Seafood Watch

Seafood Report

MONTEREY BAY AQUARIUM®

Great Lakes Region

Lake trout	*Salvelinus namaycush*
Walleye	*Sander vitreus*
Yellow perch	*Perca flavescens*
Lake whitefish	*Coregonus clupeaformis*
Lake herring (cisco)	*Coregonus artedii*
Round whitefish	*Prosopium cylindraceum*
Rainbow smelt	*Osmerus mordax*

(Fish images courtesy of the New York State Department of Environmental Conservation.)

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About Seafood Watch® and the Seafood Reports

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch® defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from the Internet (seafoodwatch.org) or obtained from the Seafood Watch® program by emailing seafoodwatch@mbayaq.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Report. Each report synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices," "Good Alternatives" or "Avoid." The detailed evaluation methodology is available upon request. In producing the Seafood Reports, Seafood Watch® seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch® Fisheries Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch's sustainability recommendations and the underlying Seafood Reports will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch® program at Monterey Bay Aquarium by calling (831) 647-6873 or emailing seafoodwatch@mbayaq.org.

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Seafood Watch® strives to have all Seafood Reports reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science and aquaculture. Scientific review, however, does not constitute an endorsement of the Seafood Watch® program or its recommendations on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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Table of Contents

Executive Summary

The Great Lakes commercial fisheries are some of the largest freshwater fisheries in the world, with a history reaching back nearly 200 years. Over this long history, the profile of commercially caught species has undergone dramatic changes in response to fluctuations in the populations of target species resulting from a suite of anthropogenic pressures. Particularly substantial declines in target species biomass occurred during the first half of the 20th century due to a combination of overfishing, habitat loss, chemical contamination, and the proliferation of invasive species that followed urban, agricultural and industrial expansion throughout the Great Lakes. In response to these dramatic declines, new management and assessment regimes were put into place in the middle of the 20th century and have continued to evolve and expand such that the Great Lakes fishery of the 21st century now much more closely resembles the fishery of the early 1900s than it has in the past 75 years. The current fishery comprises a mixture of recovered fish that have long been mainstays of the Great Lakes (e.g., lake herring and lake whitefish) as well as near-shore species that became important in the mid-20th century (e.g., walleye and yellow perch) and non-native forage species (e.g., rainbow smelt).

In this first Seafood Watch® Seafood Report on Great Lakes fisheries, seven species have been chosen as representative of the region:

1. **Lake trout (*Salvelinus namaycush*):** This long-lived species was once the dominant top predator in all of the Great Lakes, and a main target of the commercial fishery. It is moderately resilient to fishing pressure, but the combined pressures of overfishing and high levels of predation by the exotic sea lamprey served to drive lake trout populations into steep decline during the middle of the 20th century, such that by 1960 lake trout were nearly extirpated in all lakes except Lake Superior. At present, only Lake Superior supports a commercial fishery for wild-caught lake trout. In other lakes, natural reproduction has been largely unsuccessful, preventing any substantial recovery of the species, and fisheries, where present, are supported entirely by stocking. This species is therefore of moderate to high conservation concern and restoration of lake trout populations remains a major management goal throughout the Great Lakes. Lake trout from Lake Superior are deemed a "**Good Alternative**" while those from Lake Michigan and Lake Huron are given the overall seafood recommendation of "**Avoid**."

2. **Walleye (*Sander vitreus*):** This dominant near-shore predator has been a target of the Great Lakes commercial fishery since the late 19th century. It is resilient to fishing pressure and tolerant of a wide variety of environmental conditions. This has allowed walleye populations to recover quickly from environmental degradation, and the species has remained dominant in the commercial fishery, especially in Lake Erie, which traditionally was the most productive of the Great Lakes. Currently, Canadian walleye catches from Lake Erie constitute more than 97% of the total walleye catch in the Great Lakes. Walleye populations began to recover in Lake Erie as soon as nutrient abatement programs went into effect in the 1970s; however, after a period of recovery from 1970s-1990s walleye populations underwent a second period of decline in the 1990s due to highly variable recruitment. At present, populations are still recovering and a better understanding is needed of what species-specific and environmental characteristics affect

year class strength. Primarily due to this poor recruitment, walleye is recommended as a "**Good Alternative**."

3. **Yellow perch (*Perca flavescens*):** This near-shore species has an intermediate position in the aquatic food web and is often found in the same environments as walleye. It is broadly distributed in the Great Lakes and resilient to fishing pressure. Like walleye, yellow perch commercial fisheries operate primarily in Lake Erie (85%), in both US and Canadian waters. Along with walleye and lake whitefish, it is one of the three largest freshwater fish exports from Canada, with markets primarily in the US Great Lakes region. Yellow perch abundance has been highly variable since the middle of the 20th century, due to the effects of habitat loss, interactions with invasive species, and overfishing, but has recovered quickly when stresses have been removed. The 1980s were a period of record productivity for the yellow perch fisheries throughout the Great Lakes, including Lake Michigan's Green Bay, but as with walleye, perch entered a new period of decline in the 1990s. Overall, increasing populations (as evidenced by increased catch per unit effort throughout most of Lake Erie), an effective management regime, and inherently resilient life history characteristics make yellow perch caught in Lake Erie a "**Best Choice**," though some uncertainties and concerns remain around the impacts of the fishing methods used (primarily gillnets), in terms of bycatch rates and ecosystem effects. Perch in the smaller Lake Huron and Lake Ontario fisheries are in need of more comprehensive stock assessment and reductions in total mortality, and are thus recommended as "**Good Alternatives**." Current catches from Lake Michigan's Green Bay, though increasing, are relatively minor in comparison to the other Great Lakes perch fisheries, and therefore are not ranked in this report.

4. **Lake whitefish (*Coregonus clupeaformis*):** Like walleye, lake whitefish have been a long-time target of the Great Lakes commercial fishery, though, as an epibenthic fish, this species occupies deep, cold waters rather than near-shore environments. Lake whitefish are a schooling fish caught primarily from Lake Michigan and Lake Huron, and the patchy distribution of its intermingling stocks complicates stock assessment and management. Like other deepwater fish, lake whitefish underwent substantial population declines in the middle of the 19th century, but was able to recover quickly after nutrient abatement and sea lamprey control measures were put in place in the 1970s. It is currently the dominant deepwater benthic fish in the Great Lakes, as other native fish, such as the cisco, have not recovered as successfully. In some areas, lake whitefish populations are now at historic highs; however, their condition, growth, and catch rates became highly variable in the 1990s when their preferred prey, the amphipod Diporeia, disappeared in many lake areas in an apparent response to the proliferation of exotic zebra mussels. Lake whitefish have adjusted to these food web changes, first by changing their distribution to areas where Diporeia persisted, and more recently by changing their diets and utilizing alternate prey, including zebra mussels. In spite of decreased condition and changing catch rates, populations remain large, management is effective, and fishery impacts on habitats and ecosystems are generally benign for trap net fisheries and moderate for gillnet fisheries. Therefore, lake whitefish caught in trap nets are given the overall seafood recommendation of "**Best Choice**," while those caught using gillnets are considered a "**Good Alternative**."

5. **Lake herring (*Coregonus artedii*):** This relative of the lake whitefish once dominated the diets of native predators such as lake trout, but underwent a period of dramatic population decline between 1930 and 1960 due to a combination of overfishing, habitat loss, and interaction with invasive forage species such as rainbow smelt and alewife, which compete with and prey upon juvenile lake herring. Nutrient abatement and other environmental restoration measures in the 1970s allowed this moderately resilient species to enter a brief period of recovery in the 1980s and 1990s; however, recruitment remains highly variable and limits their full recovery. Because lake herring are the only surviving member of the former 7-species cisco complex in the Great Lakes, it is now commonly referred to as the lake cisco. A substantial commercial fishery for herring/cisco currently persists only in Lake Superior, where non-fishery impacts have been relatively low compared to other lakes. In this region stocks are moderately successful, though management uncertainties remain around lake herring habitat requirements and estimates of fishing mortality in both the commercial and recreational fishery. Comprehensive management of lake herring stocks is growing as the management regime recognizes that this species will play a key role in reestablishing native, self-sustaining predator-prey communities in the Great Lakes, and may be particularly important to lake trout recovery. Lake herring from Lake Superior is thus given the overall seafood recommendation of "**Good Alternative**."

6. **Round whitefish (*Prosopium cylindraceum*):** This coregonid species forms part of the native forage base of the Great Lakes. It is found in all the lakes except Lake Erie, and is moderately resilient to fishing pressure. Round whitefish are not as valuable as lake whitefish or lake herring, and are therefore primarily an alternate target for the commercial fishery. As such, it has not been well studied and little data exist on its stock status, age and size distribution, and habitat quality. Currently, round whitefish are caught primarily by tribe-licensed fisheries in Lake Huron and Lake Michigan. There are no catch limits set in these fisheries, and no biomass estimates have been made, so it is unknown whether stocks are being overexploited. In the face of so much uncertainty in the round whitefish fishery, they are provisionally given the recommendation of "**Good Alternative**," but this is subject to revision should additional data on stock status and management effectiveness become available.

7. **Rainbow smelt (*Osmerus mordax*):** This non-native forage species first arrived in the Great Lakes in the 1930s, and were seen as a nuisance as they had no commercial value, clogged nets, and competed with native species. In the mid-1960s, salmonine stocking programs were instituted with a number of motivations: to control non-native species like rainbow smelt and alewife; to support increased recreational fishing; and to aid in the recovery of lake trout populations. The first two of these goals were met successfully, but resulted in complications in rainbow smelt management—introduced predators were now successfully controlling forage populations, but this forage was essential in feeding the predator community that now supported highly lucrative recreational fisheries. Smelt had also become a favored prey of recovering native predators such as the lake trout. At the same time, smelt began to support a substantial commercial fishery. It remains a main export of the Canadian commercial fishery, ranking third by weight after whitefish and

walleye, and Canadian catches from Lake Erie now account for 90% of the commercial rainbow smelt catch in the Great Lakes. In the latter part of the 20th century, rainbow smelt stocks entered a period of highly variable recruitment, possibly as a response to excessive predation pressure and reduction of food availability in the water column associated with proliferation of zebra and quagga mussels. Currently, the outlook for smelt stocks is unclear and there is little comprehensive management, resulting in high uncertainty about stock status and fishery impacts. However, the rainbow smelt is an invasive species that has negative impacts on native forage fish by competing for food and preying on juvenile fish. It has been recognized that in order to restore the native predator-prey balance to the Great Lakes, both non-native forage and non-native predators should be removed in favor of native species such as lake herring and lake trout. Therefore, the removal of smelt by the commercial fishery is supported and a fishery managed for the elimination of this species would be desirable. The current rainbow smelt fishery is only minimally managed with no conservative catch limits set. Rainbow smelt is therefore recommended as a "**Good Alternative**."

In the chapters that follow, the history and structure of the Great Lakes commercial fishery is summarized and each of these species is analyzed in depth according to Seafood Watch® criteria: inherent vulnerability to fishing pressure; status of wild stocks; nature and extent of bycatch; effects of fishing methods on habitats and ecosystems; and management effectiveness.

Chapter 1—Great Lakes Commercial Fisheries: History, Major Issues, and Current Status

Composing the largest continuous mass of fresh water in the world (nearly 20% of the world's fresh water supply), the Great Lakes (Fig. 1) have a long history of supporting extensive commercial, sport and sustenance fisheries.

Figure 1. The Laurentian Great Lakes.

Early settlers noted fishing activity in Native American communities during the 17th and 18th centuries (Lawrie and Fahrer 1973), and commercial fishing expanded quickly with European settlement and the growth of industry around the Great Lakes. Detailed commercial catch records have been kept since as early as the late 19th century, describing fisheries largely supported by lake whitefish, lake herring, and lake trout, as well as smaller contributions (by weight or value) of other species, such as walleye, yellow perch, and deepwater ciscoes, among others (Berst and Spangler 1973; Christie 1973a; Hartman 1973; Lawrie and Fahrer 1973; Wells and McClain 1973). The commercial fisheries of today are still dominated by many of these species, including lake whitefish, walleye, yellow perch, and lake herring. Moreover, yields remain high. The largest yields in the early history of the fishery were reported in 1889 and 1899 at nearly 150 million pounds per year, while today commercial catches remain substantial at around 110 million pounds per year. A very large recreational catch has also become an integral part of the Great Lakes fishing industry, resulting in a combined value of Great Lakes commercial and recreational fishing of US $4 billion annually, with an approximately even split (USEPA 1995; Shear 2006).

In the intervening century, however, both fishery yield and the profile of species caught have undergone dramatic fluctuations. Particularly in the middle of the 20th century, the commercial fishery began to incorporate a number of species that once would have been considered "low value," including non-native species like rainbow smelt (Fig. 2).

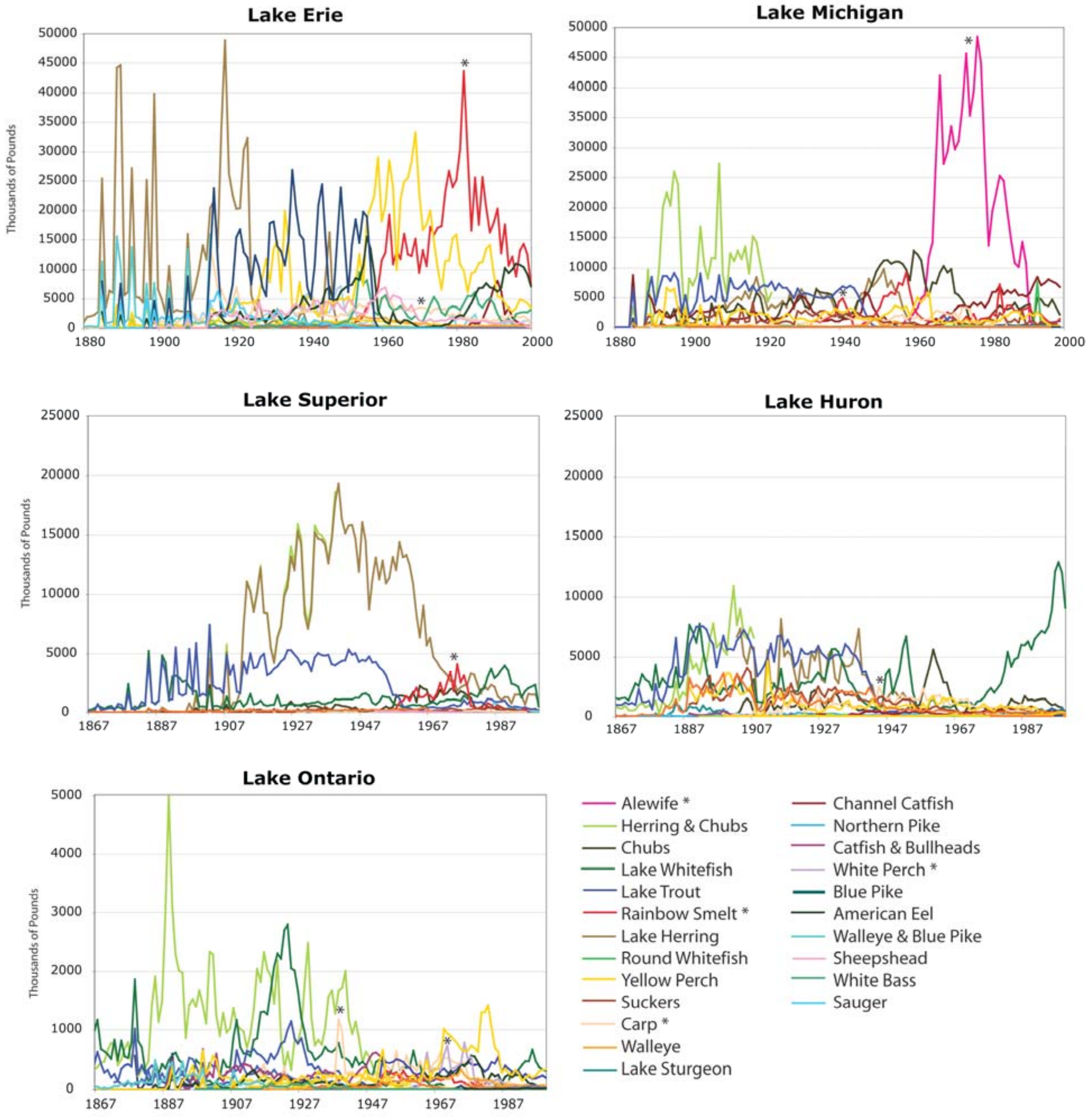

Figure 2. Species composition of commercial catches from US and Canadian waters of the Great Lakes, 1867-2000 (Figure from Baldwin et al. 2002). Non-native species denoted by asterisk (*).

These changes occurred as a result of the combined pressures of environmental degradation, overexploitation, and non-indigenous species proliferation. These three primary fishery stressors are detailed below, along with accounts of the evolution of the early commercial fishery in each lake.

Overfishing

Along with habitat disruption, the development of the fishery itself had an early and dramatic impact on native species abundance in the Great Lakes. Commercial fishing in the Great Lakes region began in the first lakes to be settled—Lake Ontario and Lake Erie—in the early part of the 19th century. Though declines in species abundance followed almost immediately, from fishery intensification, it was often difficult to perceive their onset, as fishing effort and gear efficiency increased at the same time. From 1820 through the 1880s, fishing volume increased by 20% per year (USEPA 1995). By the end of this 60-year period, a number of species were already in noted decline.

The Atlantic salmon, a key species in the Lake Ontario fishery, was one of the first to be affected by overfishing; some populations in Lake Ontario had collapsed by 1840. Lake whitefish populations declined to very low levels by the turn of the 20th century, and burbot and lake trout were also scarce by this time, though their populations then recovered temporarily to peak again around 1920. Burbot are a good example of the effects of bycatch in the Great Lakes fisheries, as they were not sought directly by the fishery but were extremely vulnerable to the large-mesh gillnets employed in the lake trout fishery (Christie 1973b). In Lake Erie, overfishing also initiated the decline of lake whitefish populations, and these declines were later exacerbated by habitat degradation and predation by the introduced sea lamprey. Similarly, lake herring populations were progressively overfished, such that their populations crashed by the mid-1920s following considerable intensification of fishing that quickly exhausted locally-concentrated stocks (Hartman 1973).

The lake sturgeon (*Acipenser fulvescens*) is often held up as a prime example of species decline due to overfishing. It was first routinely destroyed as a “coarse fish,” considered a nuisance as it was undesirable to the fishery and caused heavy damage to gear in the early-to-mid 1800s. By 1860, however, the sturgeon had become prized for its meat, roe (eggs), and swim bladder (used in the fining process for beer). By this time the population was already considerably stressed—peak production occurred in the 1880s. The sturgeon is a very slow-growing fish that matures and reproduces late in life, and as with burbot was particularly vulnerable to the large-mesh gillnets used by the commercial fishery at the time. The short time elapsed between the intensification of the sturgeon fishery (1860), peak production (1880s), and species collapse (before 1900) illustrates the speed of fishery decline that was typical in the Great Lakes. The intensification of fishing and technological advances in fishing gear that occurred throughout this time and up to the middle of the 20th century effectively masked initial population declines, leading to the particularly dramatic crashes that occurred in the first half of the century.

Habitat Degradation

The disruption of key fish habitat, spawning grounds in particular, followed settlement and rapid industrial and urban development of Great Lakes shorelines. Agricultural and urban development began in the Great Lakes region before the turn of the 19th century, though it proceeded at different rates around different lakes (Fig. 3).

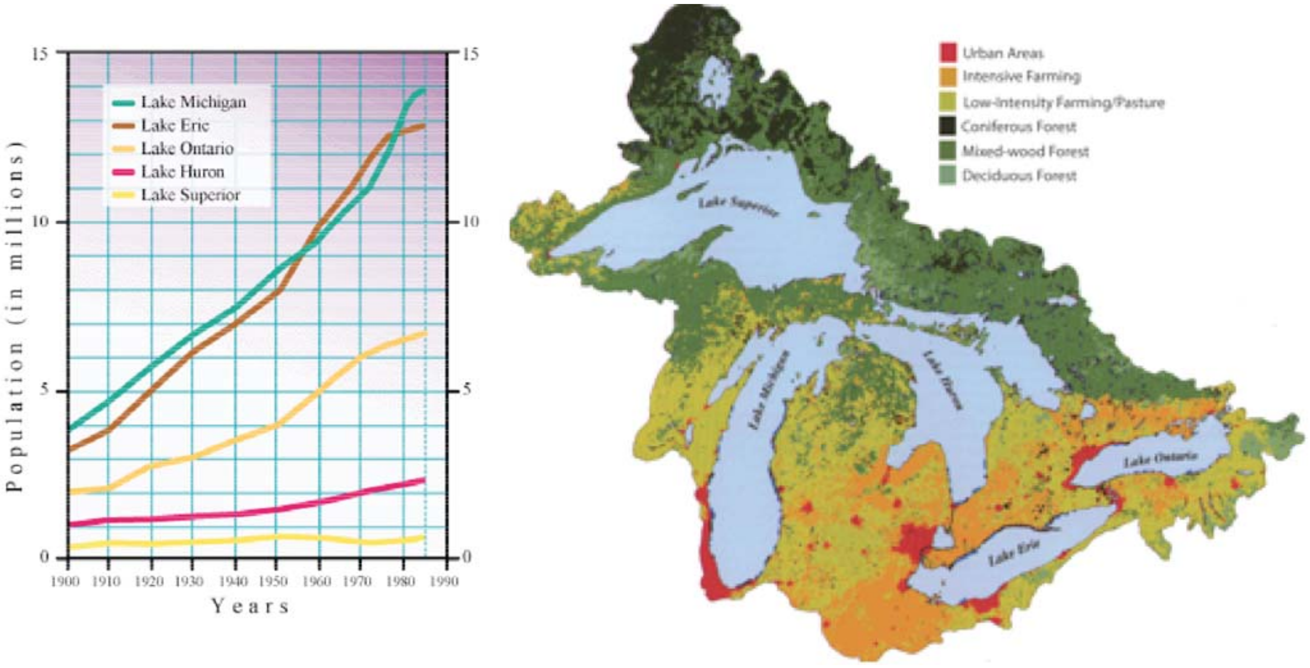

Figure 3. Population expansion and current land use profile in the Great Lakes Region (Figure from USEPA 1995).

Major contributors to habitat declines included loss of spawning areas, reduced access to spawning grounds, and pollution by toxic chemicals. Spawning areas were lost primarily due to siltation, which was caused by the increased erosion that followed deforestation and logging, and by the buildup of sawmill wastes. Access to spawning grounds was limited due to shoreline development and dam construction. Finally, pollution came from agricultural sources (increased phosphorous loading), urban sources (wastewater associated with human settlement), and industrial sources (pulp and paper, steel, and chemical industries all operated in the Great Lakes Region).

While degradation of spawning grounds directly impacted fish abundance by reducing populations, pollutants impacted the value of the fishery; fish that were too contaminated could no longer be sold on the commercial market (Holeck and Mills 2004). Furthermore, substantial eutrophication that resulted from the combination of agricultural and urban nutrient inputs negatively impacted species that required clear water and high levels of dissolved oxygen. These environmental impacts were of particular concern in the lower Great Lakes and less important in Lake Superior.

In Lake Michigan, sawdust and wastes from sawmills were clogging tributaries and lake spawning areas by the mid-19th century, and deforestation drainage and dams caused stream warming and blocked migration routes. The 20th century saw the rise of increasing industrial pollution, with Green Bay being particularly affected, and areas of anoxia (depleted oxygen) in the sediment greatly affecting benthic (sediment-dwelling) populations (Wells and McClain 1973).

Eutrophication in Lake Ontario was more apparent in near-shore areas by the early 1950s, but had become widespread by the 1970s. This nutrient pollution led to nuisance algal blooms that fouled fishing nets and likely speeded the decline of lake whitefish in the Bay of Quinte by decreasing hatching success (Christie 1973b). In Lake Erie, progressive eutrophication drove fish stocks west-to-east and further habitat degradation by siltation and pollution stopped fish from spawning in what had been key tributaries, such as the Detroit River, the Maumee River (and Bay), and the Sandusky, Cuyahoga, and Grand Rivers, which were also affected by mill dams and irregularities in stream flow (Hartman 1973). High nutrient levels eventually led to low oxygen conditions in summer and a growing "dead zone" mid-lake (Ludsin et al. 2001).

Water quality improvements put into place following the Great Lakes Water Quality Agreement in the 1970s have served to reverse many of these trends (Koonce et al. 1996), and the importance of pollution and habitat loss to structuring communities in the Great Lakes has generally decreased in recent years, relative to the mounting problem of non-indigenous species invasions. However, legacy contaminants in Great Lakes sediments continue to trigger fish consumption advisories today and new pollutants from more diffuse sources (e.g., mercury from the air and pharmaceutical residues from wastewater treatment plants) are of growing concern, primarily as low-level chronic stresses on fish (and human) community health.

Invasive Species

Although non-native species have a long history in the Great Lakes, their impacts became dominant ecosystem stressors primarily during the 20th century, as management activity began to curtail the effects of both overfishing and habitat degradation. At first the primary vectors of species invasions were deliberate introductions and the opening of canals; however, currently, ballast-water is the primary entry route, and the rate of invasion appears to be accelerating. A number of these introduced species have had profound impacts on the fisheries and ecology of the Great Lakes, and have been responsible for rapid, dramatic, and wide-scale changes to the Great Lakes food webs. A few of the most influential of these include the sea lamprey, rainbow smelt, alewife, salmonids such as Chinook salmon, and zebra and quagga mussels.

Sea lamprey (Petromyzon marinus)[1] – This parasitic eel has been implicated in the decline of lake trout, lake whitefish, and deepwater cisco populations throughout the Great Lakes. Though there are conflicting viewpoints on whether sea lamprey are native to Lake Ontario (which is open to the Atlantic Ocean, the lamprey's primary habitat) or invaded the lake during the early 19th century, it is known that lampreys first gained access to the other lakes in 1921, when the opening of the Welland Canal allowed them to spread to Lake Erie (Downs et al. 2002). Their impacts have been particularly severe in Lake Michigan and Lake Huron, where lamprey populations were large by the 1930s. Sea lampreys were not very successful in Lake Erie, however, as tributary waters were too warm to provide suitable spawning habitat. Sea lampreys feed on the body fluids of fish, and have been observed to prefer larger-bodied fish such as lake trout, populations of which were in serious decline in Lake Michigan and Lake Huron by 1940 (Emery 1985). In 1958, a chemical control was discovered by the US Fish and Wildlife Service that selectively kills larval lampreys. Treatment of streams and tributaries with lampricide in the following decades was highly successful in curtailing lamprey populations, though there have

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[1] Image courtesy of the US Fish and Wildlife Service Digital Library System.

been a number of localized resurgences in lamprey abundance in recent years, which have affected recovering populations of lake trout and lake whitefish. These have come largely from the tributaries to Lake Michigan and the St. Mary's River, from which lampreys can enter both Lake Michigan and Lake Huron. Currently, lamprey controls include application of lampricide, release of sterile males, and physical barriers.

Rainbow smelt (Osmerus mordax)[2] – This carnivorous fish is native to the Atlantic coast and, like the sea lamprey, may have been native to Lake Ontario or entered through New York's canal system during the 19th century. Its introduction to the rest of the lakes resulted from deliberate plantings of smelt eggs in Crystal Lake, within the Lake Michigan drainage basin, in 1912. Smelt were planted as forage for introduced Atlantic salmon, and their dispersal may have been aided by additional plantings in the St. Mary's River between 1906 and 1921, though these were largely considered unsuccessful (Emery 1985; Downs et al. 2002). Rainbow smelt were first noted in Lake Michigan in 1923, and by 1930 had spread to Lake Superior. Although at first considered a nuisance, smelt soon became an integral part of the ecosystem, supporting both a commercial trawl fishery in Lake Erie and Lake Michigan, and a substantial recreational fishery in Lake Superior, as well as becoming a key forage species for many Great Lakes predators (both native and introduced). However, smelt have also been implicated in the decline of a number of these predators, as adult smelt prey on juvenile native fish, and juvenile smelt compete directly with other juvenile fish for zooplankton prey. Smelt abundance in the Great Lakes became unstable in the latter half of the 20th century and may be declining to the extent that predator communities may also need to decline before predator-prey dynamics stabilize.

Alewife (Alosa pseudoharengus)[3] – Another forage fish native to the Atlantic, alewife first entered the Great Lakes sometime in the 19th century, probably accessing Lake Ontario via a section of the Erie Canal that connected the lake to New York City. It was established in Lake Ontario by 1873, had spread to Lake Erie by 1931 and soon afterwards was present throughout the other lakes (Emery 1985). Alewife populations exploded in most of the region, as many of the lakes provided suitable habitat and had depressed predator populations that could not hold alewife in check. Only in Lake Superior did alewife populations remain small, probably due to a combination of cold waters and healthier predator communities; lake trout populations persisted in Lake Superior while in decline in the rest of the Great Lakes (USGS 2006). Alewife is viewed as a nuisance species, as it has low commercial value, competes with and preys upon juvenile predator fish, and has been shown to negatively impact native forage species such as coregonids, yellow perch, and emerald shiner through competition and predation. Of greater concern, alewife is also impeding the recovery of native predator fish like lake trout through its indirect influence on predator fish reproduction. Alewives have become major forage for predator species since becoming dominant in most of the Great Lakes, and recent studies have shown that lake trout actively choose alewife over

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[2] Image courtesy of the New York State Department of Conservation.
[3] Image courtesy of the US Fish and Wildlife Service Digital Library System.

recovering native fish such as bloater. This preference is causing Early Mortality Syndrome (EMS) in larval lake trout. Alewives contain high concentrations of thiaminase, an enzyme that breaks down thiamine, and adult lake trout consuming large amounts of alewife produce eggs that are deficient in thiamine. Lake trout fry often die post-hatch, soon after yolk sac reserves have been depleted. As long as alewife remains a major prey item of lake trout, recovery of this native predator in the Great Lakes will be difficult (Tillitt et al. 2005; Brown and Honeyfield 2006).

Introduced predators – Top predator fish have been deliberately stocked in the Great Lakes since the end of the 19th century, when Chinook salmon[4] (*Oncorhynchus tshawytscha*) and brown trout (*Salmo trutta*) were introduced to provide greater fishing opportunities. In the 20th century, further predator stocking of species like Coho salmon (*Oncorhynchus kisutch*) was initiated in order to control expanding populations of rainbow smelt and alewife. Since then, these species have grown to support lucrative sport fisheries. However, their presence in the Great Lakes is somewhat controversial, as they compete with native predators for food and there is concern that continued stocking of these species is impeding the recovery of lake trout stocks (Mills et al. 1994). Furthermore, a decline in abundance of both alewife and rainbow smelt in recent years indicates that the Great Lakes cannot support the high predator density that is resulting from predator stocking coupled with some recovery of native predator populations, such as walleye, and the substantial natural reproduction of introduced Chinook salmon now occurring. It is generally agreed that predator stocking will have to be substantially reduced, if not eliminated, in order to bring back a self-sustaining and native Great Lakes fish community (Kitchell et al. 2000).

Zebra mussels and quagga mussels (Dreissena polymorpha and D. bugensis)[5] – Dreissenid mussels first appeared in the Great Lakes in the late 1980s, and since have had profound impacts on the structure of aquatic communities in the lakes. They arrived via ship ballast water from the Caspian Sea, and were first reported in Lake St. Clair in 1988. Within a decade they were present in all five Great Lakes as well as several major river drainages including the Mississippi, Ohio, Tennessee, and Hudson rivers (USGS 2007c). Initially their most visible impacts were economic, as their rapid colonization of any available hard substrate led to clogging of industrial and municipal intake pipes, causing millions of dollars of damage. However, with time their ecological impacts have emerged as even more extensive. Where they have proliferated, these mussels have restructured the environment, changing the sediment-water interface to favor some species and impede others. Their presence has facilitated the colonization of other invasive species such as the round goby (*Apollonia melanostoma*), a mussel-eating forage fish, and *Echinogammarus ischnus*, an amphipod, both species from the same native range as the zebra and quagga mussel. Their high filtration rates have substantially reduced the

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[4] Chinook salmon, image by Virgil Beck, courtesy of the Wisconsin Department of Natural Resources.
[5] Image courtesy of the USGS.

amount of plankton in the water column, causing declines in native planktivore species. Although at first zebra mussels were thought to have helped "clean up" Lake Erie by increasing water clarity, they have now been linked to outbreaks of toxic algal blooms and Type E botulism (Yule et al. 2006a). They accumulate toxins through filter feeding which are then transferred to their main predator, the round goby, and on to predator fish and piscivorous birds (Barbiero and Tuchman 2004; Bykova et al. 2006). Their most direct impact on the fishery has been through the decline of Diporeia, a burrowing amphipod that may not be able to compete with dreissenid mussels for phytoplankton. The decline of Diporeia has been linked to the decline in condition and recruitment failure of lake whitefish and yellow perch, both important commercial species, and of forage species that are not directly utilized by, but that support target species for both commercial and recreational fisheries (Vanderploeg et al. 2002). Zebra and quagga mussels are expected to continue expanding their range throughout the United States.

Other invasive species – In addition to the above species, there have been a number of other introductions with smaller or more localized impacts. White perch (*Morone americana*) arrived in the Great Lakes via the Welland Canal in 1950 and became a major competitor of yellow perch (Downs et al. 2002). The round goby, first reported in the St. Clair River in 1990, has become a dominant forage fish in near-shore areas and has been associated with outbreaks of avian botulism and the extirpation of native sculpins. *Glugea hertwigi*, a protozoan fish parasite, was first detected in Lake Erie in 1960, and was responsible for a substantial die-off of rainbow smelt in the 1960s and 1970s (Mills et al. 1993). More recently, viral hemorrhagic septicemia (VHS) was found in the Great Lakes, and a number of die-offs have occurred since 2005 affecting both high-value species (e.g., yellow perch, smallmouth bass) and low-value species (e.g., round goby). It is not known how VHS arrived in the Great Lakes but its presence has necessitated strict controls in the transport of live fish, particularly bait and hatchery fish, in order to limit the spread of this disease (USDA 2007).

Given the ongoing rate of non-native species introductions in the Great Lakes and the substantial impacts these species can have, both economically and ecologically, it is likely that species invasions will present the greatest challenge to sustainable fisheries in the Great Lakes in the near future.

Lake-specific Changes to Fish Communities, 1830-1970

The specific sequence of habitat alteration, fishing pressure, and species invasions that has led to the current species distributions in the Great Lakes has been unique to each lake. Most of the large-scale changes in species composition occurred between the beginning of intensive fishing activity during the 19th century and the institution of modern management practices in the Great Lakes, as heralded by the formation of the current Great Lakes Fishery Commission in 1955, the discovery of a successful sea lamprey control in 1958, and the signing of the US and Canadian Water Quality Agreement in 1972. Many of the early changes to the Great Lakes fisheries have been summarized by Berst and Spangler (1973), Christie (1973), Hartman (1973), Wells and McClain (1973), and more recently by Holeck and Mills (2004). The following outlines their findings for changes in fish communities in each lake from 1830 to 1970. In general, Lake Superior has been the least affected by environmental degradation and invasive species impacts, Lake Erie has been most impacted by eutrophication, and the lower lakes (Lake Erie, Lake Ontario and Lake Michigan) have been more susceptible to invasive species effects.

Lake Ontario – The early Lake Ontario fishery was focused on lake trout, lake whitefish, Atlantic salmon, lake herring, and deepwater ciscoes. Overfishing, particularly of “discrete” (highly localized) stocks, such as lake herring and lake whitefish, caused both local and lake-wide declines in the seine net fisheries of the 19th century. Atlantic salmon stocks had collapsed by 1840 and were extirpated in the lake by 1890. Deepwater cisco populations were reduced by the 1860s, coinciding with the colonization of alewife. Though deepwater ciscoes had recovered somewhat by 1900, lake whitefish, lake trout, and burbot (a nuisance incidental catch of the trout fishery) had become scarce. Lake trout was the most valuable and widely sought species, with the bulk of the catches coming from eastern Canadian waters. However, population trends were similar throughout the lake; favorable environmental conditions allowed whitefish, trout, and burbot populations to increase briefly in the 1920s, but they declined again by the 1930s. Lake herring populations also declined during this time. The following decades saw an acceleration in the changes in species composition, with lake trout, burbot, herring, and deepwater cisco populations all collapsing in the 1940s during the proliferation of rainbow smelt; walleye rising in dominance in the 1950s; and white bass, blue pike, and deepwater sculpin all disappearing. The collapse of lake trout is thought to have been initiated by overfishing during the early part of the 20th century, which made the population especially vulnerable to increasing predation by sea lamprey through the 1950s. Lake whitefish were for many years the mainstay of the Lake Ontario fishery, particularly as it persisted after lake trout and deepwater ciscoes were no longer available to the fishery. However, sea lamprey predation also affected whitefish abundance, particularly in the 1950s after the collapse of lake trout had removed the lamprey’s favored prey. The decline of the lake whitefish caused a further shift in fishery effort to yellow perch and white perch, where available. Yellow perch had been a minor, but continuous, target of the commercial fishery. During the latter half of the 20th century the lake began to reflect increasing eutrophication, with algal blooms and lower oxygen conditions affecting spawning success for some species during the 1970s, and an increase in the population of yellow perch in the open waters of Lake Ontario. By this time alewife represented the greatest biomass in the lake, and the fishery had moved from capturing a small number of relatively large, valuable fish to depending on a large number of smaller, lower value fishes.

