Strategic Plan for Lake Champlain Fisheries

Great Lakes Fishery Commission

Miscellaneous Publication 2010-03

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J. Ellen Marsden, Brian D. Chipman, Bernie Pientka, William F. Schoch, Bradley A. Young

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J.E. Marsden.[1] University of Vermont, School of Natural Resources, Aiken Center, 81 Carrigan Drive, Burlington, VT 05405, USA.
B. D. Chipman and B. Pientka. Vermont Department of Fish and Wildlife, 111 West Street, Essex Junction, VT 05452.
W.F. Schoch. New York State Department of Environmental Conservation, P.O. Box 296, Route 86, Ray Brook, NY 12977-0296.
B.A. Young. U.S. Fish and Wildlife Service, 11 Lincoln Street, Essex Junction, VT 05452.
[1]Corresponding author (e-mail: jmarsden@uvm.edu).

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PREFACE

This plan was produced under the purview of the Lake Champlain Fisheries Technical Committee whose membership during production was as follows:

- Bradley A. Young (Chairman), U.S. Fish and Wildlife Service, Essex Junction, VT
- Wayne R. Bouffard, U.S. Fish and Wildlife Service, Essex Junction, VT
- Brian D. Chipman, Vermont Department of Fish and Wildlife, Essex Junction, VT
- Lance E. Durfey, New York State Department of Environmental Conservation, Ray Brook, NY
- Shawn P. Good, Vermont Department of Fish and Wildlife, Rutland, VT
- Madeleine M. Lyttle, U.S. Fish and Wildlife Service, Essex Junction, VT
- Chet MacKenzie, Vermont Department of Fish and Wildlife, Rutland, VT
- J. Ellen Marsden, University of Vermont, Burlington, VT
- Donna L. Parrish, U. S. Geological Survey, Vermont Cooperative Fish and Wildlife Research Unit, Burlington, VT
- Bernie Pientka, Vermont Department of Fish and Wildlife, Essex Junction, VT
- William F. Schoch, New York State Department of Environmental Conservation, Ray Brook, NY
- Stephen J. Smith, U.S. Fish and Wildlife Service, Essex Junction, VT
- Nicholas R. Staats, U.S. Fish and Wildlife Service, Essex Junction, VT
- Emily C. Zollweg, New York State Department of Environmental Conservation, Warrensburg, NY

Additional contributors were Doug Facey (Saint Michael's College, Colchester, VT); Kevin Kelsey (Ed Weed Fish Culture Station, Grand Isle, VT); Mark Malchoff (Lake Champlain Sea Grant, SUNY, Plattsburgh, NY), and David A. Tilton U.S. Fish and Wildlife Service, Essex Junction, VT.

ABSTRACT

This plan identifies goals and sub-goals for the fish community and fisheries of Lake Champlain while establishing for the Lake Champlain Fish and Wildlife Management Cooperative a framework within which it can develop, deliver, and provide direction to fishery-management programs. The plan is founded on a set of guiding principles for ecosystem-based management encompassing sustainability, natural reproduction by native species, management of non-native and nuisance species, use of stocked fish, application of genetic data, protection of habitats, use of science-based management, and management accountability, with specific reference to human dimensions. Lake Champlain is large and heterogeneous, comprising five distinct basins separated by natural features and causeways and is shared by the U.S. and Canada. The lake and its tributaries, which contain 73 native and 15 non-native species of fish, have been altered by increased inputs of sediment and phosphorus and by exotic species, particularly various aquatic plants and zebra mussel (*Dreissena polymorpha*). Historically, the lake's commercial fisheries targeted primarily Atlantic salmon (*Salmo salar*), lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*), walleye (*Sander vitreus*), yellow perch (*Perca flavescens*), lake sturgeon (*Acipenser fulvescens*), and American eel (*Anguilla rostrata*); of these, Atlantic salmon and lake trout are now extirpated, and lake sturgeon and American eel are rarely seen. Early records for the commercial fishery are scarce, making its role in fish depletions obscure. In addition, the building of dams and degradation of riverine spawning areas undoubtedly contributed to the decline of lake sturgeon and to the disappearance of Atlantic salmon. The current fishery in U.S. waters is based almost entirely on angling, although anglers are allowed to sell their catch. The plan seeks tributary, nearshore, and offshore fish communities composed primarily of self-sustaining native fishes with populations of formerly abundant and threatened native species under recovery, but also with increasing populations of sport fishes, including two non-native species, brown trout (*Salmo trutta*), and steelhead (*Oncorhynchus mykiss*). In addition, management actions will, where feasible, prevent new introductions of aquatic species and suppress non-native pest species so as to minimize their impact on native species and ecosystem function. The plan concludes with a listing of informational priorities and research needed to better understand the factors and processes that affect the lake and its fishes.

INTRODUCTION

This strategic plan for Lake Champlain recognizes a need to redirect the Lake Champlain Fish and Wildlife Management Cooperative (cooperative) from an effort focused solely on restoration of lake trout and Atlantic salmon to one focusing on all major sport and non-sport fishes (see Table 1 for a list of common and scientific names of fishes in the Lake Champlain basin). The cooperative was organized in 1972 by the directors of the fish and wildlife agencies of Vermont and New York and the Northeast Regional Office of the U.S. Fish and Wildlife Service (USFWS). The Province of Quebec is not a signatory party, but the cooperative maintains close communications with the province. A Memorandum of Understanding (MOU) renewing work of the cooperative (January 1995 and as amended July 1996) called for coordinating fish and wildlife programs of interstate significance in Lake Champlain. The specific responsibilities of the cooperative, as outlined in the MOU, are to:

- Coordinate evaluation of environmental impacts on fish and wildlife resources and formulate appropriate responses
- Develop a comprehensive fish and wildlife management plan for species of interstate significance
- Encourage implementation of the comprehensive plan by the agencies with primary responsibility

The cooperative had been working under the Strategic Plan for the Development of Salmonid Fisheries in Lake Champlain, implemented in 1977 (Fisheries Technical Committee 1977). This plan reflected the primary goals at the time, which were the restoration of lake trout and Atlantic salmon fisheries. Following 1977, the importance of additional sportfishes, including walleye, yellow perch, and basses, has been recognized. In addition, the goal of lake trout management has shifted to include restoration of self-sustaining populations. The Lake Champlain Fisheries Technical Committee, formed by the cooperative, also focuses on the need to protect and restore fish that do not currently support fisheries, including lake sturgeon and American eel. Consequently, a broader strategic plan for the fisheries of Lake Champlain was needed to guide management decision making and research. This plan provides a framework for implementing the cooperative's function of initiating, developing, and providing direction to coordinated fisheries-management programs in the Lake Champlain basin. Each agency's role in coordinated fish and wildlife programs is flexible, depending on the agency's mission and capability and on the cooperative's needs.

Table 1. Fish species known to inhabit Lake Champlain and its tributaries and their legal protection status. E = endangered, T = threatened, SC = species of concern (Vermont) or special concern (QUE), VT = Vermont, NY = New York, QUE = Quebec. Endangered = immediate danger of becoming extirpated in the state, Threatened = high possibility of becoming endangered in the near future. Two additional species (American eel, lake sturgeon) are under evaluation in Quebec but do not currently have a designated legal status. Adapted in part from Langdon et al. 2006.

Family	Common Name	Scientific Name	Status
Petromyzontidae	Northern brook lamprey	*Ichthyomyzon fossor*	E-VT
	Silver lamprey	*Ichthyomyzon unicuspis*	None
	American brook lamprey	*Lampetra appendix*	T-VT
	Sea lamprey	*Petromyzon marinus*	None
Acipenseridae	Lake sturgeon	*Acipenser fulvescens*	E-VT, T-NY
Lepisosteidae	Longnose gar	*Lepisosteus osseus*	None
Amiidae	Bowfin	*Amia calva*	None
Anguillidae	American eel	*Anguilla rostrata*	SC-VT
Clupeidae	Blueback herring	*Alosa aestivalis*	Introduced
	Gizzard shad	*Dorosoma cepedianum*	Introduced
	Alewife	*Alosa psuedoharengus*	Introduced
Hiodontidae	Mooneye	*Hiodon tergisus*	T-NY
Salmonidae	Cisco (formerly lake herring)	*Coregonus artedi*	None
	Lake whitefish	*Coregonus clupeaformis*	None
	Steelhead/rainbow trout	*Oncorhynchus mykiss*	Introduced
	Atlantic salmon	*Salmo salar*	None
	Brown trout	*Salmo trutta*	Introduced
	Brook trout	*Salvelinus fontinalis*	None
	Lake trout	*Salvelinus namaycush*	None

Table 1, continued.

Family	Common Name	Scientific Name	Status
Osmeridae	Rainbow smelt	*Osmerus mordax*	None
Umbridae	Central mudminnow	*Umbra limi*	None
Esocidae	Redfin pickerel	*Esox americanus americanus*	None
	Northern pike	*Esox lucius*	None
	Muskellunge	*Esox masquinongy*	SC-VT
	Chain pickerel	*Esox niger*	None
Cyprinidae	Goldfish	*Carassius auratus*	Introduced
	Common carp	*Cyprinus carpio*	Introduced
	Rudd	*Scardinius erythrophthalmus*	Introduced
	Tench	*Tinca tinca*	Introduced
	Cutlips minnow	*Exoglossum maxillingua*	None
	Brassy minnow	*Hybognathus hankinsoni*	SC-VT
	Eastern silvery minnow	*Hybognathus regius*	None
	Golden shiner	*Notemigonus crysoleucas*	None
	Emerald shiner	*Notropis atherinoides*	None
	Bridle shiner	*Notropis bifrenatus*	SC-VT, QUE
	Common shiner	*Luxilus cornutus*	None
	Blackchin shiner	*Notropis heterodon*	SC-VT
	Blacknose shiner	*Notropis heterolepis*	None
	Spottail shiner	*Notropis hudsonius*	None
	Rosyface shiner	*Notropis rubellus*	None
	Spotfin shiner	*Cyprinella spilopterus*	None
	Mimic shiner	*Notropis volucellus*	None
	Northern redbelly dace	*Phoxinus eos*	None
	Sand shiner	*Notropis stramineus*	None
	Finescale dace	*Phoxinus neogaeus*	None
	Bluntnose minnow	*Pimephales notatus*	None
	Fathead minnow	*Pimephales promelas*	None

Table 1, continued.

