STRATEGIC PLAN FOR LAKE CHAMPLAIN FISHERIES

Prepared by the Fisheries Technical Committee
of the Lake Champlain Fish and Wildlife Management Cooperative

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Table of Contents

EXECUTIVE SUMMARY

This Strategic Plan provides a framework for implementing the Lake Champlain Fish and Wildlife Management Cooperative's function of initiating, developing and providing direction to coordinated fisheries management programs in the Lake Champlain basin. The plan addresses the fish community and fisheries of Lake Champlain; regulation and management of water quality and land use, while relevant to fishes, are not directly addressed here because other agencies have primary responsibility for water quality and land use regulation. Fish community goals and sub-goals are outlined, and the role of each of the agencies in the coordinated programs is described. The Plan is based on guiding principles for ecosystem management, sustainability, natural reproduction of native species, management of non-native and nuisance species, use of stocking, application of genetics, protection of habitats, use of science-based management, and management accountability, with specific reference to human dimensions of fisheries management.

Lake Champlain is a large, heterogeneous lake, comprising four distinct basins separated by a combination of geographic features and causeways constructed over shallow bars. Habitats, trophic state, watershed use, and fish fauna vary among these basins. The large watershed of the lake drains forested, agricultural, and urban areas. Lake Champlain and its tributaries currently contain 88 species of fishes, of which 15 are non-native. Anthropogenic changes of concern in the lake include contaminated sediments in Cumberland Bay, Outer Malletts Bay, and the Burlington Barge Canal, and presence of mercury and PCBs in fish flesh. Sediment and phosphorus inputs into the lake have attracted public and political attention; exotic species, particularly aquatic plants and zebra mussels, have invaded wetland and shoreline habitats.

Biological assessments of fish populations have occurred sporadically since the first formal survey conducted by New York in 1929. Historically, commercial fisheries primarily targeted lake whitefish, walleye, yellow perch, lake sturgeon, eel, and lake trout. These fisheries may have contributed to the decline of lake sturgeon in the main lake and lake whitefish in Missisquoi Bay. The building of dams and degradation of riverine spawning areas undoubtedly contributed to the decline of lake sturgeon and disappearance of Atlantic salmon, but the disappearance of lake trout by the late 1890s is difficult to explain. The current fishery on the lake is almost entirely based on angling, with the most popular species being the four salmonid species, walleye, yellow perch, basses, smelt, and pikes. Commercial harvest in the U. S. waters of Lake Champlain consists only of the sale of fish caught by angling, or licensed sale of bait fish. While a number of fish species were stocked in the lake historically, stocking is currently limited to lake trout, landlocked Atlantic salmon, steelhead, brown trout, and walleye.

The Strategic Plan outlines sub-goals for the three major components of the lake's fish community, and describes the associated benefits, risks, and indicators for each sub-goal:

The fish community of the tributary zone will be composed primarily of a diversity of self-sustaining native fishes characterized by

- Populations of brown trout and rainbow trout sufficient to provide fishing opportunities

- Increased returns of Atlantic salmon to tributary streams, sufficient to support a viable sport fishery and natural production of smolts
- Recovery of lake sturgeon populations sufficient for removal from Vermont's list of threatened species
- Increasing numbers of American eels consistent with global efforts for their rehabilitation
- Maintenance and expansion of existing walleye populations, sufficient to support a viable sport fishery
- Maintenance or improvement of habitat conditions suitable for fish species identified as being of greatest conservation need, including quillback, redhorses, eastern sand darter, and channel darter.

The fish community of the nearshore zone 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 existing yellow perch populations sufficient to support a quality sport fishery
- Monitoring and maintenance of population levels of nearshore fishes including smallmouth bass, largemouth bass, and northern pike populations sufficient to support quality sport fisheries
- Restored, self-sustaining, fishable population of muskellunge in the lake and lower tributaries sufficient to support a quality sport fishery

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 smelt that support a recreational fishery
- Populations of stocked Atlantic salmon at levels consistent with potential restoration 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 multiple spawning populations, including historical spawning areas that still contain suitable habitat
- A forage base with sufficient abundance to support salmonid and walleye populations
- Suppressed sea lamprey populations utilizing a mixture of traditional (lampricides and barriers) and alternative control measures, with a wounding rate below 25 AI-AIII wounds per 100 lake trout
- Stable populations of native species such as burbot and lake herring/cisco that characterize a healthy fish community

In addition, management actions will, when possible, prevent new introductions of aquatic species and suppress non-native species to minimize their impact on native species and ecosystem function. Management actions to support healthy fish communities are outlined and discussed; the Plan concludes with a listing of information priorities that will directly facilitate management decisions and actions, and research that will lead to a better understanding of factors and processes that affect the lake and its fishes.

GOAL STATEMENT

> *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 (*Great Lakes Fishery Commission 1997)

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INTRODUCTION

The Lake Champlain Fish and Wildlife Management Cooperative (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. The Province of Quebec is not a signatory party, but the Cooperative maintains close communication and coordination with the Province. A Memorandum of Understanding renewing the Lake Champlain Fish and Wildlife Management Cooperative (January 1995 and as amended July 1996) calls for coordinated fish and wildlife programs of interstate significance in Lake Champlain. The specific responsibilities of the Cooperative, as outlined in the MOU, are to:

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

The Cooperative is currently working under the 1977 strategic plan: "A Strategic Plan for the Development of Salmonid Fisheries in Lake Champlain". This plan reflected the primary goals at the time, which were the restoration of lake trout and Atlantic salmon fisheries. Since 1977, the importance of additional sportfish species, 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 is needed to guide management decision-making and research efforts.