Lake Erie – The commercial fishery in Lake Erie has always been one of the most productive in the Great Lakes, with annual catches in some years exceeding the combined production of all of the other lakes. This is in large part due to its diverse habitats, from the warm shallow waters of the western basin to the colder, deeper waters of the eastern basin. This habitat variety has also fostered the greatest diversity in species targeted by the commercial fishery. The early (pre-1900) fishery focused on blue pike, walleye, sauger, lake whitefish, and lake trout. Lake trout had been a target in Lake Erie beginning with the Native American subsistence fisheries, and supported a substantial commercial fishery in the deeper waters of the eastern basin during the 19th century. However, populations were declining by the late 1800s, reaching commercial insignificance by 1930, and completely extirpated from Lake Erie by the 1970s.

Lake herring was likewise very important to the early fishery in Lake Erie, with hundreds of millions of pounds harvested between the 1880s and the 1970s. As with lake trout, herring populations underwent severe declines in the first half of the 20th century, collapsing in 1920. By the 1950s, herring were no longer a part of the Lake Erie fishery. In contrast with trout, however, the herring declines were marked by wide fluctuation in abundance that reflected both variability in year class strength and the discrete nature of herring stocks that underwent progressive decline. These declines were driven initially by overfishing and later exacerbated by eutrophication, which drove herring stocks west to east as the western and central basins grew too hypoxic for herring to persist.

In response to the decline of herring and lake trout, fishery effort turned to lake whitefish. Intensified fishing effort for this species was reliant on much reduced populations of only lake-spawning fish, as siltation and pollution had eliminated populations that had previously spawned in the Detroit River and Maumee Bay by 1918. As with lake trout and lake herring, lake whitefish are cold-water species at the edge of their southern range in Lake Erie; the changing environmental conditions in the lake induced greater year class strength variability in the whitefish population, hastening their decline. Detailed catch reports collected since 1915 show alternating periods of high and low yield of lake whitefish that indicate the population had lost its stress buffering capacity.

As eutrophication progressed, even warm-water mesotrophic species were negatively impacted. Walleye populations, already stressed by the elimination of tributary-spawning stocks, were fluctuating substantially by the middle of the 20th century, with a peak catch of 16 million pounds in 1956 followed by a dramatic decline to only 1 million pounds in 1962. Short-term increases that followed were the product of one or two strong year classes. As the irregularity of year classes continued to affect western and central basin populations, fishing intensity greatly increased in the eastern basin, where the isolated stocks had always yielded much smaller catches but which were also a great deal more stable that those in the western and central waters. In US waters, commercial walleye fishing intensity remains low relative to Canadian waters. The fishery for blue pike, a species related to the walleye, also increased dramatically around 1950, leading to a collapse shortly thereafter. This species is no longer found in the Great Lakes. The loss of fish stocks in the western and central basins of Lake Erie in particular were thought to be in part a reaction to the disappearance of *Hexagenia* mayflies, an important food item, as eutrophication in Lake Erie progressed.

The yellow perch is, like the walleye, a mesotrophic species that has long been important in the Lake Erie fishery. As catches of lake whitefish and lake herring declined, its importance increased, leading to high catches exceeding 10 million pounds in the 1930s. As with walleye, yellow perch year class strength also became variable beginning in the 1950s. Fishing intensity and some single strong year classes resulted in later peaks in commercial catch; however, overall population declines continued in the middle of the 20th century, with a high catch of 33.7 million pounds in 1969 being followed by substantial declines until management actions began to improve water quality in the late 1970s. During the 1960s, as all valuable populations were declining, fishing intensity for invasive rainbow smelt increased dramatically; however, infection of rainbow smelt by the parasite *Glugea hertwigi* caused steep declines in catches of this species during the 1960s.

Lake Huron – The Lake Huron fishery has been active since the early 19th century, when settlements were established and local fish trading became common. In 1831 a seine net fishery was established in Canadian waters near the Fishing Islands, targeting primarily lake whitefish and ciscoes. A commercial gillnet fishery first opened in Georgian Bay in 1834. Since then, Lake

Huron has supported the 3rd largest commercial fishery in the Great Lakes, primarily through Canadian fisheries in Georgian Bay, the North Channel, and the open lake and US fisheries in the open lake and in Saginaw Bay. The fishery targeted lake trout, lake whitefish, walleye, sauger, and ciscoes, with nearly constant production until the late 1930s when sea lamprey predation began to affect catches of lake trout and whitefish. This caused a continuing decline in commercial catches of these valuable species through the 1960s, and a concurrent increase in catches of lower value species such as yellow perch and chubs. Total production of all species in Lake Huron dropped from 6,600 tons to 3,800 tons between 1940 and 1966, with lake trout disappearing from US commercial catches by 1946 and from Canadian catches in 1955 (Berst and Spangler 1973). Only Parry Sound and McGregor Bay continued to support small remnant lake trout populations, likely because there were few sea lampreys in these areas.

Sea lamprey predation was primarily responsible for the decline of lake trout, burbot, lake whitefish, and rainbow trout in Lake Huron. Other pressures on these populations included overfishing and degraded water quality. Lake whitefish catches fluctuated throughout the 20th century in response to these pressures, starting around 900 tons in 1900, increasing to 2,500 tons by 1932 and declining to only 113 tons by 1945. Single strong year classes led to further short-term peaks in production, such as the record 2,900 ton catch in 1957. Most of the lake whitefish catches in Canadian waters came from Georgian Bay, while US catches were primarily from Saginaw Bay. By the 1970s, commercial fishing in Lake Huron was in an overall depressed state, with sea lamprey predation having had the single largest effect on species composition by decimating stocks of both lake trout and burbot, species that had supported both major fisheries and high trophic level piscivores. In addition, eutrophication had caused the loss of *Hexagenia* mayflies in Saginaw Bay in the 1960s, affecting food supplies for fish.

Lake Michigan – The commercial fishery in Lake Michigan has been in operation since at least 1843, when the major target was lake whitefish. By 1860, once abundant near-shore whitefish stocks had been mostly depleted, but production remained steady as both efficiency of gear and fishing effort continued to increase and new fishing grounds were sought. Effort soon also included lake trout, lake sturgeon, and lake herring, particularly as lake whitefish catches began to drop. Increased catches of lake herring allowed production to increase dramatically at the turn of the century, but it declined soon after and fluctuated from 1911 to 1970, with a high of US $9.7 million in 1952 and a low of only US $40,000 in 1970. These changes have been influenced by both market value and changes in abundance, as well as interactions with non-indigenous rainbow smelt beginning in the 1930s.

Increasing catches of other secondary targets such as cisco, perch, sucker, and some walleye also allowed production to remain high. Non-native species were added to the commercial fishery early on, with carp being sought as early as 1893 and substantial production (1.5 million lbs) occurring by the 1930s. Rainbow smelt, which in the Great Lakes originated from a planting in the Lake Michigan watershed, was present throughout Lake Michigan by 1936, and commercial production had risen to 4.8 million pounds by 1941. This was followed by an abrupt drop in production in 1943 and fluctuations thereafter between less than one million pounds and as high as 9.1 million pounds. These fluctuations resulted from a combination of disease (reduction in stock) and changes in market value (changes in effort). Lake trout, which became the most valuable species in the fishery after the early decline of whitefish, began to decline in the middle of the 20th century and was essentially eliminated from the lake by 1950, primarily as a result of sea lamprey predation. Lake whitefish production remained between one and 2.6 million pounds between 1911 and 1950, after its precipitous decline from a high in the late 19th century of 5.5 million pounds. After 1950 it again decreased, primarily due to overfishing as deepwater trap nets progressively fished down local populations. The lake trout decline also caused an increase of lamprey predation on whitefish, but the whitefish population recovered somewhat from this by the1960s, when lamprey control methods began to take effect. The lake whitefish population then underwent a substantial if erratic increase to 1.7 million pounds by 1970.

As lake whitefish, lake sturgeon, and walleye became rare in the late 19th century, commercial production of yellow perch increased. Beginning in 1889, yellow perch became an important part of both the commercial and recreational fishery in Lake Michigan, with catches increasing to 6.3 million pounds by 1896 and remaining high at nearly 5 million pounds until the 1960s. Since then production trends have appeared to be tied to alewife abundance, with declines following the proliferation of alewife north to south due to competition between juvenile alewife and perch, and predation by adult alewife on juvenile perch. Walleye and round whitefish have both been of only minor importance in the fishery, with spikes in production corresponding to declines in other target species. Walleye abundance peaked in the middle of the 20th century and then underwent declines dramatic enough that it became rare throughout Lake Michigan by the 1970s.

Lake Superior – Commercial fisheries have operated in Lake Superior since about 1850 when European settlements were first established, and underwent modernization during the 1870s with the introduction of steam-driven technology. Early targets of the fishery were lake whitefish and lake trout, then the fishery shifted by 1915 to lake herring, which have remained the dominant catch in the fishery. The expansion of the fishery effectively ended with the arrival of the sea lamprey, first recorded in the lake in 1946. The combined pressure of sea lamprey predation and progressive "fishing down" of discrete stocks throughout the lake severely compromised the lake trout population. Within five years, a steep catch decline of about 27% per year began and lasted until the early 1960s when sharp restrictions were placed on commercial yield of lake trout.

As with lake trout, lake whitefish, the second early target of the Lake Superior fishery, also underwent substantial catch declines during the 20th century. In the first part of the century, catch rates decreased at about 6% per year, probably in response to sequential fishing down of stocks, or the loss of estuarine- and river-spawning stocks due to habitat degradation linked to the lumber industry. Then, from 1920 until 1955, catches increased 3% per year, which coincided with a likely increase in fishing effort, followed by a sharp annual decrease of 17%. This sharp decrease can be attributed to the proliferation of sea lamprey in Lake Superior, until 1960 when sea lamprey control methods began to take effect, allowing fish stock sizes to increase again.

Catches of lake herring, which became dominant in the Lake Superior fishery when lake trout and whitefish catches declined, reached a peak in 1941 with a yield of 19 million pounds. Fishing down discrete stocks appears to have occurred in this fishery as it did in the lake whitefish and lake trout fisheries, evidenced by the changing contribution of catches from different regions in the lake, which was accompanied by a decline in both catch and abundance. In US waters, Minnesota catches dominated the early herring fishery (1929-1940), followed by catches from Wisconsin (1941-1956) and finally Michigan. The contribution of Canadian yield to total herring production increased from 11% in 1965 to 50% by the early 1970s. The herring decline has been attributed to competition for food with native bloater populations, which were increasing around the middle of the 20th century, and non-native rainbow smelt, and to fishing pressure, particularly given the switch to nylon gillnets during this period, which greatly increased the efficiency of the fishery.

Apart from lake trout, lake whitefish, and lake herring, only sturgeon, walleye, and smelt ever supported substantial fisheries in Lake Superior. Catches of lake sturgeon peaked early and were not substantial in the commercial fishery after 1920, and walleye have supported intense local fisheries only in warmer, shallow bays and around islands, as the deeper, colder waters of the open lake are not suitable walleye habitat. Walleye catches have been primarily from Canadian waters, with a peak yield in 1966 of less than 400,000 pounds. Stocks were affected by environmental degradation during the middle of the 20th century, particularly due to the influence of a paper mill located downstream from a primary walleye spawning ground in the Nippigon River that supported these Canadian stocks. The non-indigenous rainbow smelt first arrived in the lake in 1930 and was integrated into the commercial fishery by 1952 with a yield of 45,000 pounds. Catches were almost entirely from US waters and increased steadily through 1960 and then remained around 1.4 million pounds per year. In addition to becoming important to the fishery, smelt also became important competitors for food with lake herring.

Current Profile of Commercially Caught Species

Management practices, environmental protection and restoration, and fishery controls instituted during the latter half of the 20th century have allowed fisheries in the Great Lakes to regain much of their historic yield and in some cases maintain or restore a number of the original fishery target species. Great Lakes commercial fisheries are now supported by a suite of species including both historically important species, such as lake whitefish and lake herring, and species formerly considered to be of low value, such as rainbow smelt. In addition, some species that have always been in the fishery but at relatively low volume have become dominant, such as walleye and yellow perch. Some species that were once dominant, such as lake trout, now support only very minor fisheries (Fig. 4). The most valuable species harvested in large quantities, in terms of price per pound, are lake whitefish, walleye, and yellow perch. In terms of quantity harvested, lake herring are a major part of the Canadian commercial fishery (Baldwin et al. 2002; FAO 2002).

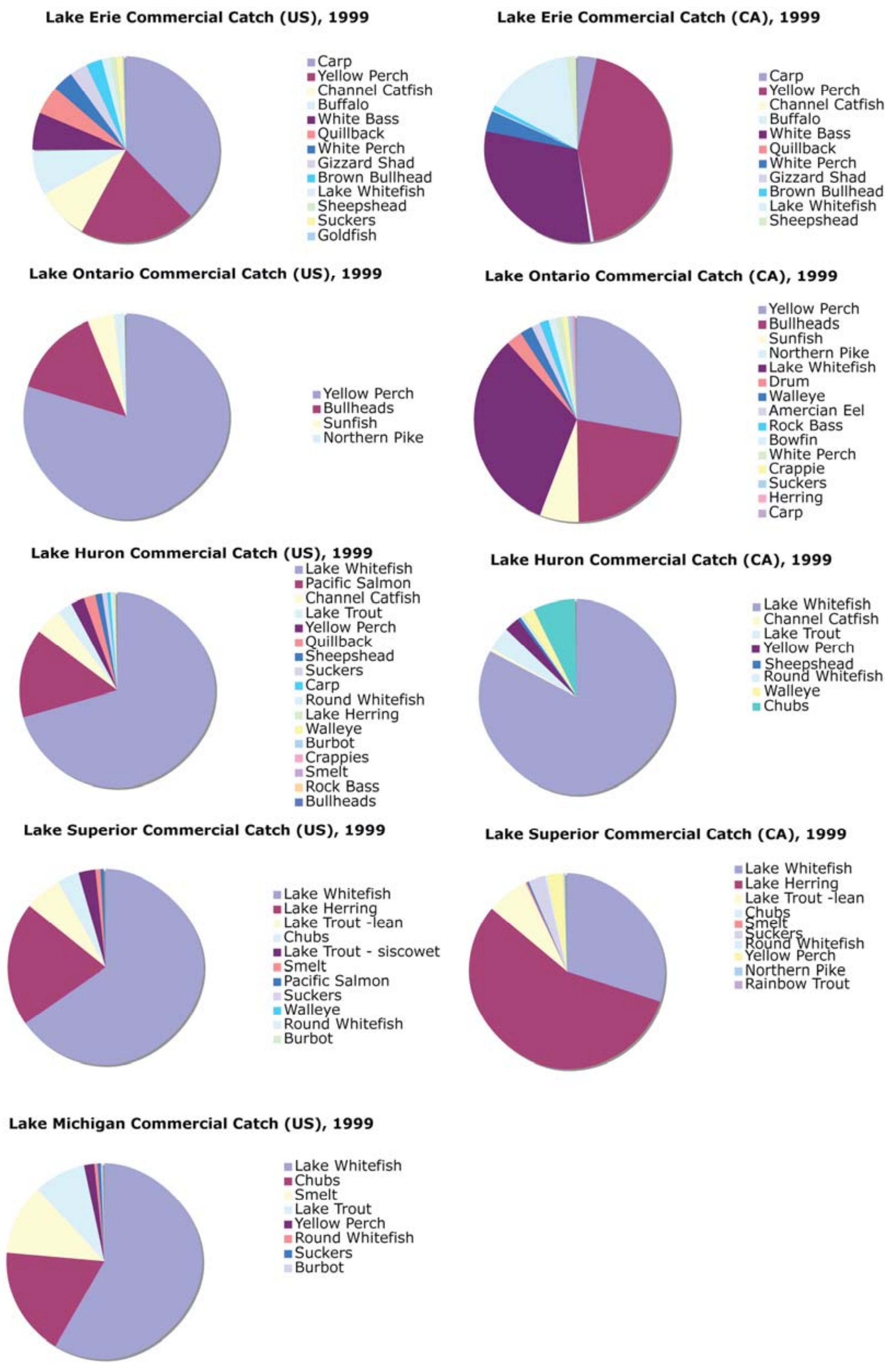

Figure 4. Current profile of commercially caught Great Lakes species in US and Canada (Figure from Baldwin et al. 2002).

For the Seafood Watch® Seafood Report on the Great Lakes region, seven species have been selected initially as representative of the Great Lakes commercial fisheries, in terms of value, conservation concern, or ecological impact. These species include: lake trout (*Salvelinus namaycush*), walleye (*Sander vitreus*), yellow perch (*Perca flavescens*), lake whitefish (*Coregonus clupeaformis*), lake herring (*Coregonus artedii*), round whitefish (*Prosopium cylindraceum*), and rainbow smelt (*Osmerus mordax*).

Lake trout was once the dominant offshore predator in all of the Great Lakes, but nearly disappeared from all lakes except Lake Superior by the 1960s, due to a combination of overfishing, spawning site degradation, and predation by the non-native sea lamprey. In spite of decades of concerted management effort, lake trout is currently self-sustaining only in Lake Superior and supports a very small commercial fishery there in addition to commercial fisheries in other lakes supported solely by stocking. Lake trout warrants the greatest conservation concern of all the species considered in this Seafood Report.

Walleye and yellow perch are both near-shore, mesotrophic species that were able to recover quickly during the 1980s after the institution of phosphorous abatement programs in the 1970s, particularly in Lake Erie. These species have always dominated near-shore fisheries and continue to be some of the most valuable catches. In the 1990s both yellow perch and walleye experienced a second period of population decline, apparently as a response to new species invasions, including dreissenid mussels and white perch (in Lake Erie). Quota management in Lake Erie has helped maintain fishery productivity in recent decades in spite of continued variability in recruitment that appears to be related to environmental (climate) conditions.

Lake whitefish was once a dominant commercial species and is now again, in spite of a mid-20th century decline. This species is representative of the efficacy of Great Lakes management in restoring native communities. Lake herring is another member of the Great Lakes coregonid community, but has not recovered to the same extent in all lakes as lake whitefish. It currently supports a substantial catch in Canadian waters of Lake Superior, where the habitat, invasive species, and contaminant stresses that affected fish communities in other lakes have not been as severe. Lake herring and lake whitefish are currently considered the best candidates for restoring the native predator-prey balance in the Great Lakes, as they are suitable prey species for predators such as lake trout (although these predators at present continue to prefer exotic forage species like rainbow smelt and alewife). Round whitefish are a less valuable species than lake whitefish, though they have at times served as a fishery substitute when yields of the more valuable species declined.

Rainbow smelt is somewhat unique in the fishery as it is an invasive species that has integrated into both the ecological community and the fishery (harvested both commercially and in the sport fishery), and this has resulted in some tension as its population is utilized in conflicting ways. Smelt are considered an undesirable species as they compete with and consume native fish and provide less suitable forage for native predators than do native prey such as lake whitefish or lake herring. However, the exotic predators that were stocked in the lake to control populations of non-native alewife and rainbow smelt now support lucrative commercial fisheries and depend on rainbow smelt for food. Furthermore, recovering populations of native predators such as lake trout now also utilize rainbow smelt for forage. The removal of this species is desirable in order to promote native predator-prey complexes, but may require a decrease in the predator population in the Great Lakes in order to ensure that the resulting communities are self-sustaining, particularly considering that native forage populations are also still in recovery.

The continuing success of the current Great Lakes fisheries depends on the careful management of existing stocks, which includes minimizing impacts to non-target species and important habitat, and preventing the suite of overfishing, species interactions, and habitat degradation that led to the early tumultuous changes in fish community composition. The modern fishery management structure, discussed in the last section of this chapter, is largely a successful body that utilizes modern research and monitoring methods to ensure continuing fishery health. However, the impacts of fishery gear remain an area of high uncertainty in the Great Lakes fisheries, as few comprehensive studies of bycatch rates and habitat effects have been conducted. Commercial gear utilized in the Great Lakes fisheries, and their known and uncertain impacts, are discussed below.

Great Lakes Commercial Fishery Gear: Impacts and Uncertainties

Commercial fishing in the Great Lakes has been characterized by progressive improvement in gear efficiency and gear type modernization, such that catch-per-unit-effort (excluding availability of species targeted) and amount of gear set has increased dramatically. In the 19th century, first pound nets and later seine nets (Fig. 5) were common in smaller fisheries such as those in Lake Michigan, Lake Superior, and Canadian waters of Lake Huron (Berst and Spangler 1973; Lawrie and Fahrer 1973). Seine nets were particularly efficient at fishing down local populations, as they tended to exploit those fish that schooled or clumped in one region, such as lake herring and lake whitefish.

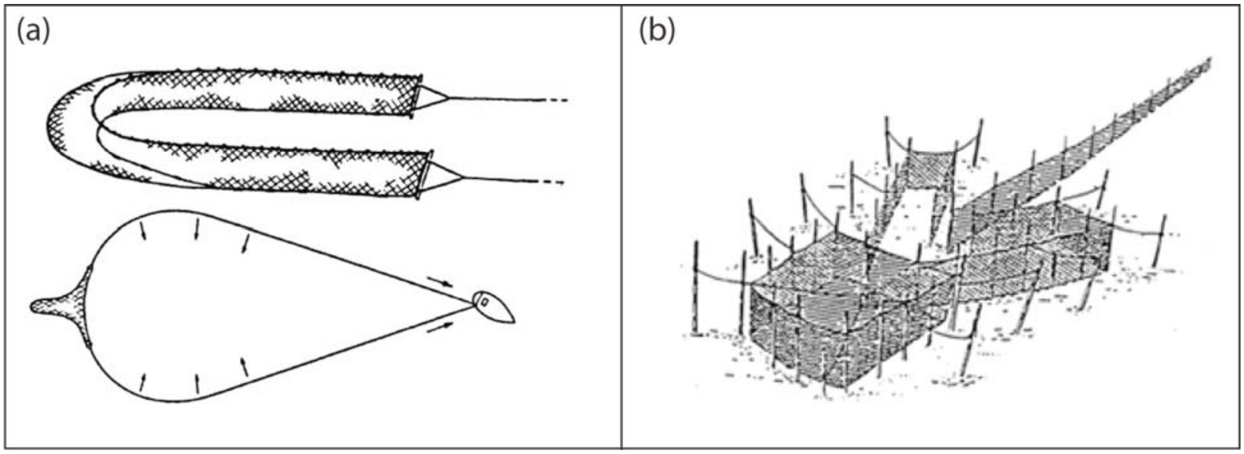

Figure 5. (a) Seine nets consist of a very long net that may also have a bag at the center. It is operated by long ropes at either end, deployed either from shore or a boat. The net surrounds an area, and is typically used for catching demersal species. **(b)** Pound nets are a type of trap net typically set near-shore. They consist of net walls open at the surface that lead to closed chambers at the bottom. They are often set near migration routes of fish, are usually hauled by hand, and are deployed from small open boats (Figures from UNFAO 2000).

These early gears were deployed either from shore or manually from small boats. However, they were quickly replaced by gillnets, which remain a primary commercial fishery gear today. Gillnets were introduced in Georgian Bay in Lake Huron as early as 1834, with use increasing substantially with the arrival of a rail line to Collingwood Harbor in 1855. In Lake Michigan, gillnets came into use in the rapidly expanding commercial fishery in the mid-1840s. Steam technology that came into use between 1870 and 1890 increased fishery efficiency by introducing steam tugs to deploy nets and steam-powered net lifters, which allowed fishermen to increase the number of nets set per boat (Berst and Spangler 1973; Lawrie and Fahrer 1973; Wells and McClain 1973).

A main driver of gillnet efficiency is the material used in constructing the nets. Gillnets consist of a sheet of netting stretched between a buoyant headrope and a weighted foot rope, which stretches the net out vertically in the water, and may be placed at the bottom or floating in the water column, depending on the fish being targeted (Fig. 6).

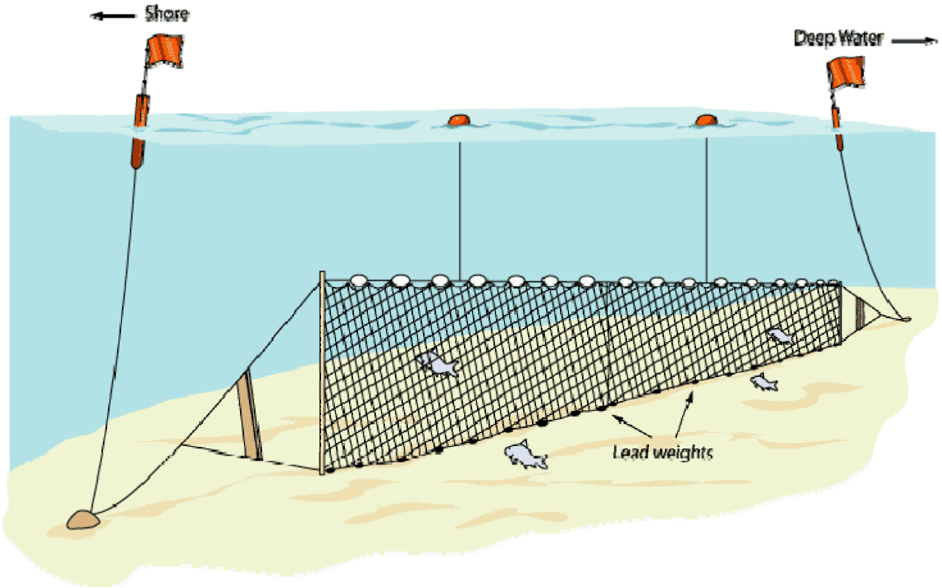

Figure 6. Schematic of gillnet (Figure from Michigan Sea Grant).

In the 1800s nets went from cotton to finer linen twine. In 1930, linen was replaced with more flexible cotton, and finally in the mid-1950s cotton was replaced by nylon. Nylon gillnets increased efficiency about 3-fold and speeded the decline of already stressed fish populations such as lake whitefish in Lake Ontario, lake trout and lake herring in Lake Superior, and lake sturgeon in all the Great Lakes.

In spite of new limits on the use of gillnets (mesh size, season, placement and effort), their high efficiency and mortality rates continue to be of concern today. Gillnet mesh size determines the size of fish targeted, and can be further tuned by seasonal and spatial considerations, but selectivity is low when target and non-target species are of similar size. For example, though commercial gillnet fisheries in many lakes currently target lake whitefish, lake trout have higher selectivity for this gear as their toothy mouth is more easily entangled in mesh. When non-target species are caught, mortality is high; gillnets can kill via suffocation or damage to gills. In Lake Superior, gillnets account for only 35% of the whitefish catch but 96% of mortality, whereas trap nets, another primary commercial gear used in the Great Lakes, catch 60% of the whitefish but kill only 3%. In the mid-1960s, as lake trout restoration efforts were underway, inspections of gillnets in Lake Michigan revealed more than 70,000 lake trout had been taken as incidental bycatch in the lake whitefish fishery. This led to a ban on gillnets in US waters of the Great Lakes in 1977; however, tribal fisheries are exempt from this ban (though the 2000 Consent Decree instituted much tighter regulation on gillnet use and an overall dramatic reduction in effort). Gillnets are often preferred, particularly in smaller fisheries, because of simplicity of use and the ability to deploy them from smaller boats, therefore lowering overall costs (Johnson et al. 2004b). Few systematic studies of bycatch in Great Lakes gillnet fisheries exist, and more monitoring is needed to ensure that overexploitation of fish stocks does not continue.

Trap nets are used throughout Canadian and US waters and in tribal fisheries, and are generally considered to have less impact on non-target species (Fig. 7). Trap nets collect live catches, have small incidence of bycatch compared to other gear, and survival of bycatch is high (Kinnunen and Pistis 2007).

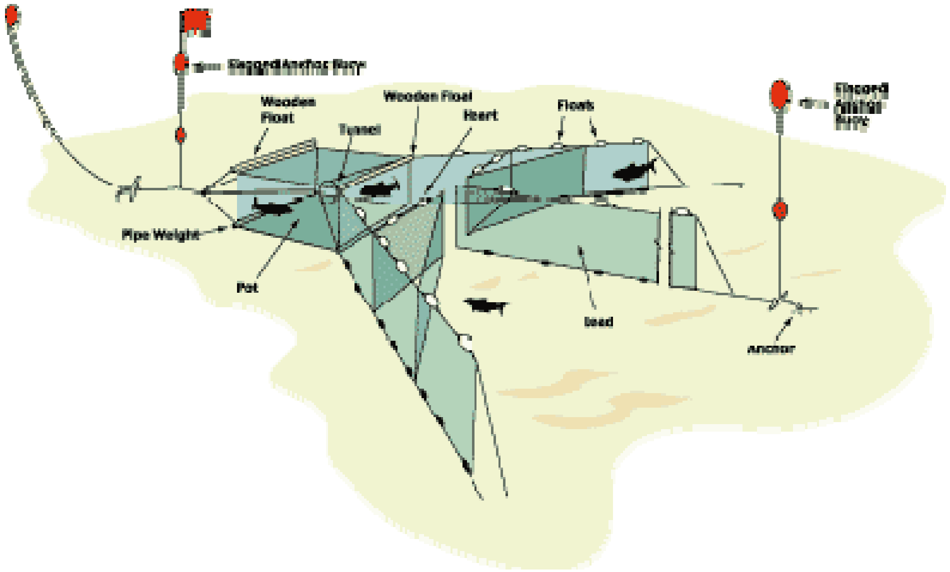

Figure 7: Trap net schematic (Figure from Kinnunen and Pistis 2007).

Management of Great Lakes Fisheries

Management activity in the Great Lakes became comprehensive during the middle of the 20th century, after the combined effects of overfishing, pollution, and impacts of introduced rainbow smelt, alewife, and sea lamprey had decimated a number of commercially important fish stocks. Although there had been some discrete monitoring and regulation of stocks and hatchery management as early as the end of the 19th century, the modern management regime of the Great Lakes fisheries was born in the 1970s.

Because the Great Lakes span jurisdictions in two countries, several States, one province, and a number of tribal lands, management of the shared fishery resources is complex and dynamic. The main coordinating body of fishery management in the region is the Great Lakes Fishery Commission (GLFC), an inter-jurisdictional agency established in 1954 by the governments of the US and Canada (Beamish et al. 2001). The Commission consists of four Canadian and four

American commissioners, who are appointed by their respective governments and supported by a secretariat in Ann Arbor, Michigan.

Within the Great Lakes Fishery Commission, each lake has a Lake Committee that undertakes research and makes recommendations on fishery quotas, sea lamprey control (the original motivation for the Commission), and other lake-specific management actions for each of the Great Lakes. Lake Committees comprise members of the actual management bodies, the states' Departments of Natural Resources and the Ontario Ministry of Natural Resources (OMNR), as applicable. In addition, tribe-licensed fisheries are managed by two management agencies: the Chippewa-Ottawa Resource Authority (CORA) and the Great Lakes Indian Fish and Wildlife Commission (GLIFWC). In 1976 the Michigan Supreme Court reaffirmed that treaties signed in 1836 and 1855 reserved some tribal fishing rights outside state regulation. This finding led to the 1985 Consent Order and the 2000 Consent Decree, now in effect. The Consent Decree establishes biological monitoring and law enforcement within CORA-managed tribal fisheries, with an Executive Council and Technical Fishery Committee comprising state, tribal, and federal biologists. Since the 2000 Consent Decree, these fisheries are managed on a species-specific rather than region-specific basis, with emphasis on restoring lake trout communities (CORA 2007; GLIFWC 2007). Some fish stock surveys and water quality monitoring in the Great Lakes region is also undertaken by the US Geological Service's Great Lakes Science Center, NOAA's Great Lakes Environmental Research Laboratory (GLERL), and the US Environmental Protection Agency (EPA).

The following reports analyze the life history characteristics, stock status, nature of bycatch, habitat and ecosystem impacts, and management effectiveness of the commercial Great Lakes fisheries for lake trout (*Salvelinus namaycush*), walleye (*Sander vitreus*), yellow perch (*Perca flavescens*), lake whitefish (*Coregonus clupeaformis*), lake herring (*Coregonus artedii*), round whitefish (*Prosopium cylindraceum*), and rainbow smelt (*Osmerus mordax*), in order to determine their sustainability.

Summary Table of Seafood Recommendations for Great Lakes Species

	Overall Seafood Recommendation		
Species	**Best Choice**	**Good Alternative**	**Avoid**
Lake trout		√ Lake Superior	√ Lake Michigan, Lake Huron
Walleye		√	
Yellow perch	√ Lake Erie	√ Lake Huron, Lake Ontario	
Lake whitefish	√ Trap Nets	√ Lake Erie, Gillnets	
Lake herring		√	
Round whitefish		√	
Rainbow smelt		√	

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Chapter 2: Lake Trout

Salvelinus namaycush

(Image courtesy of Cornell University and the New York State Department of Conservation)

2-I. Executive Summary

This Seafood Report evaluates the ecological sustainability of wild-caught lean lake trout, *Salvelinus namaycush*, from the Great Lakes region. To make an overall recommendation, commercial lake trout fisheries have been evaluated according to Seafood Watch® criteria: inherent vulnerability to fishing pressure; status of wild stocks; nature and extent of bycatch; effects of fishing methods on habitats and ecosystems; and effectiveness of the management regime. Stocks are broken down by lake—Lake Michigan, Lake Huron, and Lake Superior—to better inform consumers and seafood buyers.

Inherent Vulnerability

Lake trout are a long-lived, top predator species with a moderate rate of population increase. They are broadly distributed throughout the US and Canada and exhibit few behaviors that make them especially vulnerable to fishing mortality, which provides them with some inherent resiliency to fishing pressure. Their habitats and spawning grounds are relatively undisturbed in the Great Lakes, particularly in comparison to some near-shore species more dependent on tributaries and embayments. However, predation by the invasive sea lamprey and a reduced prey base dominated by the non-indigenous alewife and rainbow smelt are negatively impacting lake trout stock health. Lake trout are therefore deemed moderately vulnerable to fishing pressure throughout the Great Lakes.

Stock Status

Major declines in lake trout stocks occurred throughout the Great Lakes region during the middle of the 20th century as a result of overfishing and sea lamprey predation. Although many populations are in recovery, commercial fishing for lake trout is severely restricted. Lake trout are commercially fished almost exclusively from Treaty-ceded waters of Lake Michigan, Lake Huron, and Lake Superior. In all but Lake Superior the fishery is maintained by stocking, as self-sustaining and naturally reproducing populations of lake trout have not been reestablished since their original decline. Within the tribal fisheries, target mortality rates are set below 40-45% and all catches in recent years have been below the total allowable catch (TAC). However, sea lamprey predation can and has caused total mortality in some areas to exceed the target limit, leading to stock declines. These tribal fisheries are spatially very limited; no trap nets are allowed in any lake trout recovery area. Therefore, they are not expected to have a substantial impact on recovering lake trout populations basin-wide. Although lake trout populations have undergone some recovery from the dramatic declines observed in the 1950s and 1960s, they still fall well short of sustainability goals. Given the lack of naturally reproducing populations of lake trout in Lake Huron and Lake Michigan, status of wild stocks in these lakes are considered poor and critical, respectively, while in Lake Superior, where some self-sustaining populations have returned, wild stocks are considered of moderate conservation concern.

Bycatch

Lake trout are caught using both trap nets and gillnets, though gillnets are prohibited in lake trout recovery areas. Gillnets can have high impacts due to their high rates of mortality and low selectivity; however, bycatch rates in the small tribal fisheries that employ gillnets are low (<10%) and include no species of special concern. In addition, the use of gillnets in tribal fisheries is slowly being phased out in favor of trap nets, which have very low impacts and mortality. Bycatch effects in lake trout fisheries are therefore a low conservation concern.

Habitat Effects

The removal of lake trout in the limited tribal fisheries of Lake Michigan, Lake Huron, and Lake Superior has limited ecosystem-wide effects, but intensive stocking to support the fisheries is of concern, as they can impact native populations through predation, competition, disease, and loss of genetic diversity. As a result, habitat and ecosystem impacts are considered moderate.

Management

Management agencies have undertaken a concerted restoration effort for lake trout, including intensive stocking, annual stock assessments and surveys, population modeling, sea lamprey control, and restriction of both commercial and recreational fisheries. However, little successful recruitment has occurred for wild lake trout in Lake Michigan or Lake Huron. Lake Superior has had the greatest rehabilitation of natural reproduction and no longer requires stocking in many management units. In other lakes, new methods for controlling sea lamprey populations will be necessary before rehabilitation of lake trout can succeed. Management in Lake Superior is thus deemed highly effective, but management in the other Great Lakes is deemed ineffective.

Summary

Because of moderate natural vulnerability and the poor to critical condition of lake trout stocks (populations are not self-sustaining) in all but Lake Superior, they are of moderate-to-high conservation concern. Lake trout from Lake Superior is recommended as a “**Good Alternative**,” but lake trout from the remaining Great Lakes Region is recommended as “**Avoid**.”