Family	Common Name	Scientific Name	Status
	Blacknose dace	*Rhinicthys atratulus*	None
	Longnose dace	*Rhinicthys cataractae*	None
	Creek chub	*Semotilus atromaculatus*	None
	Fallfish	*Semotilus corporalis*	None
	Pearl dace	*Margariscus margarita*	None
Catostomidae	Quillback	*Carpiodes cyprinus*	SC-VT
	Longnose sucker	*Catostomus catostomus*	None
	White sucker	*Catostomus commersoni*	None
	Silver redhorse	*Moxostoma anisurum*	SC-VT
	Shorthead redhorse	*Moxostoma macrolepidotum*	None
	Greater redhorse	*Moxostoma valenciennesi*	SC-VT
Ictaluridae	Yellow bullhead	*Ameiurus natalis*	None
	Brown bullhead	*Ameiurus nebulosus*	None
	Channel catfish	*Ictalurus punctatus*	None
	Stonecat	*Noturus flavus*	E-VT
Percopsidae	Trout-perch	*Percopsis omiscomaycus*	None
Gadidae	Burbot	*Lota lota*	None
Fundulidae	Banded killifish	*Fundulus diaphanus*	None
Gasterosteidae	Brook stickleback	*Culaea inconstans*	None
Moronidae	White perch	*Morone americana*	Introduced

Table 1, continued.

Family	**Common Name**	**Scientific Name**	**Status**
Centrarchidae	Rock bass	*Ambloplites rupestris*	None
	Pumpkinseed	*Lepomis gibbosus*	None
	Bluegill	*Lepomis macrochirus*	None
	Smallmouth bass	*Micropterus dolomieui*	None
	Largemouth bass	*Micropterus salmoides*	Introduced?
	Black crappie	*Pomoxis nigromaculatus*	Introduced?
	White crappie	*Pomoxis annularis*	Introduced
Percidae	Eastern sand darter	*Ammocrypta pellucida*	T-VT, T-NY, T-QUE
	Fantail darter	*Etheostoma flabellare*	None
	Tessellated darter	*Etheostoma olmstedi*	None
	Yellow perch	*Perca flavescens*	None
	Logperch	*Percina caprodes*	None
	Channel darter	*Percina copelandi*	E-VT, SC-QUE
	Sauger	*Sander canadense*	None
	Walleye	*Sander vitreus*	None
Sciaenidae	Freshwater drum	*Aplodinotus grunniens*	None
Cottidae	Mottled sculpin	*Cottus bairdi*	None
	Slimy sculpin	*Cottus cognatus*	None
Atherinidae	Brook silverside	*Labidesthes sicculus*	Introduced

Interjurisdictional fisheries in Lake Champlain involve fish populations that, because of their geographic distribution and/or migratory patterns, fall within the boundaries of Vermont and New York and are managed by both states and, at times, by Quebec. This plan is written with the understanding that the USFWS, Vermont Department of Fish and Wildlife, and New York State Department of Environmental Conservation will each endeavor to provide staffing and funding to assume the following long-term interjurisdictional fisheries-management roles for the cooperative:

- Monitoring and assessment of the salmonid forage-base populations, particularly rainbow smelt and alewife
- Restoring lake trout and landlocked Atlantic salmon populations through hatchery production
- Implementing sea lamprey assessment and control activities on Lake Champlain to benefit lake trout and landlocked Atlantic salmon
- Enhancing restoration of self-sustaining landlocked Atlantic salmon and other species through aquatic habitat restoration
- Enhancing fish passage for landlocked Atlantic salmon and lake sturgeon
- Monitoring of American eel
- Monitoring of lake sturgeon in Vermont rivers, including the Missisquoi, Lamoille, and Winooski Rivers and Otter Creek
- Monitoring walleye populations and procuring walleye brood stock

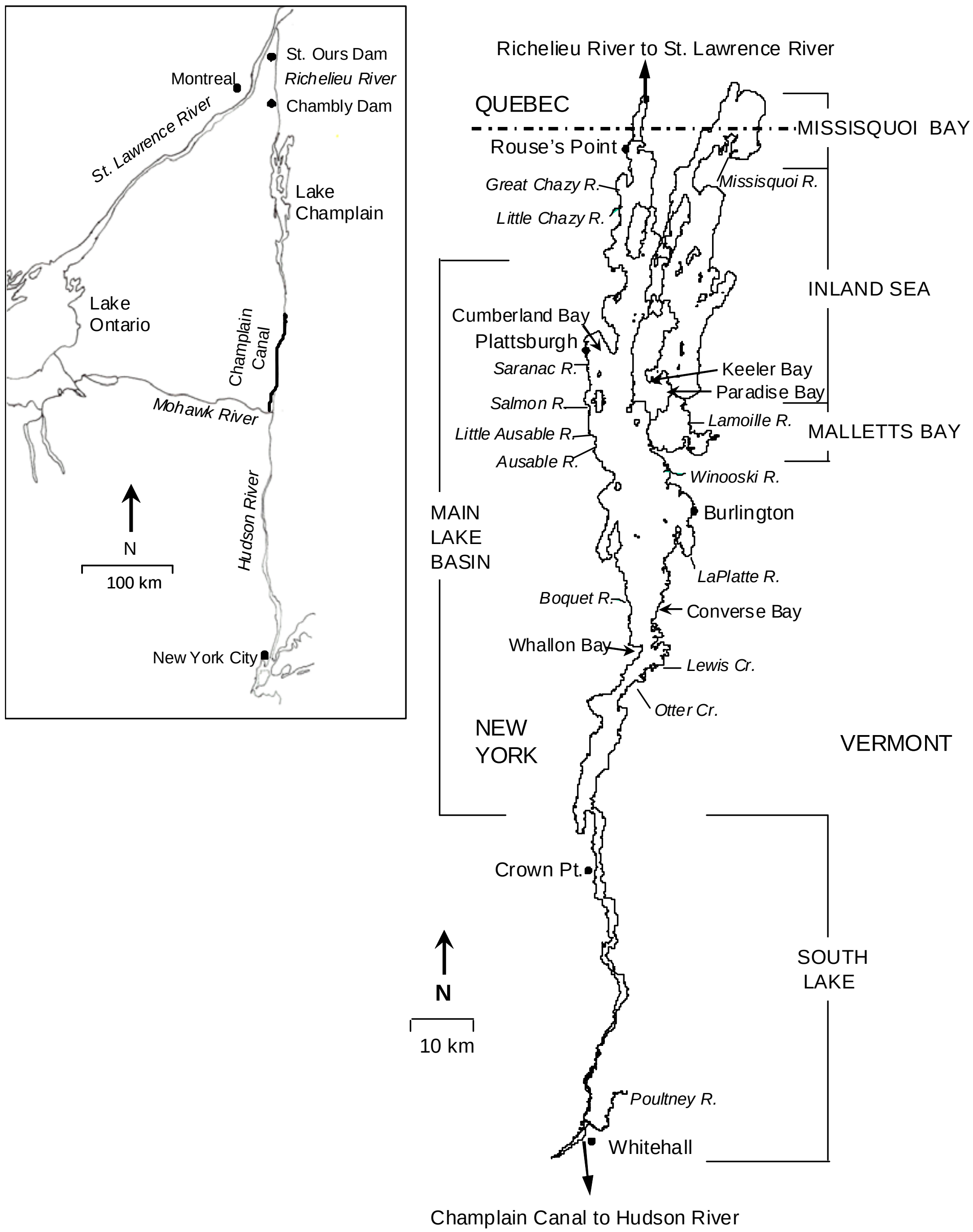
In addition to cooperative restoration or management of interjurisdictional fisheries, the service will work with the states of New York and Vermont to restore connectivity, where appropriate, to tributaries of Lake Champlain for the benefit of brook trout and other aquatic species and to assist in preventing introductions of aquatic nuisance species and, if introduced, to limit their spread among the basins of Lake Champlain. Land-use management aimed at reducing siltation and contaminant inputs, which affect fish populations, is not the primary responsibility of the cooperative and is not addressed in this plan.

The purpose of this document is to identify fish-community goals and sub-goals for Lake Champlain and to provide a framework for making progress toward the achievement of these goals. Specific population targets, implementation strategies, costs, and research needs will be addressed through separate planning processes. This plan should be updated on a regular basis, not to exceed every five years.

DESCRIPTION OF LAKE CHAMPLAIN

Lake Champlain (Fig. 1) has a surface area of 1,130 km^2 (435 mi^2) and a volume of 26 km^3 (6.2 mi^3). The lake is long (approximately 200 km (120 mi)), narrow (19 km (12 mi) at its widest), and deep (19.5-m average (64 ft), 122-m maximum (400 ft)). Sixty-two percent of the surface area lies in Vermont, to the east; 34.5% of the surface area lies in New York, to the west, and 3.5% of the surface area lies in Quebec, to the north, . The lake flows from tributary inputs in the south to its outlet, the Richelieu River, at its north end. Lake Champlain is connected naturally to the St. Lawrence River via the Richelieu River and to Lake George via the LaChute River, which flows into the lake at Ticonderoga, New York. The Champlain Canal, opened in 1823, connects the lake to the Hudson and Mohawk River drainages and to the Great Lakes via the New York State Canal System.

Fig. 1. Map of Lake Champlain showing major basins and tributaries. Inset shows geographic region, connecting rivers and canal, and the two dams on the Richelieu River, which drains Lake Champlain.



Lake Champlain is divided into five distinct basins by a combination of natural geographic features and causeways constructed over shallow bars. In addition, the south lake, contiguous with the main lake, is recognized generally as a separate basin due to its trophic characteristics:

- The south lake extends from Whitehall, New York, northward to the Crown Point Bridge and includes South Bay on the west side. This area is eutrophic and essentially riverine with extensive wetlands on both shores.
- The main lake extends from Crown Point to Rouse's Point, New York, and includes the deepest section of the lake near Split Rock Point, New York. This basin is meso- to oligotrophic and contains most of the deep, cold-water salmonid habitat in the lake. The two largest population centers in the basin, Burlington, Vermont, and Plattsburgh, New York, are located on the shores of the main lake. The Vermont shoreline has considerable agricultural use, whereas the New York shore is generally steeper, more forested, and mostly a part of Adirondack Park.
- Malletts Bay is located north of Burlington on the east side of the lake and is separated from the main lake by a railroad causeway to the west and from the Inland Sea by a road causeway (Route 2) to the north. The basin consists of a moderately deep outer bay and a smaller and shallower inner bay and is primarily mesotrophic.
- The Inland Sea is located to the east of the islands of North and South Hero, Vermont. The Inland Sea is generally mesotrophic, and receives water from Missisquoi Bay to the north. No major tributaries drain into this basin, and there are no major urban areas in the watershed. The Inland Sea and Malletts Bay lie entirely within Vermont.
- Missisquoi Bay is located to the north of the Inland Sea and drains south. The northern two thirds of the bay lie within Quebec. This shallow basin, with a maximum depth of 4.3 m (14 ft), is eutrophic and primarily supports warm-water fishes. Land use in the area is largely agricultural.