This Strategic 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 the coordinated fish and wildlife programs is flexible, depending on the agency's mission, capability, and the Cooperative's needs. Agency roles as of the date of this report are described below.

Interjurisdictional fisheries in Lake Champlain are fish populations that, because of their geographic distribution and/or migratory patterns, fall under the jurisdiction of both Vermont and New York, and are managed by both States and, to a lesser degree, by Quebec. This plan is written with the understanding that the U.S. Fish and Wildlife Service, Vermont Fish and Wildlife Department, and New York State Department of Environmental Conservation, will each provide staffing and funding to assume the following specific, long-term, interjurisdictional fisheries management roles for the Cooperative, except when appropriations are insufficient to support staffing or funding.

Monitoring and assessment of the forage base for the lake's salmonid 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 restore lake trout and landlocked Atlantic salmon

Enhance 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 and assessment of American eel

Monitoring and assessment of lake sturgeon in Vermont Rivers including the Missisquoi, Lamoille, and Winooski Rivers and Otter Creek

Walleye population monitoring, assessment and brood stock procurement

In addition to cooperation to restore or manage interjurisdictional fisheries, the U.S. Fish and Wildlife Service will work with the States of New York and Vermont on the following:

Restoring connectivity where appropriate in tributaries of Lake Champlain to benefit brook trout and other aquatic species

Providing assistance to prevent new aquatic nuisance species introductions and to limit the spread between the basins of Lake Champlain

Several additional characteristics of the ecosystem affect fish populations, including land use management to reduce siltation and contaminants in Lake Champlain; however, management of land use and contaminants is not the primary responsibility of the Cooperative, and is not addressed in this plan.

The purpose of the current document is to outline fish community goals and sub-goals for Lake Champlain and provide a framework for progress toward the goals. Specific population targets, implementation strategies, costs and research needs are addressed through separate planning processes. This strategic plan will be updated on a regular basis, not to exceed every 5 years.

GUIDING PRINCIPLES FOR LAKE CHAMPLAIN
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.

- Αν εχοσψστεμ αππροαχη το μαναγεμεντ ρεχογνιζεσ 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, 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 inherently fluctuating states that are natural to such a system.
- 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 may diminish this 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 flow, dams, dredging, and sedimentation. Management actions to increase fish production and expand distribution should emphasize the identification, protection, and rehabilitation of fish spawning, nursery, and other critical habitats

Natural reproduction

Maintain and enhance natural reproduction of fish populations

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

- Self-sustainability is important to the biological integrity of the fish community. Natural feedbacks between predator and prey can provide more effective self-organization and system resilience than external controls can provide. Changes in harvest or stocking are often too late because of the time required for detection. Genetic fitness of self-sustaining populations is likely to exceed that of stocked populations because they may benefit from natural selection through adaptations to unique and specific conditions in localized environments. Therefore, wild reproducing populations can be expected to have better survival and productivity than stocked populations.

Native Species

Preserve native species and support biodiversity.

- All native fish species, not just those that are exploited by humans, and including rare and threatened species, 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.

Exotics/non-native/naturalized species

Prevent the introduction of non-native species.

- The unintentional or unauthorized introduction of non-native species should be actively and aggressively discouraged. Establishment of non-native species can disrupt native fish communities and challenge management objectives. The risk of additional introductions of non-native species 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 careful consideration of impacts on the ecosystem, and a thorough environmental review and public input process.
- Non-native species that have become established in Lake Champlain and are likely to remain indefinitely (e.g., carp, largemouth bass, white perch) must be viewed as parts of the fish community. In addition, steelhead/rainbow trout and brown trout have become established in some tributaries, and they continue to be stocked in order to provide continued benefits to 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 fish community.

Nuisance species

Develop management strategies for species that become nuisances.

- Fish and wildlife populations in most natural situations occur in a healthy balance within their ecosystem. Certain conditions can alter this balance, causing native or introduced species to become nuisances, overabundant, or problematic in achieving fish restoration or fishery objectives. Where appropriate, develop and implement techniques to control and mitigate nuisance fish and wildlife damage and conflicts.
- Fish pathogens have the potential to alter fish communities, therefore it may be necessary to

modify culture operations and management actions to address the threat of potential pathogens.

Stocking

Use stocked fish wisely

- Stocked fish are important for: 1) providing fishing opportunities, 2) developing spawning populations of species needing rehabilitation, and 3) continuing progress in restoring the biological integrity of the fish community. Stockings 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 be cautious in the selection and stocking of particular strains of fish intended to support the recovery of native species (Fraser 2008).
- Outbreeding depression can occur when hatchery fish interbreed with wild fish. Although the within-population genetic diversity increases with outbreeding, fitness may decline (Waples 1991). Genetic and behavioral interactions between wild and hatchery fish must be considered in order to protect native stocks. Also, if stocked fish are very abundant in comparison to wild fish, the fishing effort used to harvest stocked fish may deplete wild fish (Evans and Willox 1991, Araki et al., 2007).

Human dimensions

Recognize that fisheries are an important social and cultural heritage.

- Desired conditions and the means by which we choose to achieve these conditions are social values. Stakeholders include all who use or benefit from the aquatic natural resources of the Lake Champlain basin, and their preferences may change over time. Managers will do their best to be aware of the social values and preferences of all stakeholders. Managers must recognize that social, cultural, and economic benefits to various stakeholders – both in the present and the future – are important considerations in making fishery-management decisions.
- Managing a fish community requires a long-term perspective that recognizes the shorter-term social, cultural and economic requirements.
- Stakeholders contribute critical biological, social, economic and cultural information to fisheries management agencies in support of fisheries management decision making; with decision making comes a duty to share accountability and stewardship.

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;

preservation and restoration of habitat must be the foremost concern for achieving these objectives.