Table of Sustainability Ranks for Lake Trout

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability		√		
Status of Stocks		√ Lake Superior	√ Lake Huron	√ Lake Michigan
Nature of Bycatch	√			
Habitat & Ecosystem Effects	√ Lake Superior	√ Lake Huron, Lake Michigan		
Management Effectiveness	√ Lake Superior	√ Lake Huron, Lake Michigan		

About the Overall Seafood Recommendation:

- A seafood product is ranked Best Choice if three or more criteria are of Low Conservation Concern (green) and the remaining criteria are not of High or Critical Conservation Concern.
- A seafood product is ranked **Good Alternative** if the five criteria "average" to yellow (Moderate Conservation Concern) OR if the "Status of Stocks" and "Management Effectiveness" criteria are both of Moderate Conservation Concern.
- A seafood product is ranked **Avoid** if two or more criteria are of High Conservation Concern (red) OR if one or more criteria are of Critical Conservation Concern (black) in the table above.

Overall Seafood Recommendation for Lake Trout

Lake Superior:

Best Choice 🟩 **Good Alternative** 🟨 Avoid 🟥

Lake Michigan, Lake Huron:

Best Choice 🟩 Good Alternative 🟨 **Avoid** 🟥

2-II. Introduction

Lake trout was once the dominant predator in all of the Great Lakes except Lake Erie. For more than 50 years lake trout was the most valuable commercial species in the upper Great Lakes fisheries, with lean lake trout, *Salvelinus namaycush*, constituting nearly 90% of the total lake trout catch, at a time when fishing pressure was increasing throughout the Great Lakes region. Between 1930 and 1950, overfishing and the invasion of the sea lamprey (*Petromyzon marinus*), a parasitic eel that preys on adult lake trout, combined to drive all lake trout stocks into serious decline if not complete extirpation (Figs. 1-3).

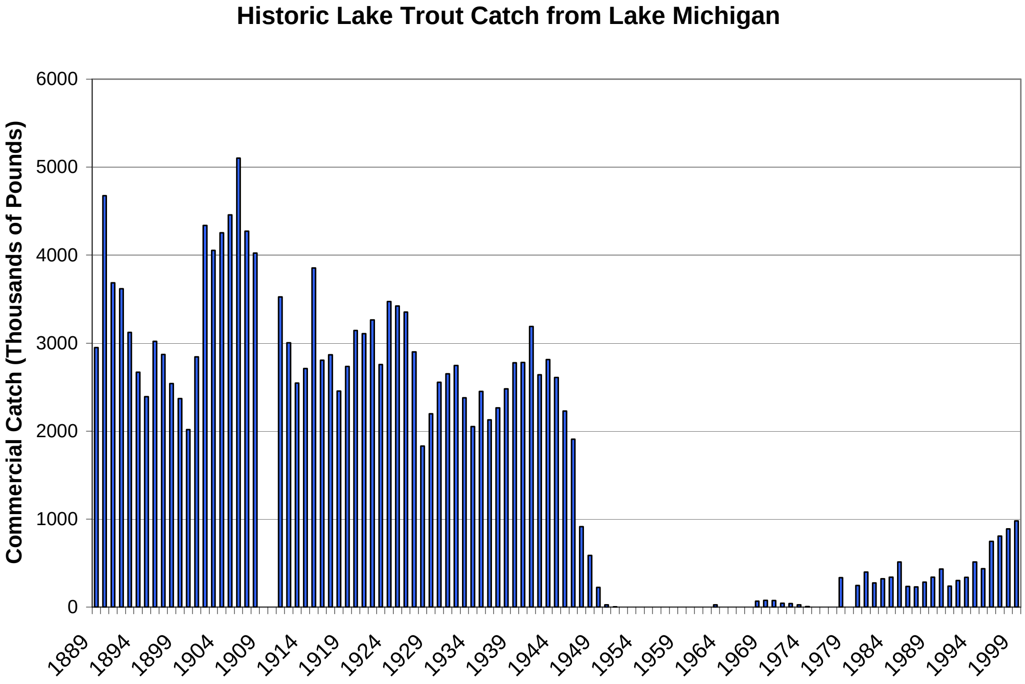

Figure 1. Commercial lake trout catch from Lake Michigan, 1889-1999 (Figure from Baldwin et al. 2002).

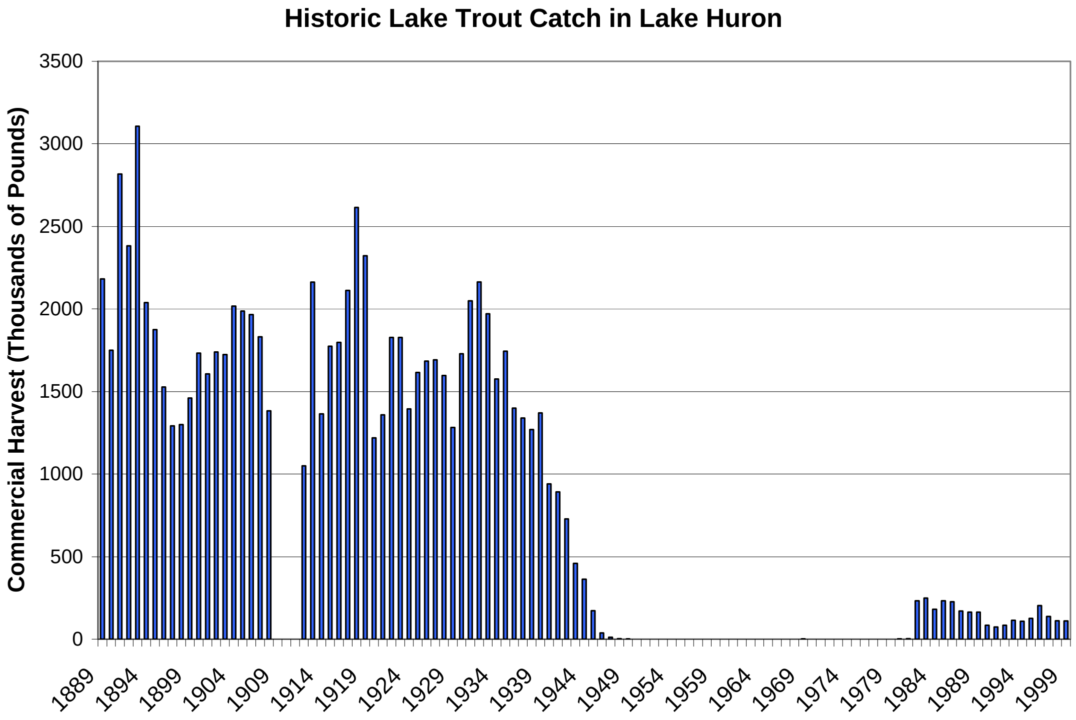

Figure 2. Commercial lake trout catch from US waters of Lake Huron, 1889-1999 (Figure from Baldwin et al. 2002).

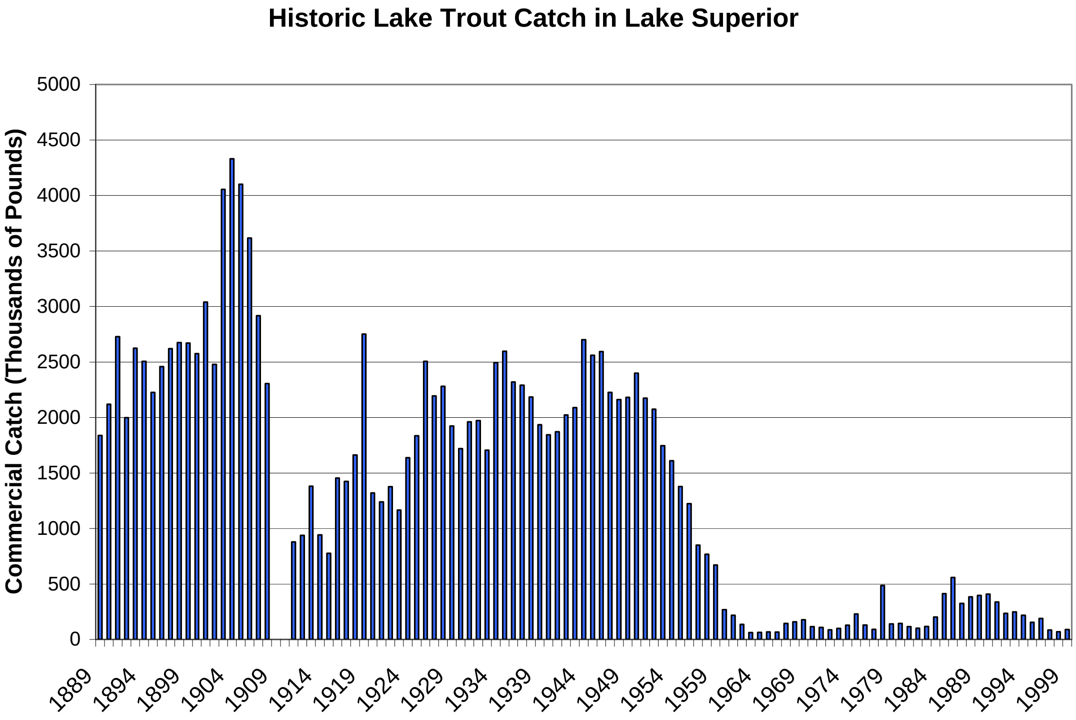

Figure 3. Lake trout commercial catch from US waters of Lake Superior, 1889-1999 (Figure from Baldwin et al. 2002).

By the 1950s, lake trout had been extirpated from most of the Great Lakes. Restoration efforts, including fishery controls, stocking programs, and lampricide application (chemical control of sea lamprey populations) were put into place beginning in the 1960s (Eshenroder et al. 1999). Stocking programs have supported some recreational and limited tribal commercial fisheries, but have been largely unsuccessful. Natural reproduction has been limited by sea lamprey predation, loss of primary preferred prey (lake herring), and thiamine deficiency from consumption of the non-native alewife. Natural reproduction has thus far been successful in Lake Superior alone, while in Lake Huron and Lake Michigan fisheries rely on stocked fish. Because of their slow growth rates and high age at maturity, lake trout rehabilitation is a slow process that will take time to rebuild sufficient spawning stocks to drive self-sustaining populations.

Commercial fisheries for lake trout are restricted to tribal fisheries in 1836 Treaty-ceded waters in Lake Michigan and Lake Huron, and to 1836 and 1842 Treaty-ceded waters and some commercial state-licensed fishing in Wisconsin waters of Lake Superior. Commercial lake trout fisheries exist in Canadian waters of the Great Lakes, but are minor compared to fisheries farther north in Saskatchewan and the Northwest Territories.

Scope of the analysis and the ensuing recommendation:
This analysis focuses on lake trout caught in commercial tribal fisheries within Lake Michigan, Lake Huron, and Lake Superior. These represent 54%, 28%, and 18%, of the US annual commercial catch of lake trout, respectively (Fig. 4).

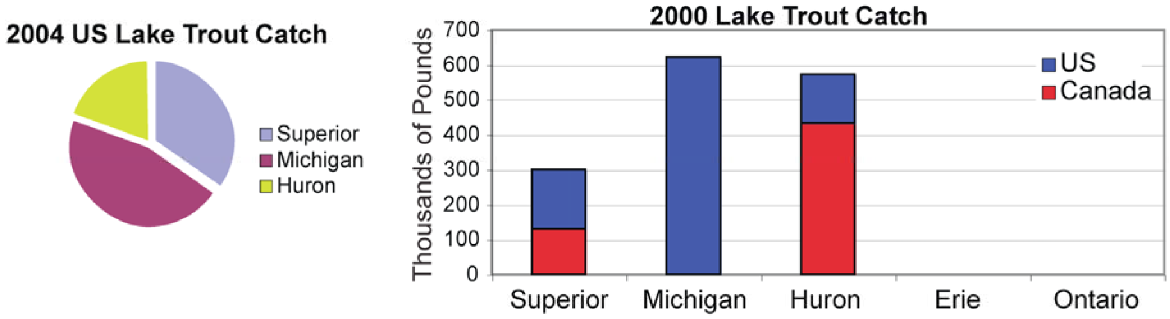

Figure 4. Distribution of lake trout catches, by lake, in US and Canadian waters (Figures adapted from Baldwin et al. 2002 and Kinnunen 2003).

Although there are some Canadian catches of lake trout, they are not a primary species for export and therefore are not considered in this report. However, management agencies that regulate catches in regions adjacent to Canadian commercial fisheries take their exploitation rates into account when assessing stock status (Woldt et al. 2006).

Availability of Science

Because of its former place as the dominant predator in the Great Lakes and the dramatic nature of its decline, the lake trout has been very well studied by researchers and management agencies alike. There exists a large body of literature on the causes of the decline and subsequent difficulties in restoration efforts.

Market Availability

Common and market names:
Lake trout, *Salvelinus namaycush*, is also known as Great Lakes trout, laker, namaycush, togue, grey trout, mountain trout, mackinaw, lake char/charr, touladi, and salmon trout.

Seasonal availability:
Lake trout is available year-round.

Product forms:
Lake trout may be marketed fresh, frozen, or smoked. Though "smoked lake trout" is typically siscowet, or oily lake trout, a substantial portion of the larger lean lake trout sold is also smoked. Smaller fish are primarily marketed fresh or frozen, as whole dressed fish or fillets.

Import and export sources and statistics:
Commercial fisheries for lake trout in the Great Lakes are generally small and restricted for the most part to Lake Superior, Lake Huron, and Lake Michigan. Although some lake trout are caught in Canadian waters of Lake Superior, this species is not a primary freshwater export for Canada. Most lake trout catches in Canada occur in the northern regions of Saskatchewan and the Northwest Territories. Canadian commercial stocks will therefore only be considered here insomuch as they affect the health and sustainability of lake trout from adjacent US waters.

2-III. Analysis of Seafood Watch® Sustainability Criteria for Wild-caught Species

Criterion 1: Inherent Vulnerability to Fishing Pressure

Lake trout (*Salvelinus namaycush*) is a widely distributed coldwater species that was once the keystone predator in all of the Great Lakes. The fish prefer water temperatures around 50ºF and are intolerant of salt and pollution. They can be found in surface waters during the spring and fall but move deeper in the water column in the summer when surface waters begin to warm. Three distinct phenotypes of lake trout were once distributed at various depths in the Great Lakes basin: lean lake trout, found primarily in inshore waters less than 70 m deep; humper trout, found on shallow offshore reefs less than 50 m deep surrounded by water deeper than 100 m; and siscowet trout, found offshore in waters 50-150 m deep (Hansen 1996). Lake trout are a non-schooling species with a range extending from Northern Canada and Alaska south into the Great Lakes region and in the US east to New England (Fig. 5).

Figure 5. Native lake trout range in the US and Canada.

Beyond this native range, lake trout has been introduced to many additional watersheds in the US (Froese and Pauly 2007). Lake trout is a moderately slow-growing and long-lived species, living well beyond 20 years (its maximum age has been listed as 50 years) and attaining a maximum size of 17 to 27 inches; the largest lake trout on record is listed at 49 inches (Froese and Pauly 2007). Lake trout typically take 6 to 8 years to reach maturity. In the Great Lakes, average age at first maturity is as early as 2 years (Lake Huron) and as late as 6 years (Lake Superior). Females mature later than males, with 50% of females reaching maturity at anywhere from 6 to 10 years of age (Woldt et al. 2006). This delayed maturation schedule makes lake trout somewhat vulnerable to depletion of spawning stocks by overfishing or other sources of mortality. Lake trout have a population doubling time of 5-15 years, yielding an intrinsic rate of increase between 0.05 and 0.15 yr^{-1} and a moderate von Bertalanffy growth coefficient of 0.05 to 0.12 (Froese and Pauly 2007).

Once mature, lake trout congregate to spawn, and may home to their previous hatchery grounds. While the extent of and mechanism for this homing instinct is still not well understood, it is thought that they use chemical cues that are imprinted shortly after hatching to find spawning sites (Bronte et al. 2002). Females can release anywhere from 400 to 5,000 eggs, depending on size and condition. Spawning occurs at night during late autumn, with multiple males and females broadcasting their eggs over hard substrate such as cobbles or boulders. Nests are not guarded but hatching success is high (70-80 %). Survival from eggs to juveniles is much smaller, however, with estimated rates of anywhere from 0.1% to 10% (Bronte et al. 2002); this translates to a reproductive potential of tens of individuals per female per year. Spawning grounds can range from offshore reefs to near-shore shoals to tributaries, depending on the lake trout strain (Fig. 6).

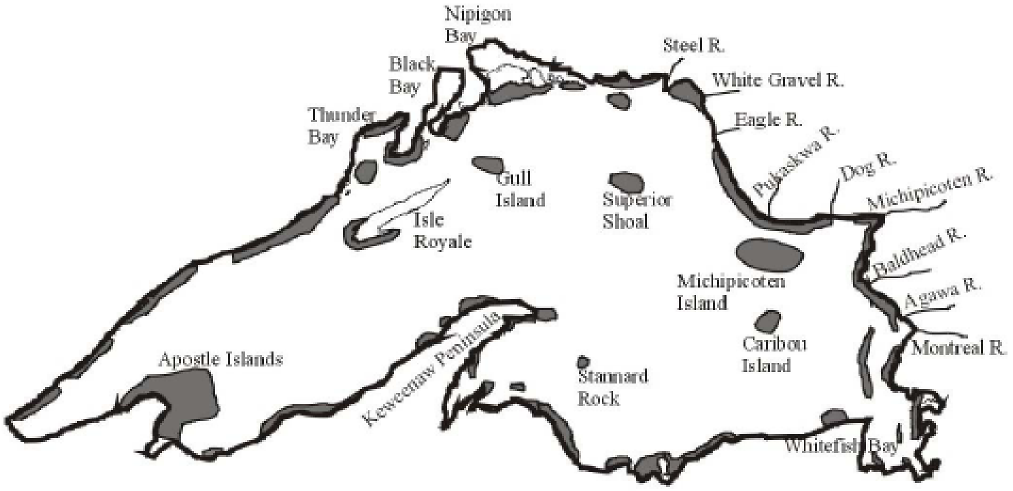

Figure 6. Known historic lake trout spawning sites in Lake Superior (Figure from Horns et al. 2003).

Lake trout eggs and fry are vulnerable to predation from a number of species including sculpins, crayfish, and non-indigenous species such as round goby and alewife (Eshenroder et al. 1999). Young lake trout consume plankton, insects, and aquatic invertebrates, while adults are primarily piscivorous. Historic diets were dominated by lake herring, ciscoes, and whitefish, while more recent diets have been dominated by non-indigenous rainbow smelt and alewife (Hansen 1996; Froese and Pauly 2007).

Although degraded habitat has been a major obstacle to the health of Great Lakes fisheries it is of less importance to lake trout, as some strains utilize offshore spawning reefs (e.g., Caribou Island, Superior Shoal, Gull Island, Fig. 6) while habitat degradation tends to be concentrated in tributaries and embayments, closer to population centers. In general there is consensus that availability of suitable habitat is not a major impediment to lake trout stocks (Eshenroder et al. 1999). There are a limited number of stocks in eastern Ontario waters of Lake Superior that have been negatively impacted by hydroelectric dams and pulp mill effluent, but these are not part of the commercially fished stock under consideration in this report (Horns et al. 2003).

A much greater impediment to lake trout rehabilitation in the Great Lakes has been interaction with invasive species. In particular, predation by sea lamprey has done at least as much as overfishing to drive lake trout stocks into decline and prevent their rehabilitation. The sea lamprey is a predatory eel native to the Atlantic Ocean that first arrived in the Great Lakes via Lake Ontario as a result of the opening of the Erie Canal in 1819. In 1913 the deepening of the Welland Canal allowed access to Lake Erie, from which the lamprey was able to spread throughout the Great Lakes. By 1946 they had reached extremely high levels and speeded the collapse of lake trout stocks already under pressure from excessive fishing (Eshenroder et al. 1999; Eshenroder and Amatangelo 2002). In many Great Lakes areas, sea lamprey has been or continues to be the greatest source of adult lake trout mortality, exceeding both commercial and recreational catch (Woldt et al. 2006).

The presence of two non-indigenous prey species also affects the health of lake trout stocks: the alewife (*Alosa pseudoharengus*) and the rainbow smelt (*Osmerus mordax*). Alewife arrived in the Great Lakes in 1913, like the sea lamprey, via the Welland Canal. Rainbow smelt was intentionally introduced to inland Michigan waters as food for other fish and escaped into Lake Michigan, from where it expanded throughout the Great Lakes. Originally regarded as nuisance fish, both alewife and smelt are now integral parts of the forage base of the Great Lakes, in many cases supporting important stocked salmonid fisheries. However, their presence has resulted in an imbalance in the naturally evolved predator-prey community. In lakes where lake herring (*Coregonus artedii*) once dominated the diets of lake trout, rainbow smelt are now the primary prey fish. In these areas, the inshore-deepwater link once maintained by herring has been broken and the behavior of lake trout may have been affected, with populations remaining near-shore for longer periods (Hansen 1996; Horns et al. 2003). In addition, alewife in particular has been linked to early mortality syndrome (EMS), wherein eggs of fish whose diets contain a large proportion of alewife are deficient in thiamine, leading to greatly increased mortality (Eshenroder et al. 1999). Finally, the populations of these prey species have undergone large-scale variability in the past 50 years, raising questions about the sustainability of these invasive fish as a forage base for growing populations of Great Lakes predators.

Table 1. Life history characteristics of lake trout.

Intrinsic Rate of Increase (r)	Age at Maturity	Growth Rate	Max Age	Max Size	Fecundity	Species Range	Special Behaviors	Sources
0.05-0.15	5-8 years	K=0.05-0.12	25-50 years	30 in.	500-5,000	Widely distributed (US and Canada)	Spawning site fidelity, sea lamprey predation	Hansen 1996; Eshenroder and Amatangelo 2002; Horns et al. 2003; Woldt et al. 2006; Froese and Pauly 2007

Synthesis

Lake trout is a long-lived, top predator species with a moderate rate of population increase (r=0.05-0.15), a moderate age at first maturity (typically mature by age 6), a mid-valued von Bertalanffy growth coefficient (K=0.05-0.12), and a high maximum age (30-50 years). The species is broadly distributed throughout the US and Canada and has moderate fecundity. In general, lake trout do not exhibit behaviors that make them especially vulnerable to fishing pressure, aside from congregation during spawning season to return to native spawning grounds (which has minimal effects as fishing is often closed during their spawning season). Lake trout habitats and spawning grounds are relatively undisturbed in the Great Lakes, particularly in comparison to some near-shore species more dependent on tributaries and embayments. However, the presence of several non-native species including the sea lamprey, alewife, and rainbow smelt has altered the biotic community of which lake trout are a part, to such an extent that their rehabilitation is threatened. Given the balance of these population characteristics, lake trout are considered to be moderately vulnerable to fishing pressure.

Inherent Vulnerability Rank:

Resilient 🟩

Moderately Vulnerable 🟨

Highly Vulnerable 🟥

Criterion 2: Status of Wild Stocks

Current commercial fishing for lake trout is limited primarily to tribal fisheries operating in 1836 Treaty-ceded waters of Lake Michigan, Lake Superior, and Lake Huron and in 1842 Treaty-ceded waters of Lake Superior. In 2005, 54% of the nearly 400,000 lbs of lake trout caught in the Great Lakes came from tribe-licensed fisheries in Lake Michigan, 28% from tribe-licensed fisheries in Lake Huron, and 18% from Lake Superior (of which 11% is tribe-licensed fisheries in Michigan waters, 6% state-licensed fisheries from Wisconsin waters, and 1% from state-licensed fisheries from Michigan waters). All but the Lake Superior catches consisted of stocked, not wild, fish.

Lake Michigan Stocks

The predator community in Lake Michigan prior to the 20th century had been dominated by lake trout. By the 1950s, however, overfishing and sea lamprey predation had decimated lake trout stocks. The current predator community is dominated by stocked fish including a number of introduced salmonines (e.g., Chinook salmon, Coho salmon, and rainbow trout, Fig. 7). These fish were introduced both to control exploding populations of the invasive alewife and to enhance recreational fishing. The target range of salmonine catch (shaded region in Fig.7, below) assumes that a large forage base is present, as was the case when alewife and rainbow smelt were very abundant (Holey and Trudeau 2005). However, recent declines in the populations of both of these invasive forage fish indicate that such a high salmonid catch range may not be realistic for Lake Michigan's current carrying capacity.

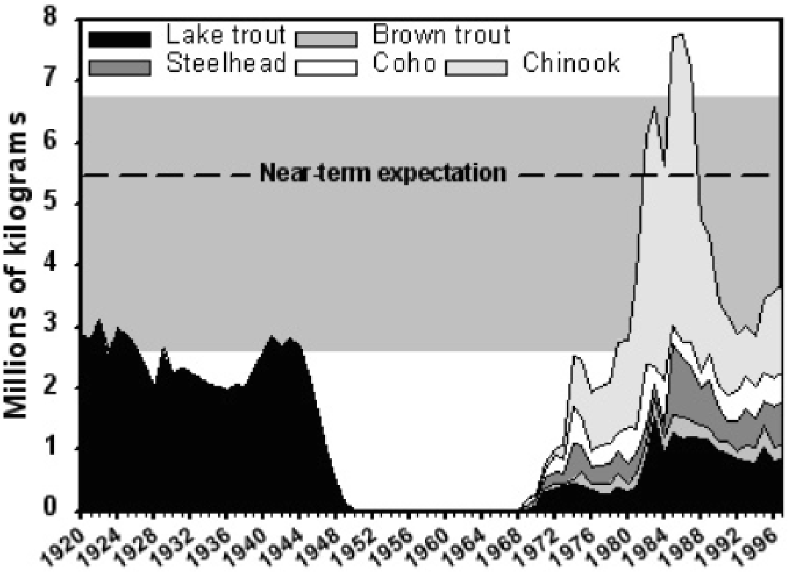

Figure 7. Lake Michigan salmonine catch, 1920-1996 (Figure from Holey and Trudeau 2005). Shaded area shows target catch range; dashed line is near-term expectation for catch.

Intensive stocking has brought total salmonine catch (primarily recreational) to meet or exceed historic catches; however, the instability of the Chinook catch, including the steep decline that followed a reduction in alewife abundance in the 1980s, illustrates how the stocked community has been at unsustainable levels. While some introduced salmonids are now naturalized, there appears to be little to no natural recruitment of lake trout in Lake Michigan. By 1996, lake trout composed only about 10% of the total salmonine fishery in Lake Michigan, and about one-half its historic yield of 4.4 million pounds (Holey and Trudeau 2005). Because of this, only limited recreational catches of lake trout are permitted, a ban on fishing within refuge areas is strictly enforced, and commercial fishing occurs only in tribal fisheries within 1836 Treaty-ceded waters, which comprise management units MM1, MM2, and MM3 (Fig. 8). In 2005, the lake trout catch from this fishery was just over 200,000 pounds (USGS 2007b), only 20% of the historically low 1996 value.

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are needed to see this picture.

Figure 8. Lake Michigan lake trout management units. Tribal fisheries operate within Deferred Zones (Figure from Dawson et al. 1997).

The combined management unit MM123 contains most of Lake Michigan’s historically important lake trout spawning reefs within its 5,000-square-mile area. Of this total area, 900 square miles have been set aside for lake trout refuge, within which retention of any lake trout is strictly prohibited. As there has been no documented recruitment of lake trout anywhere in Lake Michigan, the fisheries that operate outside this area are supported entirely by stocking, and are indirect (non-target) fisheries. The commercial tribal fisheries primarily target whitefish, but can keep and market incidental catches of lake trout. Although catches in MM123 have been within the total allowable catch (TAC) in recent years, an increase in sea lamprey mortality has led to total mortality exceeding the goal of 40% (Fig. 9).

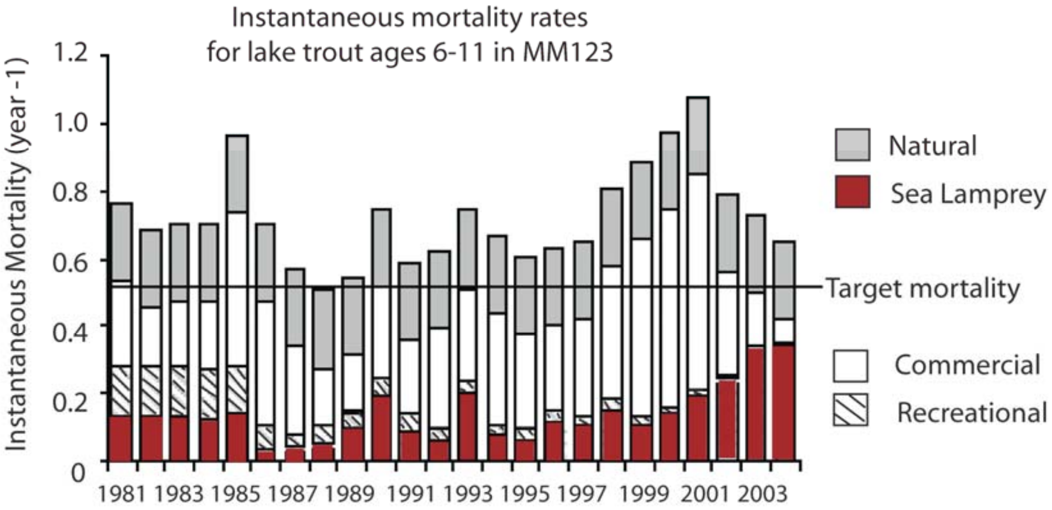

Figure 9. Lake trout mortality in management unit MM123 from fishery (commercial, recreational) sources, natural, and via sea lamprey predation (Figure from Woldt et al. 2006).

Lake trout mortality rates greater than the target maximum of 40% indicate lake trout are being overexploited. In the near term TACs should be reduced such that fishing mortality produces a sustainable yield. Better lamprey controls should also be put into place to prevent overexploitation of lake trout, particularly as lamprey predation mortality has been increasing steeply over the last decade and is now approaching the target maximum mortality independently of fishing pressure. Although total biomass increased from 2001 to 2004 (Woldt et al. 2006), and some natural reproduction (only up to sac fry stage) has been observed in deep offshore reef areas (Bronte et al. 2005), lake trout spawning stock biomass remains well below what would be necessary for a self-sustaining population (Fig. 10).

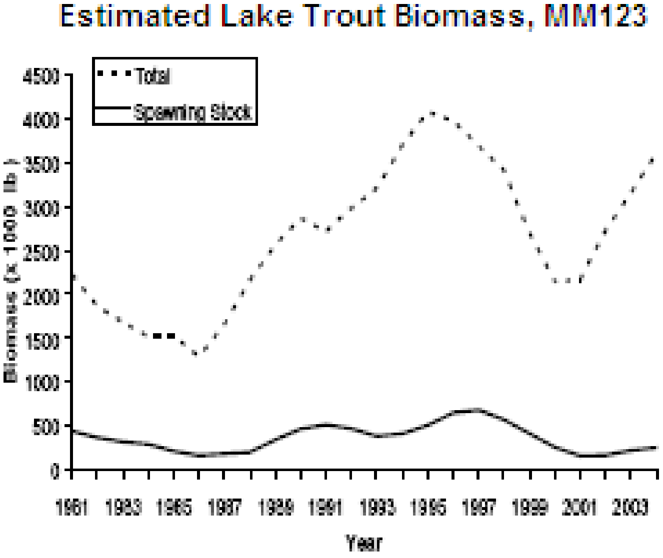

Figure 10. Total and spawning stock biomass of lake trout in management unit MM123 (Figure from Woldt et al. 2006).

The major issue for native lake trout populations remains recruitment. Though offshore reefs have the potential to produce substantial numbers of wild lake trout, with large numbers of spawning trout, extensive suitable spawning habitat, and protected offshore locations, lake trout eggs and fry are not present in sufficient numbers or in sufficient health to overcome current impediments to recruitment. These barriers include predation by forage fish (particularly invasive alewife and round goby) and Early Mortality Syndrome, a thiamine deficiency disorder that results in eggs and fry when alewife constitutes too high a fraction of the adult spawner diet (Bronte et al. 2005).

Lake Huron Stocks

In Lake Huron, the pre-1940 lake trout catch averaged from around 4 to 5.9 million pounds. The same combination of sea lamprey predation and overfishing that drove lake trout decline in Lake Michigan eliminated commercial catches in Lake Huron by 1946 in the main basin and by 1960 in Georgian Bay (Ebener 1998). However, lake trout stocking and the use of chemical lampricides to control sea lamprey predation have been more successful in Lake Huron than in Lake Michigan. Some natural reproduction was occurring by 1980, producing measurable year-classes in Thunder Bay, South Bay, and Manitoulin Island; however, this reproduction is currently insufficient to support a self-sustaining population. As in Lake Michigan, there is extensive stocking of predator fish that primarily support a recreational fishery, and only a portion of the stocked biomass is lake trout (Fig. 11).

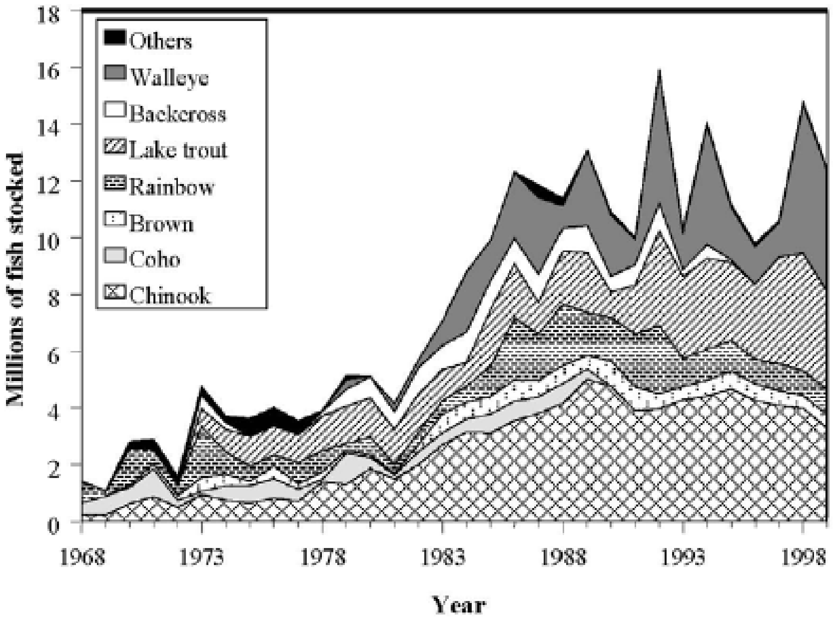

Figure 11. Stocking of predator fish in Lake Huron, 1968-1998 (Figure from Ebener 1999).

Commercial fishing for lake trout in Lake Huron occurs exclusively in MH1 (Fig. 12), supported by hatchery inputs, although there has been some recent evidence of limited natural reproduction in this management unit. The Michigan portion of MH1 lies entirely within Treaty-ceded waters, and a tribal fishery primarily targeting whitefish is allowed to keep and market some lake trout bycatch. MH1 also includes the majority of important historic lake trout spawning grounds in Lake Huron (primarily offshore reefs and shoals). The Drummond Island Refuge, within which no lake trout may be kept, is also partially located within MH1 (Fig. 12).

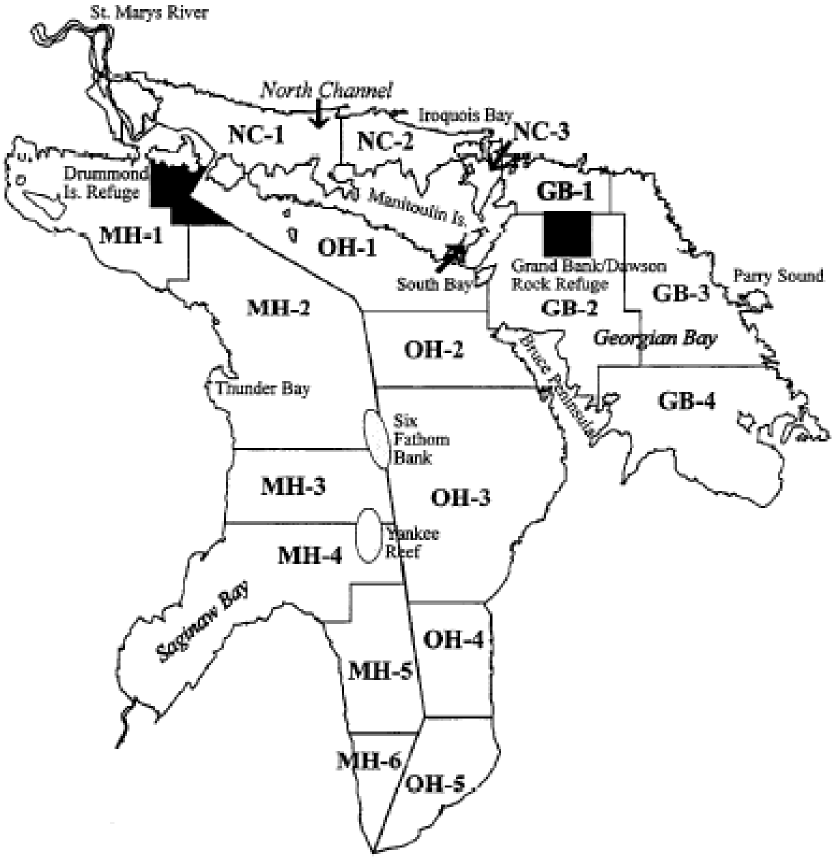

Figure 12. Map of Lake Huron showing lake trout management areas (Figure from Ebener 1998).

