6.4	Acoustic	1992	0.750	4	0.9560	Moore et al. (1995)
U.K.	Wales	Conwy	Declining	Unaltered	Wild	3.3	Acoustic	1992	0.958	24	0.9872	Moore et al. (1995)
U.K.	England	Test	Restoration	Unaltered	Wild	2.0	Acoustic	1996	0.900	30	0.9474	Moore et al. (1998)
USA	New England	Connecticut	Restoration	Altered	Wild	12.1	Acoustic	2000	0.731	134	0.9744	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	7.2	Acoustic	2000	0.837	134	0.9756	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	13.0	Acoustic	2000	0.793	134	0.9823	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	55.9	Acoustic	2000	0.783	134	0.9956	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	63.4	Acoustic	2000	0.778	134	0.9960	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	7.1	Acoustic	2000	0.964	134	0.9948	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	12.1	Acoustic	2001	0.583	156	0.9564	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	7.2	Acoustic	2001	0.725	156	0.9563	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	2.4	Acoustic	2001	0.773	156	0.8983	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	46.6	Acoustic	2001	0.804	156	0.9953	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	25.9	Acoustic	2001	0.654	156	0.9837	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	36.7	Acoustic	2001	1.000	156	1.0000	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	29.5	Acoustic	2001	0.647	156	0.9853	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	33.9	Acoustic	2001	0.909	156	0.9972	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	7.1	Acoustic	2001	0.900	156	0.9853	A. Haro, pers. comm. 2011
USA	New England	Connecticut	Restoration	Altered	Wild	5.4	Acoustic	2001	0.778	156	0.9546	A. Haro, pers. comm. 2011
USA	Maine	Narraguagus	Restoration	Unaltered	Wild	7.2	Acoustic	1997	0.678		0.9476	Kocik et al. (2009)

USA	Maine	Narraguagus	Restoration	Unaltered	Wild	7.2	Acoustic	1998	0.792		0.9682	Kocik et al. (2009)
USA	Maine	Narraguagus	Restoration	Unaltered	Wild	7.2	Acoustic	1999	0.840		0.9762	Kocik et al. (2009)
USA	Maine	Narraguagus	Restoration	Unaltered	Wild	7.2	Acoustic	2002	0.909		0.9869	Kocik et al. (2009)
USA	Maine	Narraguagus	Restoration	Unaltered	Wild	7.2	Acoustic	2003	0.836		0.9754	Kocik et al. (2009)
USA	Maine	Narraguagus	Restoration	Unaltered	Wild	7.2	Acoustic	2004	0.914		0.9877	Kocik et al. (2009)
USA	Maine	Penobscot	Restoration	Altered	Wild	19.0	Radio	1991	0.417	32	0.9550	Spicer et al. (1994)

Table 18. Empirical instantaneous survival per kilometer (S/km) estimates for Canadian rivers with stable, wild populations of Atlantic salmon.

Statistic	S/km
Min	0.9662
p1	0.9662
p5	0.9723
p10	0.9802
p20	0.9886
p25	0.9906
p50	0.9966
p75	0.9983
p80	0.9983
p90	0.9990
p95	0.9992
p99	0.9993
Max	0.9993
Mean	0.9923

Table 19. Cauchy probability density function from Penobscot River screw trap smolt catches from 2000 to 2005 (N = 6,718).

Month	Day	Total Count	Percent	Cumulative Percent	Cauchy PDF
4	21	8	0.001	0.001	0.002
4	22	4	0.001	0.002	0.003
4	23	5	0.001	0.003	0.003
4	24	7	0.001	0.004	0.003
4	25	10	0.001	0.005	0.004
4	26	12	0.002	0.007	0.004
4	27	13	0.002	0.009	0.005
4	28	41	0.006	0.015	0.005
4	29	36	0.005	0.020	0.006
4	30	81	0.012	0.032	0.007
5	1	115	0.017	0.049	0.009
5	2	158	0.024	0.073	0.010
5	3	56	0.008	0.081	0.013
5	4	262	0.039	0.120	0.016
5	5	204	0.030	0.151	0.020
5	6	217	0.032	0.183	0.026
5	7	185	0.028	0.210	0.035
5	8	319	0.047	0.258	0.048
5	9	504	0.075	0.333	0.066
5	10	457	0.068	0.401	0.086
5	11	708	0.105	0.506	0.100
5	12	722	0.107	0.614	0.096
5	13	359	0.053	0.667	0.078
5	14	393	0.058	0.726	0.058
5	15	269	0.040	0.766	0.042
5	16	319	0.047	0.813	0.031
5	17	98	0.015	0.828	0.024
5	18	283	0.042	0.870	0.018
5	19	111	0.017	0.887	0.014
5	20	100	0.015	0.901	0.012
5	21	89	0.013	0.915	0.010
5	22	65	0.010	0.924	0.008
5	23	67	0.010	0.934	0.007
5	24	47	0.007	0.941	0.006
5	25	52	0.008	0.949	0.005
5	26	46	0.007	0.956	0.004
5	27	52	0.008	0.964	0.004
5	28	32	0.005	0.968	0.003
5	29	39	0.006	0.974	0.003
5	30	24	0.004	0.978	0.003
5	31	37	0.006	0.983	0.003
6	1	16	0.002	0.986	0.002
6	2	19	0.003	0.989	0.002
6	3	8	0.001	0.990	0.002
6	4	17	0.003	0.992	0.002
6	5	14	0.002	0.994	0.002