Science-based adaptive management and accountability

Use sound science to make management decisions.

- Good ecosystem management decisions depend on a science-based approach using an adaptive, iterative process that requires timely scientific 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 the Management Cooperative.

DESCRIPTION OF LAKE CHAMPLAIN

Lake Champlain has a surface area of 1,130 km^2 (435 sq. miles) and a volume of 26 km^3 (6.2 $miles^3$). 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 percent in New York, to the west, and 3.5 percent in Quebec, to the north (Figure 1). The lake flows from tributary inputs in the south to its outlet, the Richelieu River, at the north end. Lake Champlain is naturally connected to the St. Lawrence River via the Richelieu River, and to Lake George via LaChute River, which flows into the lake at Ticonderoga, NY. The Champlain Canal, opened in 1823, connects the lake to the Hudson and Mohawk River drainages and to the Great Lakes via the Erie Barge Canal system.

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

- The South Lake extends from Whitehall, NY, 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, NY, and includes the deepest section of the lake near Split Rock Point, NY. This basin is meso- to oligotrophic and contains most of the deep, coldwater salmonid habitat in the lake. The two largest population centers in the basin, Burlington, VT, and Plattsburgh, NY, 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 is mostly contained within the 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, VT. 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 supports primarily warmwater fish species. Land use in the area is largely agricultural.

Lake Champlain has a very large watershed (21,326 km^2 or 8,234 sq. miles) compared to its surface area. In consequence, the lake level varies considerably, with an annual fluctuation of 1-2 m (3- 6.5 ft). Mean lake level is 29.1 m (95.5 feet) above sea level; record low was 28.1 m (92.4 ft) and 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 Champlain Valley of Vermont. The total 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 found in Lake Champlain. The coldwater predator population is dominated by lake trout, Atlantic salmon, brown trout, and steelhead. Coolwater species include yellow perch and walleye. Coregonid species are limited to lake whitefish and lake herring/cisco, and major forage for piscivores are native rainbow smelt and yellow perch; alewives were found in the lake in 2002 and have rapidly increased in abundance. Important warmwater sport fishes include largemouth and smallmouth bass, northern pike, pumpkinseed, and white and black crappies. Seven fish species are classified as endangered, threatened, or susceptible in Vermont, New York, or Quebec: northern brook lamprey (E-VT), American brook lamprey (T-VT), lake sturgeon (T-NY, E-VT, S-QC), mooneye (T-NY), stonecat (E-VT), eastern sand darter (T-NY, VT), and channel darter (E-VT, S-QC). An additional 14 species are listed as of special concern in Vermont, and lake sturgeon, lake herring/cisco, redfin pickerel, channel darter, and brassy minnow are listed as susceptible in Quebec (Table 1).

Habitat degradation in Lake Champlain in the early period of colonization by Europeans was primarily due to damming of rivers, introduction of sawmill wastes into tributaries, and effects of logging. Most of the major tributaries to Lake Champlain, including the Great Chazy, Little Chazy, Salmon, Little Ausable, Ausable, Boquet, Winooski, Lamoille, Missisquoi, 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, NY, in 1838. Early settlement of the Lake Champlain Valley in the early 1800s was marked by extensive timber cutting. Vermont lost approximately 60% of its forests by 1890 to 1900, though considerable additional land was cleared at some time and allowed to regrow; only about 500 ha (1,236 acres) 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 chemical wastes. The three primary areas of contaminant concern are Cumberland Bay (PCBs, PAHs, copper, and zinc), Outer Malletts Bay (arsenic and nickel), and 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 removed by dredging in Cumberland Bay in 1999-2000. In recent decades, concerns about sediment and phosphorus inputs into the lake have attracted public and political attention. The Champlain Valley on the Vermont side, the northern portion of the New York side, and in Quebec is extensively farmed, contributing to concerns about sediment runoff and phosphorus inputs into the lake. Development of former agricultural and forest land to housing and commercial property further increases sediment and nutrient runoff. Efforts to reduce the amount of phosphorus that enters the lake include wastewater treatment upgrades, nutrient and waste management of farms, streambank erosion control, and programs aimed at reducing phosphorus runoff from lawns and roads 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 sedimentation from adjacent land use. A variety of introduced species have invaded wetland and shoreline habitats; of particular concern and nuisance status are zebra mussels, Eurasian water milfoil, water chestnut, and purple loosestrife. 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, though his descriptions contain a number of apparent mis-classifications. 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 the salmonid restoration program and to assess the 1990-1997 experimental sea lamprey control program (Fisheries Technical Committee 1999). Forage base monitoring, focused on smelt, began in 1990 with the use of index trawling stations, annual assessments of lamprey wounding on lake trout, salmon, and walleye are conducted each summer or fall, and the salmonid, smelt and walleye fisheries are monitored with angler diary programs.

Commercial fishing on Lake Champlain was historically dominated by use of shoreline seines and set lines to capture lake whitefish, walleye, yellow perch, and lake trout, particularly on their spawning grounds (Halnon 1963). Additional species harvested included basses, bullhead, catfish, eels, northern pike, pickerel, rock bass, smelt, Atlantic salmon, and lake sturgeon. A commercial fishery for yellow eel by 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 eels 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 century, until the fishery was closed in 1912. 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 commercially 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 such as the building of dams and degradation of riverine spawning areas undoubtedly contributed to the decline of lake sturgeon and disappearance of Atlantic salmon. The disappearance of lake trout by the late 1890s is the most difficult 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, walleye, and yellow perch. Smelt were considered historically to be anadromous, entering Lake Champlain periodically via the Richelieu River; others reported that smelt had been introduced to the lake by stocking (Thompson 1853, Halnon 1963). Stocking of over 65 million smelt from the Cold Spring Harbor hatchery did take place in the early 1900s (Greene 1930), but most writers consider smelt to be indigenous. There are thought to be two ‘races’ of smelt in the lake, a normal sized smelt and a giant race (Greene 1930). Genetic analysis performed on Champlain smelt was inconclusive in determining the existence of different races but recommended further study using alternative genetic techniques (LaBar and Dehayes 1989; Marsden 1999). Unlike smelt in the Great Lakes, Lake Champlain smelt do not generally ascend rivers to spawn, but spawn offshore in depths around 15 m (49 ft) or greater. They are most popular during the ice fishery.