No state-licensed fisheries are permitted within MH1, but there is a substantial Canadian commercial fishery in an adjacent management unit that may have an effect on stock abundance. From 1997-2001, the commercial yield from the tribal fishery averaged 123,000 lbs. In 2000, a Consent Decree was implemented, negotiating allocation and management of fishery stocks among state and tribal interests. The Decree called for a gradual reduction in gillnet effort within tribal fisheries, and resulted in effort dropping in 2001 with a corresponding 34,000 lb drop in lake trout catch. From 2001-2005 the catch averaged just over 100,000 lbs.

By 2004, treatment of the St. Mary's river with lampricide succeeded in decreasing lamprey-associated lake trout mortality by 76% relative to mid-1990s levels. This has combined with low mortalities from both recreational and commercial fishing efforts to increase spawning stock biomass (SBB), which was very low in the 1990s. A historic trend in very high mortality rates, first from commercial fishing between 1977-1990 and then primarily due to sea lamprey predation through the 1990s, had truncated the age structure below the age of maturity for most trout (Woldt et al. 2006). Following sea lamprey treatment and catch limits, SSB has been steadily increasing (Fig. 13). Additionally, both tribal and state catches have been well below the recommended limits (see Criterion 5: Management Effectiveness), and target mortality has stayed within the 40-45% limit.

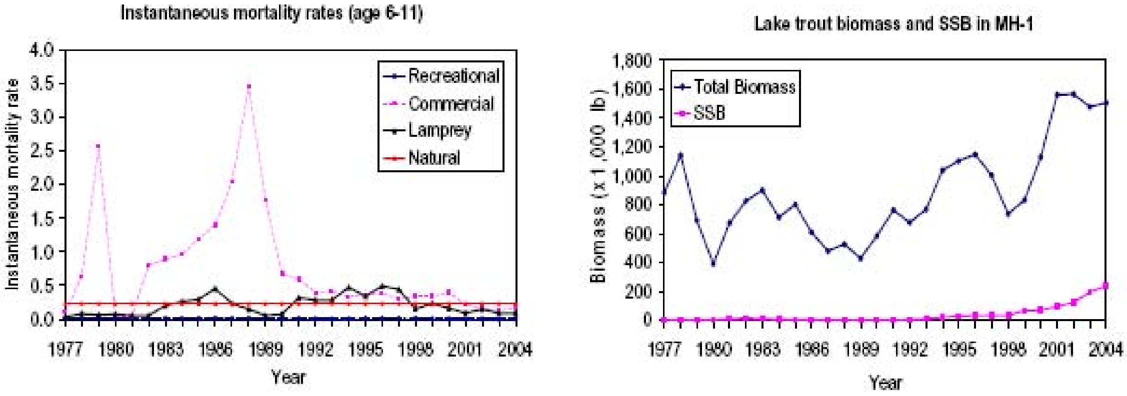

Figure 13. Mortality rates, total biomass, and spawning stock biomass for lake trout in MH1 (Figures from Woldt et al. 2006).

Lake Superior Stocks

Commercial lake trout catches from US waters of Lake Superior come from tribe-licensed Michigan and Wisconsin fisheries and state-licensed Wisconsin fisheries (Fig. 14). There are no state-licensed Michigan tribal fisheries as Michigan fisheries in Lake Superior are geared primarily towards recreational catches.

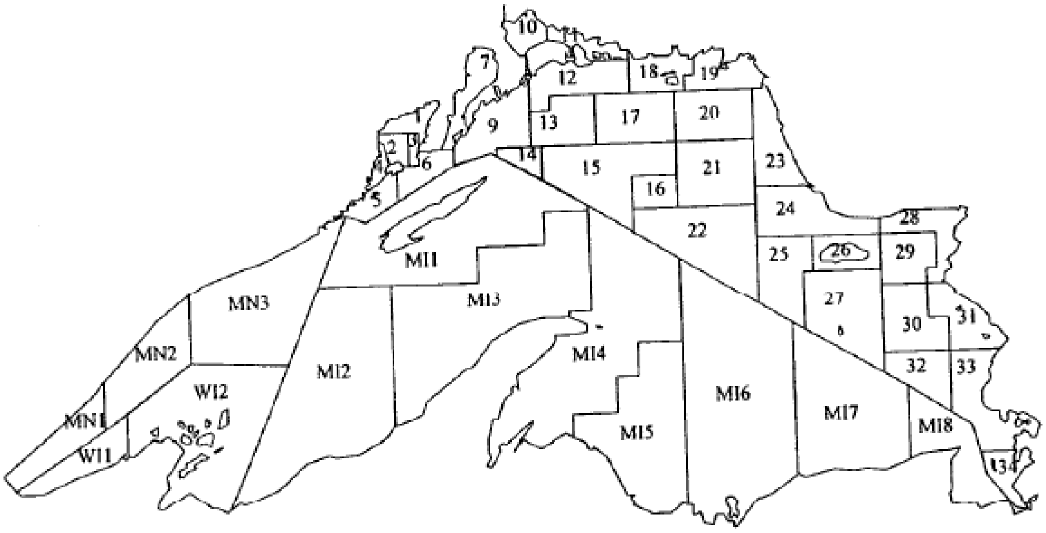

Figure 14: Lake Superior lake trout management zones.

State-licensed Wisconsin Stocks (WI1 and WI2)

A relatively small catch of lake trout in Lake Superior (6% of total) comes from state-licensed fisheries in Wisconsin waters, which include WI1 and WI2. Stocking has been successful in creating naturally reproducing populations in WI2 and was phased out in 1994 (Fig. 15).

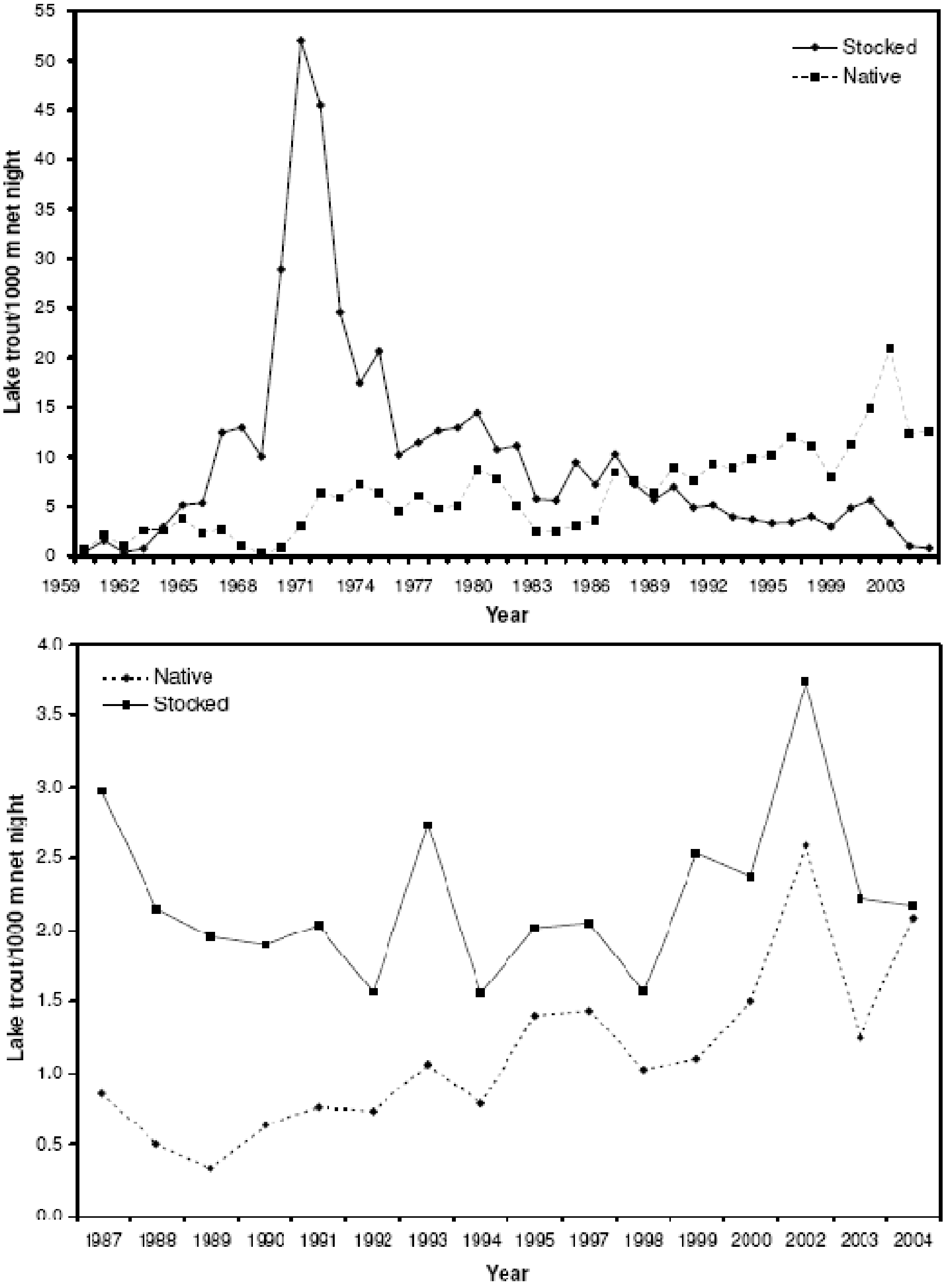

Figure 15. Catch per unit effort of stocked and native lake trout from Wisconsin waters of Lake Superior. Note stocking was discontinued in WI2 in 1994 (Figures from WIDNR 2005b).

Tribe-Licensed Michigan Stocks (MI5, MI6, MI7)

The tribal fishery in Michigan waters accounts for most of the catch of lake trout in Lake Superior, and 11% of the total Great Lakes lake trout catch. In MI5, where the fishery is concentrated around Marquette Bay and Big Bay, the commercial yield averaged 27,800 lbs from 1999-2003, with a peak of 52,700 lbs in 2000, prior to the implementation of the Consent Decree. The stocks in MI5 are in recovery, with normal age distributions, and spawning stock biomass is high compared to 1970s lows (Fig. 16). Sea lamprey predation is the dominant source of mortality in MI5, followed by recreational fishing and finally commercial fishing. Total rates are below the 40-45% target that should yield a sustainable spawning population (Woldt et al. 2006). The 2005 recommended allowable catch for lake trout in MI5 was 178,000 lbs for the tribal fishery and 9,400 lbs for the state fishery; this is the largest allowable catch out of these three management zones (MI5, MI6, MI7).

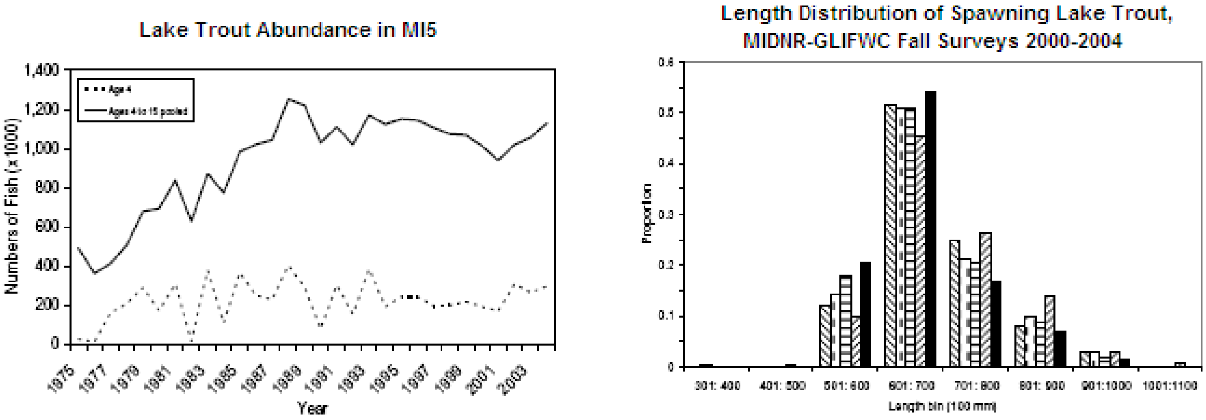

Figure 16. Lake trout abundance and spawner length distribution in MI5 (Figures from Woldt et al. 2006).

In contrast to MI5, the total biomass in management unit MI6 has declined since the mid-1990s, from 1.9 million lbs in 1995 to only 743,000 lbs in 2004 (Fig. 17). Sea lamprey predation remains the highest source of mortality for lake trout in this management unit, and commercial and recreational catches, which are allocated evenly, have remained below target levels. The 2005 recommended catch limit in MI6 is 71,800 lbs, 50% for recreational and 50% for tribal commercial fisheries.

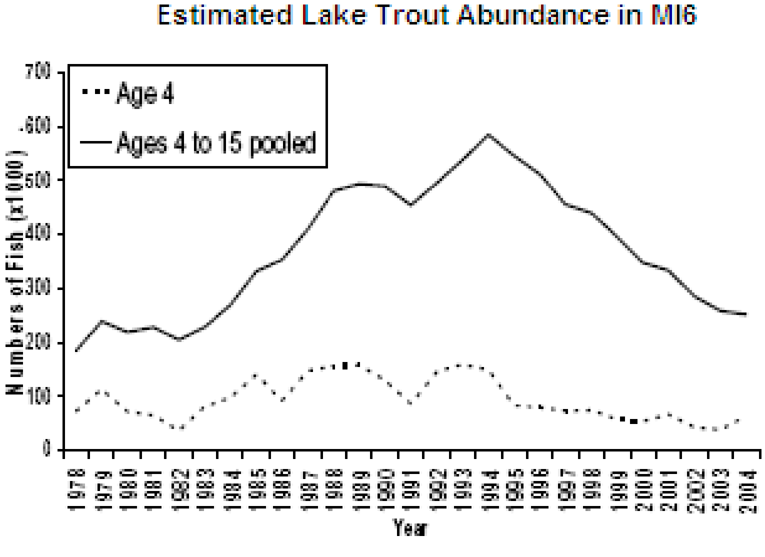

Figure 17. Lake trout abundance in MI6 (Figure from Woldt et al. 2006).

In MI7, catches are small compared to historic levels, averaging 26,000 lbs annually in the past three years compared to a peak of 104,400 lbs in 1990 (which likely exceeded sustainable yield). However, fishing-related mortality remains within target levels and abundance has stabilized (Fig. 18).

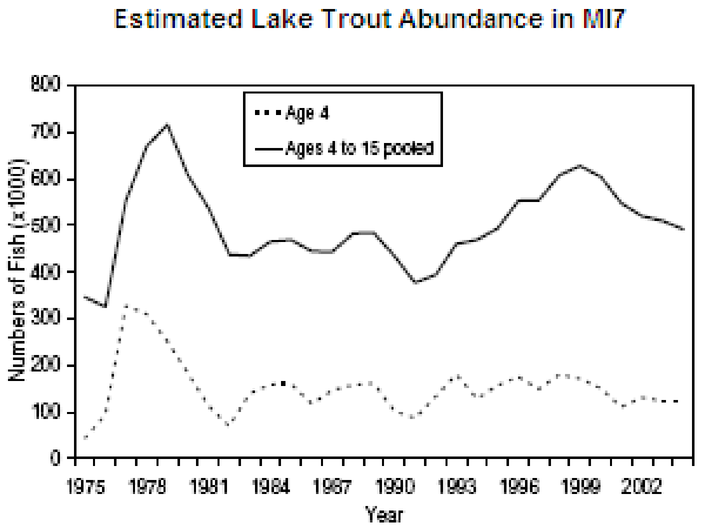

Figure 18. Lake trout abundance in MI7.

Table 2. Stock status of wild lake trout.

Status	B/B_{MSY}	Occurrence of Overfishing	F/F_{MSY}	Abundance Trends/ CPUE	Age/Size/ Sex Distribution	Degree of Uncertainty in Stock Status	Sources	SFW Rank
Not listed by IUCN	**Lake Michigan:** <50% fish and stocked to maintain appropriate biomass.	Total mortality exceeds target levels.	Fishing mortality, when combined with sea lamprey predation, is above target levels.	Trend is down.	N/A (stocked fish)	Low	Bronte et al. 2003b; Holey and Trudeau 2005	**Poor**
	Lake Huron: Fish are stocked to maintain appropriate biomass.	MH1 stock is not overfished.	Fishing mortality is below target levels for sustainable yield.	Long-term: down. Short-term: up.	N/A (stocked fish)	Low	Woldt et al. 2006	**Poor**
	Lake Superior: Lake trout biomass in MI5-7 are high.	Stocks are not overfished.	Fishing mortality in MI5 and MI7 are not above target but sea lamprey predation is high in MI6.	Long-term trend down. Short-term trend variable.	Skewed to younger fish.	Some uncertainty in MI7 stocks (no recreational creel survey data until 2001).	Woldt et al. 2006	**Moderate**

Synthesis

Lake trout are commercially fished almost exclusively from Treaty-ceded waters of Lake Michigan, Lake Huron, and Lake Superior. In all but Lake Superior the fishery is maintained by stocking, as self-sustaining and naturally reproducing populations of lake trout have not been reestablished since the major stock decline that occurred in the middle of the 20th century. This indicates that in Lake Michigan and Lake Huron wild stocks of lake trout are absent or nearly so. If the current small populations of spawning lake trout do not increase, or if recruitment to the adult populations does not improve, wild stocks in these lakes may become of critical conservation concern.

Stock assessment and modeling has determined that total mortality rates below 40-45% guarantee a lake trout population is growing (provides for sustainable yield) and catch allowances are set based on this maximum target rate. However, increasing sea lamprey abundance and associated lake trout mortality can and has caused total mortality in some areas to exceed the target limit, leading to a decline in the stock. Although in these cases commercial and recreational yields are still within the allocation, overfishing is still occurring as the B/B_{MSY} is reduced by sea lamprey predation.

Very little recovery of lake trout stocks has occurred since the dramatic declines observed in the 1950s and 1960s, and lack of natural spawning and recruitment prevents lake trout from attaining sustainable population density. In Lake Michigan and Lake Huron, where existing fisheries are supported entirely by stocked fish, wild lake trout populations are absent or nearly so. A small remnant population has persisted in Lake Huron, but stocks are still considered in poor condition. In Lake Michigan, where no successful recruitment occurs, lake trout stocks are considered to be a critical conservation concern. In Lake Superior, the only lake with substantial natural reproduction that has resulted in self-sustaining populations, wild lake trout stocks are a moderate conservation concern; continued monitoring and protection of these stocks will be critical to the rehabilitation of this once dominant Great Lakes predator.

Status of Wild Stocks Rank:

Lake Superior:

Healthy 🟩 **Moderate/Rebuilding 🟨** Poor 🟥 Critical ⬛

Lake Huron:

Healthy 🟩 Moderate/Rebuilding 🟨 **Poor 🟥** Critical ⬛

Lake Michigan:

Healthy 🟩 Moderate/Rebuilding 🟨 Poor 🟥 **Critical ⬛**

Criterion 3: Nature and Extent of Bycatch

Seafood Watch® defines sustainable wild-caught seafood as marine life captured using fishing techniques that successfully minimize the catch of unwanted and/or unmarketable species (i.e., bycatch). Bycatch is defined as species that are caught but subsequently discarded (injured or dead) for any reason. Bycatch does not include incidental catch (non-targeted catch) if it is utilized, accounted for, and managed in some way.

The majority of lake trout caught in Lake Michigan, Lake Huron, and Lake Superior is caught incidentally in large-mesh gillnet lake whitefish fisheries (Woldt et al. 2006). The overall incidental catch in the lake whitefish and lake trout fisheries can therefore be seen as the shared bycatch impact of these fisheries. Gillnets are more highly selective for lake trout than for whitefish, as the trout's toothy mouth is more easily entangled in mesh, and also account for much higher mortality than other gear types. In Lake Superior, gillnets account for only 35% of the whitefish catch but 96% of mortality—of the total incidental whitefish catch, 96% of those that die are in gillnets—whereas trap nets catch 60% of the whitefish but kill only 3%. Gillnets are still often preferred, particularly in smaller fisheries, because of simplicity of use and the ability to deploy them from smaller boats, therefore lowering overall costs (Johnson et al. 2004b).

A study of tribal lake whitefish fisheries has shown that incidental bycatch are primarily juvenile whitefish and lake trout. The lake trout comprise 82% of the incidental catch, which supports the lake trout fishery. In addition, the incidental catch includes, in descending order, longnose sucker, walleye, burbot, round whitefish, and brown trout. Combined, these species account for only about 10% of the catch and include no species of special concern (Johnson et al. 2004a).

In the mid-1960s, as lake trout restoration efforts were underway, inspections of gillnets in Lake Michigan revealed more than 70,000 lake trout had been taken as incidental bycatch to the whitefish fishery. This led to a ban on gillnets in the Great Lakes in 1977. Tribal fisheries are exempt from this ban; however, the 2000 Consent Decree has instituted much tighter regulation on gillnet use and an overall dramatic reduction in effort. Trap net use is thus increasing throughout native fisheries. Trap nets used in the whitefish fishery have much lower mortality rates than gillnets, and therefore lower impacts on lake trout (see discussion on Great Lakes fishery gear in Chapter 1).

Synthesis

Although gillnets can have high bycatch impacts due to their high rates of mortality, their limited use in these fisheries and their targeting for lake whitefish reduces their impact considerably. The primary incidental catch of the whitefish fishery, the lake trout, is conservatively managed and incidental catches coming from areas where gillnets are allowed are utilized and managed and therefore not considered bycatch according to Seafood Watch® criteria. In addition, other bycatch is low (<10%) and includes no species of special concern. Finally, the use of gillnets in tribal fisheries is slowly being phased out in favor of trap nets, which have very low impacts and mortality. Therefore, the amount of discarded bycatch in this fishery is being successfully managed, and the bycatch impact is considered of low conservation concern.

Nature of Bycatch Rank:

Low 🟩 Moderate 🟨 High 🟥 Critical ⬛

Criterion 4: Effects of Fishing Practices on Habitats and Ecosystems

Habitat Effects

Shallow water reef areas with complex structures that are more likely to be damaged by fishing gear are typically found in lake trout spawning refuge areas, which are protected from fishing. However, there has been no systematic study of the gear impacts of bottom-set gillnets and trap nets in the Great Lakes. Until such a study shows that impacts are minimal, the habitat impacts of these nets are considered of moderate conservation concern due to their bottom placement and possible impacts when hauling or setting.

Ecosystem Effects

Lake trout are a keystone predator and have the ability to structure their community through a cultivation/depensation effect: as their abundance increases, they exert additional predatory pressure on other fish, and thereby release their own juveniles from predation or competition, allowing their population to grow. Excess withdrawal of such predators could cause forage fish populations to explode and thereby hinder their own recovery (Eshenroder and Amatangelo 2002). This was evident with the decline of predators in the Great Lakes during the 1950s and 1960s, when populations of forage species, particularly invasive species such as alewife and rainbow smelt, increased dramatically. In the current system, however, there are a number of introduced predators that can fulfill the lake trout's predatory role (e.g., Chinook and coho salmon), controlling forage populations, which can provide some buffering in the system against the removal of lake trout.

Of greater concern is the effect of intensive lake trout stocking on the ecosystem. Lake trout have been stocked in the Great Lakes for most of the fishery's history—in Canada, large-scale stocking efforts have been documented as early as the 1870s—and early stocking efforts were meant to supplement fishing. They also served as unsuccessful attempts to stop or reverse wild stock depletion by overfishing. In recent years there has been recognition of some of the undesirable effects of fish stocking, particularly when fish are stocked in areas where recovery of wild populations is ongoing. Negative impacts can include: intraspecific competition between wild and stocked fish for food; stocked fish predation on eggs of native lake trout; increased fishing pressure on native stocks from anglers perceiving high abundance of stocked fish; introduction of disease to wild populations; and reduced genetic diversity (Kerr and Lasenby 2001). Studies of Ontario lakes have shown that removal of stocking programs can lead to increased recruitment of natural populations (Dunlop and Brady 1997). However, remnant or reestablishing wild populations of lake trout in Lake Michigan and Lake Huron may not yet be large enough to recover without additional supplementation from stocking, particularly as the abundance of larval lake trout predators in these lakes remains high.

Synthesis

The catch of lake trout in the tribal fisheries of Lake Michigan, Lake Huron, and Lake Superior has limited ecosystem effects, but the intensive stocking that currently supports the fisheries in Lake Michigan and Lake Huron are of concern as they may serve to suppress, rather than support, the recovery of wild populations. Stocking practices should be reviewed to ensure that negative impacts on wild populations are minimized. Due to stocking of lake trout in Lake Michigan and Lake Huron, the habitat and ecosystem effects of the fishery in these lakes are of moderate conservation concern. Contrary to Lake Michigan and Lake Huron, Lake Superior has a self-sustaining lake trout population, and correspondingly lower quantities of stocked lake trout; therefore, the effects of the Lake Superior lake trout fishery are deemed of low conservation concern, though the habitat effects of gillnets and trap nets are unknown and in need of study.

Effect of Fishing Practices Rank:

Lake Superior:

[✓ **Low** 🟩] Moderate 🟨 Severe 🟥 Critical ⬛

Lake Michigan, Lake Huron:

Low 🟩 [✓ **Moderate** 🟨] Severe 🟥 Critical ⬛

Criterion 5: Effectiveness of the Management Regime

Fisheries in tribal waters of the Great Lakes are managed under the 2000 Consent Decree, a joint agreement negotiated by the Michigan Department of Natural Resources, five tribes of the Chippewa-Ottawa Resource Authority (CORA), and the US Fish and Wildlife Service. The Decree resolves issues of allocation, management, and regulation of fishing in 1836 Treaty-ceded waters of Lake Michigan, Lake Huron, and Lake Superior.

Fishing mortality of lake trout is regulated through fishery controls that include yield and effort limits within the Treaty waters. For this purpose, a Modeling Subcommittee was established to assess lake trout stocks and set limits using current modeling techniques including statistical catch-at-age models and survey data that provide estimates of abundance and mortality as well as size- and length-at-age statistics (Woldt et al. 2006). The subcommittee has determined that the maximum allowable mortality rate for lake trout should be 40-45%. This target applies to wild populations only in Lake Superior. In Lake Michigan and Lake Huron, where natural reproduction is still insufficient, target mortality rates apply to stocked fish.

To formulate, update, and assess the efficacy of these limits, management agencies conduct several annual surveys that measure spawning stock biomass, recreational effort and catch, commercial catch, and age- and size-specific abundance. In some units, surveys have been instituted only recently; creel estimates[6] of recreational catch, for example, have been in place in MI7 only since 2001. Additional survey methods, such as winter season surveys to estimate ice fishing catches in Lake Superior, are currently being proposed.

Lake Michigan

In Lake Michigan, target catch rates that keep total mortality below 40% are being phased in. Since the institution of the 2000 Consent Decree, the commercial mortality rate has decreased

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[6] An angler survey that tracks number of fish caught, fish size, and effort (hours and number of boats/lines).

substantially. Unfortunately, sea lamprey mortality has increased in recent years, keeping the total mortality higher than the recommended limit (Fig. 19). The commercial catches have been below both the current allowable yield and the phase-in yield, yet the total combined mortality works to hinder restoration efforts.

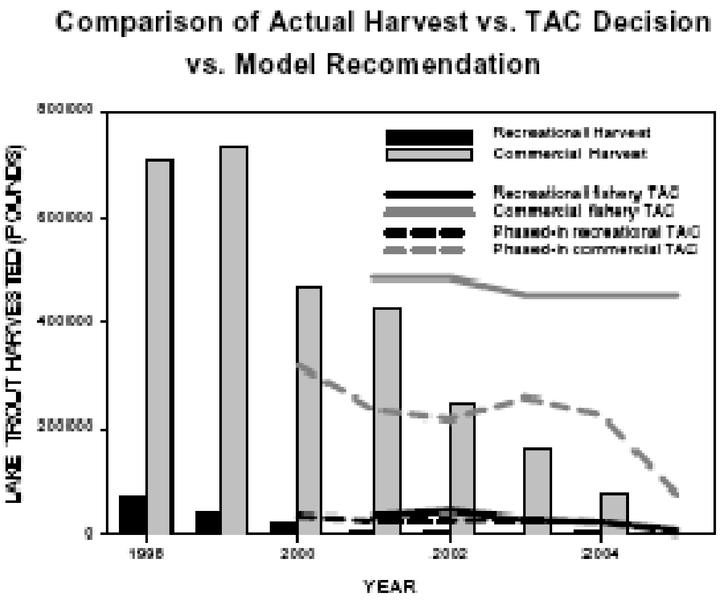

Figure 19. Lake trout catch and total allowable catch (TAC) compared to recommended phased-in limits in MM123 (Figure from Woldt et al. 2006).

Additional methods of sea lamprey control are under consideration in many lake trout management areas to reduce non-fishery mortality. In addition, different stocking practices need to be considered. Stocking is often done near-shore and lake trout return to these areas at maturity to spawn even if they represent unsuitable spawning habitat. Management agencies are now recognizing that due to the lake trout homing behavior, stocking needs to concentrate on high-quality offshore spawning reefs and protected areas.

The salmonine Fish Community Objective for Lake Michigan seeks a yield of 5.9 to 15 million pounds of total salmonine catch, with 20-25% of that being lake trout. In addition, lake trout populations should be self-sustaining (Holey and Trudeau 2005). It is not yet clear, given the current food web structure in Lake Michigan and the instability of the prey community, whether these two objectives might be mutually exclusive.

Lake Huron

In Lake Huron, the reduction in commercial effort following the 2000 Consent Decree has allowed lake trout abundance to increase. Current catches are well below the total allowable catch (Fig. 20). In addition, minimum size limits and slot limits have been used to control recreational catch. Recent treatment of the St. Mary's River with lampricide has resulted in a 76% decrease in the sea lamprey mortality rate in 2004 relative to 1995 levels.

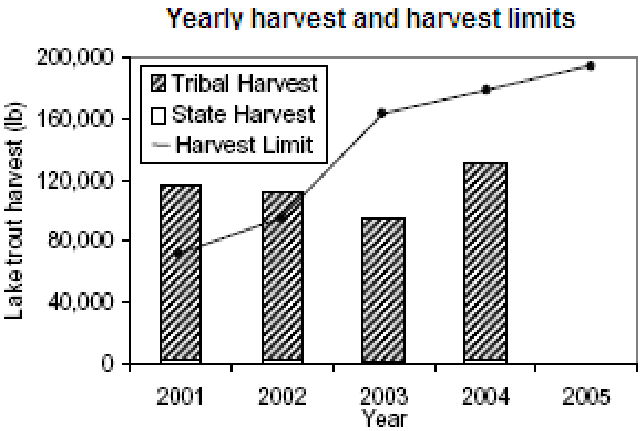

Figure 20. Catch limits and actual commercial catch in Lake Huron (MH1) (Figure from Woldt et al. 2006).

As a result of this concerted management effort, spawning stock biomass, which had been seriously truncated in the 1990s, has been steadily increasing; total lake trout biomass is now well above the 20-year average and there is some recent evidence of natural reproduction (Woldt et al. 2006). Despite these recent positive trends, substantial additional recovery of spawning stock biomass is necessary to develop a self-sustaining lake trout population in Lake Huron. Currently, restoration efforts have maintained a small remnant population in Parry Sound, within Lake Huron’s Georgian Bay (Reid et al. 2001).

Lake Superior

In Lake Superior, standard stock assessment methods are used to assess progress in lake trout restoration. Bag limits and total allowable catch are set based on catch data from all commercial fisheries, some sport fisheries, sea lamprey predation, and stocking effects (Hansen 1996). Current harvests are all well below the total allowable catch, although there is some uncertainty in recreational harvests as creel surveys only recently came into effect (Fig. 21).

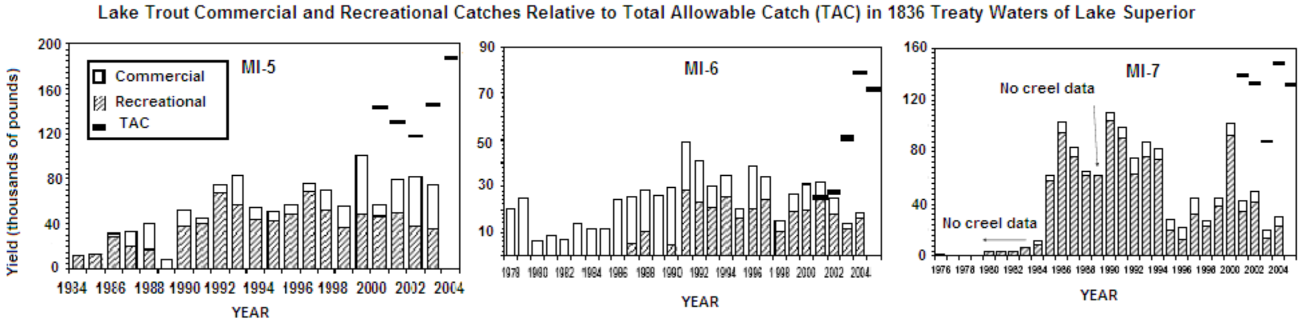

Figure 21. Lake trout catch relative to total allowable catch in 1836 Treaty-ceded waters of Lake Superior (Figure from Woldt et al. 2006).

In the tribe-licensed fisheries, lake trout are collected in spring, summer, and fall assessments, which determine population trends, age, sex, and size-at-age distributions. These are used to develop total allowable catch (TAC) values for 1842 Treaty-ceded waters. Seasons, closed areas, and catch limits regulate the Lake Superior tribal fisheries, and enforcement is provided by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) (Mattes et al. 2007). Although some hatchery planting still occurs in 1842 Treaty-ceded waters, Lake Superior lake trout management has largely moved from reliance on stocking to an emphasis on maintaining wild stocks, stocking only native strains, and maintaining the genetic diversity of lake trout stocks in Lake Superior. The Fish Community Objective for Lake Superior is:

> Achieve and maintain genetically diverse self-sustaining populations of lake trout that are similar to those found in the lake prior to 1940, with lean lake trout being the dominant form in near-shore waters, siscowet lake trout the dominant form in offshore waters, and humper lake trout the dominant form in eastern waters and around Isle Royale. (Horns et al. 2003)

Good progress is being made towards this objective, and Lake Superior is one of the only lakes where natural reproduction of lake trout has been successful. Sea lamprey controls have dramatically reduced the abundance of this invasive predator; however, populations have reached a plateau that is still above the goal of reducing sea lamprey lake trout mortality to <5%, and sea lamprey wounding rates are increasing in many areas of the lake (Horns et al. 2003).

Table 3. Commercial catch management measures for the lake trout fishery.

Management Jurisdictions & Agencies	Total Allowable Landings	Size Limit	Gear Restrictions	Trip Limit	Area Closures	Sources
MIDNR WIDNR CORA USFWS	TAC or effort limits in place.	Strict size limits exist for recreational fisheries (minimum size or slot size).	Total gillnet effort in tribal fisheries restricted by 2000 Consent Decree.	None for commercial fishery.	Fishing in refuge areas strictly prohibited.	Woldt et al. 2006

Synthesis

Management agencies in the Great Lakes have undertaken a concerted restoration effort for lake trout, including intensive stocking, annual stock assessments and surveys, population modeling, sea lamprey control, and restriction of both commercial and recreational fisheries. The effectiveness of these actions varies among lakes and jurisdictions, but in general wild lake trout populations have not recovered from 1960s declines. Success has been most difficult in developing naturally reproducing populations. Little successful recruitment has occurred for wild lake trout in Lake Michigan and Lake Huron, where the fisheries are entirely supported by stocking. Lake Superior has had the greatest rehabilitation of natural reproduction and no longer requires stocking in many management units. In other lakes, new methods for controlling sea lamprey populations will be necessary before rehabilitation of lake trout can succeed. Consequently, lake trout management in Lake Michigan, where wild lake trout have not established self-sustaining populations, has been only moderately effective. In Lake Huron stocks have shown some limited natural reproduction, spawning stock biomass is increasing, and management has kept total mortality below target levels. However, management was implemented only after serious declines and as of today the population still has not recovered from overfishing. The management of lake trout in Lake Huron is improving but considered only moderately effective. The move to support and expand native stock and diversity in Lake

Superior, coupled with successful natural reproduction of wild lake trout, result in its management regime being deemed highly effective.

Effectiveness of Management Rank:

Lake Superior:

Highly Effective 🟩 Moderately Effective 🟨 Ineffective 🟥 Critical ⬛

Lake Michigan, Lake Huron:

Highly Effective 🟩 **Moderately Effective** 🟨 Ineffective 🟥 Critical ⬛

2-IV. Overall Evaluation and Seafood Recommendation

When compared to other Great Lakes fishery targets, lake trout represents a relatively minor commercial catch, with total yield in 2005 from Lake Michigan, Lake Huron, and Lake Superior combined, well under 500,000 pounds. In contrast, total catches of lake whitefish in 2005 was approximately 8.5 million pounds. However, lake trout was once the dominant predator in the Great Lakes and an important part of the fishery, and can serve as an indicator of overall ecosystem health. Its habitat preferences (high dissolved oxygen, cool deep water) and life history characteristics impart moderate resiliency to fishing pressure, but its interactions with invasive species in the Great Lakes have coupled with excessive fishing pressure to drive it to remnant levels throughout the region. Currently, sea lamprey predation and lack of suitable forage prey are hampering its return.