6	6	11	0.002	0.996	0.001
6	7	9	0.001	0.997	0.001
6	8	4	0.001	0.998	0.001
6	9	8	0.001	0.999	0.001
6	10	3	0.000	1.000	0.001
6	11	1	0.000	1.000	0.001
6	12	1	0.000	1.000	0.001
6	13	0	0.000	1.000	0.001
6	14	0	0.000	1.000	0.001
6	15	0	0.000	1.000	0.001
6	16	0	0.000	1.000	0.001
6	17	1	0.000	1.000	0.001

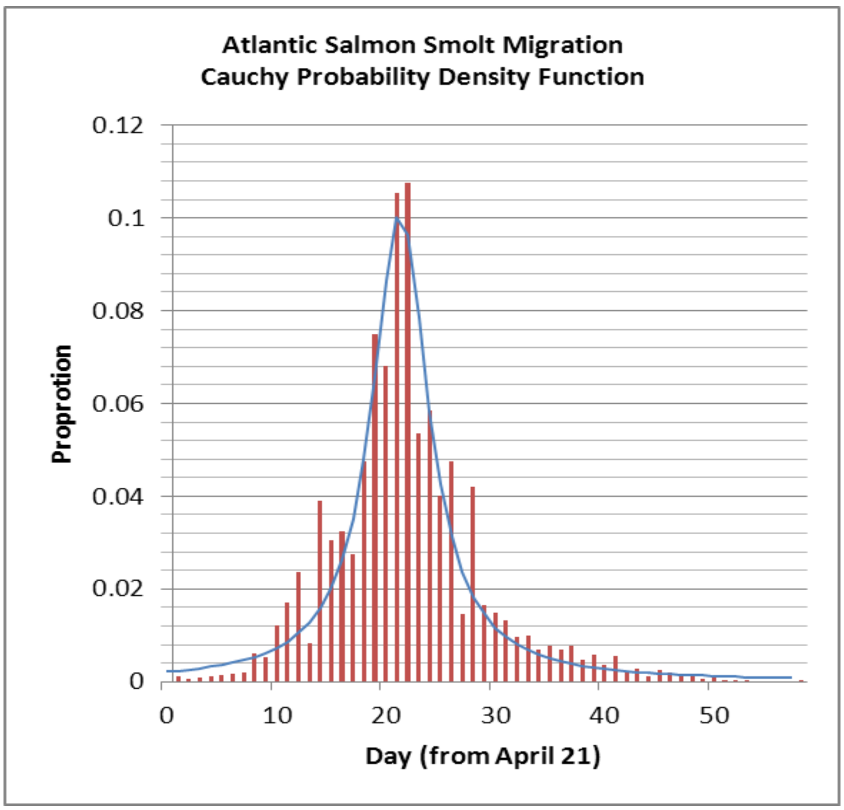
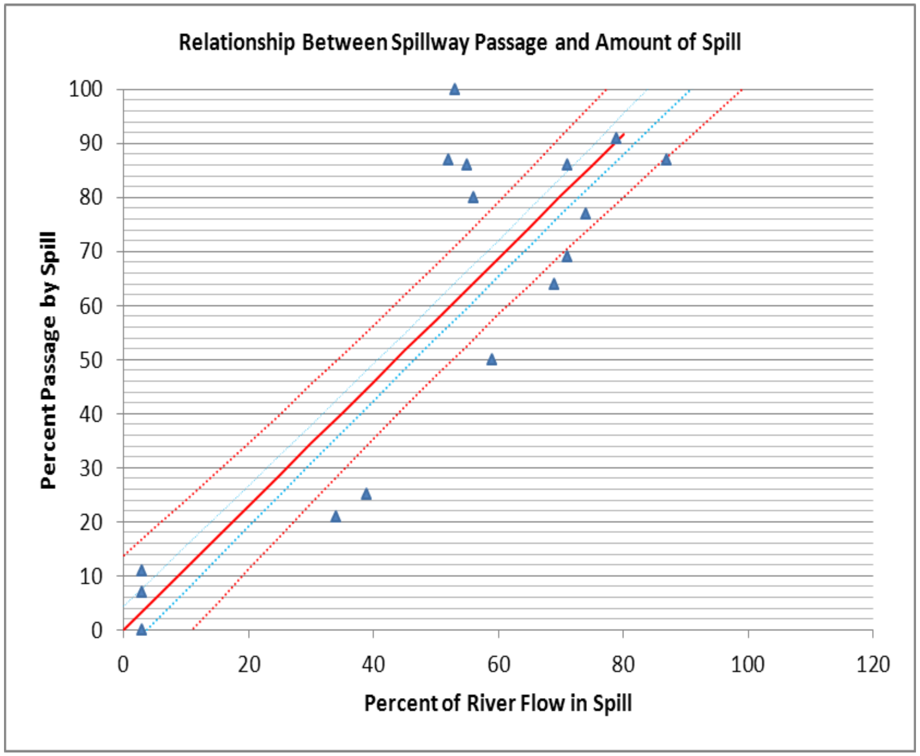