Lake Champlain has a very large watershed (21,326 km^2 or 8,234 mi^2) compared to its surface area. In consequence, the lake level varies considerably, with an annual fluctuation of 1-2 m (3.0-6.5 ft). Mean lake level is 29.1 m (95.5 ft) above sea level. The record low was 28.1 m (92.4 ft) and the record high was 31 m (102 ft). The watershed drains the largely forested Adirondack Mountains on the west, the Green Mountains on the east, and extensive agricultural areas in Quebec and the Lake Champlain Valley of Vermont. The total human population of the Lake Champlain basin was estimated at 571,000 in 2000, of which 68% live in Vermont, 27% in New York, and 5% in Quebec (Lake Champlain Basin Program 2004).

Lake Champlain and its tributaries currently contain 88 species of fishes, of which 15 are non-native (Table 1; Langdon et al. 2006). The native fish fauna is similar to that of the Great Lakes, although there are fewer species. The cold-water predator population is dominated by lake trout, Atlantic salmon, brown trout, and steelhead. Cool-water species include yellow perch and walleye. Coregonid species are limited to lake whitefish and cisco (formerly lake herring), and the major forage for piscivores are rainbow smelt and yellow perch, which are both native. Alewife was found in the lake in 2002 and has rapidly increased in abundance and is eaten by piscivores. Important warm-water sport fishes include largemouth and smallmouth bass, northern pike, pumpkinseed, and white and black crappies. Seven fish species are classified as endangered (E) or threatened (T) in Vermont, New York, or Quebec: northern brook lamprey (E-VT), American brook lamprey (T-VT), lake sturgeon (T-NY, E-VT), mooneye (T-NY), stonecat (E-VT), eastern sand darter (T-NY, VT; T-QUE), and channel darter (E-VT, SC-QC). An additional eight species are listed that are of special concern in Vermont or Quebec (Table 1).

Habitat degradation in Lake Champlain in the early period of colonization by Europeans was due primarily to damming of rivers, introduction of sawmill wastes into tributaries, and logging (Moore 1930). Most of the major tributaries, including the Great Chazy, Little Chazy, Salmon, Little Ausable, Ausable, Boquet, Winooski, Lamoille, and Missisquoi Rivers and Otter Creek, have been dammed since the 1800s, contributing to the decline of potamodromous species, such as Atlantic salmon and lake sturgeon. Atlantic salmon were last documented in the basin in the Ausable River, New York, in 1838. Settlement of the Lake Champlain Valley in the early 1800s was marked by extensive timber cutting. Vermont lost approximately 60% of its forests from 1890 to 1900, though considerable additional land was cleared at some time and allowed to regrow; only about 500 ha (1,236 acre) of primary old-growth forest remains in the state. Forest cover in Vermont has returned to approximately 78% of the landscape but is now declining due to development. Erosion during the period of deforestation may have substantially increased siltation of stream and lake substrates, altering habitat for benthic invertebrates and spawning fishes.

Historically, the basin contained little industry that generated toxic wastes. The three primary areas of contaminant concern are Cumberland Bay (PCBs, polycyclic aromatic hydrocarbons (PAHs), copper, and zinc), outer Malletts Bay (arsenic and nickel), and the Burlington Barge Canal (lead, mercury, silver, zinc, and PAHs). The presence of mercury and PCBs in fish flesh have prompted posting of fish consumption advisories by New York, Vermont, and Quebec. Sediments contaminated with PCBs were dredged from Cumberland Bay in 1999-2000. In recent decades, concerns about sediment and phosphorus inputs into the lake have attracted public and political attention.

The Lake Champlain Valley on the Vermont side, the northern portion of the New York side, and most of Quebec is farmed extensively, contributing to concerns about sediment runoff and phosphorus inputs. Development of former agricultural and forest land into housing and commercial property further increased sediment and nutrient runoff. Efforts to reduce the amount of phosphorus that enters the lake include wastewater treatment upgrades, nutrient and waste management on farms, streambank erosion control, and phosphorus reduction in developed areas. Although phosphorus inputs have been reduced in the lake in recent years, phosphorus levels in some lake segments remain problematic. Additional habitat damage has occurred along the shorelines of Lake Champlain, particularly the draining and filling of wetlands for development and increased sedimentation. Approximately 35-50% of the wetlands in the basin have been lost.

HISTORICAL AND CURRENT FISHERY AND FISH COMMUNITY

The earliest published account of fishes in Lake Champlain was by Zadock Thompson in his Natural History of Vermont (1853). He described 48 species in the basin, although his descriptions contain a number of apparent misclassifications. The first formal biological survey was conducted by the state of New York in 1929 (Greeley 1930). Subsequently, two limnological surveys were conducted, but the only comprehensive fish-population inventory was done from 1971 to 1977 (Anderson 1978). Fisheries sampling continued through 1997, largely focused on salmonids as part of salmonid restoration, to evaluate the 1990-1997 experimental sea lamprey control program (Fisheries Technical Committee 1999). Forage-base monitoring, focused on rainbow smelt, began in 1990 with the use of trawling index stations. Assessments of lamprey marking on lake trout, Atlantic salmon, and walleye are conducted each summer or fall, and the salmonid, rainbow smelt, and walleye fisheries are monitored via angler diaries.

Commercial fishing on Lake Champlain was historically dominated by use of seines, trapnets, and set lines fished for lake whitefish, walleye, yellow perch, and lake trout, particularly on their spawning grounds (Halnon 1963). Additional species harvested included basses, bullheads, channel catfish, American eel, northern pike, chain pickerel, rock bass, rainbow smelt, Atlantic salmon, and lake sturgeon. A commercial fishery for American eel (yellow life stage), using electroshocking and baited pots, was authorized in Vermont in 1982, but no fishing took place after the 1980s; the Vermont statute permitting commercial fishing for American eel was repealed in 2002. The contribution of these fisheries to species declines and extirpations is unknown except, perhaps, for lake sturgeon and lake whitefish. Up to 60,000 lake whitefish were harvested annually around the turn of the 19th century until the fishery was closed in 1912 (Halnon 1963). The commercial fishery for lake whitefish in Quebec waters of Missisquoi Bay continued until 2004 when harvests declined to a point at which the fishery was no longer viable. Lake sturgeon harvests prior to 1913 averaged over 100 fish annually but declined to less than 15 fish per year in the 1950s and 1960s (Halnon 1963). Other factors in addition to commercial fishing, such as the building of dams and degradation of riverine spawning areas, undoubtedly contributed to the decline of lake sturgeon and the disappearance of Atlantic salmon. The disappearance of lake trout by the late 1890s is the most difficult loss to explain; no data were collected on population characteristics or abundance prior to and during the period of decline (Plosila and Anderson 1985).

Other species of commercial- and sport-fishing importance were rainbow smelt and yellow perch. Rainbow smelt were considered historically to be anadromous, entering Lake Champlain periodically via the Richelieu River. Others reported that rainbow smelt had been introduced to the lake by stocking (Thompson 1853; Halnon 1963). Stocking of over 65 million rainbow smelt from the Cold Spring Harbor hatchery took place in the early 1900s (Greene 1930), but most writers consider rainbow smelt to be indigenous. Two “races” of rainbow smelt are thought to be in the lake—one of normal size and one giant (Greene 1930). Genetic analysis was inconclusive in determining the existence of different races (LaBar and Dehayes 1989; Marsden 1999). Unlike rainbow smelt in the Great Lakes, Lake Champlain rainbow smelt typically do not ascend rivers to spawn but spawn offshore in depths around 15 m (49 ft) or greater.

Fish stocking of various species was considered to be beneficial and involved private citizens as well as state agencies. Non-native species that were deliberately introduced include Chinook salmon (*Oncorhynchus tshawytscha*), kokanee salmon (*Oncorhynchus nerka*), cutthroat trout (*Oncorhynchus clarkia*), grayling (*Thymallus arcticus*), brown trout, rainbow trout, American shad (*Alosa sapidissima*), black crappie, largemouth bass, and common carp. Stocking of native species, such as brook trout, lake trout, Atlantic salmon, brown bullhead, walleye, yellow perch, rainbow smelt, lake whitefish, rock bass, and channel catfish, also occurred (Langdon et al. 2006). The great majority of the introductions failed to establish with the notable exceptions of common carp, largemouth bass, and black crappie. Limited numbers of brown trout and steelhead were stocked again in the 1970s, and stocking persists to provide diversity for the recreational fishery.

The current fishery in Lake Champlain is almost entirely based on angling. Although commercial licenses are still issued in Quebec, the commercial fishery has not been active since 2004.

Popular sport fisheries include the four salmonid species (lake trout, Atlantic salmon, steelhead, and brown trout), walleye, yellow perch, basses, and northern pike. Charter fishing has declined since the mid-1990s due to an overall reduction in the salmonid fishery as a consequence of sea lamprey predation. Sea lamprey increased in abundance after the long-term control program began in 2002, and declines, presumably due to effective control, began to be seen in 2007. Ice fishing (mainly for yellow perch, walleye, and rainbow smelt) is popular, because, even when the main lake is ice-free, many bays are ice covered. Yellow perch are fished year-round, and its status has been controversial. Yellow perch in Lake Champlain are relatively small with few in the harvest greater than 22 cm (9 in). Anglers have expressed concern that the species has been overfished, but sampling suggests the species may actually be over-abundant and slow growing.

Currently, commercial harvest in the U.S. waters of Lake Champlain consists solely of the sale of fish caught by angling or by licensed bait dealers. The majority of fish sold are yellow perch, although rainbow smelt and panfish (Centrarchidae) are also marketed. Few records of catch or sale of fish exist, although an estimate from 1991 suggests that from 91 to 388 metric tons (200,000 to 745,000 lbs) of fish were sold.

Invasive species are a major concern in Lake Champlain. In addition to the 12 fishes accepted as introduced and 3 of debated status, 12 plants, 18 molluscs, incompletely inventoried crustaceans and other invertebrates, and two fish pathogens (largemouth bass virus first seen in 2002 and pike lymphosarcoma first seen in the late 1990s) have established. In addition, water chestnut (*Trapa natans*) and Eurasian water milfoil (*Myriophyllum spicatum*), which are found in dense beds particularly in the southern portion of the lake, have measurably altered fish habitat. Zebra mussels (*Dreissena* *polymorpha*), introduced in the south lake in 1993 and now found throughout the lake, are also altering benthic habitats and invertebrate communities. As a result of concerns about introduction of non-native species, use of bait fish in Vermont was restricted in 2002 to 16 native species. In 2007, the discovery of viral hemorrhagic septicemia (VHS) in the Great Lakes resulted in emergency regulations by Vermont and New York to restrict transportation of stocked fish and bait fish. A variety of introduced species other than fishes have invaded wetland and shoreline habitats. Of particular concern and nuisance status are zebra mussel, Eurasian water milfoil, water chestnut, and purple loosestrife.

New York and Vermont work together to match fishing regulations as closely as possible, given socioeconomic constraints. A reciprocal license agreement allows anglers from either state to fish portions of the lake that share the state boundary (http://www.dec.ny.gov/permits/6411.html; http://www.vtfishandwildlife.com/lawsdigest.cfm).