In Lake Michigan, lake trout stocks are in decline with total mortality (including commercial and recreational fishing, sea lamprey predation, and natural mortality) exceeding the 40% goal that would result in a sustainable population. Despite stocking, lamprey controls, fishing restrictions, and the establishment of refuge areas, spawning has not led to successful recruitment from the wild population in Lake Michigan. In Lake Huron, spawning and recruitment have been somewhat more successful, and the abundance of spawning adults is increasing. However, stocks in these two lakes are still far from recovery, and lake trout from these regions is recommended as “**Avoid**”.

Lake trout rehabilitation in Lake Superior has been more successful, and self-sustaining lake trout populations have now become established in some parts of the lake. Furthermore, management has taken positive steps to concentrate on wild populations, stock only native strains, and work to maintain genetic diversity. Because the stocks in Lake Superior are in recovery, and management has been effective, lake trout from this region is recommended as a “**Good Alternative**.”

Table of Sustainability Ranks for Lake Trout

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability		√		
Status of Stocks		√ Lake Superior	√ Lake Huron	√ Lake Michigan
Nature of Bycatch	√			
Habitat & Ecosystem Effects	√ Lake Superior	√ Lake Huron, Lake Michigan		
Management Effectiveness	√ Lake Superior	√ Lake Huron, Lake Michigan		

Overall Seafood Recommendation for Lake Trout

Lake Superior:

Best Choice 🟩 **Good Alternative 🟨** Avoid 🟥

Lake Michigan, Lake Huron:

Best Choice 🟩 Good Alternative 🟨 **Avoid 🟥**

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Chapter 3: Walleye

Sander vitreus

(formerly *Stizostedion vitreum*)

(Image courtesy of US Fish and Wildlife Service Digital Image Library)

3-I. Executive Summary

Walleye (*Sander vitreus*) is a widely distributed near-shore predator in the Great Lakes, found throughout Canada and the United States from Quebec to the Northwest Territories and south from Alabama to Arkansas. It is native to the Great Lakes and the St. Lawrence and Mississippi River basins, and has been introduced to the Atlantic, Pacific, and Gulf drainages.

Walleye has been a target of the Great Lakes commercial fisheries since the late 19th century, and its natural resilience to environmental change has allowed it to maintain its dominance in the fishery and aided its quick recovery from declines where other Great Lakes species were less successful. The primary fisheries for walleye are concentrated in Canadian waters of Lake Erie and Lake Huron. Walleye catches from these waters accounted for 98.7% of the total commercial yield of walleye in 2004 (more than 97% from Lake Erie, the remainder from Lake Huron); the remaining 1.3% came primarily from tribe-licensed fisheries in Lake Michigan (56% of US total) and Lake Huron (37% of US total) (DFO 2006a; USGS 2007b).

After a marked decline in walleye abundance between 1900 and 1970, substantial recovery in walleye stocks in Lake Erie allowed for the reinstitution of commercial fishing in the lake. Other jurisdictions remained protected from commercial fishing and are now managed for sport angling only. After this initial period of decline, many walleye stocks recovered to levels close to pre-1970s highs; however, walleye spawning success is sensitive to environmental fluctuations, and large-scale fluctuations in year-class strength during the 1990s brought another period of decline. Restrictive catch limits and increased research efforts aimed at developing better stock assessment practices were instituted in 2000 to reverse this decline, and led to new methods to determine total allowable catch (TAC) allocations in Lake Erie. These management actions have prevented overfishing and reduced uncertainty around stock status; however, there is a continuing lack of knowledge of the links between spawning stock biomass, environmental variables, and year class strength (YCS). Continuing variability in YCS coupled with a population structure skewed to younger fish call for a continuation of cautious fishery management.

Stationary gillnets are the primary gear used in the walleye fishery, and lack of data on bycatch rates in this fishery is of concern as these nets are known to have low species selectivity and high mortality. However, the majority of the species present with walleye are either commercially landed (yellow perch) or too small to be captured in the large-mesh gillnets used in the fishery. Similarly, direct habitat damage by this gear has not been well studied, and is therefore considered of moderate conservation concern. The ecosystem effects of removing walleye are minimal. Walleye is not a major prey of any other species in Lake Erie or Lake Huron. In Lake Huron, where the decreasing forage base is subject to excessive predatory pressure due to large-scale predator stocking, the removal of some predators may be beneficial to the walleye fishery, though non-native predators such as the Chinook salmon consume a much greater proportion of the available forage than walleye.

Though some uncertainties remain around the effects of the gear used in capturing walleye, the management of the Lake Erie walleye fishery has been highly successful in maintaining populations in the face of year-class variability and the associated steep decline in the 1990s. Given the inherent resiliency of the species, its moderate vulnerability to fishing pressure, and the rebuilding of stocks in Lake Erie, Great Lakes walleye are recommended as a "**Good Alternative**."

Table of Sustainability Ranks for Walleye

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability		√		
Status of Stocks		√		
Nature of Bycatch		√		
Habitat & Ecosystem Effects		√		
Management Effectiveness		√		

About the Overall Seafood Recommendation:

- A seafood product is ranked **Best Choice** if three or more criteria are of Low Conservation Concern (green) and the remaining criteria are not of High or Critical Conservation Concern.
- A seafood product is ranked **Good Alternative** if the five criteria "average" to yellow (Moderate Conservation Concern) OR if the "Status of Stocks" and "Management Effectiveness" criteria are both of Moderate Conservation Concern.
- A seafood product is ranked **Avoid** if two or more criteria are of High Conservation Concern (red) OR if one or more criteria are of Critical Conservation Concern (black) in the table above.

Overall Seafood Recommendation for Walleye

Best Choice 🟩 **Good Alternative** 🟨 Avoid 🟥

3-II. Introduction

Walleye (*Sander vitreus*) is a native Great Lakes predatory fish broadly distributed throughout North America from as far south as the Mississippi and Gulf drainages to as far north as the Northwest Territories in Canada, and ranging east to west from the Atlantic to the Pacific. It has been caught commercially in the Great Lakes fishery since the late 19th century. As is true with many Great Lakes species, a combination of overfishing, habitat degradation (particularly loss of spawning grounds), and interaction with invasive species has led to serious population declines in walleye stocks. A small number of stocks were affected as early as the late 19th century, while other stocks experienced gradual declines from 1900-1940. More rapid, severe declines were observed throughout the Great Lakes region between 1940 and 1970 (Fig. 1). These declines resulted from several successive weak year-classes driven by a combination of high exploitation, environmental contaminants, and interaction with invasive species such as rainbow smelt (*Osmerus mordax*) and alewife (*Alosa pseudoharengus*), non-native forage species that compete with and prey upon young walleye (Schneider and Leach 1979). This was a time during which Great Lakes fish assemblages were undergoing substantial changes with the decline of many overfished species and the proliferation of a number of non-indigenous species (Schneider and Leach 1979; Kelso et al. 1996). The walleye population decline led to reductions in commercial walleye catches of 88% in Lake Huron and up to 99% in Lake Michigan and Lake Superior from pre-1970 historic maximum catches. By the mid-1970s, only western Lake Erie stocks had recovered to any appreciable degree. This recovery was largely due to reduced exploitation but may also have been influenced by location-specific resilience of the stock related to lower densities of alewife and smelt in walleye spawning and nursery habitats.

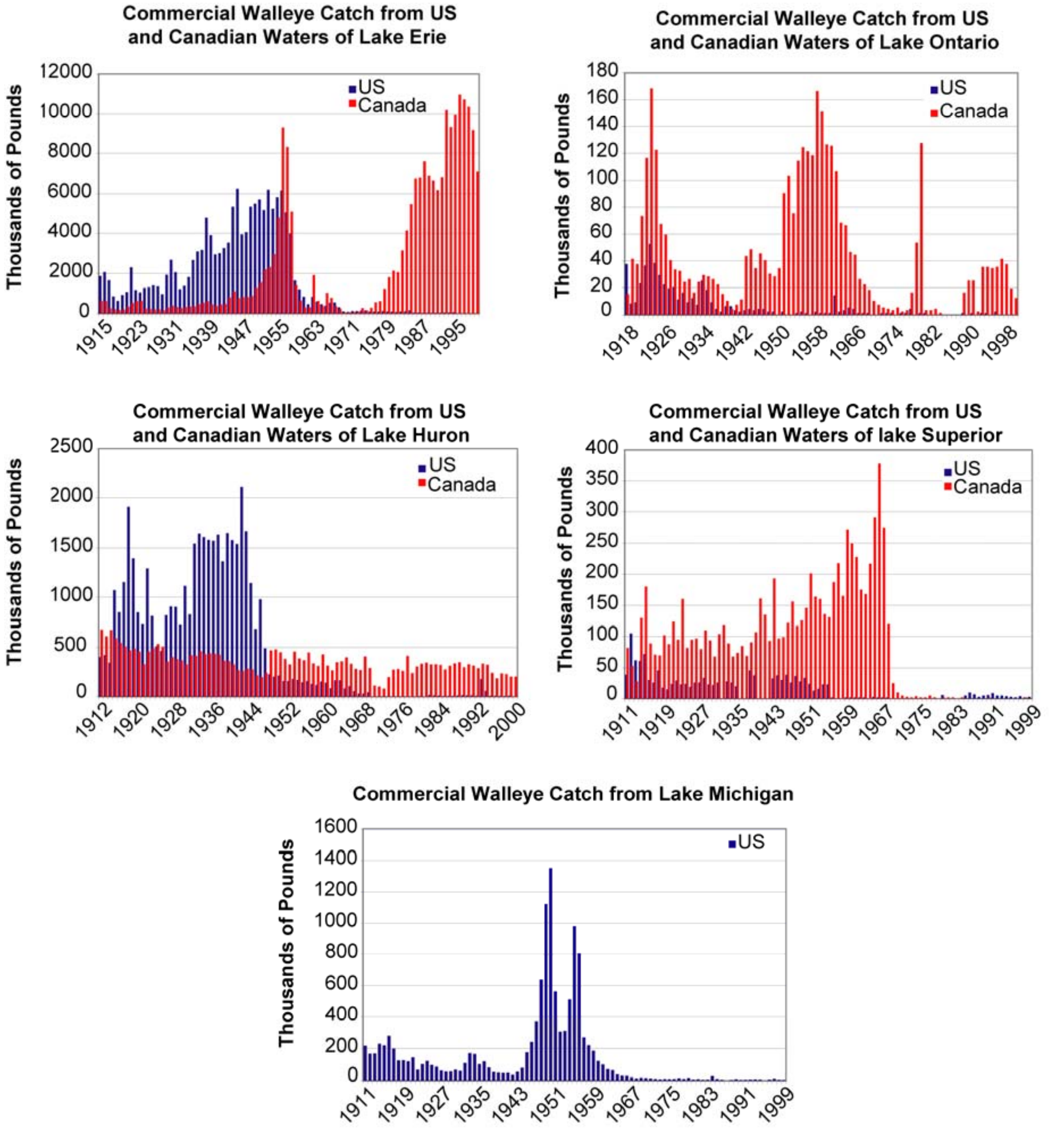

Figure 1: Historic commercial catches of walleye in US and Canadian waters of the Great Lakes (Figure from Baldwin et al. 2002).

During the period of overall decline from 1900-1970, only five walleye stocks maintained relatively stable populations: those in the Wisconsin waters of Lake Superior; eastern Lake Erie; the Southern Lake Huron-Lake St. Clair region; northern Lake Huron; and in parts of Georgian Bay. These stocks were subject to only minor pollution problems and light exploitation. The recovered western Lake Erie stocks are now part of a commercial catch that exceeds the pre-1970s historic maximum (Schneider and Leach 1979).

The mid-20th century declines in walleye abundance resulted in the closure of commercial walleye fisheries in many jurisdictions during the 1970s, and a number have awarded walleye protected sport status. In the United States, these management actions have resulted in primarily recreational fisheries, while in Canada commercial walleye catches from Lake Erie dominate the freshwater fishery both in biomass caught and in economic value. In both cases, management action has led to substantial recovery of walleye stocks throughout the Great Lakes, although a new period of decline began in the 1990s (Fig. 2).

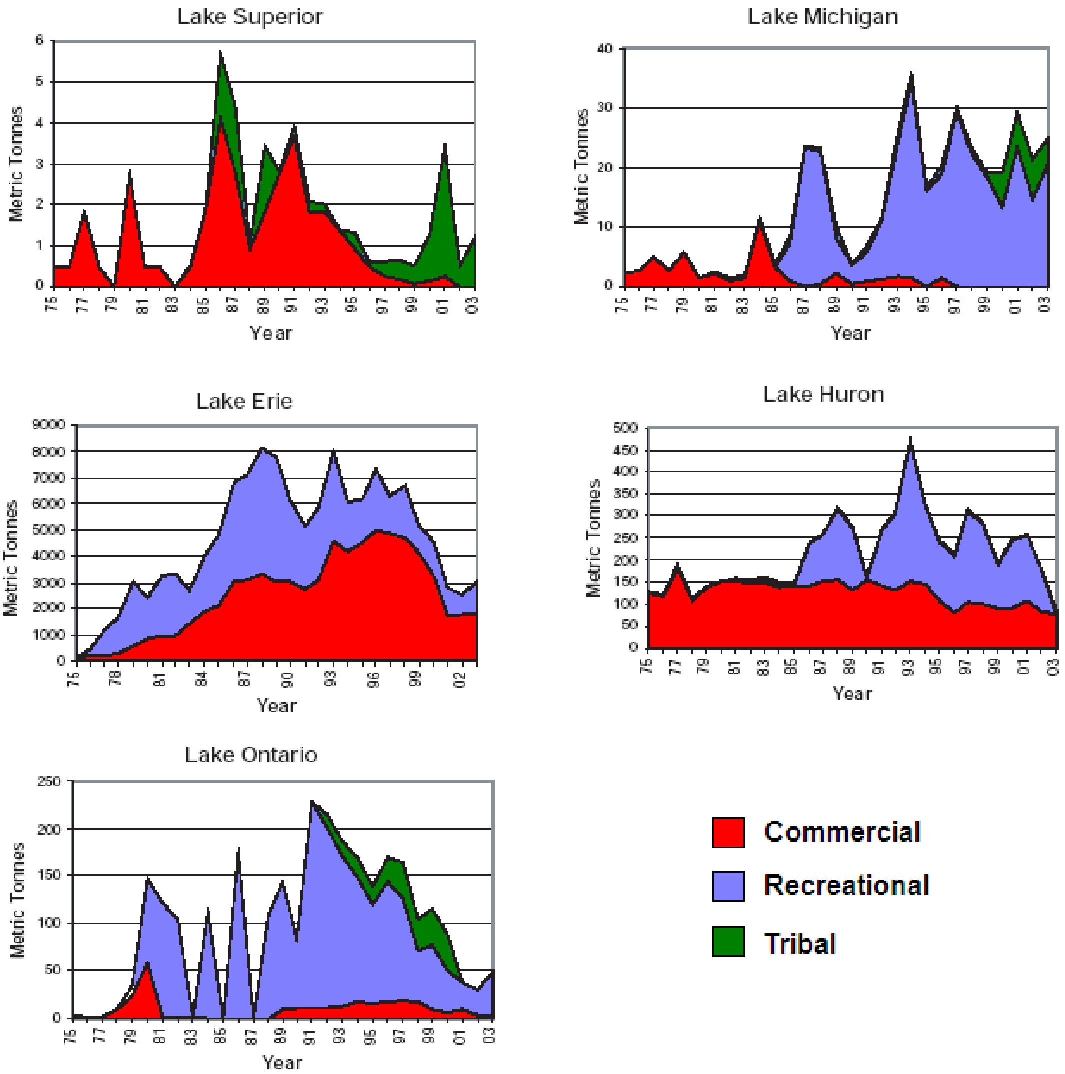

Figure 2: Commercial walleye catches from US and Canadian waters of the Great Lakes, 1975-2003. Note the difference in scale; Lake Erie catches are 20 times larger than the next largest catch, from Lake Huron (Figure from Knight 2005).

The closure of the fisheries in the first half of the 1970s allowed the walleye population in the western basin of Lake Erie to rebound quickly, increasing the fishable stock from a low of around 80,000 fish in 1970 to nearly 14 million fish in 1976 (Nepszy et al. 1991). This led to a dramatic increase in the sport catch, particularly in Ohio waters, and to the reopening of the Ontario commercial fishery in 1976 under an international quota system (Nepszy et al. 1991;

Locke et al. 2005). By 1977, the combined sport and commercial catch of walleye in the western, central, and eastern basins of Lake Erie equaled the peak commercial catch in the mid-1950s (Fig. 3).

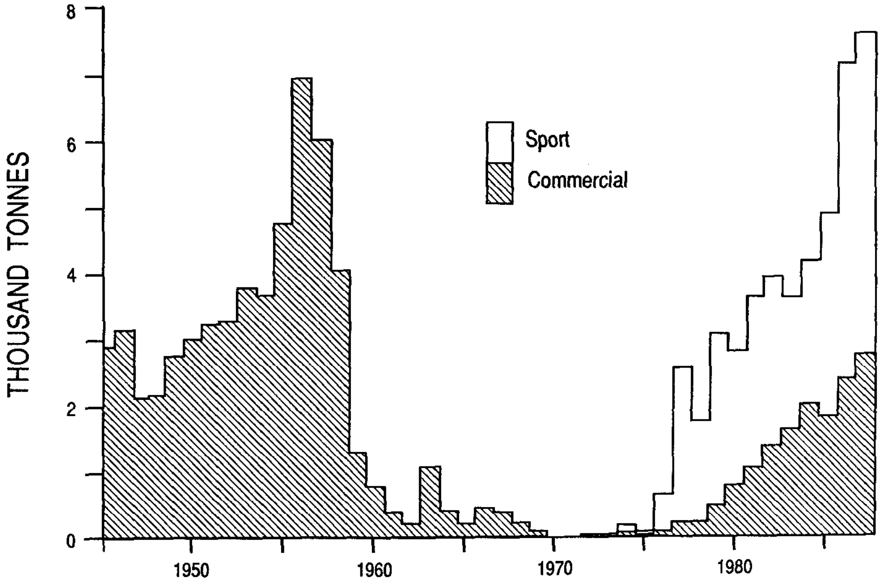

Figure 3: Total sport and commercial walleye catch from Lake Erie, 1945-1987 (Figure from Nepszy et al. 1991).

The commercial catch from Canadian waters of Lake Erie now accounts for more than 97% of the total Great Lakes walleye catch. All recommendations to follow will therefore be driven by the status of this fishery. Canadian catches from Lake Huron account for most of the remaining commercial catch, with only minor catches coming from US waters of Lake Huron and Lake Michigan (Baldwin et al. 2002; Kinnunen 2003).

Scope of the analysis and the ensuing recommendation:
This analysis will focus on commercial walleye catches from Canadian waters of Lake Erie and to a lesser extent commercial catch from Lake Huron.

Availability of Science

The Great Lakes fisheries are some of the most intensively studied and managed in the world, and as such an extensive body of literature exists on their ecology and management. Beginning in the mid-1970s, stock assessment surveys were initiated to determine the status of a number of important Great Lakes stocks, including walleye, and in many jurisdictions these stage-structured assessments continue on an annual basis. However, the Great Lakes have undergone, and continue to undergo, substantial ecological change, particularly in regard to species composition. These shifts in the food web structure of Great Lakes ecosystems have led to often unexpected interactions among species and with pollution, habitat alteration, and more recently climate change. This complex suite of environmental pressures has led to large uncertainty in the trajectory of many Great Lakes stocks.

Market Availability

Common and market names:
Walleye, *Sander vitreus* (*Stizostedion vitreum* until 2003), is also known as yellow pickerel, pickerel (Canada), yellow pike, yellow walleye, and dore (France, Canada).

Seasonal availability:
Frozen walleye is available year-round. Fresh walleye is available nearly year-round, with open lake fishing occurring between June and October and ice fishing (northern inland Canadian lakes) from December through April (FFMC 2007).

Product forms:
Walleye is available fresh as whole fish (head on or off, dressed) or fillets (skin on or off), and frozen as fillets or fingers (7-12 cm strips).

Import and export sources and statistics:
The majority of walleye sold in the US comes from Canadian sources, primarily from Lake Erie. Walleye is one of Canada's three largest freshwater fish exports, together with yellow perch and lake whitefish, and is the most valuable in terms of price per pound (Fig. 4).

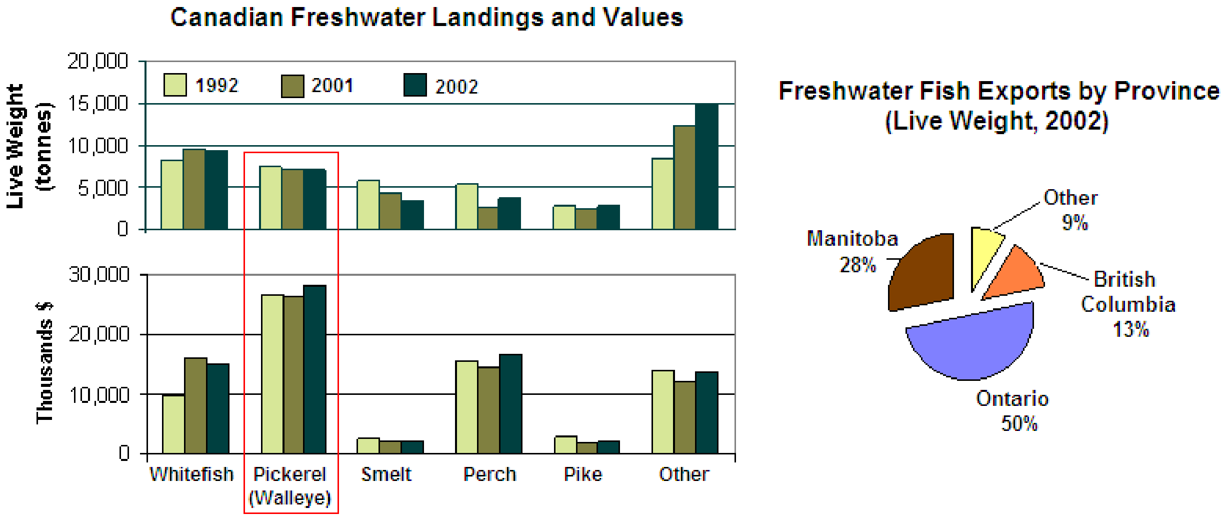

Figure 4: Freshwater Exports from Canada (Figure from FAO 2002).

The US imports about 6.6 million pounds of fresh and frozen walleye annually from Canada, primarily as frozen fillets, but also as fresh whole fish, fresh fillets, and frozen block (NMFS 2007). Approximately 90% is from Great Lakes sources, with about 87% coming from Lake Erie and about 3% from Lake Huron. The amount of walleye imported is roughly 75 times the combined commercial and tribal walleye catch from US waters of the Great Lakes (USGS 2007). For this reason, the recommendations issued here for walleye are driven by the analysis of Canadian fisheries in Lake Erie and Lake Huron.

3-III. Analysis of Seafood Watch® Sustainability Criteria for Wild-caught Species

Criterion 1: Inherent Vulnerability to Fishing Pressure

Walleye (*Sander vitreus*) is found throughout the United States and Canada, from Quebec to the Northwest Territories in the north and from Alabama to Arkansas in the south. Its native range includes the Great Lakes and the St. Lawrence and Mississippi River basins. Because it is a very popular sport fish, it has also been widely introduced to waters outside its native range, and can now be found in the Pacific, Atlantic, and Gulf drainages. Walleye can inhabit both fresh and brackish waters, but prefer cold to cool fresh water (55-68ºF) not exceeding 50 feet in depth (MIDNR 2007b).

Walleye is the terminal (top) predator in many near-shore habitats within the Great Lakes. Walleye fry consume primarily small aquatic crustaceans (copepods, cladocerans) and some small fish, while adults feed opportunistically on fish and larger invertebrates. It is a visual predator adapted to hunting in low light conditions, and as a consequence their eyes are sensitive to sunlight. In clear waters, walleye are most active between dusk and dawn, moving to deeper water or under cover of submerged objects during daylight. In turbid waters walleye may feed throughout the day. Their populations are often associated with yellow perch and smallmouth bass. Walleye diets can be very adaptable to available prey; in the Great Lakes walleye generally feed on shiners, smelt, gizzard shad, and alewife. In some lakes walleye are consumed by pike and muskellunge (MIDNR 2007b).

Walleye growth rates can be variable, and depend on prey availability, environmental conditions, and population density. In many lakes walleye growth has been observed to be sexually dimorphic; females grow faster and attain larger sizes than males, and mature males grow slower than both females and immature males. Growth is high when population density is low and decreases at higher densities (Schneider et al. 1989; Henderson et al. 2003). Walleye are specialist piscivores, and grow best on diets dominated by fish (Sass and Kitchell 2006; Graeb et al. 2005). The availability of forage fish prey therefore has a substantial impact on walleye growth and condition. However, walleye can, at the expense of growth, exploit other prey such as benthic invertebrates when fish are not available. Walleye growth also increases with temperature; southern Great Lakes populations grow faster and mature earlier than stocks in northern regions of Canada (OMNR 2005). Males mature at between 2 and 4 years of age or above 350 mm total length (TL), whereas females mature at around age 5 or above 480 mm TL. Walleye reproduce a maximum of eight times in their lifetime, have a maximum age of approximately 10 years, though the oldest walleye on record was 29 years old, and can reach more than 76 cm (30 inches) in length (Downs et al. 2002).

Walleye spawn when water temperatures are between 40ºF and 55ºF, typically in spring (April-June), and spawning occurs over firm substrates (rocks, gravel, or sand). Spawning success is highly dependent on environmental conditions, particularly temperature and fluctuations in water level. High temperatures can cause early hatching and low temperatures can delay hatching or suppress plankton crucial to the early walleye diet, while water level fluctuations can reduce spawning habitat or strand walleye eggs (ONMNR 2005). The number of eggs laid by each female varies according to size and body condition, but can reach 400,000 eggs (OHDNR 2005). The population growth rate of walleye stocks is moderate, with a von Bertalanffy growth coefficient (K) for walleye between 0.3 and 0.4. He et al. (2005) suggested stage-structured values of K could be more informative, as the parameters affecting growth of age-0 walleye are likely different from those affecting adults (He et al. 2005). The minimum population doubling time for walleye has been recorded as 4.5-14 years (Froese and Pauly 2007).

Walleye typically spawn early relative to other fish species and grow quickly, resulting in an early size advantage. Early spawning minimizes the amount of time during which walleye compete with other fish for zooplankton prey, and allows them to begin consuming fish as early as at 30 mm length, which optimizes their body condition and growth rates.

Despite their moderate resilience, adaptable diet, and ability to withstand low oxygen conditions, habitat quality for walleye was severely degraded leading up to the period of steep population declines in the middle of the 20th century. As early as the turn of the century, river-spawning stocks were affected by logging and expanding agriculture, which clogged river ways and increased sedimentation. By 1900 a number of dams had been built that also blocked traditional spawning grounds (Fielder et al. 2005), and severe eutrophication in the mid-1970s further degraded habitat and spawning grounds. Since then, nutrient controls and walleye stock management has led to some recovery; however, loss of wetlands, shoreline alteration, and the channelization of tributary streams used for spawning are still affecting walleye populations (LEC 2004). Stocks in some Great Lakes, including Lake Huron and central Lake Erie, are still dependent on other, larger stocks—notably those from western Lake Erie—to “seed” their resident populations via migration (Nepszy et al. 1991; Fielder et al. 2005). This dependence on a smaller number of more robust stocks increases their vulnerability to fishing pressure.

Table 1. Life history characteristics of walleye.

Intrinsic Rate of Increase (r)	Age at Maturity	Growth Rate	Max Age	Max Size	Fecundity	Species Range	Special Behaviors	Sources
0.05-0.15	2-4 years	K=0.3-0.4	29 years	30 inches	High (up to 10^5 eggs per female)	Broad: Throughout North America	No special vulnerability to gear; substantially compromised habitat outside of Lake Erie (in recovery); rely on stable prey populations.	He et al. 2005; Locke et al. 2005; OHDNR 2005; ONMNR 2005; Froese and Pauly 2007; MIDNR 2007b

Synthesis

Walleye are a somewhat adaptable species, able to survive under a variety of environmental conditions (low dissolved oxygen, clear to mildly eutrophic waters), and able to exploit both fish and invertebrate prey. However, they grow best when fish prey is available and therefore the stability of prey fish populations, at question in many Great Lakes regions, may affect walleye population success. In addition, the sensitivity of walleye spawning success to environmental variables like temperature and water level fluctuations, and the degradation of many of their spawning grounds throughout the Great Lakes via habitat alteration, makes walleye populations moderately vulnerable to fishing pressure.

Inherent Vulnerability Rank:

Resilient 🟩 **Moderately Vulnerable 🟨** Highly Vulnerable 🟥

Criterion 2: Status of Wild Stocks

Lake Erie

Walleye stocks in Lake Erie are somewhat segregated, with large populations present in the more productive central and western basins and a historically smaller but more stable population in the eastern basin (Fig. 5). The western and central basin fisheries historically produced the highest commercial walleye yield in the Great Lakes. In contrast, catches from the eastern basin have always been relatively small, though fishery effort increased substantially in the mid-20th century when western and central basin stocks were in decline and populations of previously important whitefish and blue pike (a particular walleye strain) had crashed (Schneider and Leach 1979; Nepszy et al. 1991). Currently, the commercial yield of walleye comes almost entirely from Ontario waters of Lake Erie. Catches from US waters are primarily recreational, with a very small commercial catch from Pennsylvania waters (830 pounds in 2005 compared to yields of over 4 million pounds in the Ontario fishery).

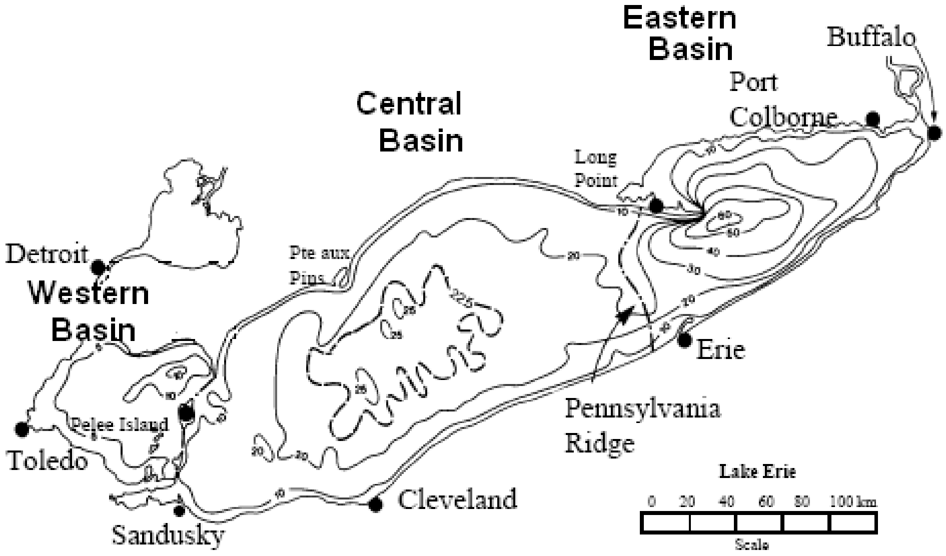

Figure 5. Lake Erie (Figure from Ryan et al. 2003). The western and central basins are shallower, more productive, and populated by warm water species such as walleye and yellow perch. The deeper and more oligotrophic eastern basin provides habitat for fish preferring deeper, colder water, such as lake whitefish.

Western/Central Basin Stocks

After the institution of cleanup efforts in Lake Erie in the mid-1970s and the closure of the commercial fishery, the western basin stocks recovered quickly, and by the early 1980s constituted a major portion of the commercial catch. Central basin stocks recovered more slowly. Despite some evidence of reproductive success, their recovery was heavily dependent on dispersal from the western basin, as the central basin appears to lack good walleye spawning grounds (Nepszy et al. 1991). The initial period of recovery from the mid-1970s to the early 1980s was somewhat short-lived, as walleye populations between 1982 and 1999 were characterized by extremely variable year-class strength (YCS), with years of very strong classes (1982, 1986, 1991, 1996, 1999) interspersed with years in which YCS dropped to near zero (1983, 1989, 1992, 1995) (Fig. 6).

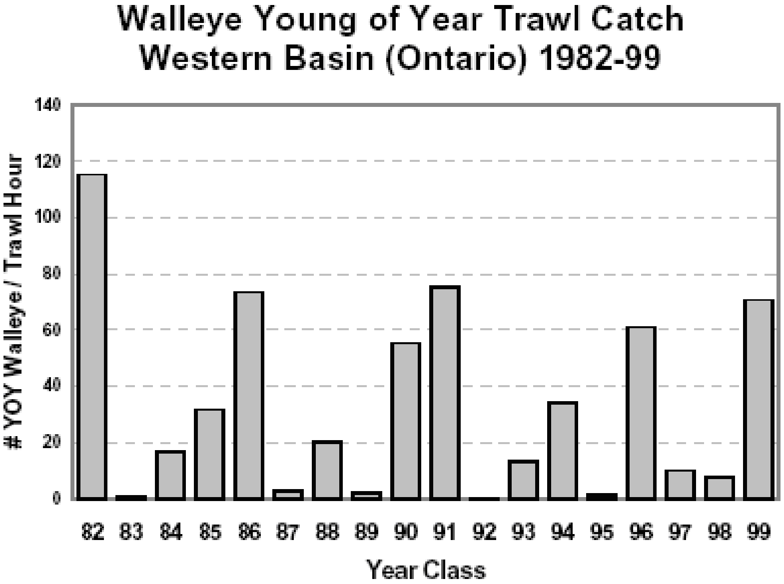

Figure 6. Walleye year class strength (YCS) as measured by abundance of young-of-the-year in Lake Erie's western basin, 1982-1999 (Figure from Locke et al. 2005).

The proximity of years with strong cohorts and those with very weak ones suggests a density-dependent mechanism may be controlling walleye spawning success. However, a number of factors can impact walleye spawning and recruitment, including lake productivity and interaction with invasive species. In Lake Erie, two species in particular are thought to affect walleye populations: zebra mussels, which have substantial impacts on lake trophic status through their high filtration rates, and thus have impacted the lake's carrying capacity for forage species; and white perch, which can compete with walleye for fish prey. Gopalan et al. (1998) summarized concurrent changes in Lake Erie's trophic condition and species abundance thought to affect overall fish recruitment (Fig. 7), highlighting some of these interactions.

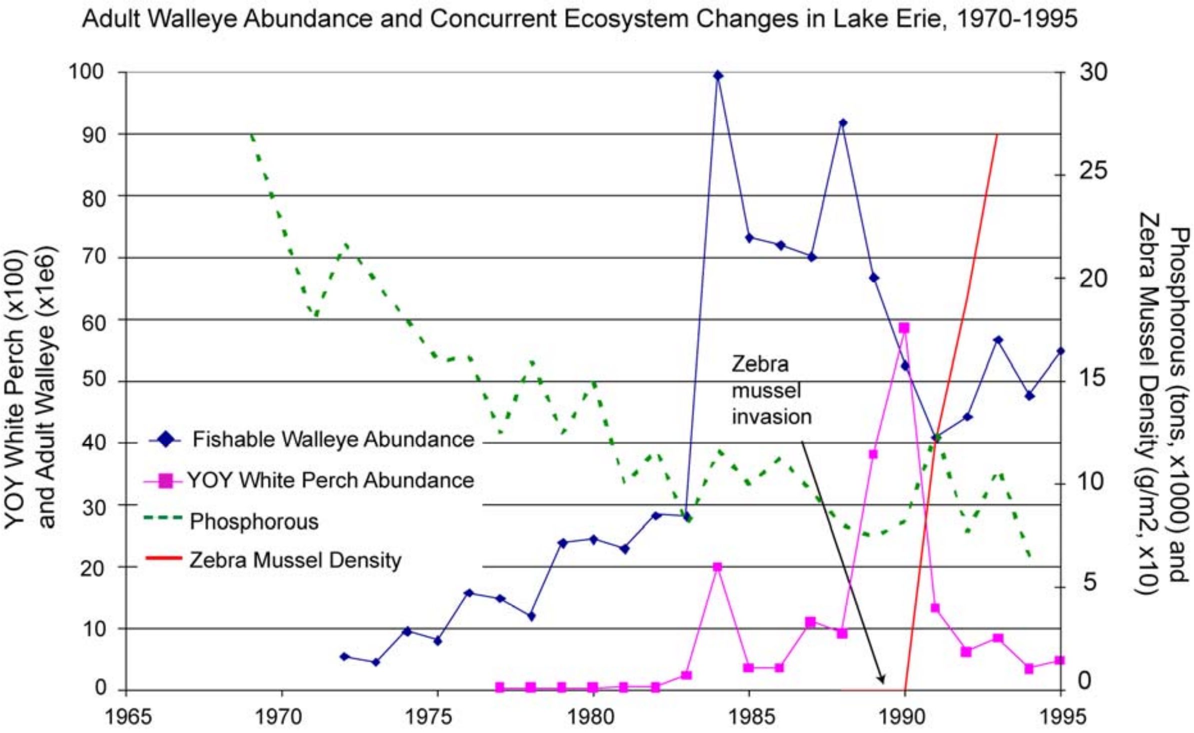

Figure 7: Concurrent changes in adult walleye abundance, young of the year (YOY) white perch abundance, phosphorous load, and zebra mussel density in Lake Erie between 1970 and 1995 (Figure from Gopalan et al. 1998).