Stocking of various species was considered to be a beneficial activity, and involved private citizens as well as state agencies. Non-native species that have been deliberately stocked include Chinook salmon, kokanee salmon, cutthroat trout, grayling, brown trout, rainbow trout, American shad, black crappie, largemouth bass, and carp. Stocking of native species such as brook trout, lake trout, Atlantic salmon, brown bullheads, walleye, yellow perch, rainbow smelt, lake whitefish, rock bass, and channel catfish also occurred (Langdon et al. 2006). The great majority of these introductions failed to establish new populations, with the notable exception of carp, largemouth bass, and black crappie. Limited brown trout and steelhead stocking began again in the 1970s and persists in order to add diversity to the recreational fishery.

The current fishery in Lake Champlain is almost entirely based on angling; although commercial licenses are still permitted in Quebec, the commercial fishery has not been active since 2004. Popular sport fisheries include the four salmonid species, walleye, yellow perch, basses, and pikes. Summer tournaments bring substantial revenues to the area, with several focusing on bass fishing. Ice fishing, mainly for yellow perch, walleye, and smelt, is popular, as even when the main lake is open, many bays are ice-covered for several months. Yellow perch are fished year-round. The status of this species 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 overabundant and slow-growing. Charter fishing has declined since the mid 1990s due to an overall reduction in the salmonid fishery as a consequence of sea lamprey predation.

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

Non-native, invasive species are a significant concern in Lake Champlain; 15 non-native fish species and 12 non-native plant species are established in the lake, in addition to approximately 18 molluscs, crustaceans, and other invertebrates, and two fish pathogens: largemouth bass virus, first seen in 2002, and pike lymphosarcoma, first seen in the late 1990s. 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 significantly altered fish habitat. Zebra mussels, 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 a list of 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.

New York and Vermont work together to have their respective fishing regulations on Lake Champlain match as closely as possible, given political 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).

FISH COMMUNITY SUB-GOALS

A general goal for Lake Champlain fish management is to provide for fish communities based on enduring populations of naturally reproducing fish and on the wise use of stocked fish. In addition, these fish communities are intended to offer the best available social, cultural, and economic benefits and contribute to a healthy environment. The following sub-goals will shape fish-community management in Lake Champlain. Sub-goals are described separately for the tributary, nearshore, and offshore pelagic fish communities. Fish species that use more than one habitat are generally described under the habitat in which critical life phases occur, e.g., Atlantic salmon and lake sturgeon spawn and are particularly vulnerable to angling in tributaries; sea lamprey spawn in tributaries but their fisheries impact occurs in the lake. A distinction is made between steelhead, which are stocked only into Lake Champlain, and rainbow trout, which are stocked only in tributaries; they are each different life stages of the same species, *Oncorhynchus mykiss*. Where possible, relevant benefits, risks, and indicators are identified. Management actions intended to improve aquatic ecosystem function are identified.

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

Tributary Fish Community

Tributary Fish Community - Sub-goals

The fish community of the **tributary zone,** defined as the areas 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 rainbow trout sufficient to provide fishing opportunities
- Increased returns of Atlantic salmon to tributary streams, sufficient to support a viable sport fishery and natural reproduction
- Recovery of lake sturgeon populations sufficient for removal from Vermont's list of endangered species
- Increasing numbers of American eels consistent with global efforts for their rehabilitation
- Maintenance and 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, redhorses, eastern sand darter, and channel darter.

Brown trout, rainbow trout: addressed under Offshore Fish Community (rainbow trout and steelhead are discussed together)

Atlantic salmon*:* Lake Champlain supported indigenous populations of landlocked and/or sea-run Atlantic salmon (Plosila and Anderson 1985). Atlantic salmon 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, Boquet rivers in New York and the Winooski, Lamoille, Missisquoi rivers and Otter Creek in Vermont (Greeley 1930). Atlantic salmon was the first species in Lake Champlain to show declines as a result of harvest and habitat changes, primarily stream sedimentation and damming. The species was last documented in the basin in the Ausable River, NY, in 1838. Sustained stocking began in 1972; current fall spawning runs and river and lake fisheries are maintained by annual stockings of approximately 240,000 salmon smolts and 450,000 salmon fry. Through coordination within the Cooperative, 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 broodstock being held at a Vermont state hatchery. In recent years, "wild" adults have been collected from the spawning run in the fall and stripped of eggs to 1) supplement the eggs collected from the domestic broodstock, 2) periodically replace broodstock, and 3) develop a Lake Champlain specific strain. In New York, a landlocked salmon broodstock was established at Little Clear Pond from a variety of Atlantic salmon strains. "Wild" adults in the pond are collected during the spawning run and stripped of eggs to 1) provide eggs for rearing yearlings or fry for stocking, 2) to annually replenish the Little Clear Pond broodstock, and 3) to periodically replace a separate, captive broodstock used to supplement demand for additional fish for stocking. Currently, New York is in the process of switching over the Little Clear broodstock to the Sebago strain of landlocked salmon. The landlocked salmon fishery has been monitored through a salmonid angler diary program conducted since 1972.