Table 20. The relationship between the spill passage route and the amount of spill from data by Shepard (1991, 2010).

Project	% Spill	% Spillway Passage	Source
West Enfield	3	66	Shepard (1991)
West Enfield	3	42	Shepard (1991)
West Enfield	3	51	Shepard (1991)
Milford	39	42	Shepard (1991)
Milford	55	30	Shepard (1991)
Milford	56	18	Shepard (1991)
Milford	52	23	Shepard (1991)
Milford	79	8	Shepard (1991)
Milford	69	22	Shepard (1991)
Milford	34	3	Shepard (1991)
Veazie	87	21	Shepard (1991)
Veazie	71	10	Shepard (1991)
Veazie	53	12	Shepard (1991)
Veazie	74	12	Shepard (1991)
Veazie	59	9	Shepard (1991)
Orono[23]	71	17	Shepard (2010)
Orono[24]	4	5	Shepard (2010)
West Enfield[25]	3	6	Shepard (1991)



Linear Regression

Parameter	Est value	St dev	t student	Prob(>|t|)
b0	0	0	1.8E+308	0
b1	1.146495	0.078433	14.61744	7.16E-10
R2	0.934403		F	213.6697
R2(adj)	0.934403		Prob(>F)	2.79E-10

[23] Data used in the analysis, however 13 percent of study fish used the downstream fishway.
[24] Data not used in the analysis since 42 percent of study fish used the downstream fishway.
[25] Data not used in the analysis due to unusual spill conditions.

Table 21. Maximum and minimum values for immediate turbine entrainment survival of Atlantic salmon smolts at hydroelectric project on the Penobscot River (NMFS, unpublished data, 2012).

Project	Estimate	Turbine Unit	Entrainment Survival
Orono	Minimum	1	0.777
Orono	Maximum	1	0.804
Orono	Minimum	2	0.817
Orono	Maximum	2	0.837
Orono	Minimum	3 & 4	0.801
Orono	Maximum	3 & 4	0.968
Stillwater	Minimum	1 & 3	0.978
Stillwater	Maximum	1 & 3	0.993
Stillwater	Minimum	4	0.743
Stillwater	Maximum	4	0.928
Milford	Minimum	3	0.930
Milford	Maximum	3	0.989
Milford	Minimum	4 to 6	0.927
Milford	Maximum	4 to 6	0.989
West Enfield	Minimum	1	0.958
West Enfield	Maximum	1	0.986
Min			0.743
P25			0.814
p50			0.929
p75			0.980
Max			0.993
Mean			0.902

Table 22. Nocturnal migration activity of Atlantic salmon smolts.