The period between 1980 and 1995, during which substantial YCS variability in walleye stocks were noted, coincided both with the continued decrease in phosphorous loading, affected through nutrient controls, and with the dramatic rise in abundance of the invasive zebra mussel, which further reduced nutrient concentrations in the water column, driving Lake Erie towards an oligotrophic state. The dramatic decrease in walleye abundance in the 1990s led the Lake Erie Committee (LEC) to model population abundance relative to catch and maximum sustainable yield (MSY) in order to set protective catch limits on walleye. Because the carrying capacity of Lake Erie for fish had changed during this time, it was not possible to use one single model to describe maximum sustainable yield. Their modeling therefore explicitly considered walleye MSY over three distinct periods of varying abundance: (1) considering all data between 1978 and 2000; (2) considering data from 1984 to 2000; and (3) considering only 1994-2000 data (Locke et al. 2005). This lead to three different MSY levels and contrasting pictures of walleye catches relative to MSY in the past 30 years (Fig. 8).

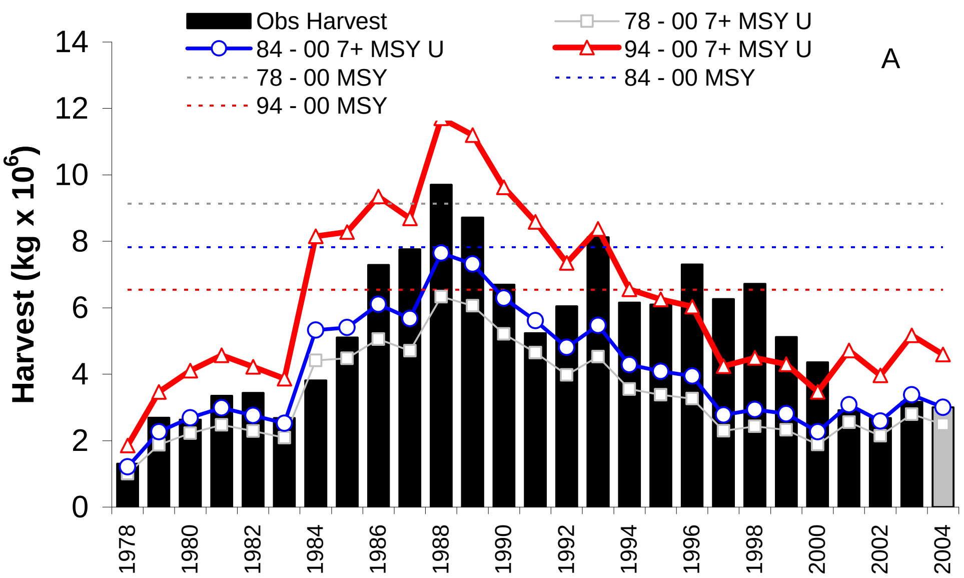

Figure 8: Maximum sustainable yield (dotted lines), observed catch (bars), and estimated catch (solid lines) of walleye in Lake Erie based on three data sets (1978-2000, 1984-2000, and 1994-200). All walleye age 7 and older are combined in the 7+ group (Figure from Locke et al. 2005).

Whether we consider the broadest (1978-2000) or the most conservative of these estimates (1994-2000 data that do not include the higher walleye biomass observed in the past), it is apparent that the MSY of walleye was exceeded a number of times in the past. On the other hand, it is also clear that the strict catch allowances put into place at the end of the 1990s resulted in a decrease in total catch to reach stable, sustainable levels by the year 2000. The 1990s decline in walleye abundance due to poor year classes in 1992, 1995, and 1997-1998 prompted management action in 2001 to restrict walleye catches. During this restrictive period, 2002 and 2004 were also poor spawning years. By 2003, however, the reduced exploitation combined with the strongest year class in 20 years resulted in some population recovery. Over the past decade, fishing effort has remained below the MSY predicted by any of the three models above. However, large variability in year class strength (YCS) in recent decades and concern over the age structure of Lake Erie walleye populations still trouble the fishery. The lack of good recruitment during the 1990s led to a decrease in the mean age of walleye, reducing the catch per unit effort (CPUE) of age-3+ walleye by nearly ten-fold (Fig. 9).

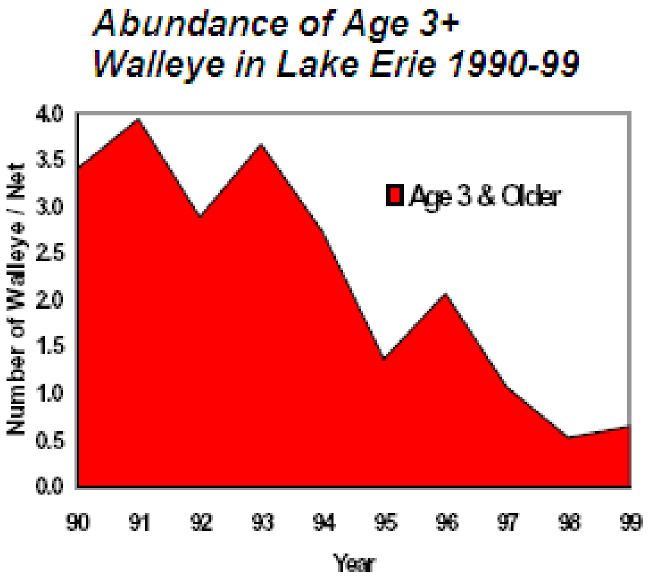

Figure 9: Walleye year class strength (YCS) and change in age structure as reflected by western basin stocks from Ontario waters of Lake Erie. From LEC 2005 Walleye Management Plan (Figure from Locke et al. 2005).

Because of this trend, the Lake Erie Committee has taken steps to limit commercial catch of low year-class-strength cohorts. Despite the strong class in 2003, total allowable catch (TAC) in 2004 was reduced in order to protect the small year-2 (2002 year class) population and help to balance the age structure.

The 2004 catch coming from the managed quota area (central and western basin) was 99.7% of the TAC, from both commercial and sport efforts. In general, angling (sport) effort continued a 20+ year declining trend, while commercial gillnet effort decreased 24% to the lowest value since 1980. At the same time, gillnet catch per unit effort (CPUE) increased for the fourth consecutive year.

The increase in CPUE is promising as it shows an increase in abundance; however, the age structure of walleye in Lake Erie is still of concern. Though mean age in sport catches increased in 2004 to 5.1, above the 30-year mean of 4, the mean age in commercial catches decreased to 3, below the long-term mean of 3.5. The 2004 sport catch was 46% age-3 and 30% age 4, while the commercial catch was 49% age 3, 11% age 4, and 27% age 1 (Thomas et al. 2005). Eastern basin sport and commercial catches continue to be older, with a greater proportion of age-7 walleye than the western and central basins.

The Lake Erie Committee (LEC) has determined, through a combination of population modeling and monitoring approaches, the following categories for walleye population status (Thomas et al. 2005):

- <15 million walleye: Fishery in Crisis
- 15-20 million walleye: Fishery in Rehabilitation
- 20-25 million walleye: Low Quality Fishery
- 25-40 million walleye: Maintenance Fishery
- >40 million walleye: High Quality Fishery

In general, walleye populations from 2000 were considered to be in "Rehabilitation," with strong year classes in 2003 moving the population towards "High Quality" by 2005 (USEPA 2005). However, the highly variable YCS over the past 15 years has resulted in a fishery oscillating between "Rehabilitation" and "High Quality" with little stability (Fig. 10).

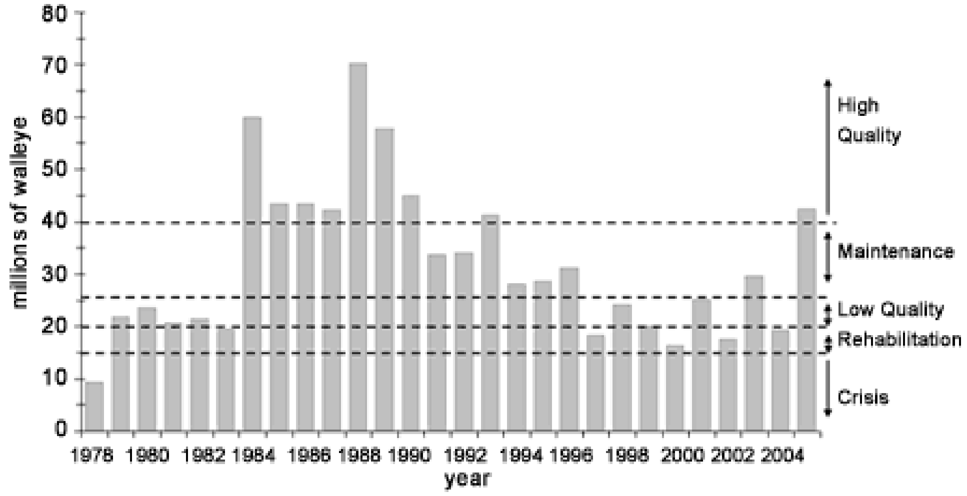

Figure 10: Status of walleye population in Lake Erie, 1978-2005. From USEPA Detroit River-Western Basin Lake Erie Indicator Project (Figure from USEPA 2005).

The variability in walleye year class strength continues. The drivers of walleye YCS are primarily environmental, and include rainfall, temperature, and competition/predation. Many of the effects can be indirect and synergistic, making prediction of YCS difficult. After the very strong 2003 year class the 2005 year class was poor, prompting a substantial reduction in TAC for 2007 (from 9.886 million, 5.93 of which were actually caught, to 5.36 million) in order to protect the 2-year-old population (LEC 2007).

Eastern Basin Stocks

The eastern basin stocks in Lake Erie were likely shielded from some of the invasive interaction effects experienced by walleye in the central and western basins, as their spawning grounds along the New York shoreline were free of rainbow smelt during the period of steep decline from 1940-1970, preceding the closure of the fishery. Though alewife and sea lamprey were present during this period and had substantial effects on other native Great Lakes fish, they too were not very abundant within walleye habitat in Lake Erie. The abundance of emerald shiner, a major prey of walleye, has been linked to rainbow smelt abundance in other areas and during other time periods, but remained relatively steady from 1940 to 1970. Walleye recruitment also remained stable until the 1970s.

Less extensive stock data are available for eastern basin walleye stocks than for western and central basin stocks, as they have traditionally been managed outside of the TAC area by the New York State Department of Environmental Quality and the Ontario Ministry of Natural Resources. However, in an effort to expand the walleye stock assessment model for the eastern basin stocks to include spatially explicit stocks as well as a description of broad-scale walleye movement among Lake Erie's basins and tributaries, the LEC has recently begun incorporating Ontario commercial gillnet data and New York and Pennsylvania angling data along with survey data from Ontario and New York for the eastern basin. The resulting picture of the eastern basin walleye stock is still preliminary, and its accuracy is limited because walleye movement into the eastern basin from the west has yet to be incorporated. However, eastern basin walleye abundance estimated by this preliminary assessment was, as of 2004, the lowest in the 1940-1970 time series (Fig. 11).

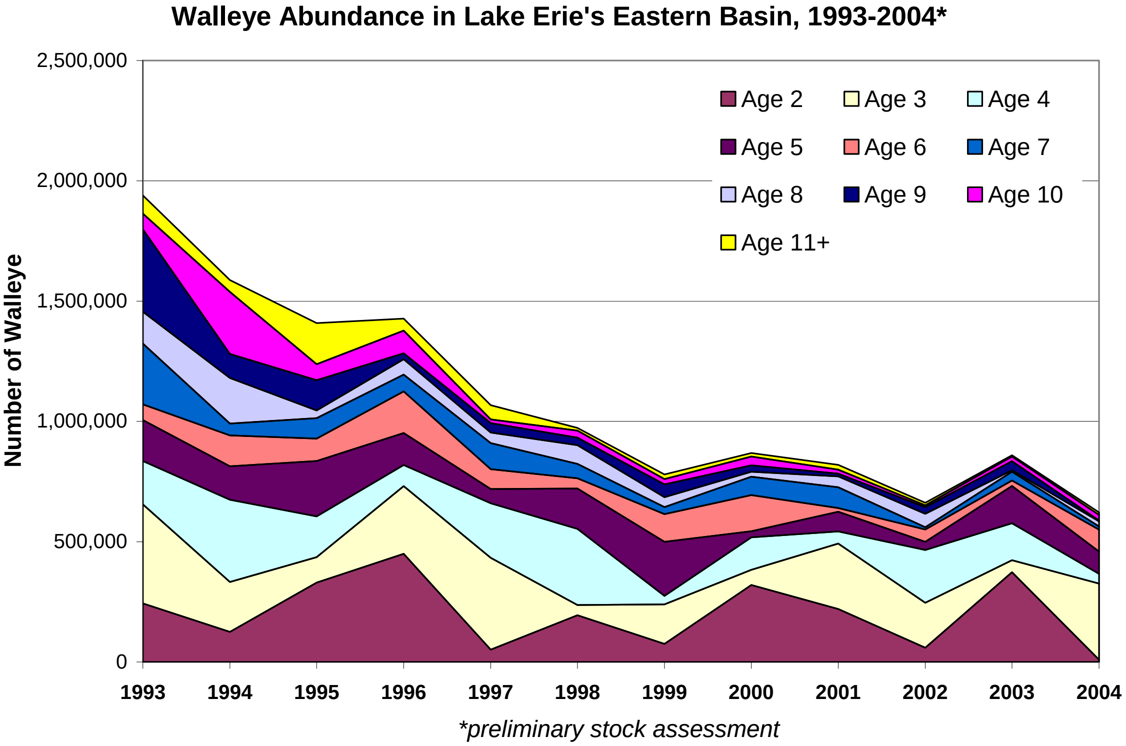

Figure 11: Walleye abundance in eastern Lake Erie, from LEC Walleye Task Group preliminary assessment (Figure from Thomas et al. 2005).

Lake Huron

Once the dominant near-shore predator in Lake Huron, walleye currently inhabits its shallow (<20 m deep), warmer waters including most of Saginaw Bay, the North Channel, a narrow near-shore area in eastern Georgian Bay, and southern Lake Huron (Fig. 12) (Colby et al. 1991). The Saginaw Bay stock was at one time second only to Lake Erie's in size, supporting an extensive commercial fishery in the mid 19th century (Mrozinski et al. 1991). Presently, the bulk of the commercial catch is from Ontario gillnet fisheries in the North Channel, Georgian Bay, and southern waters of the main basin, though state- and tribe-licensed gillnet and trap net fisheries operate throughout Lake Huron. Canadian walleye catches from Ontario waters of Lake Huron account for approximately 3% of the total commercial catch of walleye from all of the Great Lakes (Kinnunen 2003), with the remaining 97% coming from Canadian waters of Lake Erie. Stocks from Lake Huron's US waters, on the other hand, are primarily managed as recreational (sport) fisheries.

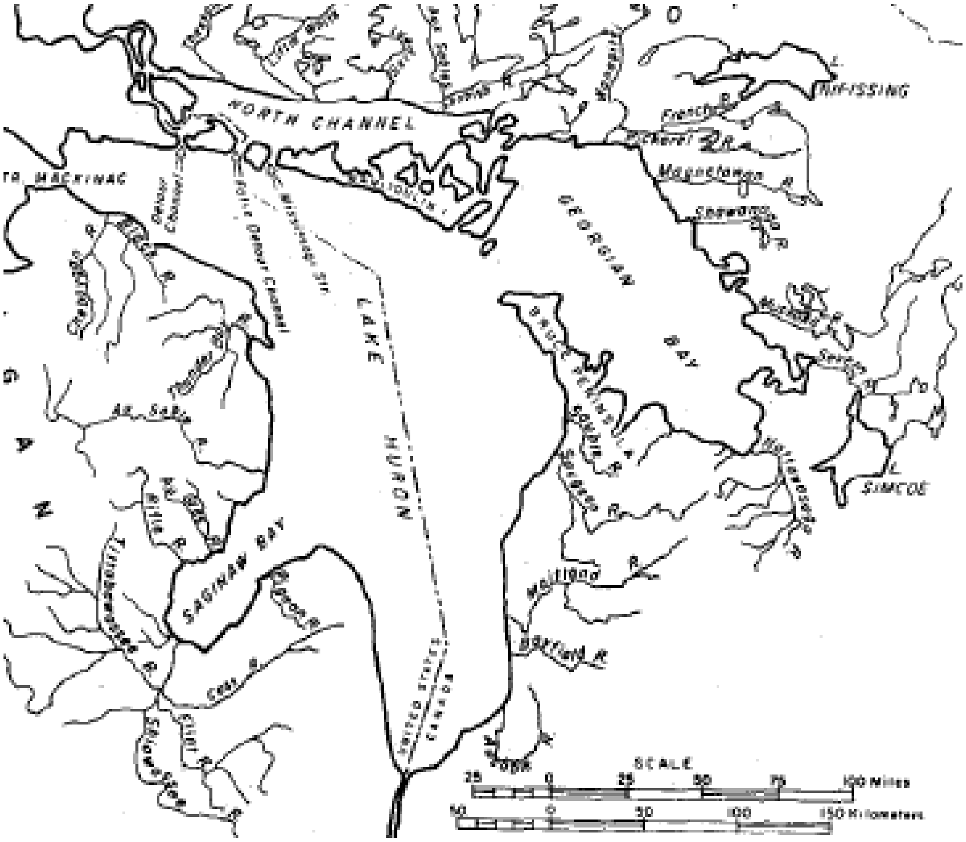

Figure 12. Lake Huron, including the North Channel, Georgian Bay, and Saginaw Bay (Figure from DesJardine et al. 1995).

Georgian Bay and the North Channel are generally oligotrophic (nutrient-poor), though these areas have historically seen a substantial amount of logging industry activity. Between 1930 and 1950, a period when many of the Great Lakes were suffering from eutrophication (nutrient enrichment) and other chemical contamination, water quality remained good in these regions. Despite this, walleye stock size did not recover to former long-term averages after the crash in the first third of the 20th century. Of 14 distinct original Lake Huron stocks reviewed by Reckahn and Thurston (1991), only three stocks had achieved moderate-to-high abundance by 1989: those from the lower French River, St. Mary's River, and southern Lake Huron.

The French River region of Georgian Bay has mixed stock derived from Lake Nipissing's slow-growing walleye population. While stocks in Lake Nipissing are controlled by predator-prey dynamics, the more oligotrophic waters of Georgian Bay place greater environmental control on recruitment; factors such as temperature can have a substantial effect on year class strength.

The St. Mary's walleye stock inhabits a busy waterway, and has been impacted by both ecological change and management restoration efforts targeted at walleye and other species. Walleye, lake trout, rainbow trout, and Atlantic and Chinook salmon were stocked in the river during the 1980s. Rainbow smelt, pink salmon, alewife, sea lamprey, threespine stickleback, and white perch all invaded these waters, and water flow manipulation, hydroelectric dams, and contaminants all impacted water quality.

The southern Lake Huron stock is actually composed of a number of stocks originating in the Detroit and St. Clair rivers and Lake Erie, Lake Huron, and Lake St. Clair. This mixed population supported a stable and productive trap net fishery in Ontario waters through the mid 1980s. At present, the commercial catch from Ontario waters of southern Lake Huron is largely derived from Lake Erie fish (60-70%), with another 10-20% originating in Lake St. Clair's Thames River (Fielder et al. 2005).

Walleye populations in Lake Huron remain below historic yields, though some success has been achieved in creating naturally spawning populations. In Georgian Bay and the North Channel, in particular, intensive fisheries, habitat loss, and predator stocking policies that exacerbate a predator-prey imbalance are suppressing walleye recovery (Mohr and Ebener 1999), and stocking programs have been used to bolster the natural population. However, this has led to a decrease in genetic diversity of Georgian Bay stocks (Scribner and Liskaukas 2005). Furthermore, in the general southern Ontario region walleye age structure has been skewed to younger fish, prompting concern; fewer age classes are present and maximum age is lower in these populations than in other regions, and some populations lack an adequate number of spawning females (ONMNR 2005).

The Fish Community Objective (FCO) for Lake Huron walleye calls for a sustainable catch of 1.54 million pounds per year. The current annual yield is below 660,000 pounds, and may indicate that carrying capacity of the lake is not sufficient to support the desired population (DesJardine et al. 1995). There are currently uncertainties in the health of the forage base, with non-indigenous stocks in particular (rainbow smelt, alewife) on the decline. However, for the time being this has had some positive influence on the health of walleye stocks. In 2003, when alewife populations were substantially reduced in Lake Huron, walleye spawning success rose dramatically. This is probably a result of decreased predation by alewife on larval walleye and possibly decreased competition between young walleye and young alewife as well. Though the out-of-balance predator/prey ratio in the lake (and particularly in Saginaw Bay) is of greatest concern for other stocked predator fish such as Chinook salmon, the declining forage base may limit walleye productivity in the future (MIDNR 2005).

Table 2. Stock status of walleye.

Stock	Status	B/B_{MSY}	Occurrence of Overfishing	F/F_{MSY}	Abundance Trends/ CPUE	Age/Size/ Sex Distribution	Degree of Uncertainty in Stock Status	Sources	SFW Rank
Lake Erie (Western/ Central Basins)	Not listed by IUCN.	Above B_{MSY}	Not overfished	Fishing mortality within F_{MSY}.	Long-term trend is up. Short-term trend is variable.	Age distribution skewed.	Low	Nepszy et al. 1991; Gopalan et al. 1998; Locke et al. 2005	Moderate
Lake Erie (Eastern Basin)	Not listed by IUCN.	Fully fished.	Unknown	Unknown	Long-term trends variable. Short-term trends declining.	Age/size distribution skewed.	Moderate	Schneider and Leach 1979; Nepszy et al. 1991; Thomas et al. 2005	Unknown
Lake Huron	Not listed by IUCN.	Unknown	Unknown	Unknown	Long-term and short-term trends variable.	Distribution skewed.	Moderate	Mohr and Ebener 1999; Fielder et al. 2005a; MIDNR 2005; OMNR 2005; Scribner and Liskaukas 2005	Unknown

Synthesis

The Lake Erie walleye stocks represent the vast majority (>97%) of the commercial walleye catch in the Great Lakes region, and therefore the status of these stocks drive the overall recommendation. In the western and central basin, where populations are largest, walleye stocks recovered substantially from mid-20th century lows, then declined during the 1990s, and have since stabilized and recovered again following restoration efforts and catch restrictions aimed at rebuilding populations. These catch restrictions have ensured that overfishing is not currently occurring and populations remain above the biomass at maximum sustainable yield. Extensive collection of fishery dependent and independent data reduces uncertainty around stock status as much as can be expected given the continuing lack of knowledge of the links between spawning stock biomass, environmental variables, and year class strength (YCS). However, continuing variability in YCS, including several recent years with poor classes, and a population structure that is skewed to younger cohorts (primarily age-3 and younger) indicate that management must remain cautious. The status of western/central basin Lake Erie walleye stocks is therefore considered to be moderate/rebuilding.

In the eastern basin of Lake Erie, stocks are fully fished and there is higher uncertainty in the status of the stocks, as the eastern basin is regulated under a different management regime than the LEC, which sets allocations for stocks from the central and western basins. Preliminary assessments of eastern basin stocks indicate that both age and sex distributions are skewed. However, catch limits are in place and further assessments are ongoing. Eastern Lake Erie walleye stocks are therefore also considered to be moderate/rebuilding.

Lake Huron stocks similarly receive a “moderate” ranking, though in the case of these stocks the assessment is driven by lack of knowledge. Populations are recovering from mid-century declines, but population size relative to maximum sustainable yield is unknown, little fishery independent data are available on stock health, and the age, size, and sex distributions are unknown.

Status of Wild Stocks Rank:

Healthy 🟩 **Moderate/Rebuilding 🟨** Poor 🟥 Critical ⬛

Criterion 3: Nature and Extent of Bycatch

Seafood Watch® defines sustainable wild-caught seafood as marine life captured using fishing techniques that successfully minimize the catch of unwanted and/or unmarketable species (i.e., bycatch). Bycatch is defined as species that are caught but subsequently discarded (injured or dead) for any reason. Bycatch does not include incidental catch (non-targeted catch) if it is utilized, accounted for, and managed in some way.

Commercial fisheries operating in Ontario waters of both Lake Erie and Lake Huron use gillnets to capture walleye. Gillnets are recognized as gear with low selectivity and high mortality rates, and as such can present substantial bycatch issues when species of special concern or species that cannot be utilized by the fishery are vulnerable to the mesh size used (see discussion in Chapter 1). No systematic study of bycatch rates in the Ontario commercial walleye fishery is available, though it is recognized in the Lake Huron fishery that research in this area is needed (Fielder and Thomas 2006).

In the walleye fishery, the catch is made up largely of commercially utilized species such as walleye and yellow perch, and non-native or lower-food-web forage species, including rainbow smelt, trout-perch, white bass, emerald shiner, spottail shiner, and round goby (Bur et al. 2006). Because the majority of these fish are substantially smaller than walleye, it is likely that nets sized for commercially-sellable walleye will not be very selective for these species. Furthermore, the capture of immature walleye appears to be a greater problem for small-mesh gillnet fisheries such as the yellow perch fishery, where bycatch of immature walleye was tracked during a study in 2000 (LEC 2004). However, some surveys have found rare species such as lake sturgeon, which has special conservation status in the Great Lakes, present in Lake Erie’s western and central basins (Bur 2005). Their presence increases the risk associated with uncertainty in bycatch rates in the walleye fishery and warrants further research.

Synthesis

The uncertainty in bycatch rates in commercial walleye fisheries in Lake Erie is high, with no systematic study available. Although the majority of the species present with walleye are either commercially landed (yellow perch) or too small to be captured in the large-mesh gillnets used in the fishery, gillnets are known to have low selectivity and high mortality. Further research is warranted and the possible presence of lake sturgeon in the area raises additional concerns. The commercial walleye fishery is therefore given a “moderate” bycatch rank.

Nature of Bycatch Rank:

Low 🟩 **Moderate 🟨** High 🟥 Critical ⬛

Criterion 4: Effect of Fishing Practices on Habitats and Ecosystems

Habitat Effects

The commercial walleye fisheries in Lake Erie and Lake Huron employ stationary gillnets, which when set on the ocean bottom in marine systems are considered to cause moderate habitat damage. Because the impacts of such gear on Great Lakes bottom habitats have not been studied, their use in the walleye fishery is also considered to have moderate habitat impacts. When set in midwater, stationary gillnets cause minimal habitat damage.

Ecosystem Effects

Walleye is the terminal predator in Lake Erie and a dominant near-shore cool water predator in Lake Huron. Because it is a specialist piscivore that is born earlier than other fish and enters piscivory quickly, it is not an important prey item for other fish, and its removal therefore does not reduce food availability for other species. On the other hand, it competes with other predator fish for food, and such competition can be substantial in areas where there is a lot of predatory pressure on an unstable forage base. In many Great Lakes systems, ecosystem changes driven by intensive predator stocking, nutrient reduction measures, or the introduction of invasive species such as zebra mussel, rainbow smelt, and alewife, have led to a decrease in the availability of or unstable boom and bust cycles in populations of forage prey, and of non-native alewife and rainbow smelt in particular. In Lake Erie, the biomass of age-0 fish has decreased in recent decades, most likely due to the combined effects of nutrient abatement and species invasions (Fig. 13) (Murray et al. 2007).

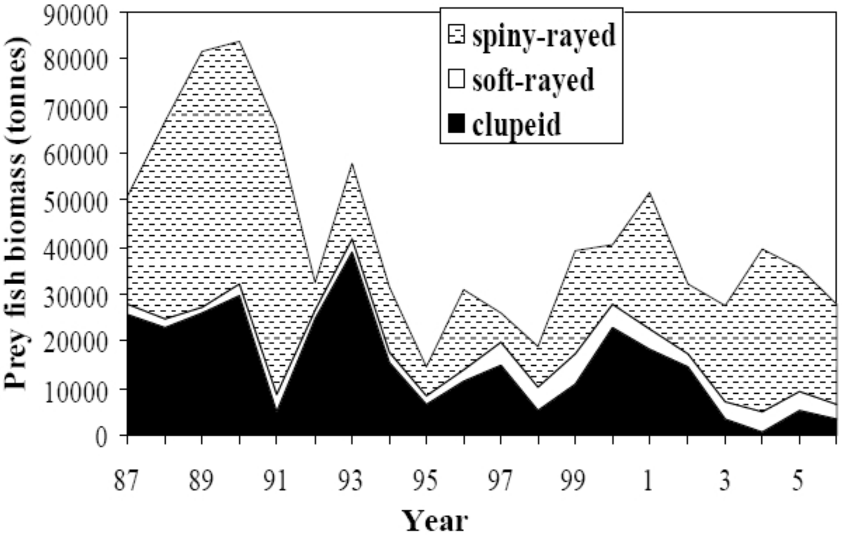

Figure 13: Mean biomass of prey fish in western Lake Erie, 1987-2006, by category (spiny-rayed = age-0 white perch, white bass, yellow perch, walleye, and freshwater drum; soft-rayed = age-0 rainbow smelt, emerald shiner, spottail shiner, chubs, trout-perch, and round gobies; clupeids = age-0 gizzard shad and alewife) (Figure from Murray et al. 2007).

In Lake Huron, where loss of prey species has been more substantial, overstocking of predator species for the sport fishery has been implicated in these losses. In such systems, control of predator populations is warranted to ensure that prey populations do not collapse. It could be argued that the removal of predators by the fishery in such a system is beneficial; however, it is apparent in the case of Lake Huron that consumption of prey biomass by stocked Chinook salmon has the greatest impact, with walleye consuming a relatively small proportion of the available prey (Fig. 14) (Dobiesz and Bence 2005).

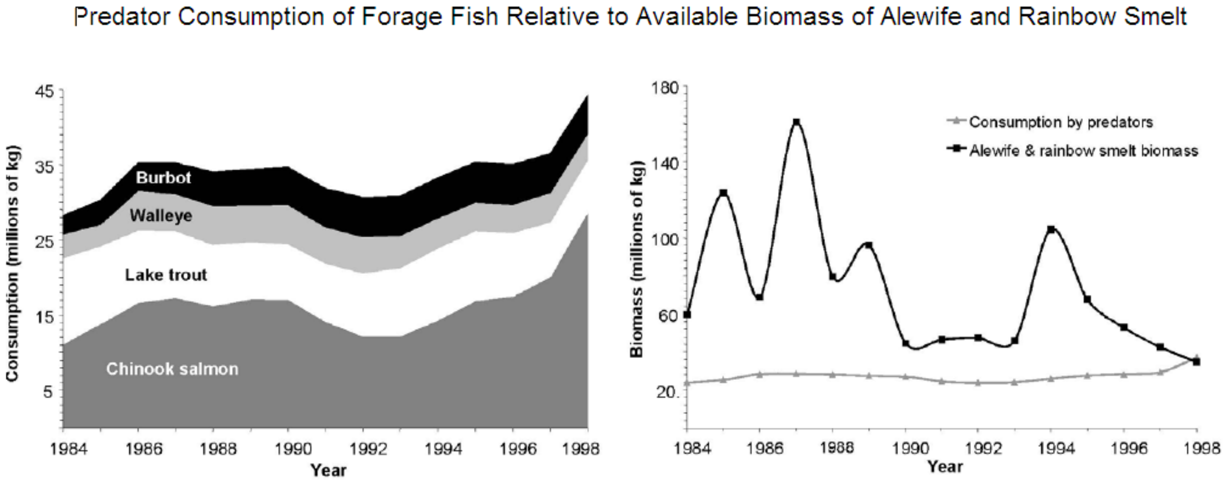

Figure 14: Prey biomass consumption by predator species in Lake Huron and consumption and biomass of alewife and rainbow smelt, 1984-1998 (Figure from Dobiesz and Bence 2005).

In the Ontario fishery predator-prey imbalances pose less of a problem than in US waters, as stocking of predator fish for sport fishing is not as prevalent.

Synthesis

Midwater gillnets are considered to have minimal habitat impacts, whereas in the absence of published studies bottom-set gillnets are of moderate concern. The walleye fisheries in Lake Erie and in Lake Huron, which could set gear either at midwater or on the lake bottom, are therefore also considered of moderate conservation concern. The ecosystem effects of removing walleye are considered benign, as walleye are not a major prey of any other species in Lake Erie or Lake Huron. In Lake Huron, where the decreasing forage base is subject to excessive predatory pressure due to large-scale predator stocking, the removal of some predators may be beneficial. Provided the removal of walleye is sustainably managed, the effect of fishing practices on habitats and ecosystems in these fisheries is considered to be a moderate conservation concern.

Effect of Fishing Practices Rank:

Benign 🟩 **Moderate 🟨** Severe 🟥 Critical ⬛

Criterion 5: Effectiveness of the Management Regime

Lake Erie

The Lake Erie Committee (LEC) is a binational group comprising senior members from several state and provincial agencies, including the Michigan Department of Natural Resources (MDNR), the New York State Department of Environmental Conservation (NYSDEC), the Ohio Department of Natural Resources (ODNR), the Ontario Ministry of Natural Resources (OMNR), and the Pennsylvania Fish and Boat Commission (PFBC). The Committee manages walleye on an allocation basis; the total allowable catch (TAC) set each year is shared among the jurisdictions (Fig. 15).

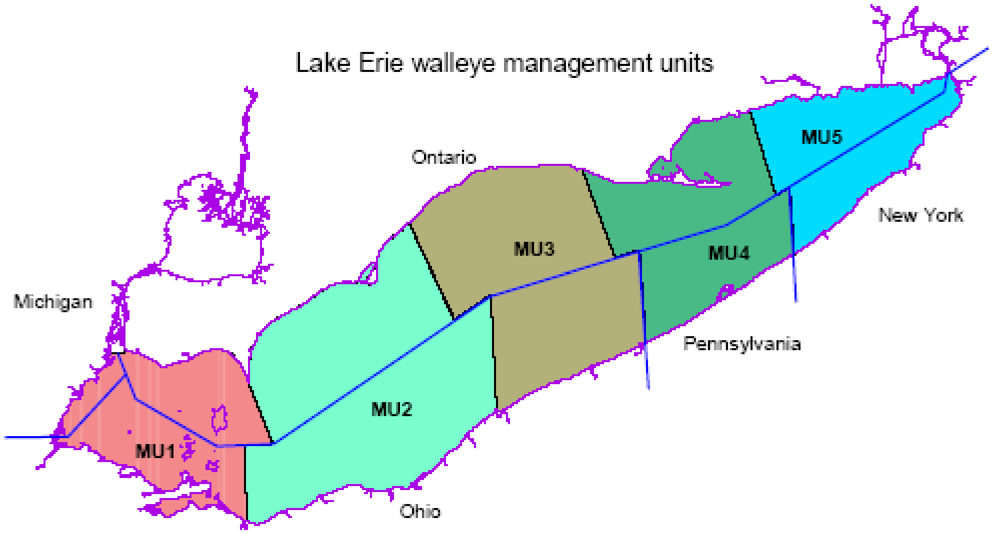

Figure 15: Management Units in Lake Erie (Figure from the Walleye Task Group report, Thomas et al. 2005).

Over recent years, the LEC has established a record of responsive and conservative walleye management that seeks to utilize the best available scientific methods. Following the walleye decline from the late 1980s to the early 1990s, the LEC instituted a Coordinated Percid Management Strategy (CPMS) that sought to rehabilitate walleye populations. The TAC was lowered to a much more restrictive value (30% below the previous target) and maintained until 2003. The objectives of this strategy were to: (1) reverse the observed walleye population declines; and (2) conduct research to improve abundance estimates and TAC determinations that would lead to sustainable catch levels. The first objective was partially met within three years, and in fulfillment of the second objective, the Committee had moved to state-of-the-art statistical and population modeling techniques to understand walleye stock status. These methods are continually updated as techniques evolve (Thomas et al. 2005).

Prior to the CPMS, walleye quotas, which had been in place since the mid-1970s, were based on walleye abundance estimates that used primarily fishery dependent data, estimated annual mortality rates, and survey data for only young-of-the-year (YOY) walleye. After the 1990s declines, it was decided that the population projections were too optimistic and stock analysis needed to incorporate catch-at-age analysis as well as additional fishery independent (survey) data (Locke et al. 2005). Through the CPMS process, the LEC moved to a statistical catch-at-age model that estimates abundance and mortality at various life stages and used longer time series to track population abundance (LEC 2004). The CPMS also instituted a number of controls on the walleye fishery. In Ontario, the commercial fishery was reduced and seasonal closures were instituted in the sport fishery. In sport fisheries in US waters of Lake Erie, minimum size limits were instituted in addition to creel (sport catch) and seasonal restrictions.