GUIDING PRINCIPLES

(adopted January 2006, revised March 2008)

Ecosystem Management

Manage the lake as a whole ecosystem, recognizing the complex interrelationship of all species, including humans, and their environment.

- An ecosystem approach to management recognizes and incorporates all aspects of the ecosystem and is conducted within natural rather than political boundaries. Ecosystem management requires various agencies that manage different components of the ecosystem—water quality, habitat, fisheries, biodiversity, and human and political dimensions—to work together toward a common goal of a healthy ecosystem.

Sustainability

Recognize limits on lake productivity

- A healthy aquatic ecosystem is characterized by a diverse array of species with a functional, adaptive organization that has evolved naturally and continues to evolve. Management should strive to maintain ecosystem health while recognizing the fluctuating states that are inherent in natural systems.
- The amount of fish that can be harvested from a healthy aquatic ecosystem without adverse consequences is limited and is largely determined by the nutrients in the environment, habitat variables, and the ability of a fish population to respond to exploitation.
- Because humans can diminish their productive capability, healthy, naturally reproducing fish communities can only be ensured by managing human activities as part of the ecosystem. Fish populations at all trophic levels can be endangered by factors causing excessive mortality, such as: (1) overfishing, (2) stocking more predators than the forage base can sustain, (3) failing to control undesirable non-native species, and (4) loss of critical habitats caused by changes in river flow, dams, dredging, and sedimentation. Management actions aimed at increasing fish production and range expansion should emphasize the identification, protection, and rehabilitation of spawning, nursery, and other critical habitats.

Natural Reproduction

Maintain and enhance natural reproduction of fish populations

Diverse fisheries and fish communities composed of naturally reproducing native fish populations provide the most predictable, sustainable, and cost-effective benefits to society, including social, cultural, and economic benefits. These benefits are also accrued from certain naturalized fish species, including steelhead, brown trout, largemouth bass, and black and white crappies.

Self-sustainability is important to the biological integrity of a fish community. Natural feedbacks between predator and prey provide more effective self-organization and system resilience than external controls. Genetic fitness of self-sustaining populations is likely to exceed that of stocked populations because the former are exposed to natural selection throughout their life, making them better adapted to specific conditions in localized environments. Therefore, wild reproducing populations may exhibit higher survival and productivity than stocked populations.

Native Species

Preserve native species and support biodiversity

- All native fish species, including rare and threatened species and not just those that are exploited by humans, are important to the integrity of the fish community.
- Indigenous species that are currently abundant should be maintained, and those that are depleted should be protected and enhanced.

Non-Native and Naturalized Species

Prevent the introduction of non-native species

- The unintentional or unauthorized introduction of non-native species should be actively discouraged. Establishment of non-native species can disrupt native fish communities and challenge management objectives. The risk of additional introductions must be minimized. New introductions should elicit a rapid response to eliminate the species or limit its spread. No new non-native species will be intentionally introduced into the Lake Champlain watershed by fisheries managers without a careful consideration of its impact on the ecosystem and a thorough environmental review and public input process.
- Non-native species that have established in Lake Champlain and are likely to remain indefinitely (e.g., common carp, largemouth bass, and white perch), must be viewed as parts of the fish community. In addition, steelhead and brown trout have naturalized in some tributaries and continue to be stocked to benefit the fishery. The term “rehabilitation,” when applied to communities containing such species, means the recovery of lost fishery production and fishery values and not a complete return to a pristine state.

Nuisance Species

Develop management strategies for species that become nuisances

- Most fish and wildlife populations typically achieve a healthy balance in natural ecosystems. Certain conditions can alter this balance, causing native or introduced species to become overabundant to such a level that they then become nuisances or problematic for achieving fishery objectives. Techniques to control and mitigate the damage resulting from nuisance fish should be developed and implemented.
- Fish pathogens have the potential to alter fish communities, making it necessary to modify culture operations and management actions.

Stocking

Use stocked fish wisely

- Stocked fish are important for: (1) providing fishing opportunities, (2) developing spawning populations of species needing rehabilitation, and (3) maintaining progress in restoring the biological integrity of fish communities. Stocking must be conducted judiciously to satisfy a variety of needs identified by society.

Genetics

Maintain genetic fitness of fish populations

- Genetic diversity, both within and among fish stocks, is important to overall species fitness and adaptability.
- Managers have a responsibility to maintain genetic diversity through protection of locally adapted stocks and to select cautiously the strains of fish used in the recovery of a native species (Fraser 2008).
- Outbreeding depression can occur when hatchery fish interbreed with wild fish. Although within-population genetic diversity increases with outbreeding, fitness may decline (Waples 1991). To protect native stocks, genetic and behavioral interactions between wild and hatchery fish must be considered. Also, if stocked fish are very abundant in comparison to wild fish, the fishing effort used to harvest stocked fish may deplete the wild fish (Evans and Willox 1991; Araki et al. 2007).

Human Dimensions

Recognize that fisheries are an important social and cultural heritage

- Desirable fish communities and the means chosen to achieve them reflect social values. The stakeholders of concern here include all who use or benefit from the aquatic natural resources of the Lake Champlain basin. Fishery managers will do their best to maintain awareness of the social values and changing preferences of all stakeholders. Managers must recognize that social, cultural, and economic benefits to stakeholders—now and in the future—are important considerations in decision making.
- Managing a fish community requires a long-term perspective that also recognizes short-term social, cultural, and economic values.
- Stakeholders contribute critical biological, social, economic, and cultural information to fisheries management in support of decision making. With decision making comes a duty for fisheries managers to share accountability and stewardship with stakeholders.

Habitats

Protect and restore fish habitats

- Protecting and rehabilitating critical fish habitat, including tributary, embayment, and inshore spawning and nursery areas, is required to sustain productive fisheries over the long term. Maintenance of quality habitat is fundamental to fish and fish-community conservation.

Science-Based Adaptive Management and Accountability

Make science-based management decisions

- Good ecosystem-management decisions depend on a science-based approach using an adaptive, iterative process that requires timely information provided through conventional surveys; broad-based, long-term monitoring; and research.
- Public understanding and support will be improved when management decisions are clear, are based on the best available information, and require accountability.
- Fish-community goals and objectives should be quantifiable and measurable.

- Management must be coordinated among agencies. Lake Champlain fisheries-management agencies must share information, work toward consensus, and be accountable for their actions.
- Collaborative decision making must be sensitive to the different mandates, sub-goals, and constituencies of the agencies involved in interjurisdictional fishery management.

GOAL STATEMENT

(Adopted from the Great Lakes Fishery Commission 1997)

To secure fish communities, based on foundations of stable self-sustaining stocks, supplemented by judicious stocking of hatchery-reared fish, and provide from these communities an optimum contribution of fish, fishing opportunities and associated benefits to meet needs identified by society for: wholesome food, recreation, cultural heritage, employment and income, and a healthy aquatic ecosystem

FISH-COMMUNITY SUB-GOALS

As stated more formally at the beginning of this plan, the overall goal for fish-community management is to provide for enduring populations of naturally reproducing fish and for the wise use of stocked fish. In addition, such fish communities are intended to provide the best available social, cultural, and economic benefits and to contribute to a healthy environment. The following sub-goals will shape fish-community management in Lake Champlain. Sub-goals are described by species for the tributary, nearshore, and offshore fish communities and for non-native species. The accompanying narratives for fish species that are part of more than one community are typically given under the community in which critical life phases occur, e.g., Atlantic salmon and lake sturgeon spawn in and are particularly vulnerable to angling in tributaries; sea lamprey spawn in tributaries but their greatest impact occurs on the offshore community. Where possible, relevant benefits, risks, and indicators are identified, and management actions intended to improve ecosystem function are identified.

Sub-goals and indicators are intended to provide general directions for interstate and binational management of the lake’s fish community and fisheries. Specific objectives, actions, costs, implementation plans, and milestones have been or will be developed for individual species as needed. A strategic plan for salmonid management developed in 1977 has not been updated (Fisheries Technical Committee 1977) and is being replaced by this document. A management plan for walleye was developed in 1998 (Anderson et al. 1998) and continues to guide walleye management by Vermont Fish and Wildlife.

Tributary Fish Community

Species Sub-Goals

The fish community of the tributary zone, defined as the area between the fall line and the lake, will be composed primarily of a diversity of self-sustaining native fishes characterized by:

- Populations of brown trout and steelhead sufficient to provide fishing opportunities
- Increased stream returns of Atlantic salmon sufficient to support a viable sport fishery and natural reproduction
- Recovery of lake sturgeon populations sufficient for its removal from Vermont's list of endangered species
- Increased numbers of American eel consistent with global efforts for their rehabilitation
- Expansion of existing walleye populations sufficient to support a viable sport fishery and natural reproduction
- Maintenance or improvement of habitat conditions suitable for fish species identified as being of greatest conservation need, including quillback, redhorse suckers (*Moxostoma* spp.), eastern sand darter, and channel darter

Brown and Steelhead Trout (see Offshore Fish Community)

Atlantic Salmon

Lake Champlain historically supported populations of landlocked and/or sea-run Atlantic salmon (Plosila and Anderson 1985) that were abundant in the northern part of the lake and in the larger tributaries, including the Great Chazy, Little Chazy, Saranac, Salmon, Little Ausable, Ausable, and Boquet Rivers in New York; the Winooski, Lamoille, and Missisquoi Rivers in Vermont, and Otter Creek in Vermont (Greeley 1930). Evidence for anadromous Atlantic salmon in Lake Champlain is tenuous. The debate about the presence of sea-run fish is based in part upon confusion among river names, such that runs in the "Champlain River" could be attributed to either the Richelieu or the Great Chazy Rivers (Webster 1982). Atlantic salmon was the first species in Lake Champlain to show declines as a result of harvest and habitat changes caused primarily by stream sedimentation and damming. The species was last documented in the basin in the Ausable River, New York, in 1838. Sustained stocking began in 1972, and spawning runs and river and lake fisheries are maintained by annual stockings of approximately 240,000 smolts and 450,000 fry. The USFWS was mandated by Federal statute (The Lake Champlain Special Designation Act of 1990) to support this valuable inter-jurisdictional species through hatchery production. In Vermont, the majority of these fish originated from a Sebago Lake, Maine, strain with the domestic brood stock being held at a Vermont hatchery. In recent years, feral adults have been collected from the spawning run and stripped of eggs to: (1) supplement the eggs collected from the domestic brood stock, (2) periodically replace brood stock, and (3) develop a Lake Champlain strain. In New York, a landlocked salmon brood stock was established at Little Clear Pond from a variety of strains. Adults in the pond are collected during the spawning run and stripped of eggs to: (1) provide yearlings or fry for stocking, (2) to annually replenish the Little Clear Pond brood stock, and (3) to periodically replace a separate, captive brood stock used to supplement demand for additional stocking. Currently, New York is in the process of switching over the Little Clear brood stock to the Sebago strain of landlocked salmon. The landlocked salmon fishery has been monitored since 1972 via angler diaries.