Lake sturgeon*:* Lake sturgeon were historically abundant in Lake Champlain and are currently listed as a state endangered species 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 lake sturgeon abundance have been attributed to overharvest and loss of access to spawning habitat due to dam construction. Historic spawning grounds were found in the Missisquoi, Lamoille and Winooski rivers, and Otter Creek. Recent investigations have documented the presence of adult sturgeon during the spawning season in both the Lamoille and Winooski rivers. Lake sturgeon eggs have been collected in the Lamoille, Winooski and Missisquoi rivers. Lake sturgeon larvae have been collected with driftnets 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*:* Eels ascend the Richelieu River as yellow eels and spend approximately 10 to 20 years in Lake Champlain before returning to the Atlantic Ocean for spawning. The Richelieu River connects northern Lake Champlain to the St. Lawrence River and supported a commercial eel fishery until it was closed in 1998 because harvest dramatically declined. The rebuilding of two dams on the river has been partly to blame for the decline (Verdon et al. 2003). The dams at Saint-Ours and Chambly, Québec were refurbished in the mid 1960s. Evidence of the impact of these dams on American eel recruitment to Lake Champlain can be seen in eel surveys in 1979 and 1985. Mark-recapture studies conducted in three Lake Champlain bays, Paradise, Keeler, and Converse, indicated a decline in estimated population size (LaBar and Facey 1983) and an increase in average size of American eel caught, reflecting an aging population that has not been sufficiently supplemented 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 St 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. Between 2005 and 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 prevent introduction of pathogens and parasites (namely *Anguillicola crassus*).

Walleye*:* Walleye are native to Lake Champlain and they provided an important commercial seining fishery until the early 1900s (Anderson et al.1998). The walleye sport fishery dates back to the late 1800s when popular walleye fisheries existed in Missisquoi Bay and the Missisquoi River during the spring. 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 commercial fishery in the 1970s and reduction of creel limits. 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) over harvesting, 3) competition with salmonids for forage (primarily rainbow smelt), and 4) impacts from recent invasions of non-native species such as zebra mussels, white perch and Eurasian milfoil. Current stocking efforts were initiated in 1986 when NYDEC began collecting walleye eggs from the South Bay spawning population. In 1988 the VTDFW began collecting eggs for the program from Vermont tributaries to Lake Champlain. In 1992, the VTDFW developed a coolwater 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 to stock. Eggs are collected annually from adult walleye captured in tributaries to Lake Champlain and reared in ponds at the state hatchery, LCWA ponds, or LCWA mobile hatchery. One to 8.6 million fry and 12,000 to 182,000 fingerlings were stocked annually into Lake Champlain between 1988 and 2007.

Tributary Fish Community - Benefits

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

Tributary Fish Community - Risks

As tributary water quality has improved over the past several decades, habitat for sea lamprey larvae has also improved, possibly contributing to the current over-abundance of parasitic sea lamprey. Lampricide treatments of tributary streams and deltas have the potential to impose additional stresses on some 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.

Tributary Fish Community - 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 both 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 increase of fish species identified as being of greatest conservation need, such as quillback, redhorses, stonecat, eastern sand darter, and

channel darter.

Nearshore Fish Community

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
- Monitoring and maintenance of population levels of nearshore fishes including smallmouth bass, largemouth bass, and northern pike populations sufficient to support quality sport fisheries
- Maintenance of existing yellow perch populations sufficient to support a viable sport fishery
- Restored, self-sustaining, fishable population of muskellunge in the lake and lower tributaries sufficient to support a quality sport fishery

Walleye: addressed under Tributary Fish Community.

Yellow perch: Yellow perch size and abundance varies by location in Lake Champlain. In the early 1990s, the yellow perch in the northern end of the lake were reported as generally stunted in size and very slow growing (Vermont Department of Fish and Wildlife, 1991), whereas in the southern section of the lake yellow perch numbers were lower, but the growth rates were higher.

Predation levels on yellow perch and interspecific competition have changed with the proliferation of the invasive white perch and alewife populations and the increase in numbers of nesting double-crested cormorant. 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 alewives feed on juvenile yellow perch (Mason and Brandt 1996). The cormorant population on Young Island initially grew exponentially, until control efforts began in 2002; the majority of their 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 sunfish and bass, and all are targeted by anglers. The pumpkinseed, rock bass and smallmouth bass are native to Lake Champlain. White crappie and largemouth bass are introduced, and black crappie and bluegill are believed to also be introduced, either by early angler ‘stocking’ or 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 benefits 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 were historically "widespread but uncommon" from Missisquoi River to Otter Creek (Thompson 1853), but by the 1970s their range was reduced to the Missisquoi River. A chemical spill in the 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 they originate from fish stocked in Otter Creek and in the Great Chazy River.

Nearshore Fish Community - Benefits

- A diversity of sport-fishing opportunities in the nearshore zone

The benefit of the sub-goals for the nearshore zone is a diversity of fishes to support recreational fisheries at a variety of locations, while also providing for recovery of reduced fish populations to enhance fish community health.

Nearshore Fish Community - Risks

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

- Continued changes in water quality
- The abundance of zebra mussels
- Proliferation of invasive aquatic macrophytes
- The recent invasion of alewives
- The protection of wetland and other critical habitats from development-related degradation
- Pressure from sport fishing

Changes in anthropogenic nutrient inputs and sediments and proliferation of invasive macrophytes and zebra mussels are modifying nearshore fish habitat and may lead to changes in species diversity. Northern pike, bass, and sunfish - light-tolerant fish adapted to weedy habitats - may increase in number. Expansion of zebra mussels across soft sediments may change food availability for fish species such as yellow perch, lake sturgeon, and lake whitefish that have demersally-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 cormorants could start feeding on alewife and reduce predation pressure on smelt and consumption of 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.