Since the CPMS was in place from 2000-2003, the walleye decline has been reversed, though the population has not yet been restored to previous highs due to continued variability in year class strength. Walleye year class strength is particularly sensitive to environmental conditions, and it is therefore difficult to predict the trajectory of population growth from year to year. In addition, the population biomass necessary to produce a strong year class is not well understood. Finally, the introduction of invasive species can have sudden, unanticipated and non-manageable effects on the predator-prey dynamics of a system, and therefore on walleye stock status. Though these are factors that management agencies such as the LEC have little or no control over, they can interfere with the effective management of walleye stocks and exacerbate the effects of fishery exploitation. In the face of this uncertainty, the LEC has responded to changes in walleye stock abundance proactively, changing the TAC to preserve not only total walleye biomass, but also to support a healthier age structure, protecting fish from poor year classes and ensuring a sufficient spawning population (Thomas et al. 2005).

Lake Huron

The Lake Huron Committee (LHC) consists of members from Michigan DNR, Ontario MNR, and the Chippewa-Ottawa Resource Authority. As a response to the GLFC's Joint Strategic Plan for Management of the Great Lakes, a set of Fish Community Objectives (FCOs) were developed for Lake Huron, including one for walleye. The goal of the walleye FCO is to: "reestablish and/or maintain walleye as the dominant cool-water predator over its natural range with populations capable of sustaining a catch of 0.7 million kg [1.54 million pounds]"(DesJardine et al. 1995). The current average total yield is well below half that, despite concerted stocking efforts. There are some concerns that such high levels of stocking, used to support sport and commercial fisheries, can damage the ability of the natural stock to recover due to a reduction in genetic diversity. Stocking programs are now attempting to stock a diverse mix of fish from natural tributary strains, as opposed to the Lake Michigan stocks used in the mid-1990s.

The main obstacles to walleye rehabilitation currently in Lake Huron are degraded spawning habitats, which must be rehabilitated before sufficient self-sustaining populations can be successful. In the meantime, there is a need to balance catch regulations and management activities, as stocking is occurring for a number of predator species all sharing the same forage base. In addition, much of the walleye stock caught in Lake Huron actually originates in Lake Erie and Lake St. Clair. With 60-70% of the walleye in Ontario waters of Lake Huron's main basin originating in Lake Erie, walleye management practice in Lake Erie will have substantial impacts on the health of the Lake Huron fishery (Scribner and Liskaukas 2005).

Table 3. Commercial catch management measures for the walleye fishery.

Management Jurisdictions & Agencies	Total Allowable Landings	Size Limit	Gear Restrictions	Trip Limit	Area Closures	Sources
Lake Erie Committee, Great Lakes Fishery Commission, Ontario Ministry of Natural Resources	Determined by LEC	Only as mesh size restriction in gillnets.	Mesh size restrictions in place.	None.	None for commercial fishery.	(LEC 2004; Locke et al. 2005; Thomas et al. 2005; LEC 2007)

Synthesis

Given the size of the Lake Erie fishery and its impact on the Lake Huron fishery, the effectiveness of the Lake Erie management regime dictates the overall state of walleye management in the Great Lakes commercial walleye fishery. This regime has, in the years since the 1990s decline in walleye abundance, reacted responsively to changes in walleye abundance, reducing TAC to protect vulnerable cohorts during years of weak recruitment, and keeping population assessment measures updated and based on sound science. This has led to the reverse of a severe declining trend despite highly variable recruitment and has kept the overall population safe from overfishing. The management of the Lake Erie walleye fishery is therefore deemed moderately effective, and would be highly effective if a bycatch management plan was in effect. Because of the lack of successful self-sustaining walleye populations in Lake Huron and the current stocking program in place, its management regime is also only deemed moderately effective.

Effectiveness of Management Rank:

Highly Effective 🟩 [✓ **Moderately Effective** 🟨] Ineffective 🟥 Critical ⬛

3-IV. Overall Evaluation and Seafood Recommendation

Walleye has been a staple of the Great Lakes commercial fishery since the end of the 19th century. It is a fairly resilient species, widely distributed throughout North America, capable of surviving under a variety of environmental conditions and of utilizing a variety of both fish and invertebrate prey. As such, they have been able to withstand, or rebound from, habitat change and deterioration more successfully than many other Great Lakes species. However, their spawning success is sensitive to environmental fluctuations, and thus their recovery has not been absolute. Large-scale fluctuations in year-class strength can make walleye particularly vulnerable to fishing pressure, as was evidenced during the 1990s declines of walleye in Lake Erie, where the major commercial fishery for walleye now operates.

The Lake Erie walleye stocks represent more than 97% of the commercial walleye catch in the Great Lakes, and are divided into the western/central basin stocks and the eastern basin stocks. The western/central basin stocks have always been the largest and most productive walleye stocks of all the Great Lakes. These stocks made a rapid and successful recovery from mid-20th century lows but declined again during the 1990s, driven by poor year classes combined with high fishing pressure. The institution of the Coordinated Percid Management Strategy by the Lake Erie Committee led to very restrictive catch limits and increased research efforts aimed at developing better stock assessment practices, and these management actions have prevented overfishing and ensured that populations remain above the biomass at maximum sustainable yield. Increasing the collection of fishery independent data has also reduced uncertainty around stock status; however, there is a continuing lack of knowledge of the links between spawning stock biomass, environmental variables, and year class strength (YCS). Continuing variability in YCS coupled with a population structure skewed to younger fish call for a continuation of cautious fishery management.

In the eastern basin of Lake Erie, stocks have always been much smaller than in the western/ central basin stocks, but were also more stable through the middle of the 20th century. However, fishing pressure in the eastern basin has steadily increased, and these stocks are likely to be more fully fished. As they are currently managed primarily outside of the main Lake Erie allocation zone that encompasses the western/central basin stocks, there is higher uncertainty in the status of eastern Lake Erie walleye. Preliminary assessments of eastern basin stocks indicate that both age and sex distributions are skewed; however, catch limits are in place and further assessments are ongoing.

Commercial walleye catches from Canadian waters of Lake Huron are relatively minor compared to those from Lake Erie, but still substantially larger than any US catch. Though populations on the US side, primarily from Saginaw Bay, are well studied, uncertainty in the status of the Canadian stocks is high. Populations are recovering from mid-century declines, but population size relative to maximum sustainable yield is unknown, little fishery independent data are available on stock health, and the age, size, and sex distributions are unknown. It is known, however, that up to 70% of the stocks in the main basin of Lake Huron actually originate in Lake Erie, and as such the health of the Huron fishery may in fact be driven by the health of the Erie fishery. This also highlights the fact that rehabilitation of walleye spawning grounds in Lake Huron still has some way to go before local spawning stocks and healthier, more genetically diverse walleye populations can thrive.

The directed effects of the fishery on the environment are thought to be low to moderate, but not enough data are available to sufficiently reduce uncertainty. No data are available on bycatch rates in commercial walleye fisheries in Lake Erie or Lake Huron, though the majority of the species present with walleye are either commercially landed (yellow perch) or too small to be captured in the large-mesh gillnets used in the fishery. Gillnets are known to have low selectivity and high mortality; therefore, further research is warranted. The possible presence of lake sturgeon in the area raises additional concerns.

The gillnets used in the walleye fisheries in Lake Erie and in Lake Huron are stationary, and direct habitat damage to lake bottoms has not been well described. The habitat impacts of these fisheries are therefore of moderate conservation concern. The ecosystem effects of removing walleye are likely benign, as walleye are not a major prey of any other species in Lake Erie or Lake Huron. In Lake Huron, where the decreasing forage base is subject to excessive predatory pressure due to large-scale predator stocking, the removal of some predators may be beneficial, though non-native predators such as Chinook salmon consume a much greater proportion of the available forage than walleye.

Though some uncertainties remain around the effects of the gear used in capturing walleye, the management of the Lake Erie walleye fishery has been highly successful in maintaining populations in the face of year-class variability and the associated steep decline in the 1990s. This binational regime has, in the years since the 1990s decline in walleye abundance, reacted responsively to changes in walleye abundance, reducing TAC to protect vulnerable cohorts during years of weak recruitment, and keeping population assessment measures updated and based on sound science. This has led to a fishery that has been able to reverse a severe declining trend despite highly variable recruitment and has kept the overall population safe from overfishing. Management has also sought out scientific advice on best management practices and continual improvement of their understanding of walleye population dynamics.

Walleye is deemed a moderately resilient species due to life history characteristics coupled with habitat loss and interactions with invasive species. Population abundance in the Canadian commercial fishery operating in Lake Erie, which in essence accounts for all of the Great Lakes catch, has increased steadily since mid-20th century lows but faltered again in the 1990s after a series of weak year classes, and is currently still rebuilding. There is still some concern regarding the use of gillnets in the fishery, as this gear is associated with low selectivity and high mortality rates, thus there is the potential for bycatch to become a substantial issue. However, other ecosystem effects of the fishery are low and the management of the Lake Erie fishery has been deemed highly effective. Overall, walleye is thus recommended as a “**Good Alternative**”.

Table of Sustainability Ranks for Walleye

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability		√		
Status of Stocks		√		
Nature of Bycatch		√		
Habitat & Ecosystem Effects		√		
Management Effectiveness		√		

Overall Seafood Recommendation for Walleye

Best Choice 🟩

Good Alternative 🟨

Avoid 🟥

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Chapter 4: Yellow Perch

Perca flavescens

(Image by Duane Raver, courtesy of USFWS Digital Library System)

4-I. Executive Summary

Yellow perch (*Perca flavescens*) is found widely in the US and Canada including all the regions from Nova Scotia south to South Carolina, west to Kansas, and north across the Montana border through much of Alberta to the southern Northwest Territories. It is a popular sport fish and has been introduced through much of the western United States where its native range did not originally extend.

Commercial fisheries for yellow perch currently exist throughout the Great Lakes, but by far the majority (85%) is caught from US and Canadian waters of Lake Erie. It is currently one of the three largest freshwater fish exports from Canada, with markets primarily in the US Great Lakes region. Smaller yellow perch fisheries exist in Lake Ontario (8% of total catch), Lake Huron (6% of total catch), and Lake Michigan's Green Bay (1% of total catch). The recommendations made in this report will be driven by the status of yellow perch populations and management in Lake Erie.

As occurred with many other Great Lakes species, yellow perch abundance fluctuated dramatically in the period between 1940 and 2000, due to the effects of habitat loss (particularly loss of spawning habitat), interaction with invasive species such as alewife, dreissenid mussels, and white perch, and overfishing. It is a testament to their inherent resiliency that yellow perch populations have tended to rebound quickly when pressures are removed. In the 1980s, as nutrient abatement programs and the initial spread of invasive mussels reversed the effects of eutrophication, which had dominated from the 1950s through the 1970s, and the invasive alewife began to decline in many lakes, yellow perch populations grew to historic levels. In the 1990s, however, a new period of decline began. Though the causes behind this recent decline are still being debated, it coincided with a period of continued invasive mussel proliferation that pushed a number of Great Lakes systems towards oligotrophy, reducing nutrient availability to juvenile perch. At the same time, populations of double-crested cormorants, a piscivorous bird once endangered in the Great Lakes, began to rebound as a result of contaminant declines. Cormorants are now thought to consume a substantial number of yellow perch in regions near nesting colonies and this has been of particular concern in Lake Ontario, Lake Huron, and Lake Michigan's Green Bay.

The 1990s yellow perch decline prompted an overhaul of Lake Erie stock assessment and management procedures, resulting in a TAC-setting system that incorporates substantial fishery independent and dependent data and environmental factors. The new management measures have been highly effective in maintaining yellow perch populations in Lake Erie, despite some year-class-strength and recruitment variability. Of most continuing concern is the lack of a systematic study of fishery gear impacts in the yellow perch fishery, both in terms of bycatch issues and the effect of removing yellow perch in a system where the forage base appears unstable. The gillnets used in the Canadian fishery, for example, have been shown to capture some immature walleye. Though this number is small compared to the size of the yellow perch catch (less than 5%), the effect of removing immature walleye from a population that has also seen substantial declines in recent years is still unknown but may be substantial.

Overall, increasing populations (as evidenced by increased catch per unit effort throughout most of Lake Erie), an effective management regime, and inherently resilient species characteristics make yellow perch caught in Lake Erie a "**Best Choice**," though some uncertainties and concerns remain around the impacts of the fishing method (primarily gillnets) in terms of bycatch rates and ecosystem effects. In Lake Huron and Lake Ontario, where the yellow perch fishery is much smaller, stock assessments need to be further developed and management effectiveness is complicated by the presence of cormorants that may be a substantial factor in structuring perch populations. Without a good sense of how many yellow perch are being taken by both fisheries and cormorants, and without good measures of population abundance, there is no way to accurately determine whether current exploitation rates are appropriate in the fisheries of these two lakes. Yellow perch from these smaller fisheries in Lake Huron and Lake Ontario are therefore recommended as "**Good Alternatives**."

Table of Sustainability Ranks for Yellow Perch

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability	√			
Status of Stocks	√ Lake Erie	√ Lake Huron, Lake Ontario		
Nature of Bycatch		√		
Habitat & Ecosystem Effects		√		
Management Effectiveness	√ Lake Erie	√ Lake Huron, Lake Ontario		

About the Overall Seafood Recommendation:

- A seafood product is ranked Best Choice if three or more criteria are of Low Conservation Concern (green) and the remaining criteria are not of High or Critical Conservation Concern.
- A seafood product is ranked **Good Alternative** if the five criteria "average" to yellow (Moderate Conservation Concern) OR if the "Status of Stocks" and "Management Effectiveness" criteria are both of Moderate Conservation Concern.
- A seafood product is ranked **Avoid** if two or more criteria are of High Conservation Concern (red) OR if one or more criteria are of Critical Conservation Concern (black) in the table above.

Overall Seafood Recommendation for Yellow Perch

Lake Erie:

[✓ **Best Choice** 🟩] Good Alternative 🟨 Avoid 🟥

Lake Huron, Lake Ontario:

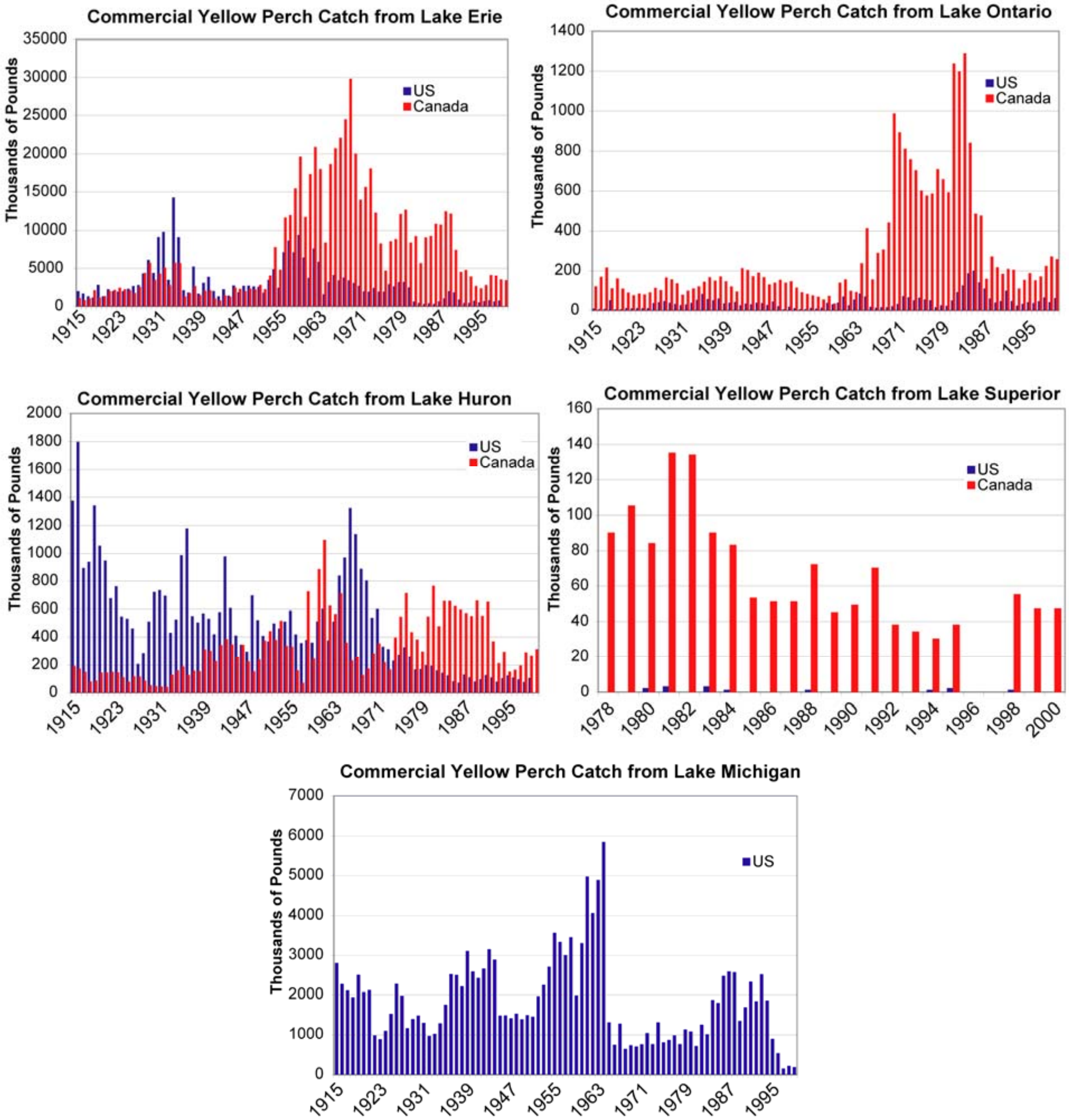
Best Choice 🟩 [✓ **Good Alternative** 🟨] Avoid 🟥

4-II. Introduction

Yellow perch (*Perca flavescens*) is native to Canada from Nova Scotia through Alberta, and in the United States its native range includes most of the country east of the Rockies and as far south as North Carolina. It has also been stocked in many other US states and river drainages, and can now be found in drainages in the west extending from the Pacific Ocean to the Bering Sea. It is a temperate freshwater fish preferring cool summer temperatures (64-77ºF) and clear waters with moderate vegetation, and is often found in the same environment as its larger percid relative, the walleye.

Yellow perch are visual predators, feeding primarily at dusk and dawn, and rarely at night. Young consume primarily zooplankton, switch to benthic invertebrates in their first year, and can consume both invertebrates and fish as adults. Their diets are fairly plastic and can vary according to prey abundance, and they feed actively all year round (Downs et al. 2002). Yellow perch occupy an intermediate position in aquatic food webs, as they prey on other fish but are also consumed by top predator fish such as walleye and northern pike.

Yellow perch were not in great commercial demand in the first half of the 20th century, when more valuable stocks such as blue pike and whitefish were in high demand. However, depletion of these more valuable stocks in the mid-20th century led to increasing catches of yellow perch in Lake Erie, Lake Huron, Lake Ontario, and Lake Michigan. Lake Superior provided only fringe yellow perch habitat in its shallow bays and tributaries; the majority of its deep, cold, oligotrophic waters were not suitable yellow perch habitat. Catches in the Great Lakes then fluctuated as yellow perch stocks responded to the combined stresses of fishing pressure, habitat loss, and competition with invasive species (Fig. 1).



Commercial Yellow Perch Catch from Lake Erie

Commercial Yellow Perch Catch from Lake Ontario

Commercial Yellow Perch Catch from Lake Huron

Commercial Yellow Perch Catch from Lake Superior

Commercial Yellow Perch Catch from Lake Michigan

Figure 1. Commercial yellow perch catches from US and Canadian waters of the Great Lakes. Note that scales are substantially different; catches from Lake Erie, Lake Michigan, and Lake Ontario historically dominated. The commercial fishery in Lake Michigan's main basin closed in 1997. Currently, the majority of wild-caught perch comes from Lake Erie (Figure from Baldwin et al. 2002).

In Lake Erie, peak yellow perch catches occurred in US waters from the late 1920s to the mid-1930s, though yellow perch at that time were relatively unimportant in the Lake Erie commercial fishery as other more valuable fish dominated (Ryan et al. 2003). By 1950, however, stocks of lake herring, lake whitefish, and blue pike, once the mainstays of the commercial fishery, had undergone severe decline brought on by overfishing, the population explosion of the invasive rainbow smelt (*Osmerus mordax*), and environmental degradation (Hartman et al. 1980). At this time, the fishery switched to exploiting the lake's percids: yellow perch and walleye. Over the next decades, yellow perch catches grew rapidly from annual averages of 4 million pounds (1940s) to a high of 34 million pounds in 1969 (partially reflecting the very large 1965 year class). Peak yellow perch catches occurred lakewide (both US and Canadian waters) in the 1950s and 1960s. Shortly thereafter, however, stocks began to decline and by the mid-1970s had fallen to less than 10 million pounds, apparently due to recruitment failure. No strong year classes were produced between 1966 and 1975, and recruitment destabilized (Fig. 2) (Hartman et al. 1980).

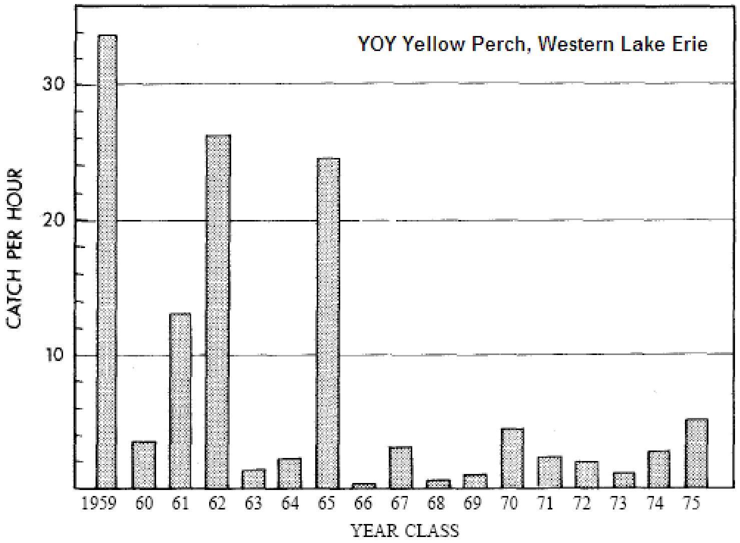


Figure 2: Abundance of young-of-the-year (YOY) yellow perch in Lake Erie, 1959-1975 (Figure from Hartman et al. 1980).

In the 1980s, partially as a result of management practices instituted in Lake Erie in the mid-1970s, yellow perch entered another period of population expansion. Their numbers reached near record levels, but declined again during the 1990s, coinciding with the oligotrophication that resulted from dreissenid mussel proliferation in the lake. The filtration of the lake's water by zebra and quagga mussels reduced nutrient availability in the water column and led to a decline in zooplankton abundance, thereby reducing food available to juvenile perch.

A stricter management strategy was undertaken in Lake Erie at the end of the 1990s to reverse the declines observed in both yellow perch and walleye populations. Though year class strength has continued to vary, yellow perch remain a major commercial catch in Lake Erie, which currently yields about 85% of the total Great Lakes yellow perch catch. Canadian waters account for 66% of this catch, while US waters account for 19%. The Canadian yellow perch catch is one of the three largest catches in the freshwater Canadian fisheries, together with walleye and lake whitefish (Baldwin et al. 2002; FAO 2002).

Yellow perch catches in Lake Huron, much as in Lake Erie, were secondary to more valuable commercial catches in the first half of the 20th century. Changes in market demand led to highly variable catches, ranging from a high of 242,000 pounds in 1942 to a low of 60,000 pounds in 1959. Yellow perch were typically caught using small-mesh gillnets when lake trout or lake whitefish were not available (Smith 1995). As occurred in other Great Lakes, a combination of negative impacts of the invasive alewife (*Alosa pseudoharengus*) and habitat degradation in the middle of the 20th century led to a decline in the yellow perch population in Lake Huron. The population has remained fairly low since then, though some populations appear to be improving. Commercial catches from Lake Huron currently account for 8% of the total yellow perch catch in the Great Lakes, of which 6% is from Canadian waters and 2% is from US waters (Baldwin et al. 2002).

In Lake Ontario yellow perch abundance has varied substantially depending on location. Catches increased dramatically in the middle of the 20th century, then declined due to the negative effects of the introduced alewife and of habitat disruption. The largest yellow perch catches were from the Bay of Quinte and the eastern Outlet Basin, whereas western and central Lake Ontario catches were always relatively minor. Yellow perch catches from the Bay of Quinte underwent three distinct, and declining, periods: between 1905 and 1924, catches amounted to more than 60% of the lakewide totals; between 1925 and 1959 catches accounted for about 37%; and between 1960 and 1969 Bay of Quinte catches accounted for only 19-25%. In this last period, catches outside the bay were increasing dramatically (Fig. 3) (Christie 1973a).

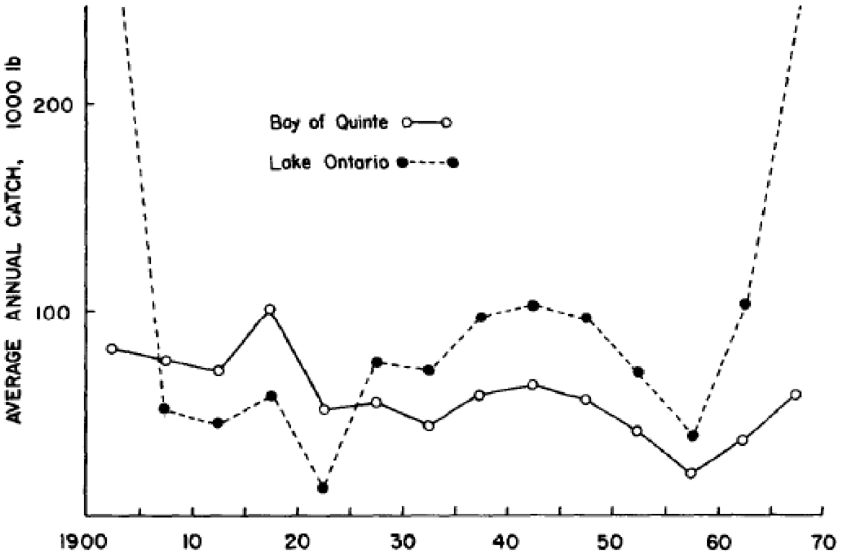


Figure 3: Trends in yellow perch catches in Lake Ontario (Figure from Christie 1973a).

High abundance of yellow perch in the 1960s and 1970s likely coincided with increased nutrient inputs combined with decreased predator abundance in the lake. From 1976-1977, there was a major alewife decline, which was followed by a substantial increase in yellow perch (Hoyle et al. 2007) as larval yellow perch were released from alewife impacts. When alewife abundance increased in the 1990s, yellow perch stocks fell, until alewife populations began to decline again in the mid-1990s (Stewart et al. 1999). Currently, commercial catches from Lake Ontario constitute 6% of the total Great Lakes catch, with 4% coming from Canadian waters and 2% from US waters (Baldwin et al. 2002).

In Lake Michigan yellow perch appears to have followed 20-25 year abundance cycles. Populations increased in the 1970s and continued to be strong through the 1980s, followed by a strong decline in the 1990s. The commercial fishery in the main basin was closed in 1997.

Following the closure, the year class in 1998 was the strongest in ten years (though not as strong as those in the 1980s), becoming the strong adult class of 2003. Good year classes were produced in 2003 and 2005, and moderately strong year classes were produced in 2002 and 2004 (Mangan 2006). Though much lower than historic levels, the increased yellow perch abundance allowed the Green Bay commercial fishery to expand. The strong year classes produced between 2002 and 2005 led to a proposed 3-fold increase in commercial quota from 20,000 to 60,000 pounds. Currently, Lake Michigan's fisheries are primarily managed for recreational catches. Between 2000 and 2005 the commercial catches from state-licensed fisheries in Wisconsin averaged about 26,000 lbs, substantially lower than the 1999 catch of nearly 173,000 lbs. Catches from Wisconsin waters in these years have represented between 80 and 99% of the total commercial yellow perch catch from Lake Michigan. Catches from Lake Michigan represent only 1% of the total Great Lakes yellow perch catch (Baldwin et al. 2002; Kinnunen 2003b), but the Lake Michigan fishery may expand if populations continue to grow.

Scope of the analysis and the ensuing recommendation:
This analysis will focus on the yellow perch fishery in Lake Erie, which accounts for the majority (85%) of Great Lakes yellow perch catches and the bulk of US yellow perch imports from Canada. Catches from US and Canadian waters in Lake Huron and Lake Ontario make up most of the balance (8% Lake Huron, 6% Lake Ontario), while US catches from Lake Michigan are very small and account for only 1%, and no yellow perch fishery exists in the cold, oligotrophic waters of Lake Superior (Fig. 4). The status of yellow perch populations in Lake Erie will therefore drive the overall recommendation for yellow perch in the Great Lakes region.

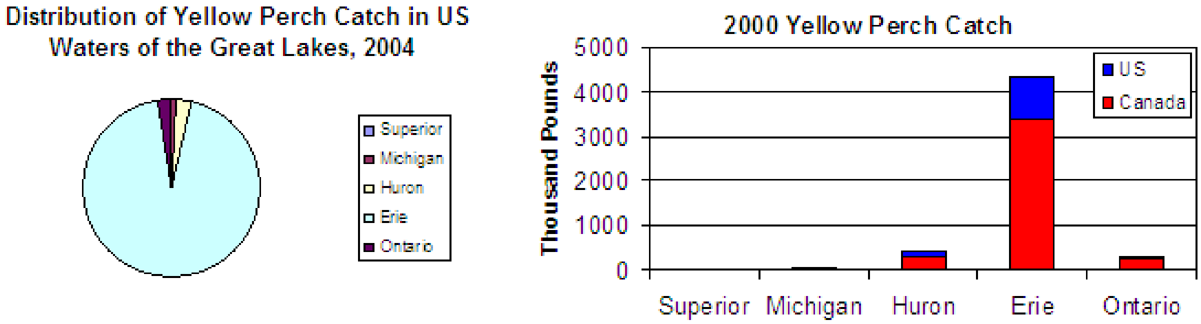


Figure 4: US and Canadian distribution of yellow perch catch, 2000 and 2004 (Figures adapted from Baldwin et al. 2002 and Kinnunen 2003b).

Availability of Science

Yellow perch stock assessments have occurred throughout the Great Lakes since the 1970s, when a period of decline in percids (walleye and yellow perch, both important species in the commercial fisheries) led to implementation of new fishery and ecosystem management practices, including increased stock monitoring. Yellow perch stocks throughout the basin experienced severe declines in the 1990s, which led to much concerted research effort into the suite of environmental factors that could play a role in these declines—habitat loss, fishing pressure, and invasive species. Consequently, a large body of work is available that deals with yellow perch stock status, particularly in Lake Erie where the majority of commercial fishing occurs. As with most Great Lakes studies available, these tend to concentrate on ecosystem factors (temperature, species interactions) and there is less information available on the effects of fishing practices themselves (e.g., habitat disruption, bycatch).

Market Availability

Common and market names:
Yellow perch, *Perca flavescens*, is also known as lake perch, ringed perch, raccoon perch, Ned, yellow Ned, redfin, and redfin perch.

Seasonal availability:
Yellow perch is available year-round.

Product forms:
Yellow perch can be found fresh or frozen, sold primarily as scaled, skin-on fillets.

Import and export sources and statistics:
The largest market for yellow perch in the United States is in the Great Lakes region, where fresh perch fillets can attain the highest price per pound. US demand for yellow perch makes it one of Canada's largest and most valuable freshwater fishery exports, together with walleye and whitefish (Fig. 5).

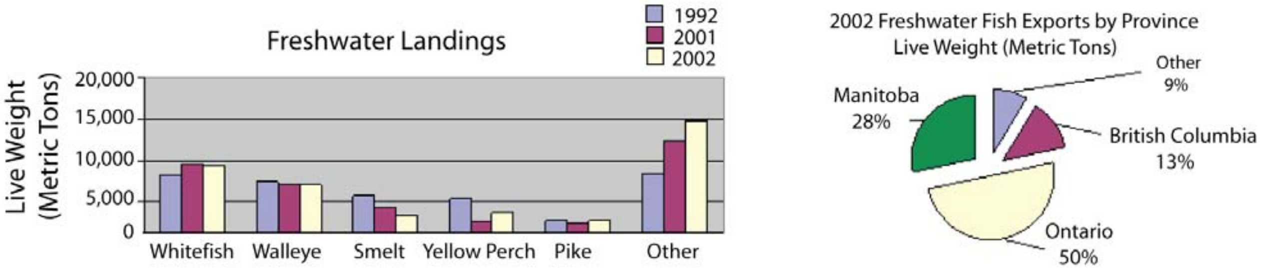


Figure 5: Canada's freshwater fish exports in 2002 (Figures from FAO 2002).

The demand for yellow perch in the Great Lakes region has been estimated to reach about 50-100 million pounds annually (Hinshaw 2006). Currently, close to two million pounds are commercially harvested within the US, primarily from Ohio waters of Lake Erie. Nearly twice that, just under four million pounds, is imported, nearly all of it from Canadian commercial Great Lakes fisheries operating in Ontario (Baldwin et al. 2002; FAO 2002; Hinshaw 2006).

4-III. Analysis of Seafood Watch® Sustainability Criteria for Wild-caught Species

Criterion 1: Inherent Vulnerability to Fishing Pressure

Yellow perch (*Perca flavescens*) is broadly distributed throughout North America. Its native range extends from Nova Scotia west through most of Alberta and to the Northwest Territories in Canada, and south into the US as far as North Carolina in the east and Kansas in the west (Downs et al. 2002). Its range has been further expanded by largely deliberate introduction as sport and food fish as far west as the Pacific Ocean and north to the Bering Sea.

In the Great Lakes region, yellow perch occupy an intermediate trophic position. Young yellow perch are planktivorous, while adults consume both zooplankton and benthic invertebrates. They are visual predators that feed at dusk and dawn, and form schools during the day that are thought to protect the young from predation and compensate for poor swimming ability. Major predators of yellow perch include walleye, northern pike, and cormorants.

Yellow perch are a cool-water (64-77°F) temperate species requiring mesotrophic waters that sustain sufficient zooplankton density to support juveniles. Some populations spawn over near-shore aquatic vegetation, which require clear water, while populations in areas without vegetation, such as Lake Michigan’s main basin, spawn over rocks or other hard substrates. Clear waters are also crucial for successful hatching, as siltation can inhibit or prevent egg development (Ryan et al. 2003). Given these conditions, yellow perch populations can expand relatively rapidly, as they mature quickly and can produce many offspring. The minimum doubling time for yellow perch populations ranges between 1.4 and 4.4 years, corresponding to a high intrinsic growth rate (r=0.16-0.495) (Froese and Pauly 2007). Yellow perch caught in the Great Lakes typically reach 7 years of age, though one study in Lake Michigan reported perch as old as 15 years (Marsden and Robillard 2004), and typically grow to 6-10 inches (152-254 mm) total length.

Age at maturity in yellow perch depends on food availability, environmental conditions, and gender. Yellow perch are sexually dimorphic, with larger, slower-growing females maturing at age 2-4 while males reach maturity between years 1 and 3. Spawning success in yellow perch is a function of the fecundity of the female population, the size of the spawning stock, and in particular the body condition of females in the autumn prior to spawning (Henderson et al. 2000). Spawning occurs when water temperature reach 45-52ºF (typically April through early June in the Great Lakes). Adults move from deep water in the winter to shallow spawning grounds, where females release egg strands up to six feet in length that drift along the bottom, often becoming entangled in aquatic vegetation. Fecundity is strongly related to fish size; in Lake Erie, an 8-inch female perch can produce on average 17,000 eggs, while a 10-inch female produces nearly 40,000 eggs. A very large (12-inch) fish can produce as many as 74,000 eggs (Fig. 6) (Hartman et al. 1980).

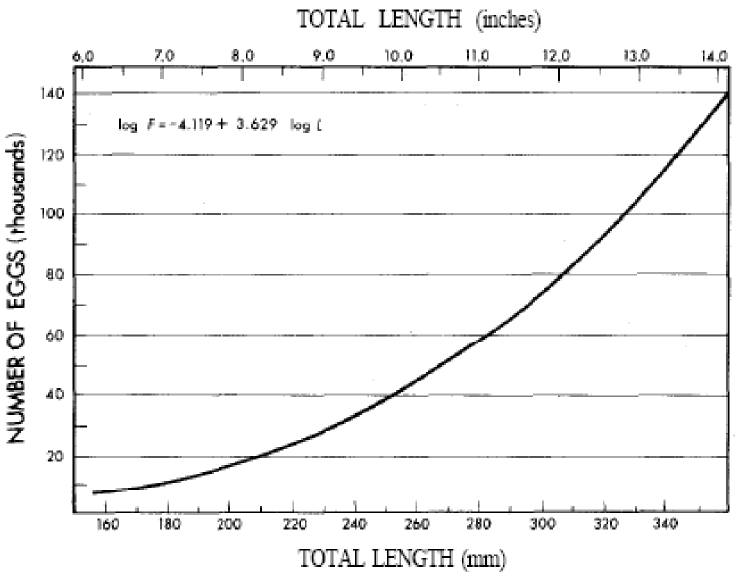


Figure 6: Relationship between total length and fecundity (number of eggs) in Lake Erie yellow perch (Figure from Hartman et al. 1980).