Lake Sturgeon

Lake sturgeon was abundant historically in Lake Champlain and is currently listed as endangered in Vermont and threatened in New York. Lake Champlain supported a small commercial fishery that harvested from 50 to 200 sturgeon annually in the late 1800s and early 1900s (Moreau and Parrish 1994). Annual harvest declined rapidly in the late 1940s, and the fishery was closed in 1967. Severe declines in abundance have been attributed to overharvest and loss of access to spawning habitat due to dam construction. Historically used spawning grounds were found in the Missisquoi, Lamoille, and Winooski Rivers and in Otter Creek. Recent investigations have documented the presence of adult sturgeon during the spawning season in both the Lamoille and Winooski Rivers. Eggs have been collected in the Lamoille, Winooski, and Missisquoi Rivers, and larvae have been collected with drift nets in the Lamoille and Winooski Rivers but have not been found in the Missisquoi River. Sampling for eggs and larvae in Otter Creek was unsuccessful. Management emphasis has been placed on restoration of the native genetic strain, if feasible, in preference to supplementing the population with stocks from outside the basin.

American Eel

American eel ascend the Richelieu River in the yellow eel life stage and spend approximately 10 to 20 years in Lake Champlain before returning to the Atlantic Ocean for spawning. The Richelieu River (Fig. 1) connects northern Lake Champlain to the St. Lawrence River and supported a commercial eel fishery until it was closed in 1998 because harvest declined dramatically. The rebuilding in the mid-1960s of two dams on the river at Saint-Ours and Chambly, Québec, has been partly to blame for the decline (Verdon et al. 2003). Evidence of the impact of these dams on American eel recruitment to Lake Champlain can be seen in surveys in 1979 and 1985. Mark-recapture studies conducted in three Lake Champlain bays (Paradise, Keeler, and Converse) indicated a decline in population size (LaBar and Facey 1983) and an increase in individual size, reflecting an aging population that has not been supplemented sufficiently by recruits. In 1997, an eel ladder was constructed at the dam in Chambly, and, in 2001, a fish ladder and an eel ladder were built at Saint-Ours. Faune Québec, in cooperation with a commercial fisher's union and Hydro-Québec, initiated a ten-year American eel stocking program in 2005 in the Richelieu River to further enhance eel recruitment. From 2005 to 2008, 2.8 million elvers from the Atlantic Coast were transferred to the upper Richelieu River. Each lot of elvers was submitted to a standardized health assessment to minimize the threat of introduction of pathogens and parasites (namely *Anguillicola crassus*). Results from these efforts remain to be determined.

Walleye

Walleye are native to Lake Champlain and provided an important commercial seine fishery until the early 1900s (Anderson et al.1998). The walleye sport fishery dates back to the late 1800s when popular spring walleye fisheries existed in Missisquoi Bay and the Missisquoi River. Walleye was the most important game fish in Lake Champlain (30% of the anglers interviewed were fishing for walleye) until the early 1980s (Anderson 1978). Declines in walleye harvest, particularly in the northern part of the lake, prompted closure of the Canadian commercial fishery in 1971 and reduction in the daily creel limit in Vermont in 1978. The specific cause of the decline has not been identified but may be related to several factors, including: (1) habitat degradation in spawning tributaries, (2) overharvesting, (3) competition with salmonids for forage (primarily rainbow smelt), and (4) impacts from recent invasions of non-native species, such as zebra mussel, white perch, and Eurasian milfoil. Current stocking efforts were initiated in 1986 when New York began collecting walleye eggs from the South Bay spawning population. In 1988, Vermont began collecting eggs from tributaries to Lake Champlain. In 1992, it developed a cool-water rearing program at the Bald Hill Fish Culture Station and, in cooperation with the Lake Champlain Walleye Association (LCWA), began raising walleye fry and fingerlings for stocking. Eggs are collected annually from walleye captured in tributaries, and the larvae are reared in ponds at the state culture station, LCWA ponds, or LCWA mobile hatchery. From 1988 to 2007, 1.0-8.6 million fry and 12-182 thousand fingerlings were stocked annually into Lake Champlain.

Benefits

The tributaries of Lake Champlain historically supported reproduction by potamodromous species, such as Atlantic salmon, and provided feeding habitat for catadromous species (American eel). Tributaries were also critical habitat for a diversity of lotic fish species, of which several are threatened or endangered (northern brook lamprey, American brook lamprey, stonecat, channel darter, and eastern sand darter). Actions that improve the health and persistence of these species are often linked to actions that improve tributary habitat. Stream bank stabilization and contaminant reduction also improve nearshore habitats by reducing sediment and contaminant inputs.

Risks

As tributary water quality has improved over the past several decades, the habitat for sea lamprey larvae has also improved, possibly contributing to the current over-abundance of parasitic-phase sea lamprey. Lampricide treatments of tributary streams and deltas have the potential to impose additional stresses on vulnerable stream and nearshore biota. Removal of dams to improve access to spawning grounds for Atlantic salmon, walleye, and lake sturgeon may also increase the habitat available for larval sea lamprey, thus increasing the area exposed to lampricides.

Indicators

- Increased returns of spawning Atlantic salmon to tributaries, as measured at existing fish passage facilities
- Increased numbers and size of Atlantic salmon in angler catches from the lake and its tributaries
- Increased numbers of lake sturgeon in assessments
- An increase in American eel counts at the Chambly Dam on the Richelieu River
- Increased angler harvest of walleye in Lake Champlain and its tributaries
- Angler satisfaction with tributary fisheries
- Continued presence or an increase of fish species identified as being of greatest conservation need, such as quillback, redhorse suckers, stonecat, eastern sand darter, and channel darter

Nearshore Fish Community

Sub-Goals

The fish community of the nearshore zone, comprising littoral and wetland habitats, will be composed primarily of a diversity of self-sustaining native fishes characterized by:

- Increased populations of walleye sufficient to support a quality sport fishery
- Maintenance of population levels of smallmouth bass, largemouth bass, and northern pike sufficient to support quality sport fisheries
- Maintenance of yellow perch populations sufficient to support a viable sport fishery
- A restored, self-sustaining population of muskellunge sufficient to support a quality sport fishery

Walleye (see Tributary Fish Community)

Yellow Perch

Yellow perch size and abundance varies by location in Lake Champlain. In the early 1990s, yellow perch in the northern end of the lake were reported to be stunted (Vermont Department of Fish and Wildlife 1991), whereas, in the southern section of the lake, numbers were lower, but growth rate was higher. Predation on yellow perch and interspecific competition have changed with the proliferation of the invasive white perch and alewife and with the increase in numbers of nesting double-crested cormorant (*Phalacrocorax auritus*). White perch and alewife directly and indirectly compete with yellow perch. The diets of yellow and white perch may overlap in both the juvenile and adult stages; in late summer, both species tend to eat small fishes and chironomids in Missisquoi Bay (Parrish and Margraf 1994; White and Facey in press). Additionally, white perch eat yellow perch eggs and alewife feed on juvenile yellow perch (Mason and Brandt 1996). The cormorant population on Young Island grew exponentially initially, until control efforts began in 2002. Most of its diet has been yellow perch, although, by 2008, large numbers of alewife were noted in cormorant stomachs (Duerr 2007).

Centrarchids

Lake Champlain has seven species of panfish and bass, and all are targeted by anglers. Pumpkinseed, rock bass and smallmouth bass are native to Lake Champlain, white crappie and largemouth bass were introduced, and black crappie and bluegill are believed to also have been introduced, either by an unauthorized stocking or by invasion via the Champlain Canal (Langdon et al. 2006; Table 1). Bass fishing in Lake Champlain has become increasingly popular in recent years, and the species are targeted by both professional and non-professional anglers. Since the mid-1990s, the increase in bass fishing and bass tournaments has brought substantial economic benefit to the local communities along Lake Champlain and increased interest in bass fishing. Bass fishing is concentrated in the northern and southern portions of the lake.

Esocids

The Lake Champlain basin is home to four species of esocids: northern pike, muskellunge, redfin pickerel, and chain pickerel. Muskellunge was historically "widespread but uncommon" from the Missisquoi River to Otter Creek (Thompson 1853), but, by the 1970s, its range was reduced to the Missisquoi River. A chemical spill in that river in 1979 apparently eliminated this muskellunge population. Recent genetic analysis from muskellunge collected below the dams on the Missisquoi River and above and below the dams on Otter Creek indicate that it originated from fish stocked in Otter Creek and the Great Chazy River.

Benefits

The benefits relating to the sub-goals for the nearshore zone comprise widespread recreational fisheries supported by a diversity of fishes and recovery of non-sport fishes that enhance fish-community health.

Risks

The composition, structure, and function of the nearshore-zone food web will be governed largely by:

- Continued changes in water quality
- The abundance of zebra mussel
- Proliferation of invasive aquatic macrophytes
- The abundance of the recently established alewife
- The protection of wetland and other critical habitats from development
- Sport-fishing pressure

Changes in anthropogenic nutrient inputs and sediments and proliferation of invasive macrophytes and zebra mussel are modifying nearshore fish habitat and may lead to changes in species diversity. Northern pike, various bass, and panfish—light-tolerant fish adapted to weedy habitats—may increase in number. Expansion of the zebra mussel population across soft sediments may change food availability for fish species, such as yellow perch, lake sturgeon, and lake whitefish, which have demersal-feeding life stages. If alewife numbers expand, some species (for example, the emerald shiner and yellow perch) may suffer from increased predation and competition. Alternatively, high alewife numbers may decrease the level of predation on other species. Predators, such as salmonids, walleye, and double-crested cormorants, could feed more on alewife and on rainbow smelt and valued species, such as basses and yellow perch. In addition, the recent increase in popularity of basses and pike among sport anglers may require expanded monitoring.