Time of Day Description	Nocturnal Movement (%)	Source
Night and Twilight	79.2	Kocik et al. (2009)
Night and Twilight	81.8	Kocik et al. (2009)
Night and Twilight	95.4	Kocik et al. (2009)
Hour 2100 -0500	84.0	Aarestrup et al. (2002)
Hour 1800 - 0600	73.0	Martin et al. (2009)
Nighttime Hours[26]	81.6	Ibbotson et al. (2006)
Nighttime Hours[27]	67.1	Ibbotson et al. (2006)
Hour 1800 - 0600	85.9	Koed et al. (2006)
Night	73.5	Spencer et al. (2010)
Night	58.8	Spencer et al. (2010)
Hour 1900 (sunset) - 0500 (sunrise)	79.7	Shepard (1994)
Hour 1900 (sunset) - 0500 (sunrise)	77.9	Shepard (1993)
Hour 1900 (sunset) - 0500 (sunrise)	74.4	Shepard (1991)
Hour 1900 (sunset) - 0500 (sunrise)	84.8	Shepard (2010)
Nighttime Hours	85.0	Jonsson and Jonsson (2011)
Min	58.8	
P25	74.0	
p50	80.7	
p75	84.8	
Max	95.4	
Mean	78.8	

[26] Nocturnal movement during weeks 1 and 2 of the migration period.
[27] Nocturnal movement during weeks 3 and 4 of the migration period.

Table 23. Efficiency of downstream fish passage facilities for Atlantic salmon smolts in the United States (B. Rizzo, U.S. Fish and Wildife, 2011, personal communication).

Project	State	River	Turbine Flow (cfs)	Bypass Flow (cfs)	Bypass Flow (%)	Bypass Efficiency (%)
Holyoke Project – Hadley Station	MA	Connecticut	8000	325	4.1	68
Holyoke Project – Hadley Station	MA	Connecticut	8000	325	4.1	75
Holyoke Project – Hadley Station	MA	Connecticut	8000	325	4.1	63
Holyoke Project – Canal #1	MA	Connecticut	7000	155	2.2	97
Turners Falls Project – Cabot Station	MA	Connecticut	13000	260	2.0	85
Wilder Project	VT	Connecticut	10500	200	1.9	91
Wilder Project	VT	Connecticut	10500	324	3.1	94
Wilder Project	VT	Connecticut	10500	550	5.2	96
Wilder Project	VT	Connecticut	10500	200	1.9	69
Wilder Project	VT	Connecticut	10500	324	3.1	71
Wilder Project	VT	Connecticut	10500	550	5.2	88
Wadams Project	NY	Bouquet	150	10	6.7	100
Weldon	ME	Penobscot	7240	140	1.9	45
Weldon	ME	Penobscot	7240	140	1.9	59
West Enfield	ME	Penobscot	9000	157	1.7	50
Bar Mills	ME	Saco	3120	120	3.8	79
Orono	ME	Stillwater	1740	70	4.0	44
Min						44.0
P25						63.0
p50						75.0
p75						91.0
Max						100.0
Mean						74.9

Table 24. Parameters used in the Spill Response Model for Species Protection Plan based on “not likely” (using the minimum values for the turbine entrainment, percent nocturnal migration, and downstream fish passage efficiency parameters), “less likely” (using 25th and 75th percentile values for the parameters) and “more likely” (using 50th percentile value for the parameters) conditions for turbine entrainment, percent nocturnal migration, and downstream fish passage efficiency.

Spill Response Model Scenario	Starting Day	Turbine Entrainment Survival (%)	Nocturnal Migration (%)	Fish Passage Efficiency (%)	Days of Night-time Spill	Percent Night-time Spill (%)	Days of Day and Night-time Spill	Percent Day and Night-time Spill (%)
SPP / Not Likely (minimum)	May 1	0.743	0.588	44	14	100	14	25
SPP / Less Likely (25th percentile)	May 1	0.814	74.0	63	14	100	14	25
SPP / More Likely (50th percentile)	May 1	0.929	80.7	75	14	100	14	25
SPP / Less Likely (using 75th percentile)	May 1	0.993	84.8	91	14	100	14	25

Table 25. Survival predicted for the Spill Response Model for the not likely (using the minimum values for the turbine entrainment, percent nocturnal migration, and downstream fish passage efficiency parameters) less likely (using the 25th and 75th percentiles) and more likely (50th percentile) scenarios. The confidence intervals are those from the linear regression of the relationship between the spill passage route and the amount of spill from Table 20.

Spill Response Model Scenario	Lower 95% CI	Regression Prediction	Upper 95% CI
SPP / Not Likely (using minimum values)	0.9196	0.9215	0.9235
SPP / Less Likely (using 25th percentile values)	0.9694	0.9706	0.9717
SPP / More Likely (50th percentile values)	0.9930	0.9933	0.9937
SPP / Less Likely (using 75th percentile values)	0.9998	0.9998	0.9998

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