Nearshore Fish Community - 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 in 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

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 smelt that support a recreational fishery
- Stocking of sufficient Atlantic salmon to support restoration 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 spawning populations lake-wide, including historical spawning areas that still contain suitable habitat
- A forage base with sufficient abundance to support salmonid and walleye populations
- Suppressed sea lamprey populations utilizing a mixture of traditional (lampricides and barriers) and alternative control measures, including barriers, with a wounding rate below 25 wounds per 100 lake trout
- Stable populations of native species such as burbot and lake herring/cisco that characterize a healthy fish community

Atlantic salmon: addressed under Tributary Fish Community.

Lake trout: Lake trout populations disappeared from Lake Champlain by 1900. After sporadic stocking of lake trout in the late 19th century and in the 1950s and 1960s, a sustained stocking program began in 1973 focused on reestablishing 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; annual stocking rates have been variable and range from 39,000–271,863 yearling equivalents (5 fall fingerlings = 1 spring yearling; Fisheries Technical Committee 1999; Figure 1). Stocking rates were decreased by approximately half in 1995 to compensate for increased survival and consequent potential consumption pressure on the rainbow smelt forage base with continuing sea lamprey control; 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 recent stockings focused on the 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 broodstock for Lake Champlain is now in question due to the emergence of the VHS virus in New York.

Despite high lamprey wounding rates (30-98%), survival of feral adults since lamprey control began has been good (approximately 50% survival), spawning occurs at multiple sites in the Main Lake, and fry production is high. However, the proportion of unclipped lake trout seen during assessments of the spawning population since 1982 has averaged 4% and was 1.2% in 2005. This low level of unclipped fish in assessments might be attributable to natural reproduction or errors during the clipping process. The lake trout fishery has been monitored with a salmonid angler diary program since 1972.

Brown trout, steelhead: Although not endemic, both species are considered to be a component of the current Lake Champlain fish community; they provide a diversity of fishing opportunities, an important social benefit, and a potential management tool for a changing forage base. The current brown trout stocking program began in 1977; sustained steelhead stocking began in 1972. The current strain of steelhead used for stocking is the Chambers Creek strain, obtained from the Salmon River Hatchery in New York. Beginning in 2007, steelhead stocking in NY was suspended because of the potential to introduce the fish disease Viral Hemorrhagic Septicemia or VHS with steelhead reared at the Salmon River Hatchery. Future NY steelhead stocking will be dependent upon an alternate hatchery being able to raise Champlain's steelhead allotment. Both Vermont and New York stock the Rome Hatchery 'domestic' strain of brown trout. The current annual stocking target for steelhead and brown trout is 30% of the 491,000 target for total salmonid yearling equivalents: approximately 78,000 steelhead and 68,000 brown trout were stocked annually in the mid 2000s. Like Atlantic salmon, brown trout and steelhead/rainbow trout have the potential to produce both a lake and tributary-based fishery, diversifying the type and timing of fishing opportunities.

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. Fishing was primarily conducted using shoreline seines on spawning grounds in fall. Between 1893 and 1904, 62 - 94 licenses were issued per year in Vermont, and the fishery yielded 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 lbs) in 1972 to 35 kg (77 lbs) in 2004, the last year in which harvesting occurred. The only historic study focused on lake whitefish in Lake Champlain was in 1930 (VanOosten and Deason 1931); data from recent research suggest that spawning populations at historic spawning sites in the South Lake and Missisquoi Bay are severely depleted or gone.

Forage fish species: Rainbow smelt, yellow perch, and emerald shiners have historically constituted the bulk of the prey available to Lake Champlain predators. Smelt also provide a popular target for ice fishing in Lake Champlain. Smelt are 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 predatory 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 age 1-2 year-old smelt. Trawl catches measured as catch-per-unit-effort (CPUE = number of smelt collected in 55 minutes of trawling) oscillate between years from very high numbers to very low numbers. Main lake smelt catch is generally lower than in the Inland Sea/Northeast Arm areas (median CPUE of 100-200 vs. 700-1000 smelt, respectively).

In recent years non-native fish have become a major component of the prey assemblage. These include young-of-year white perch (first documented in 1984) and alewife (first documented in 2003).

Sea lamprey: The status of sea lamprey as an endemic in Lake Champlain is the subject of some debate, primarily because historic records do not mention sea lamprey or sea lamprey wounds prior to the 1800s. However, genetic data suggest that they are native to the lake (Waldman et al. 2004, Bryan et al. 2005). If they are native, changes to the Lake Champlain ecosystem and habitat must have contributed substantially to their current population imbalance with their host fish species. An experimental control program involving use of permanent and seasonal barriers and application of TFM and Bayluscide to 13 tributaries and five deltas began in 1990, and a long-term control program began in 2002. Despite relatively intensive control efforts, wounding rates of lake trout were reduced only to 31 wounds/100 lake trout (in 1992), and rose to 98 wounds/100 lake trout in 2006 (Fisheries Technical Committee 1999, Marsden et al. 2003). 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 and centralized agency for sea lamprey control efforts on Lake Champlain. If this recommendation is implemented, the USFWS would continue to conduct annual population assessments of sea lamprey and participate in treatments, and would have an added role as applicant to both the Vermont and New York permitting processes for use of lampricides in the Lake Champlain watershed. The recommendation has not been implemented at this time. While the use of lampricides continues to be the primary method for controlling sea lamprey populations in the Great Lakes, Finger Lakes and Lake Champlain, there is considerable research being done to look for other feasible methods of control.