Indicators

Indicators that nearshore sub-goals are being met are:

- Stable or increasing numbers of walleye in assessments
- Stable catch rates for smallmouth bass, largemouth bass, and northern pike in assessments and recreational fisheries
- Maintenance of yellow perch catches in assessments and recreational fisheries
- Evidence of consistent reproduction and recruitment of muskellunge in rivers
- Angler satisfaction with nearshore fisheries

Offshore Fish Community

Sub-Goals

The offshore fish community (pelagic and benthic) will be characterized by:

- Abundant populations of lake trout, Atlantic salmon, brown trout, and steelhead that provide a diversity of fishing opportunities
- Populations of rainbow smelt large enough to support a recreational fishery
- Stocking of sufficient Atlantic salmon to support re-establishment of self-sustaining populations
- Increasing numbers of naturally produced lake trout consistent with progress toward a self-sustaining population
- A stable population of lake whitefish with widespread spawning populations, including in those historically used spawning areas that are still suitable
- A forage base of sufficient abundance to support salmonid and walleye populations
- Suppression of sea lamprey populations utilizing a mixture of traditional (lampricides and barriers) and alternative control measures, including barriers, such that the marking rate on lake trout is below 25 per 100 fish
- Stable populations of native species, such as burbot and cisco, that characterize a healthy fish community in north temperate oligotrophic lakes

Atlantic Salmon (see Tributary Fish Community)

Lake Trout

Lake trout populations had disappeared from Lake Champlain by 1900 (Plosila and Anderson 1985). After sporadic stocking of lake trout in the late 19th century and in the 1950s and 1960s, a sustained stocking program began in 1973 to re-establish a fishery. The specific objective developed in 1977 was to "reestablish a lake trout fishery by 1985 that will annually provide at least 45,000 additional man-days of fishing with an approximate yield of 18,000 lake trout averaging 5 lb (2.3 kg) each" (Fisheries Technical Committee 1977). Since 1973, over 5 million lake trout have been stocked with annual stocking rates ranging from 39,000–272,000 yearling equivalents (5 fall fingerlings = 1 spring yearling; Fisheries Technical Committee 1999). Stocking rates were decreased by approximately half in 1995 to compensate for an anticipated increased survival owing to fish saved due to sea lamprey control and a potentially higher consumption of rainbow smelt. Annual stocking rates have since stabilized between 68,000 and 90,000 yearlings. Several different lake trout strains have been stocked with the majority of Vermont's stocking focused recently on a Lake Champlain strain (progeny of feral lake trout from Lake Champlain). In New York, stocking efforts have recently focused on the Finger Lakes strain. Wild-caught Seneca Lake fish are used as an egg source for rearing yearlings for stocking. The use of this brood stock for Lake Champlain is now in question due to the discovery of VHS in New York.

Despite high lamprey marking rates (30-98%) since lamprey control began, survival of feral adults has been good (~50%), spawning occurs at multiple sites in the main lake, and fry production is high. However, since 1982, the proportion of unclipped (presumably wild) lake trout seen during assessments of the spawning population has averaged only 4% and was 1.2% in 2005. This low level of unclipped fish in assessments may reflect natural reproduction or errors in fin clipping. The lake trout fishery has been monitored via salmonid angler diaries.

Brown Trout, Steelhead

Although not endemic, both species are well accepted as components of the fish community. They provide a diversity of fishing opportunities, which is an important social benefit, and a potential management tool for utilizing a changing forage base. The current brown trout stocking program began in 1977, and sustained steelhead stocking began in 1972. The Chambers Creek strain of steelhead is currently used for stocking and is obtained from the Salmon River Hatchery, New York. Beginning in 2007, steelhead stocking in New York was suspended because of the potential to introduce VHS from the Salmon River Hatchery. In the future, steelhead stocking from New York will depend on an alternative hatchery source. Vermont and New York stock the Rome Hatchery domestic strain of brown trout. Currently, the stocking target for steelhead and brown trout is 30% of the 491,000 total annual target for salmonid yearling equivalents. Approximately 78,000 steelhead and 68,000 brown trout were stocked annually in the mid-2000s.

Lake Whitefish

Lake whitefish supported a commercial fishery in Lake Champlain in the 1800s through the early 1900s until the fishery was closed in the U.S. in 1912 (Halnon 1963). Fishing was primarily for spawning fish using shoreline seines. From 1893 to 1904, Vermont issued 62-94 licenses per year, and the yield was up to 60,000 fish annually (Halnon 1963). In the fall of 1912, 64 licensed fishermen harvested 70,000 pounds (32 metric tons) of fish (Halnon 1963). Commercial fishing continued in the Quebec waters of Missisquoi Bay, but the number of licenses issued was reduced from 12 in the mid-1900s to 4 in 1974 (Mongeau 1979; Trioreau and Fortin 1985). Whitefish spawned in the bay, but the bay is too shallow and eutrophic to support a resident population. The harvest in

Missisquoi Bay declined steadily from 13,214 kg (29,132 lb) in 1972 to 35 kg (77 lb) in 2004, the last year in which harvesting occurred. The only historical study focused on lake whitefish in Lake Champlain was in 1930 (Van Oosten and Deason 1939. Data from recent research suggest that spawning populations at historical spawning sites in the South Lake and Missisquoi Bay are severely depleted or gone.

Forage Fish

Rainbow smelt, yellow perch, and emerald shiner have historically constituted the bulk of the prey available to Lake Champlain predators. Rainbow smelt also provides a popular target for ice fishing. Rainbow smelt is not harvested in tributaries, as is common elsewhere, as spawning largely occurs in the lake. Forage-fish abundance has been measured since the early 1990s, primarily through annual sampling of rainbow smelt by trawl and hydroacoustics. These efforts were designed to monitor the prey base in the face of increased predator survival that resulted from sea lamprey control. Managers can respond to increased pressure on the prey base by manipulating predator numbers through harvest control and stocking. Rainbow smelt populations in Lake Champlain are characterized by an age structure dominated by ages 1-2. Trawl catches expressed as catch-per-unit-effort (CPUE) (CPUE = number collected in 55 min of trawling) oscillate between years of very high numbers to very low numbers. Rainbow smelt CPUE in the main lake is generally lower than in the Inland Sea (median CPUE of 100-200 vs. 700-1,000, respectively). In recent years, non-native fish have become a major component of the prey assemblage. These include young-of-the-year (YOY) white perch (first documented in 1984) and alewife (first documented in 2003).

Sea Lamprey

The status of sea lamprey as native to Lake Champlain is the subject of debate, primarily because historical records do not mention sea lamprey or sea lamprey marks prior to the 1800s. However, genetic data suggest that they are native to the lake (Waldman et al. 2004; Bryan et al. 2005). If the species are native, changes to the Lake Champlain ecosystem and habitat must have contributed substantially to their current population imbalance with their host fishes. Experimental control involving the use of permanent and seasonal barriers and the application of the lampricides TFM and Bayluscide to 13 tributaries and 5 deltas began in 1990, and long-term control began in 2002 (Fisheries Technical Committee 1999; Marsden et al. 2003). Despite relatively intensive control efforts, marking rates on lake trout fell in 1992 to only 31 per 100 fish, then rose to 98 per 100 fish in 2006 before declining again to 31 per 100 fish in 2008. A wide range of other fish species are also attacked by sea lamprey.

In 2007, the cooperative convened a Sea Lamprey Summit with the Great Lakes Fishery Commission, resulting in a recommendation to place the USFWS as the lead, central agency for control on Lake Champlain. If this recommendation is implemented, the USFWS would continue to conduct annual population assessments of sea lamprey, participate in treatments, and have an added role as applicant to Vermont and New York for the permits needed for use of lampricides in the watershed. The recommendation has not yet been implemented. While considerable research is being done to find alternatives to lampricides, these chemicals continue to be the primary method for controlling sea lamprey populations in the Great Lakes, Finger Lakes, and Lake Champlain.

To facilitate investigation of non-chemical alternatives for sea lamprey control in Lake Champlain, the Lake Champlain Sea Lamprey Control Alternatives Workgroup, a federal advisory committee, was formally established by the Secretary of the Interior in 2006. The workgroup consists primarily of representatives of stakeholder organizations, with participation from state and federal agencies working collectively to restore fishery resources in the basin. As a federal advisory committee, the workgroup provides an opportunity for stakeholders to give policy and technical advice that may be useful in finding or deploying alternatives to lampricides. The workgroup reports to the Secretary of the Interior through the USFWS and the cooperative. Specific responsibilities of the workgroup are to: (1) provide advice regarding the implementation of sea lamprey control methods that are alternatives to lampricides, (2) recommend priorities for research to be conducted by cooperating organizations and for demonstration projects to be developed and funded by state and federal agencies, and (3) assist federal and state agencies with the coordination of alternative sea lamprey control research to advance the state of the science in Lake Champlain and the Great Lakes.

Burbot

Burbot is a minor commercial species in the Great Lakes but does not appear to have attracted any fishery interest in Lake Champlain. Burbot has not been monitored in Lake Champlain, although catch and size data were collected from 1982 to 1997 as part of the summer assessment of lake trout. The population status of burbot is unknown. Burbot and lake trout are the only native deepwater predators, thus, predation on rainbow smelt by burbot is of interest for forage-fish management.

Benefits

Benefits from achieving the offshore pelagic sub-goals are:

- A sport fishery based on a variety of salmon and trout
- Restoration of a predator fish community that is not dependant upon hatchery inputs
- A prey base capable of sustaining a predator fish community as well as a recreational fishery

Risks

The uncertainty and risk associated with achieving the sub-goals are high. Reduction of sea lamprey populations during the 1990-1998 experimental period resulted in increased survival of lake trout and Atlantic salmon. Concerns about depletion of rainbow smelt populations resulted in a decision to reduce stocking of lake trout in the late 1990s. The number of stocked Atlantic salmon remained stable due to angler preferences. These changes recognize the value of the sport fishery and reflect an effort to maintain a balance between the numbers of predator fish stocked and prey-fish abundance. Achievement of the sea lamprey control target of <25 marks per 100 lake trout will protect Atlantic salmon, steelhead, lake whitefish, and walleye and improve lake sturgeon restoration. Stocking has produced a population of lake trout with high survival and diverse year-class structure that supports an extensive sport fishery. However, despite successful spawning and fry production lakewide, little to no natural recruitment to the adult population has been detected. Impediments to recruitment have not yet been identified. Successful re-establishment of Atlantic salmon may be negatively affected by poor adult survival due to sea lamprey predation, low availability of or inhibited access to suitable stream habitat, and competition with other juvenile salmonids in streams.

Indicators

Indicators that offshore pelagic sub-goals are being met are:

- An abundance of rainbow smelt characterized by multiple age-classes
- Angler satisfaction with the rainbow smelt harvest
- Increased catch and size of Atlantic salmon in assessment and recreational fisheries
- Reproduction of naturally reproduced lake trout such that they comprise <15% of the fall assessments measured over multiple year-classes
- A reduction of sea lamprey marking to <25 marks per 100 lake trout
- An increased number and size of brown trout and steelhead in angler catches
- The maintenance of lake trout catch rates with an increase in average size

Non-Native Species

Sub-Goals

Management of non-native species in Lake Champlain shall consist of:

- Preventing new introductions
- Suppressing nuisance non-native species, where possible, to minimize their impact on native species and ecosystem functions

Of the 15 species of fishes that are known to have been accidentally or deliberately introduced into Lake Champlain, three (brown trout, steelhead, and largemouth bass) comprise an important component of the fishery. Brown trout and steelhead populations continue to be maintained by stocking. Introduction of new species of fishes by deliberate stocking is actively discouraged by the cooperative. Control of other vectors of accidental introduction, such as bait-fish transport, fish importation, and bilge- and ballast-water transport, are being addressed (Marsden and Hauser 2009). Introduction via the Champlain Canal is under review by the USFWS and the Lake Champlain Basin Program.