To facilitate investigation of non-chemical alternatives for sea lamprey control in Lake Champlain, the Lake Champlain Sea Lamprey Control Alternatives Workgroup (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 Lake Champlain Basin. As a Federal advisory committee, the Workgroup provides an opportunity for stakeholders to give policy and technical advice about sea lamprey control techniques that may provide useful alternatives to lampricides. The Workgroup reports to the

Secretary of the Interior through the Service and the Cooperative. Specific responsibilities of the Workgroup are to: (1) provide advice regarding the implementation of sea lamprey control methods alternative to lampricides, (2) recommend priorities for research to be conducted by cooperating organizations and 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 are a commercially important species in the Great Lakes, but do not appear to have attracted any fishery interest in Lake Champlain. They have not been monitored in Lake Champlain, although burbot catch and size data were collected from 1982 to 1997 as part of the summer lake trout assessment program. The population status of burbot is unknown. Burbot and lake trout are the only native deepwater predators, thus the role of burbot on predation of smelt is of interest to forage fish management.

Offshore Fish Community - Benefits

Benefits from meeting offshore pelagic indicators 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

Offshore Fish Community - Risks

The uncertainty and risk associated with achieving these fishery objectives are both high. Reduction of sea lamprey populations during the 1990-1998 experimental control 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; numbers 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 wounds per 100 lake trout will protect stocks of salmon, trout, lake whitefish, and walleye, and improve progress toward lake sturgeon restoration. Lamprey wounding rates on lake trout have risen since the inception of the long-term control program, to close to 100 wounds/100 lake trout in 2006, but declined to an estimated 31 wounds/100 lake trout in 2008.

Stocking has restored a population of lake trout with high survival and diverse year-class representation that supports a healthy sport fishery. However, despite successful spawning and fry production lake-wide, little to no natural recruitment has been detected. Impediments to recruitment have not yet been identified. Successful restoration 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 tributaries.

Indicators

Indicators that offshore pelagic sub-goals are being met are

- Abundant rainbow smelt characterized by multiple age classes
- Angler satisfaction with smelt harvest
- Increased catch and size of Atlantic salmon in assessment and recreational fisheries
- Proportion of naturally reproduced lake trout in fall assessments that consistently exceeds 15% of multiple year classes
- Reduction of sea lamprey wounding to < 25 wounds per 100 lake trout
- Increased number and size of brown trout and steelhead in angler catches
- Maintenance of lake trout catch rates and an increase in average size caught by anglers

Non-native Species

Non-native Species - Sub-goals:

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

- Preventing new introductions of aquatic species
- Where possible, suppressing non-native species to minimize their impact on native species and ecosystem functions.

Of the fifteen 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 non-native fishes by deliberate stocking is actively discouraged by the Lake Champlain Management Cooperative. Control of other vectors of accidental introduction of non-native species, such as baitfish movement, fish importation, bilge and ballast water transport, are being addressed (Marsden and Hauser, 2009). Non-native aquatic species movement via the Champlain Canal, is under review.

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 via the canal; all three are established in the lake, but are not utilized by anglers, and no effects on the local 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 or its fishery. Two additional species deserve detailed mention due to their potential importance to the fishery (white perch) or impacts on the lake's 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 lake-wide, and have begun 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 (2005, 2006) indicate that they may 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 abundant, apparently opportunistic feeders they have the potential to affect food availability for other species.

Alewife: Alewife were first noted in the Lake Champlain basin in Green Pond, NY in the 1960s; they appeared in Lake St. Catherine, VT, in 1997, presumably introduced by anglers. Alewife were found in Missisquoi Bay in 2002, and young-of-year alewife were 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 Lake Champlain 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. Salmonid species that consume alewives exhibit thiamine deficiency, which results in early mortality syndrome (EMS). EMS affects the offspring of lake trout and salmon and could be a major impediment to establishment of reproducing populations of these two species.

Non-native Species Management - Benefits
Prevention of new non-native species introductions and suppression, where possible, of established species, is a major contribution to maintaining the ecosystem health and community structure in the lake.

Non-native Species Management - Risks
Several non-native species already established in the Great Lakes (such as Eurasian ruffe *Gymnocephalus cernuus* and quagga mussels *Dreissena bugensis*) have not yet appeared in Lake Champlain. Round goby (*Apollonia*/*Neogobius melanostomus*) are now highly abundant throughout the St. Lawrence River and have become a dominant element in the food chain. Other species (such as zebra mussels *Dreissena polymorpha*, white perch, and alewife) are present in Lake Champlain and continue to increase in abundance. 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.

The recent addition of alewife to Lake Champlain creates substantial uncertainty. Alewife may contribute to diversity of the forage for salmonids and allow increases in stocking and fishery yields. Alternatively, alewife may compete with smelt, resulting in no net increase in forage abundance. Smelt are an important diet item for every pelagic fish predator in Lake Champlain and provide an important winter fishery. Competition with or larval predation by alewife may affect smelt population dynamics and, in consequence, threaten the smelt, salmon and trout fisheries. Addition of alewife to salmonid diets may result in thiamine deficiencies in the adult fish and consequent early mortality syndrome (EMS) in their fry, adding a significant impediment to potential restoration of lake trout and Atlantic salmon.

Non-native Species Management - Indicators
Indicators of successful management actions are

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

species

Management Actions to Support Healthy Fish Communities

Healthy Fish Communities - Sub-goals

Management actions that support healthy fish communities will include

- Protecting native species assemblages
- Protecting the genetic diversity and integrity of native fishes
- Protecting and rehabilitating native fishes
- Protecting and enhancing populations of rare and endangered fishes
- Achieving sea lamprey wounding rates of <25 per 100 lake trout
- Maintaining the integrity of existing food webs
- Protecting and rehabilitating critical fish habitat, including tributary and nearshore spawning and nursery areas
- Encourage appropriate 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

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

Species of greatest conservation need

In addition to the harvestable species addressed above, additional native species present in the Lake Champlain 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 species 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 darters are threatened in both New York and Vermont, and channel darters are 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. There are historical reports (Greeley 1930) of 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 limited sampling that might target 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 larval populations. Both species are vulnerable to land-use changes that alter stream habitats, and to lampricides that target sea lamprey.

Sauger were once abundant in portions of Lake Champlain and were captured in considerable numbers as recently as the 1980s. Sauger were present in all sections of the lake except for the Main Lake, although they were more abundant in the southern portion of the lake (Anderson 1978). Recent netting surveys of the South Bay, where sauger were formerly abundant, failed to capture a single sauger. 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, both NY and VT have enacted regulation changes that virtually eliminate potential angler harvest of sauger.

Healthy Fish Communities - Benefits

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

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

Healthy Fish Communities - Risks

Major threats to biodiversity include the unintentional introduction of new species, habitat loss, and pathogens. Introduction of exotic species can occur through a variety of means, including stocking programs, navigation channels, unauthorized releases, or accidental transport on trailers, boats, waders or in bait buckets and live wells. Parasitism by sea lamprey impacts goals of restoring healthy salmonid populations. Habitat loss includes degradation of water quality, flow changes, siltation, and changes in connectivity.

Fish diseases are also a threat to fish communities. For many years an important part of the fish management of Lake Champlain has been to prevent the introduction and limit the distribution of fish pathogens. With the recent introduction of several pathogens elsewhere around the country including Heterosporis, Spring Viremia of Carp and of particular concern, the introduction of Viral Hemorrhagic Septicemia (VHS) in the Great Lakes; new restrictions have been instituted on the movement of fish among water bodies, and the operation and movement of fish in hatcheries and the use of wild and cultured fish in the baitfish industry to protect Lake Champlain fish populations.

Management agencies for Lake Champlain draw from 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 for the continued management of fish pathogens.

Healthy Fish Communities - 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 wounding rates that meet management objectives

Information Priorities

The Guiding Principles 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. On-going monitoring and assessment programs are listed below. 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.

- Larval sea lamprey abundance and intra-basin distribution
- Parasitic sea lamprey wounding rates on salmonids, walleye, and lake sturgeon
- Adult sea lamprey trapping: abundance trends 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 midwater trawling and hydroacoustic sampling
- American eel monitoring and assessment
- Periodic monitoring for pathogens
- Angler opinion surveys
- Contaminant monitoring
- Fish community monitoring
- Lake sturgeon distribution, abundance, age structure, and spawning success
- Estimates of the abundance, age, growth, and condition factors of spawning walleye stocks, lamprey wounding rates, and contribution of stocked walleye to spawning populations

Additional information and research that will directly facilitate management decisions and actions include:

- Expand current monitoring programs as needed.
- Develop/implement additional species-specific monitoring programs, e.g., basses, lake whitefish, burbot, esocids, non-game fishes.
- Investigate factors that affect fish survival, spawning success, and abundance, e.g., habitat connectivity.
- Investigate human dimensions of the Lake Champlain fishery, including creel surveys and stakeholder attitude surveys.
- Develop/implement long-term periodic pathogen monitoring program.
- Evaluate impacts of aquatic nuisance fish species, e.g., sea lamprey, 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 Lake Champlain Fisheries Technical Committee and Management 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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Table 1. Fish species known to inhabit Lake Champlain and its tributaries, and their legal protection status. E=endangered, T=threatened, S=susceptible, VT=Vermont, NY=New York, CAN=Canada. Endangered: in immediate danger of becoming extirpated in the state Threatened: with high possibility of becoming endangered in the near future. Additional species are under evaluation in Quebec and Canada 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*	none
Clupeidae	Blueback herring	*Alosa aestivalis*	introduced
	Gizzard shad	*Dorosoma cepedianum*	introduced
	Alewife	*Alosa psuedoharengus*	introduced
Hiodontidae	Mooneye	*Hiodon tergisus*	T-NY
Salmonidae	Lake herring/cisco	*Coregonus artedii*	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
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*	none
	Chain pickerel	*Esox niger*	none

Cyprinidae	Goldfish	*Carassius auratus*	introduced
	Carp	*Cyprinus carpio*	introduced
	Rudd	*Scardinius erythrophthalmus*	introduced
	Tench	*Tinca tinca*	introduced
	Cutlips minnow	*Exoglossum maxillingua*	none
	Brassy minnow	*Hybognathus hankinsoni*	none
	Eastern silvery minnow	*Hybognathus regius*	none
	Golden shiner	*Notemigonus crysoleucas*	none
	Emerald shiner	*Notropis atherinoides*	none
	Bridle shiner	*Notropis bifrenatus*	SC-CAN
	Common shiner	*Luxilus cornutus*	none
	Blackchin shiner	*Notropis heterodon*	none
	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
	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*	none
	Longnose sucker	*Catostomus catostomus*	none
	White sucker	*Catostomus commersoni*	none
	Silver redhorse	*Moxostoma anisurum*	none
	Shorthead redhorse	*Moxostoma macrolepidotum*	none
	Greater redhorse	*Moxostoma valenciennesi*	none
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
Centrarchidae	Rock bass	*Ambloplites rupestris*	none
	Pumpkinseed	*Lepomis gibbosus*	none
	Bluegill	*Lepomis macrochirus*	introduced?
	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, E-CAN
	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, E-CAN
	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

	Stonecat	*Noturus flavus*	E-VT
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