Among the accidentally or illegally introduced species, black and white crappie are now naturalized and contribute to sport-fishing diversity in the warmer waters of the lake. Blueback herring and gizzard shad entered the lake via the Champlain Canal, and brook silversides likely entered also via the canal. All three species are established in the lake and are not utilized by anglers; no effects on lake ecology have been noted. Tench, introduced to the Richelieu River as escapees from an unauthorized aquaculture operation, have not yet made an impact on the lake fish community or the fishery. Two additional species are of concern due to their potential importance to the fishery (white perch) or to their impacts on the ecosystem (alewife).

White Perch

White perch gained access to Lake Champlain in 1984 via the Champlain Canal (Hawes and Parrish 2003). They have since spread lakewide, and have started to gain importance in the sport fishery. Ecological impacts of this species in Lake Champlain are, at present, unknown. Recent studies of adult white perch diets in Missisquoi Bay indicate that these species feed largely on benthic invertebrates and zooplankton in early summer and shift to small fish and benthic invertebrates, especially chironomids, later in the summer (White and Facey, in press; Couture 2006). As an abundant, apparently opportunistic feeder, it has the potential to affect food availability for other species.

Alewife

Alewife was first noted in the Lake Champlain basin in Green Pond, New York, in the 1960s. Alewife appeared in Lake St. Catherine, Vermont, in 1997, presumably introduced by anglers. Alewife was found in Missisquoi Bay in 2002, and YOY alewife was sampled in large numbers in the main lake in 2007. A major die-off of YOY alewife was noted in the Inland Sea in February 2008 and in the south lake in March 2008. The discovery of alewife in the lake presents new challenges to managers. The alewife could exert some major influences on the lake's fish communities. Alewife prey on the larvae of many native fish species, impact the zooplankton community, and contain high levels of thiaminase (Eck and Wells 1987; Mason and Brandt 1996; Fitzsimons et al. 1999; Madenjian et al. 2008). Salmonid species that consume alewife exhibit thiamine deficiency, which results in early mortality syndrome (EMS). EMS affects the offspring of lake trout and Atlantic salmon and could be a major impediment to re-establishment of reproducing populations of these two species (Fitzsimons et al. 1999).

Benefits

Prevention of new introductions and suppression, where possible, of established species is important for maintaining ecosystem health and community structure in the lake.

Risks

Several non-native species already established in the Great Lakes, such as ruffe (*Gymnocephalus cernuus*) and quagga mussel (*Dreissena bugensis*) have not yet appeared in Lake Champlain. Round goby (*Apollonia/Neogobius melanostomus*) are now highly abundant throughout the St. Lawrence River and has become a dominant element in the food chain. Zebra mussel, white perch, and alewife were recently established in Lake Champlain and continue to increase in abundance. Alewife may contribute to diversity of forage for salmonids and allow increases in stocking and fishery yields. Alternatively, alewife may compete with rainbow smelt, resulting in no net increase in forage abundance. Rainbow smelt is an important diet item for every pelagic fish predator in Lake Champlain and provides an important winter fishery. Competition with or larval predation by alewife may affect rainbow smelt population dynamics and, in consequence, threaten the rainbow smelt, Atlantic salmon, and steelhead fisheries. Alterations in ecosystem structure or function may provide opportunities for new non-native species to colonize and expand, leading to further instability of community structure.

Indicators

Indicators of successful management actions are:

- No new accidental or unauthorized introductions
- Stabilization or reduction in the range or abundance of non-native nuisance species

MANAGEMENT ACTIONS TO SUPPORT HEALTHY FISH COMMUNITIES

Sub-Goals

Management actions that support healthy fish communities will include:

- Protecting native biodiversity
- Protecting the genetic diversity and biological integrity of native fishes
- Rehabilitating native fishes
- Protecting and enhancing populations of rare and endangered fishes
- Achieving sea lamprey marking rates of <25 per 100 lake trout
- Maintaining the integrity of existing food webs
- Protecting and rehabilitating critical fish habitat, especially tributary and nearshore spawning and nursery areas
- Encouraging government agencies to implement policies that would reduce contaminant concentrations in fish to levels that result in no sport-fish consumption advisories and that cause no impairment of fish and wildlife reproduction

The introduction of invasive species and the alteration of habitat through altered hydrology, increased sedimentation, and degradation of water quality has resulted in the declines of several native species that are now listed as endangered, threatened, or of special concern (Table 1) and has warranted special management consideration.

Species of Greatest Conservation Need

In addition to the harvestable species addressed above, other native species present in the basin are important due to: (1) their ecological role or (2) the uncertain or endangered status of their populations. Cooperation with state and federal agencies that manage habitat and water quality will benefit fish and the biodiversity that supports them. The status of species of greatest conservation need (threatened or endangered) is listed in Table 1. For example, eastern sand darter is threatened in both New York and Vermont, and channel darter is endangered in Vermont. Eastern sand darters are found in the lower sections of the Missisquoi, Lamoille, Winooski, and Poultney Rivers; channel darters occur in the Winooski, LaPlatte, and Poultney Rivers. Greeley (1930) reported channel darters in the Great Chazy River and on the New York side of Lake Champlain, but there are no recent records of this species from these locations. Successful sampling for both species is very dependent on river flows and lake levels, and both species rely on shifting depositional substrates, so it is difficult to estimate annual population changes. Further development of population assessment methods could clarify the distribution, abundance, and population trajectory of these species. Similarly, the distribution and abundance of mooneye is virtually unknown, due to the limited amount of sampling that would encounter this species. Two additional species of note are the northern and American brook lamprey (endangered and threatened in Vermont, respectively). Their distribution and abundance are known only to the extent that they appear as bycatch in annual stream assessments of sea lamprey larvae. Both species are vulnerable to land-use changes that alter stream habitats and to lampricides that target sea lamprey.

Sauger was once abundant in portions of Lake Champlain and was captured in considerable numbers as recently as the 1980s. Sauger was present in all sections of the lake except for the main lake, although it was more abundant in the southern portion of the lake (Anderson 1978). Recent netting surveys of the South Bay, where sauger was formerly abundant, failed to capture a single one. Sauger also disappeared within the last 30 years from the upper reaches of the St. Lawrence River. This species has attracted little attention in Lake Champlain, and little is known about its current status. However, as a protective measure, regulatory changes have been enacted by both New York and Vermont that virtually eliminate the angler harvest of sauger.

Benefits

Benefits from protecting biodiversity, maintaining or improving community structure, and reducing contaminants are:

- Self-sustaining populations supporting sustainable fisheries
- Increases in native fish diversity and improved habitat and water quality
- A more aesthetically pleasing environment

Risks

Major threats to biodiversity include the unintentional introduction of new species, habitat loss, and pathogens. Introductions can occur through a variety of means, including stocking programs; navigation channels; unauthorized releases; accidental transport on trailers, boats, and waders; or bait-bucket and live-well transfers. Parasitism by sea lamprey impacts the goals of restoring healthy salmonid populations. Habitat loss includes degradation of water quality, flow changes, siltation, and changes in connectivity. For many years, an important part of the fish management of Lake Champlain has been to prevent the introduction of and limit the distribution of fish pathogens. With the recent introduction of pathogens elsewhere, including heterosporis, spring viremia of carp, and, of particular concern, the introduction of VHS in the Great Lakes, new restrictions have been instituted for the transport of fish between water bodies, on the operation of and movement of fish between hatcheries, and on the use of wild and cultured fish in the bait-fish industry, all to protect Lake Champlain fish populations. To deal with fish pathogens, management agencies on Lake Champlain use their cooperative fish health programs, including the New England Fish Health Guidelines, the Great Lakes Fish Disease Control Policy and Model Program, and the Northeast Fish Health Committee Guidelines for Fish Importation.

Indicators

Indicators of successful management actions are:

- Increased catches of native and wild fish in assessments and fisheries
- Increased sightings of rare and endangered fish species
- Sea lamprey marking rates that meet management objectives

INFORMATION PRIORITIES

The Guiding Principles for this plan state that good ecosystem-management decisions depend on the availability of timely scientific information provided through broad-based, long-term monitoring and research. Priorities for management and research are documented in implementation plans associated with annual reports of the Fisheries Technical Committee. Limited resources frequently constrain the acquisition of sufficient data; additional resources and effort may be needed to fully develop some of these monitoring and research efforts. Ongoing monitoring and assessment programs are listed below:

- Larval sea lamprey abundance and intra-basin distribution
- Parasitic sea lamprey marking rates on salmonids, walleye, and lake sturgeon
- Adult sea lamprey trapping and selected mark-recapture population estimates
- Lake trout spawning-stock assessment
- Landlocked Atlantic salmon spawning stock and nearshore population assessments
- Tributary assessment of landlocked Atlantic salmon smolt production from fry stocking
- Forage-fish (rainbow smelt) assessment, including mid-water trawling and hydroacoustic sampling

- American eel monitoring and assessment
- Periodic monitoring for pathogens
- Angler opinion surveys
- Contaminant monitoring
- Fish-community monitoring
- Assessment of lake sturgeon distribution, abundance, age structure, and spawning success
- Assessment of the abundance, age, growth, and condition of walleye, sea lamprey marking rates, and contribution of stocked walleye to spawning populations

Additional information and research needs that may benefit management decision making include:

- Develop/implement additional species-specific monitoring programs (e.g., for basses, lake whitefish, burbot, esocids, and non-game fishes)
- Investigate factors that affect fish survival, spawning success, and abundance (e.g., habitat connectivity)
- Investigate the human dimensions of the fishery using, for example, creel and stakeholder-attitude surveys
- Develop/implement long-term periodic pathogen monitoring
- Evaluate impacts of aquatic nuisance fish (e.g., sea lamprey and alewife)

CONCLUSION

As the Lake Champlain system continues to change, further changes in the fish community and fisheries are likely to occur. Changes in nutrient levels and climate may affect the fish community and the latitude for fisheries management. Stocking, harvest controls, habitat protection and rehabilitation, sea lamprey control, and public outreach are tools that fisheries managers can use to achieve the goals outlined in this document. Fish-community and fisheries monitoring programs provide information to track change and to predict the future. Information-based decision making is important in a rapidly changing system where uncertainty and risk are high. The Fisheries Technical Committee and cooperative will strive to achieve the fish-community goals described in this document. These goals offer a blueprint for providing sustainable benefits and for improving ecosystem health.

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LITERATURE CITED

Anderson, J.K. 1978. Lake Champlain fish population inventory, 1971-1977. Federal Aid Project F-12-R, Job II-1, Vermont Fish and Game Dept., Essex Junction, VT.

Anderson, J., Chipman, B.D., Claussen, J., MacKenzie, C., Palmer, E., and Wiggins, T. 1998. A plan for management of walleye fisheries in Lake Champlain: Vermont waters, 1998-2002. Vermont Dept. of Fish and Wildlife, Waterbury, VT.

Araki, H., Cooper, B., and Blouin, M.S. 2007. Genetic effects of captive breeding cause a rapid, cumulative fitness decline in the wild. Science **318**: 100-103.

Bryan, M.B., Zalinski, D., Filcek, K.B., Libants, S., Li, W., and Scribner, K.T. 2005. Patterns of invasion and colonization of sea lamprey (*Petromyzon marinus*) in North America as revealed by microsatellite genotypes. Molecular Ecol. **14**: 3757-3773.

Couture, S.C. 2006. The effects of white perch (*Morone americana*) on the plankton community of Missisquoi Bay, Lake Champlain. M.S. thesis, Univ. Vermont, Burlington, VT.

Duerr, A. 2007. Population dynamics, foraging ecology, and optimal management of double-crested cormorants on Lake Champlain. Ph.D. dissertation, Univ. Vermont, Burlington, VT.

Eck, G.W., and Wells, L. 1987. Recent changes in Lake Michigan's fish community and their probable causes, with emphasis on the role of alewife (*Alosa pseudoharengus*). Can. J. Fish. Aquat. Sci. **44**(Suppl. 2): 53-60.

Evans, D.O., and Willox, C.C. 1991. Loss of exploited, indigenous populations of lake trout, *Salvelinus namaycush*, by stocking of non-native stocks. Can. J. Fish. Aquat. Sci. **48**: 134-147.

Fisheries Technical Committee. 1977. A strategic plan for development of salmonid fisheries in Lake Champlain. Lake Champlain Fish and Wildlife Management Cooperative. U.S. Fish Wildl. Serv., Essex Junction, VT.

Fisheries Technical Committee. 1999. A comprehensive evaluation of an eight year program of sea lamprey control in Lake Champlain. Lake Champlain Fish and Wildlife Management Cooperative, Essex Junction, VT.

Fitzsimons, J.D., Brown, S.B., Honeyfield, D.C., and Hnath, J.G. 1999. A review of early mortality syndrome in Great Lakes salmonids and its relationship with thiamine. Ambio. **28**: 9-15.

Fraser D.J. 2008. How well can captive breeding programs conserve biodiversity? A review of salmonids. Evol. Appl. **1**: 535-586.

Great Lakes Fishery Commission. 1997. A joint strategic plan for management of Great Lakes fisheries [online]. Available from http://www.glfc.org/fishmgmt/jsp97.pdf [accessed 4 October 2010].

Greeley, J.R. 1930. Fishes of the Lake Champlain watershed. *In* A biological survey of the Champlain watershed. Supplement to the 19th annual report of the New York State Conservation Department. *Edited by* E. Moore. NY State Cons. Dept. pp. 48-87.

Greene, C.W. 1930. The smelts of Lake Champlain. *In* A biological survey of the Champlain watershed. Supplement to the 19th annual report of the New York State Conservation Department. *Edited by* E. Moore. NY State Cons. Dept. pp. 105-129.

Halnon, L.C. 1963. Historical survey of Lake Champlain's fishery. Vermont Fish and Game Job Compl. Rep. F-1-R-10 Job 6. Essex Junction, VT.

Hawes, E.J., and Parrish, D.L. 2003. Factors affecting the expansion of white perch in Lake Champlain. J. Great Lakes Res. **29**: 268-279.

LaBar, G.W., and D.E. Facey. 1983. Local movements and inshore population sizes of American eels in Lake Champlain, Vermont. Trans. Am. Fish. Soc. **112**: 111-116.

LaBar, G.W., and DeHayes, D.H. 1989. Stock identification of rainbow smelt from Lake Champlain. Natl. Marine Fish. Assn.

Lake Champlain Basin Program. 2004. Lake Champlain basin atlas, vers. 3.0 [online]. Available from: http://www.lcbp.org/Atlas/index.htm [accessed 4 October 2010].

Langdon, R.W., Ferguson, M.T., and Cox, K.M. 2006. Fishes of Vermont. Vermont Dept. of Fish and Wildl., Waterbury, VT.

Madenjian, C.P., O'Gorman, R., Bunnell, D.B., Argyle, R.L., Roseman, E.F., Warner, D.M., Stockwell, J.D., and Stapanian, M.A. 2008. Adverse effects of alewives on Laurentian Great Lakes fish communities. North Am. J. Fish. Manage. **28**: 263–282.

Marsden, J.E. 1999. Smelt study on Lake Champlain. Vermont Dept. of Fish and Wildl., Waterbury, VT.

Marsden, J.E., and Hauser, M. 2009. Exotic species in Lake Champlain. J. Great Lakes Res. **35**: 250-265.

Marsden, J.E., Chipman, B.D., Nashett, L.J., Anderson, J.K., Bouffard, W., Durfey, L.E., Gersmehl, J.E., Schoch, W.F., Staats, N.R., and Zerrenner, A. 2003. Evaluation of the eight-year sea lamprey control program on Lake Champlain. J. Great Lakes Res. **29**(Suppl. 1): 655-676.

Mason, D.M., and Brandt, S.B. 1996. Effect of alewife predation on survival of larval yellow perch in an embayment of Lake Ontario. Can. J. Fish. Aquat. Sci. **53**(7): 1609-1617.

Mongeau, J-R. 1979. Dossiers des poissons du bassin versant de la Baie Missisquoi et de la Riviere Richelieu, 1954 a 1977. Government du Quebec, Ministere du Tourisme de la Chasse et de la Peche. Rapp. Tech. No. 06-24.

Moore, E. [ED.]. 1930. A biological survey of the Champlain watershed. Supplemental to the 19th annual report of the NY State Cons. Dept., Albany, NY.

Moreau, D.L., and Parrish, D.L. 1994. A study of the feasibility of restoring lake sturgeon to Lake Champlain. Tech. Rep. No. 9. Lake Champlain Basin Program, Grand Isle, VT.

Parrish, D.L., and Margraf, F.J. 1994. Spatial and temporal patterns of food use by white perch and yellow perch in Lake Erie. J. Freshwater Ecol. **9**: 29-35.

Plosila, D.S., and Anderson, J.K. 1985. Lake Champlain salmonid assessment report. Fisheries Tech. Comm., Lake Champlain Fish and Wildlife Management Cooperative, Essex Junction, VT.

Thompson, Z. 1853. Natural history of Vermont. C. E. Tuttle Co. Publisher, Rutland, VT.

Trioreau, M., and Fortin, R. 1985. Description de la structure generale d'une population de grand coregone (*Coregonus clupeaformis*) a la Baie Missisquoi et evaluation de taux d'expoitation. Universite du Quebec a Montreal.

Verdon, R., Desrochers, D., and Dumont, P. 2003. The Richelieu River and Lake Champlain American eel: a search for a regional-scale solution to a large scale problem. Am. Fish. Soc. Symp. **33**: 125-138.

Vermont Department of Fish and Wildlife. 1991. A report of the Yellow Perch Task Force to the Fish and Wildlife Board. Essex Junction, VT.

Van Oosten, J., and Deason, H.J. 1939. The age, growth, and feeding habits of the whitefish, *Coregonus clupeaformis* (Mitchell), of Lake Champlain. Trans. Am. Fish. Soc. **68**: 152-162

Waldman, J.R., Grunwald, C., Roy, N.K., and Wirgin, I.I. 2004. Mitochondrial DNA analysis indicates sea lampreys are indigenous to Lake Ontario. Trans. Am. Fish. Soc. **133**: 950-960.

Waples, R.S. 1991. Genetic interactions between hatchery and wild salmonids: lessons from the Pacific Northwest. Can. J. Fish. Aquat. Sci. **48**: 124-133.

Webster, D.A. 1982. Early history of the Atlantic salmon in New York. NY Fish Game J. **29**: 26-44.

White, J. D., and D. E. Facey. 2009. Diet overlap between native yellow perch (*Perca flavescens*) and invasive white perch (*Morone americana*) in Missisquoi Bay, Lake Champlain, Vermont. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie 30(8): 1189-1192

MISCELLANEOUS PUBLICATIONS

February 1993	What's next? The prediction and management of exotic species in the Great Lakes (report of the 1991 workshop). E.L. Mills, J.H. Leach, C.L. Secor, and J.T. Carlton. 22 p.
August 1993	A survey of fish-community and habitat goals/objectives/targets and status in Great Lakes areas of concern. J.H. Hartig. 95 p.
August 1993	Toward integrating remedial-action and fishery-management planning in Great Lakes areas of concern. J.H. Hartig. 34 p
September 1994	Walleye-rehabilitation guidelines for the Great Lakes area. P.J. Colby, C.A. Lewis, R.L. Eshenroder, R.C. Haas, L.J. Hushak. 112 p.
April 1996	A lake trout restoration plan for Lake Superior. M.J. Hansen [ED.]. 34 p.
August 1998	A lake trout rehabilitation guide for Lake Huron. M.P. Ebener [ED.]. 48 p.
2003-01	A rehabilitation plan for walleye populations and habitats in Lake Superior. M.H. Hoff [ED.]. 22 p.
2003-02	A lake sturgeon rehabilitation plan for Lake Superior. N.A. Auer [ED.]. 28 p.
2003-03	A brook trout rehabilitation plan for Lake Superior. L.E. Newman, R.B. DuBois, and T.N. Halpern [EDS]. 40 p.
2006-01	A mid-decade review of progress under a "strategic vision of the Great Lakes Fishery Commission for the first decade of the new millennium." 45 p.
2006-02	Application of a dichotomous key to the classification of sea lamprey marks on Great Lakes fish. Ebener, M.P., E.L. King, Jr., T.A. Edsall. 22 p.
2007-01	A joint strategic plan for management of Great Lakes fisheries. Great Lakes Fishery Commission [ED.]. 28 p.
2007-02	Application of a dichotomous key to the classification of sea lamprey Petromyzon marinus marks on lake sturgeon Acipenser fulvescens. Patrick, H.K., T.M. Sutton, and W.D. Swink. 24 p.
2008-01	A guide for the rehabilitation of lake trout in Lake Michigan. Bronte, C.R., C.C. Krueger, M.E. Holey, M.L. Toneys, R.L. Eshenroder, and J.L. Jonas. 40 p.
2008-02	A strategic plan for the rehabilitation of lake trout in Lake Erie, 2008-2020. Markham, J.L., Cook, A., MacDougall, T., Witzel, L. Kayle, K., Murray, M., Fodale, M., Trometer, E., Neave, F., Fitzsimons, J. Francis, J. Stapanian, M. 42 p.
2010-01	Genetic guidelines for the stocking of lake sturgeon (*Acipenser fulvescens*) in the Great Lakes Basin. A.B. Welsh, R.F. Elliott, K.T. Scribner, H.R. Quinlan, E.A. Baker, B.T. Eggold, J.M. Holtgren, C.C. Krueger, and B. May. 62 p.
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