Fecundity can also be affected by population density and the availability of food. Yellow perch populations are prone to "stunting," where perch populations will not grow as quickly, or to as large a size, under sub-optimal conditions (heavy competition, low food resources, etc.). In such cases, perch often mature earlier and their fecundity (number of eggs, egg quality) will be lower. Fishing mortality that removes all larger/older fish can have substantial effects on yellow perch population stability, as it reduces not only the number of yellow perch at maturity, but also the number of times adult perch can spawn in their lifetime.

Once hatched, larval yellow perch drift in the pelagic zone. During this larval stage, yellow perch first feed from a yolk sac, then move to active feeding on zooplankton at around 7 mm in length. Young of the year (YOY) perch switch to consuming benthic invertebrates during midsummer. As adults, yellow perch consume a combination of zooplankton, benthic macroinvertebrates, and fish. One of the more resilient characteristics of yellow perch is a relatively plastic diet, which allows it to take advantage of available prey more readily than other fish. In Lake Erie, for example, yellow perch consume primarily zooplankton and benthic invertebrates, but in autumn, after other fish populations have spawned, can consume a variety of small forage fish (Bur et al. 2007). White perch (*Morone americana*), a non-native species that competes with the yellow perch, on the other hand, maintains a higher proportion of zooplankton in its diet year-round. Flexibility in the yellow perch diet has allowed it to adapt well to lower-trophic level changes occurring in the Great Lakes throughout the latter half of the 20th century, such as reduced overall zooplankton abundance following zebra mussel proliferation during the 1990s.

In spite of this native resilience, however, there have been a number of non-fishery pressures that have affected yellow perch populations in the Great Lakes. Beginning in the middle of the 20th century, eutrophication, loss of macrophyte beds, and competition with invasive species including alewife (*Alosa pseudoharengus*) and white perch, led to reduced spawning, recruitment failure, and a general decline in yellow perch populations (Ryan et al. 2003). Nutrient abatement measures and a decline in alewife numbers beginning in the mid-1970s led to a resurgence in yellow perch populations in the 1980s that peaked at or above historic levels (Stewart et al. 1999; LEC 2004; Hoyle et al. 2007). Since then, however, the invasion of dreissenid mussels has moved the lake from mesotrophic to oligotrophic conditions. Although the high filtering capacity of these mussels initially resulted in a beneficial "cleanup" of the Great Lakes, leading to improved populations of a number of species that had declined during earlier eutrophic periods (particularly in Lake Erie), they eventually began to reduce the total amount of zooplankton present in many of the Great Lakes. This had a negative impact on many species including yellow perch, which rely on zooplankton prey during their juvenile stage (USGS 2007a). As a result, recruitment failure caused a dramatic decline in yellow perch populations in the 1990s. In some areas of Lake Huron and Lake Ontario, the recovery of double-crested cormorants (*Phalacrocorax auritus*) has also been reducing yellow perch populations. These fish-eating birds, once threatened in the Great Lakes, have increased as much as eight-fold in Lake Huron and Lake Ontario, and have been estimated to consume up to 48% of year-1 yellow perch, and 20% of age-2 and age-3 yellow perch (Burnett et al. 2002; Fielder and Thomas 2006).

Table 1. Life history characteristics of yellow perch.

Intrinsic Rate of Increase (r)	Age at Maturity	Growth Rate	Max Age	Max Size	Fecundity	Species Range	Special Behaviors	Sources
0.16-0.495	1-4 years	K=0.17-0.19	15 years	10-15 inches	17,000-74,000 eggs/female, depending on size.	Broadly distributed throughout North America.	Require mesotrophic conditions, clear water and aquatic vegetation for spawning.	(Hartman et al. 1980; Ryan et al. 2003; Marsden and Robillard 2004; Froese and Pauly 2007)

Synthesis

Yellow perch is a fairly resilient species, with diets and growth rates that can change in response to environmental conditions. It reaches maturity quickly (at 1-4 years) and can produce a large number of eggs, particularly with increasing size. At low population density and with adequate prey availability, populations can double over a short time. Nonetheless, yellow perch are vulnerable to habitat loss, as clear water is necessary for successful spawning. In the Great Lakes, habitat degradation through declining water quality resulted in substantial declines in the mid-20th century. In addition, interactions with invasive species (most notably competition with alewife and white perch and the oligotrophication and loss of zooplankton associated with dreissenid mussels) have led to instability in yellow perch spawning and recruitment, particularly during the 1990s. In spite of these non-fishery impacts, the rapid rebuilding of yellow perch populations that occurred when some of these stresses were removed (for example, the 1980s population growth when nutrient mitigation programs began to reverse eutrophication and alewife populations declined) have demonstrated an inherent resilience in this species.

Inherent Vulnerability Rank:

Resilient 🟩 Moderately Vulnerable 🟨 Highly Vulnerable 🟥

Criterion 2: Status of Wild Stocks

Lake Erie

Long-term Trends

After steep declines observed in the Lake Erie yellow perch fishery in 1970s, the increase in yellow perch populations during the 1980s seemed to indicate a complete recovery, with abundance reaching historic highs. However, this population growth reflected a movement of the Lake Erie ecosystem through an ideal mesotrophic state as nutrient abatement programs from the 1970s and initial effects of the zebra mussel invasion reversed the eutrophication of the mid-20th century. This helped restore an important benthic prey item for the yellow perch, the *Hexagenia* mayfly (Masteller and Obert 2000), and allowed for the return of aquatic macrophytes crucial for yellow perch spawning success. However, the ecosystem continued on the trajectory of nutrient reduction as dreissenid mussel populations expanded and has continued to change in response to human activity and new species invasions and expansions.

In the 1990s, a second abrupt decline in yellow perch abundance occurred, largely driven by loss of suitable spawning habitat, overexploitation, and competition with the invasive white perch. The expansion of filter-feeding mussels drove Lake Erie's trophic status too far towards oligotrophy, decreasing food supply to planktivorous larval yellow perch and reducing recruitment (Fig. 7).

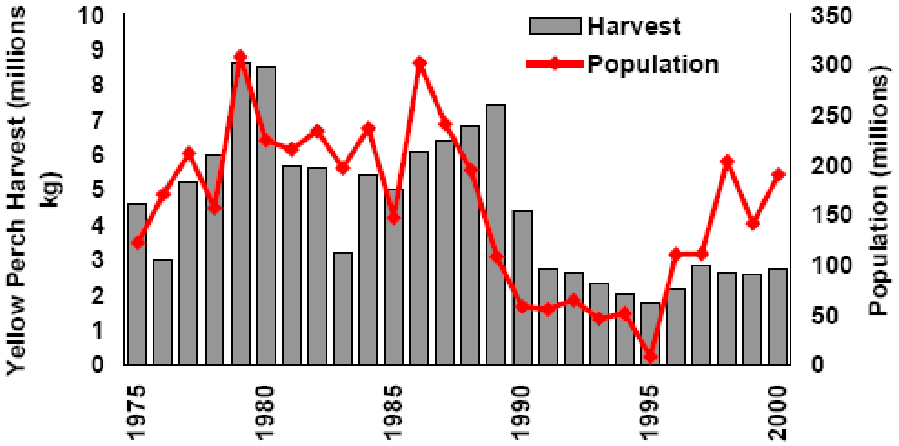


Figure 7: Yellow perch commercial catch and estimated abundance, 1975-2000 (Figure from Ryan et al. 2003).

The precipitous decline in yellow perch in the 1990s led to management action that substantially reduced exploitation and the rebuilding of stocks. There were several good yellow perch year classes through 2000 (Ryan et al. 2003).

Current Status

In recent years recruitment of yellow perch has remained highly variable, though with a number of very strong year classes, 2003 and 2005 in particular. In general, the total allowable catch (TAC) in Lake Erie has increased or remained the same, even between 2001 and 2003, when a conservative management strategy was undertaken to help reverse declining trends in both yellow perch and walleye populations under the auspices of the Lake Erie Committee's Coordinated Percid Management Strategy (CPMS) (LEC 2004).

TACs in Lake Erie are allocated by management unit (Fig. 8), and the distribution of these quotas among recreational and commercial catches differs from jurisdiction to jurisdiction. Historically, 80% of Lake Erie's yellow perch catch has come from the western basin and from the western end of the central basin (MU1 and MU2) (Belore et al. 2005).

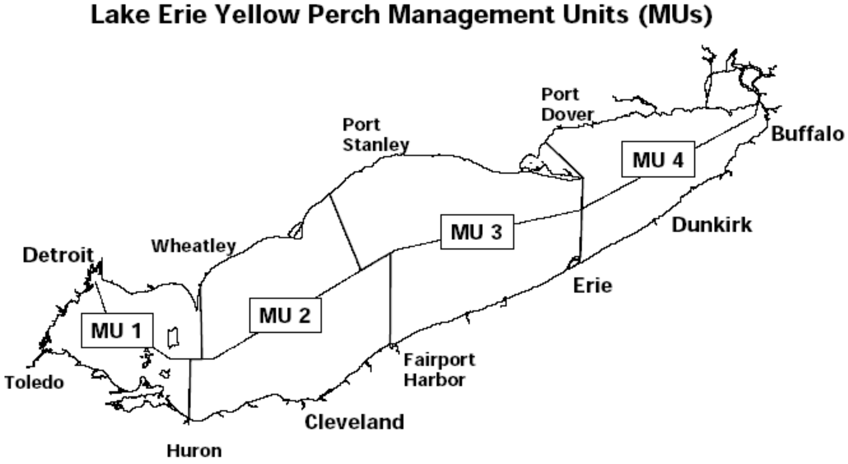


Figure 8: Yellow perch management units in Lake Erie (Figure from Belore et al. 2005).

The TAC for yellow perch in Lake Erie was set at 9.9 million fish in 2003, increased to 11 million in 2004 and 11.7 million in 2005, and then increased substantially to 16.48 million fish in 2006 when the strong 2003 year class would have recruited to the fishery. Catch in 2006 was closer to the 2004-2005 TACs, however, at 11.1 million pounds. To protect smaller 2002 and 2004 size classes, the TAC was reduced to 11.389 million fish in 2007 (LEC 2007). Generally, however, TAC and catch have remained relatively steady since 2000. In many jurisdictions, effort has remained constant or declined while catch per unit effort (CPUE) has increased, a strong positive sign that yellow perch populations are expanding (Fig. 9 through Fig. 12).

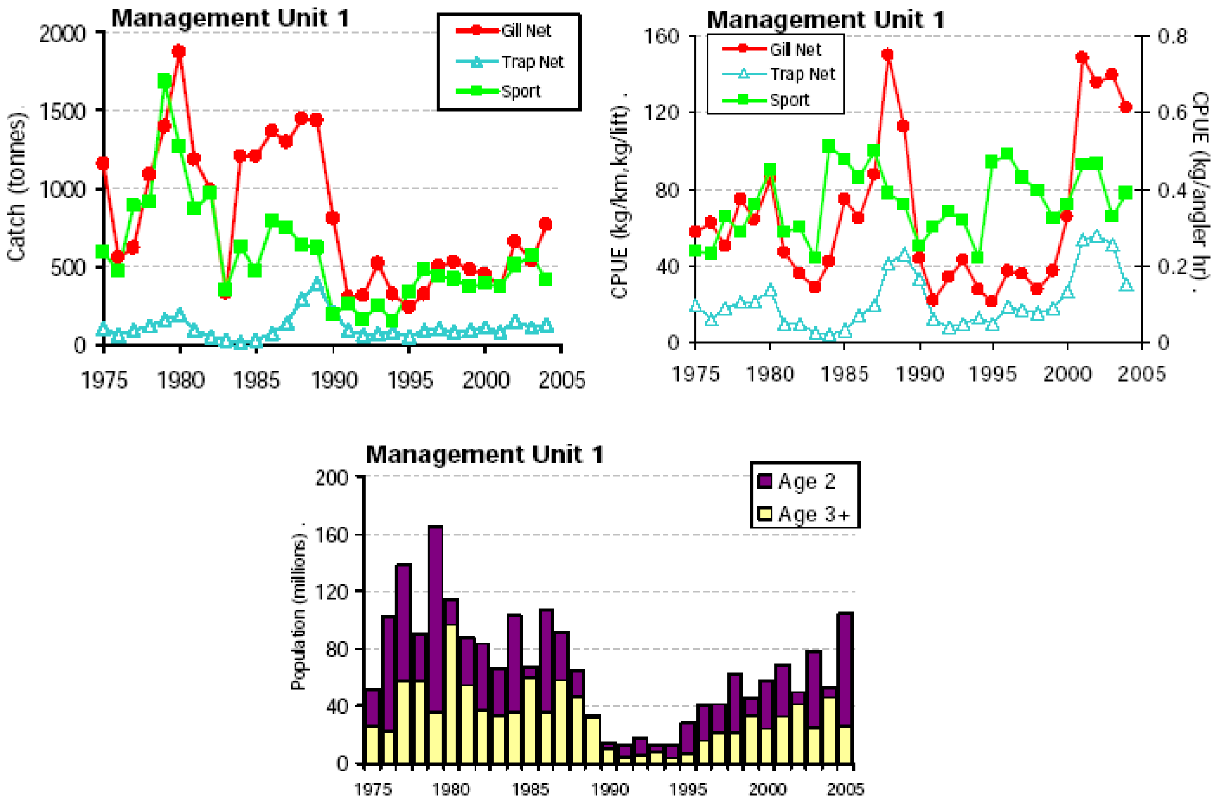


Figure 9: Annual catch, catch per unit effort, and population age composition in MU1 (Figure from Belore et al. 2005).

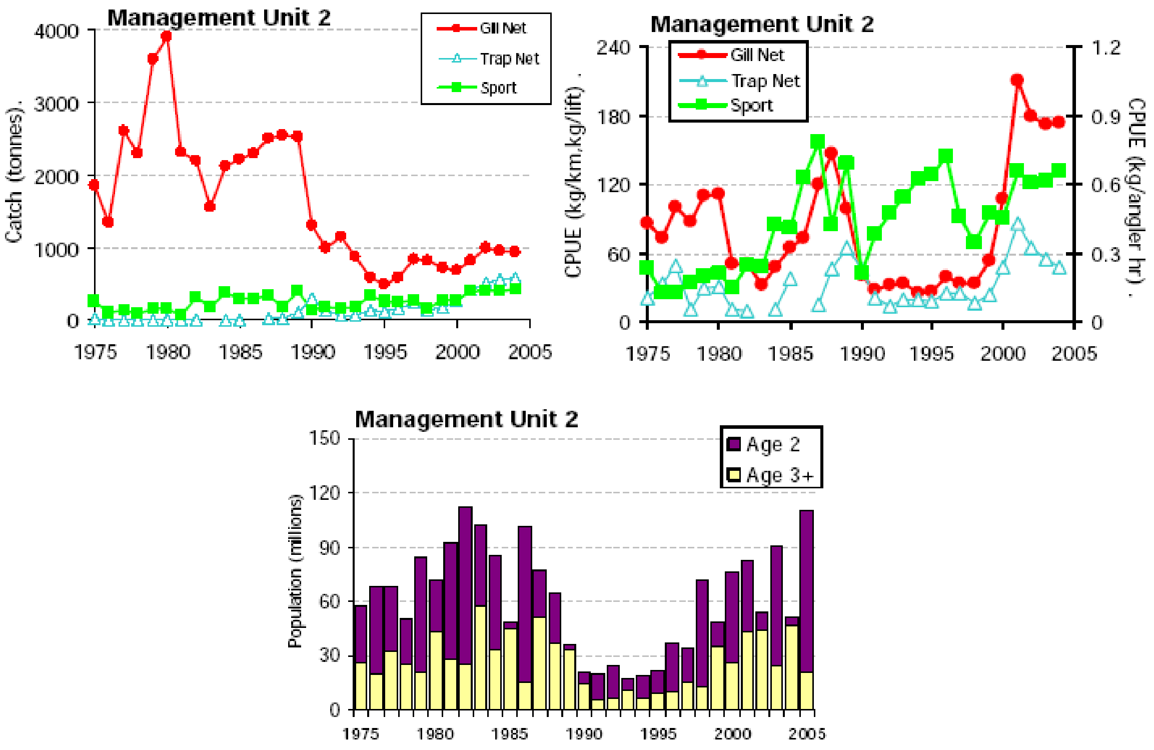


Figure 10: Annual catch, catch per unit effort, and population age composition in MU2 (Figure from Belore et al. 2005).

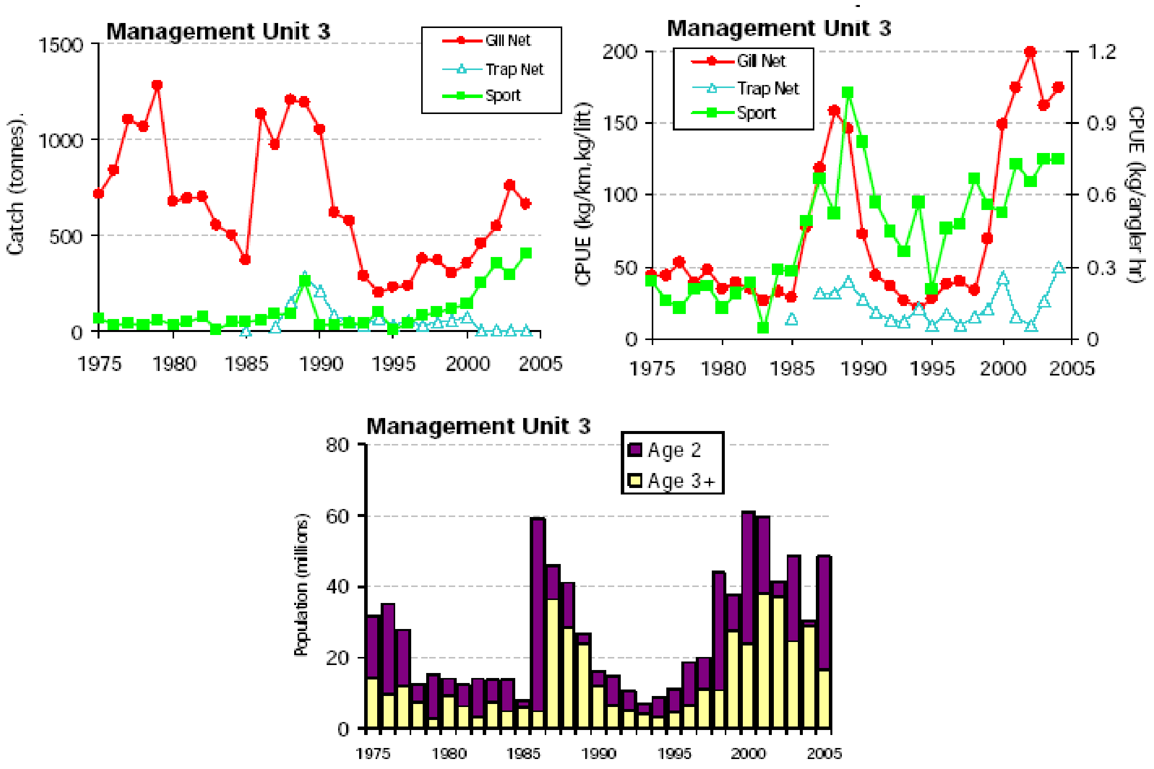


Figure 11: Annual catch, catch per unit effort, and population age composition in MU3 (Figure from Belore et al. 2005).

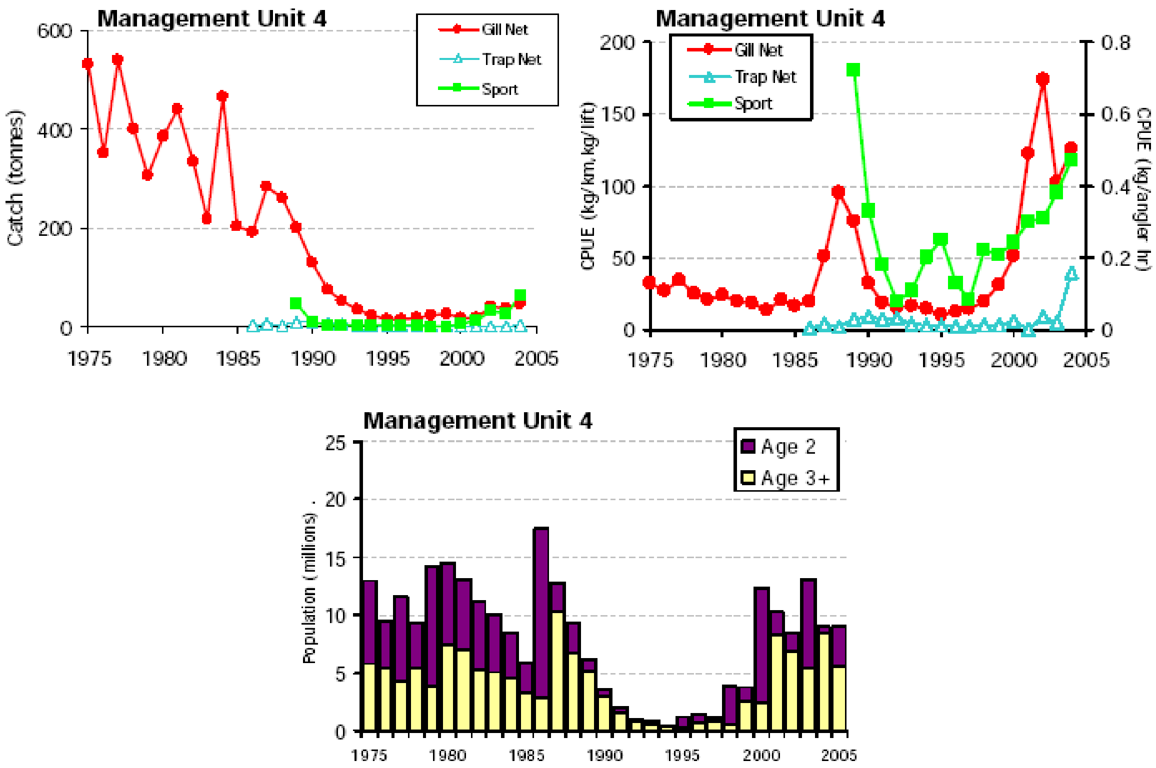


Figure 12: Annual catch, catch per unit effort, and population age composition in MU4 (Figure from Belore et al. 2005).

Despite some year-to-year fluctuations, yellow perch populations throughout Lake Erie show an increasing trend, with abundance considerably restored relative to mid-1990s lows. However, variable recruitment and year class strength indicate that populations remain sensitive to environmental changes and interactions with other species. In 2004 there was a substantial decrease in the abundance of yellow perch in MU1, coinciding with decreases in exotic populations of alewife, round goby, and white perch. This concurrent decrease may have been due to decreased availability of zooplankton prey, which are important to many forage fish species. In 2005, age-0 yellow perch abundance was below 15-year means, and age-3+ abundance was projected to be down by as much as 50% (Bur et al. 2006). Variable recruitment leads to an imbalanced age structure, and the fishery consequently relies more heavily on single age classes. Stock management will have to remain conservative, protecting weak year classes from overexploitation by the fishery, as was done in 2007 when TAC was decreased to protect the 2002 and 2004 size classes currently recruiting to the fishery.

Lake Ontario

Long-term Trends

Historically, the Bay of Quinte and the eastern Outlet Basin yielded the largest commercial yellow perch catches of yellow perch in Lake Ontario (Fig. 13). In contrast, catches from western and central areas of Lake Ontario were relatively minor (Smith 1995).

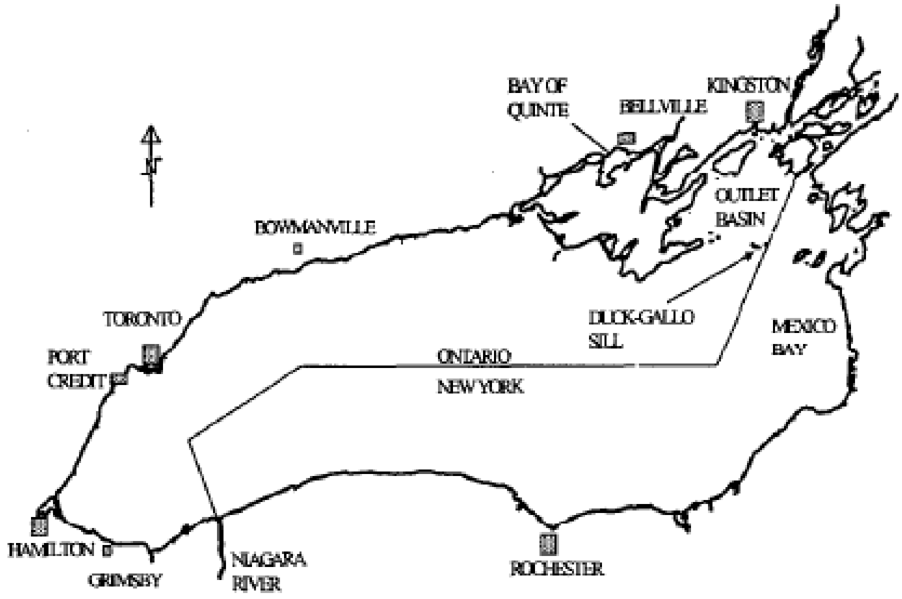


Figure 13: Lake Ontario (Figure from Stewart 1999, p.170).

Within the Bay of Quinte, yellow perch abundance was low in the 1980s and increased in the mid-1990s. This appears to have coincided with the invasion of the zebra mussel. Mussel filtering of the water column increased water clarity and abundance of aquatic macrophytes in Lake Ontario's bays, providing improved yellow perch spawning grounds, as occurred in Lake Erie.

In the New York waters of eastern Lake Ontario, yellow perch populations in the 1990s were so small that the sport fishery began to move effort to other species. Stock depletion was due to a combination of fishing pressure and predation by alewife on larval perch. Despite strong year classes between 1991 and 1995, the population did not recover. This was attributed to additional predation pressure by double crested cormorants, which have been estimated to consume 48% of the age-1, 20% of age-2, and 20% of age-3 yellow perch (Burnett et al. 2002). Their effect was particularly high near the vicinity of Little Galloo Island, where large colonies of cormorants took more fish annually than either the sport or commercial yellow perch fisheries (Johnson et al. 2002), and in Ontario waters, where cormorants are abundant.

Current Status

Yellow perch abundance in Lake Ontario has remained highly variable, increasing along the southern shore but decreasing in the eastern basin (Hoyle et al. 2007). Bay of Quinte populations are relatively large but have been declining; however, age-0 catches during 2005 indicate a strong year class. Commercial catches, which declined between 1999 and 2002, remained relatively stable between 2002 and 2005. Eastern Lake Ontario populations remain low due to continued cormorant predation (LOC 2006), and fishing effort has decreased due to low prices for yellow perch in this region. In contrast, yellow perch populations near Putneyville, New York, where cormorant density is very low, have increased dramatically.

In Canadian waters of Lake Ontario, the 2005 yellow perch catch increased somewhat over the 2004 catch, which showed a 72% decline since 1999. However, total catch was still only 22% of the quota (Fig. 14).

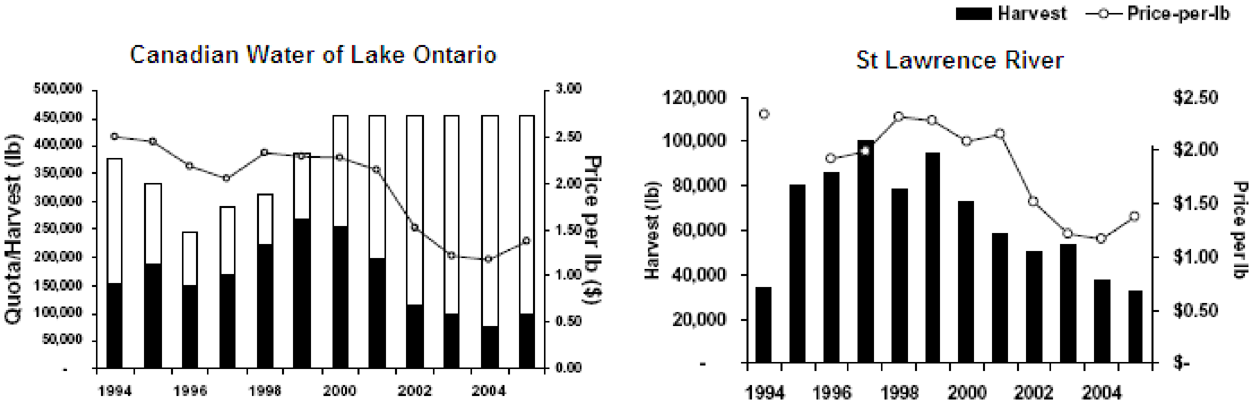


Figure 14: Yellow perch commercial catch relative to quota and price in Canadian waters of Lake Ontario and the St. Lawrence River (Figure from LOC 2006). Bars represent quota, with black shading the proportion actually caught. Lines represent price per pound.

Both New York and Ontario management agencies have now instituted programs to control double crested cormorant populations. Between 1999 and 2002 the New York State Department of Environmental Quality (NYSDEQ) was able to reduce cormorant predation on yellow perch by 1.3 million fish by oiling cormorant eggs to reduce hatching success. Ontario is currently implementing a similar program.

Lake Huron

Long-term Trends

Historically, yellow perch were found throughout Lake Huron (Fig. 15), and were particularly abundant in Saginaw Bay (Fielder et al. 2005a). In the main basin, yellow perch populations were somewhat smaller, and have been in decline or have disappeared altogether since the early 1980s. In Ontario waters along the southeastern shore, populations have remained strong. In Saginaw Bay, abundance during the late 1980s was very high, leading to slow yellow perch growth. However, low recruitment in the late 1990s led to increased growth, though coupled with concern regarding population stability.

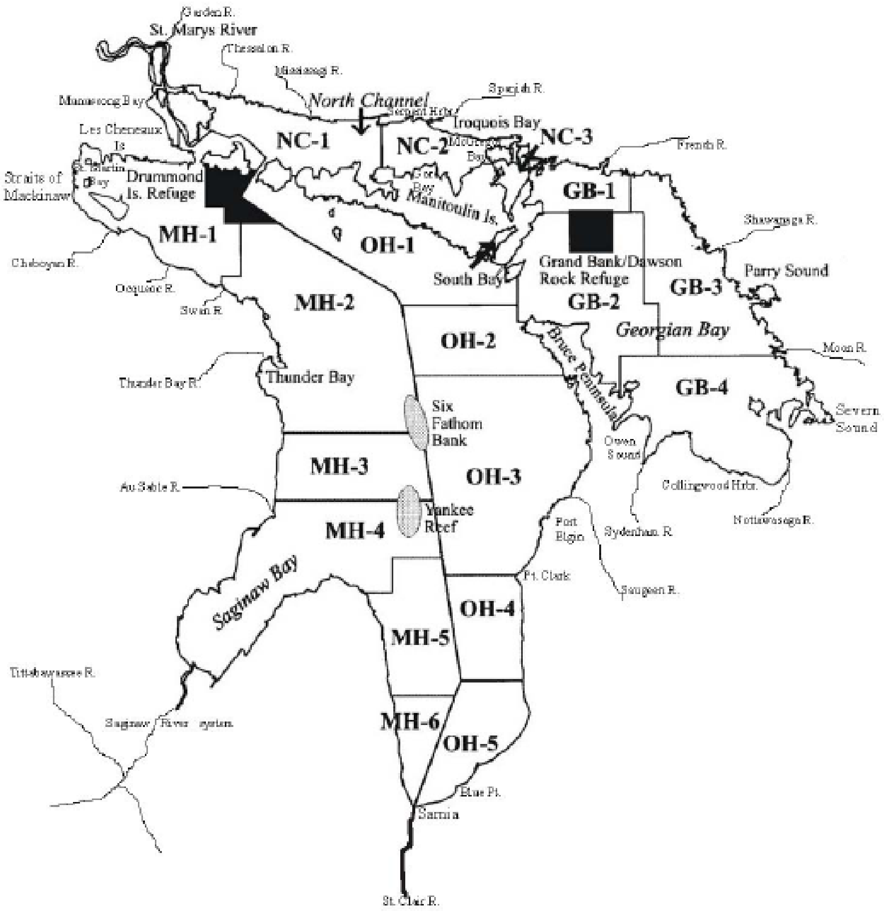


Figure 15: Lake Huron management units (Figure from Ebener 2005).

Current Status

Michigan began to manage the yellow perch fishery in Lake Huron primarily for recreational use in the mid-1960s; however, commercial fisheries operate with gillnets and trap nets throughout all other portions of the lake. Commercial yellow perch catch comes almost entirely from Ontario waters of the main basin. The St. Mary's River population is likewise stable and supports a commercial fishery in Canadian waters. In Saginaw Bay, there is a major recreational yellow perch fishery with yields near historical levels (Ebener 2005). Populations in Les Cheneaux Islands and parts of Georgian Bay and the Northern Channel have been in decline due to cormorant predation. Double-crested cormorant density in these areas has increased eight-fold since the late 1980s, and Lake Huron is developing a cormorant management plan to reduce predation. Between 2002 and 2005, however, several good year classes were produced such that population sizes of juvenile perch in Les Cheneaux Islands and the St. Mary's River are now better than short-term historic levels. It remains to be seen if these fish successfully recruit to the fishery and whether this increased abundance will develop into a long-term trend.

Table 2. Stock status of yellow perch.

Status	**B/B_{MSY}**	**Occurrence of Overfishing**	**F/F_{MSY}**	**Abundance Trends/CPUE**	**Age/Size/Sex Distribution**	**Degree of Uncertainty in Stock Status**	**Sources**	**SFW Rank**
Not listed.	Lake Erie: At or above B_{MSY}	Overfishing occurred during 1990s, but not currently occurring (catches remain within TAC).	Fishing mortality within F_{MSY}	Long-term trend: Up (from 1970s lows). Short-term trend: Variable, but generally increasing, with CPUE up.	Distributions somewhat skewed to younger fish due to recruitment failure in 1990s.	Low. Both fishery dependent and independent data collected several times a year.	(LEC 2004; Belore et al. 2005; Bur et al. 2007)	**Healthy**
	Lake Ontario: Unknown.	Not occurring, but TACs may be high as catches remain well below.	Unknown	Long-term: Down in Ontario and New York Waters but up in Bay of Quinte. Short-term: Decreasing in areas with cormorant predation, increasing otherwise.	Unknown.	Moderate. Some stock assessment done but not as comprehensive as Lake Erie. Cormorant predation effect may be confounding fishery effect.	(Smith 1995; Burnett et al. 2002; LOC 2006; Hoyle et al. 2007)	**Moderate (many factors variable or unknown)**
	Lake Huron: Unknown, but populations decreasing in many regions.	Unknown.	Unknown	Canadian populations supporting commercial fisheries in Saginaw Bay and St. Mary's River have stable-to-increasing populations.	Size structured skewed to smaller fish in Saginaw Bay where population density has remained high.	Moderate. No information on age structure, less fishery independent data collected than Lake Erie.	(Mohr and Ebener 1999; Ebener 2005; Fielder et al. 2005a)	**Moderate (many factors variable or unknown)**

Synthesis

In Lake Erie, initial ecosystem restoration initiatives put in place during the late 1970s to halt eutrophication, overfishing, and habitat loss combined with temporarily favorable ecosystem changes in the 1980s (the arrival of dreissenid mussels, which helped "clean up" the lake from its former eutrophic state) to create an ideal environment for yellow perch growth, leading to fishery yields approaching historic highs. Unfortunately the system continued to evolve and the environment became more and more oligotrophic. The high abundances of the 1980s could not be sustained and the 1990s brought another period of substantial population decline, when overfishing clearly occurred as catch quotas did not decrease as quickly as perch abundance. This dramatic decline prompted the Lake Erie Committee to adopt a more conservative management approach to yellow perch populations. This approach included more fishery independent survey data, longer time series, and the incorporation of environmental variables into yellow perch population models. Since its implementation, perch numbers in Lake Erie are once again on the rise, catch per unit effort is increasing, and stocks appear to be nearing more stable high values again, despite some variability in year class strength, indicating that yellow perch stocks in Lake Erie are healthy.

In Lake Ontario and Lake Huron, the situation is less clear, as stock status varies widely depending on location, and appears to be correlated with the presence of nesting double-crested cormorants. In Lake Ontario, yellow perch populations are increasing on the southern shore but decreasing in the eastern basin, where cormorant predation appears to have a substantial impact. In the Bay of Quinte in the eastern basin, populations increased dramatically in the 1990s but have been declining in more recent years. Commercial catch in eastern Lake Ontario was relatively stable between 2000 and 2005. In Lake Huron, yellow perch populations in Saginaw Bay remain close to historical levels, while those in Les Cheneaux Islands, and areas of the North Channel and Georgian Bay were in decline for most of the past decade, probably in response to increased cormorant predation. However, strong year classes produced in recent years, particularly in 2003 and 2004, have led to a steep increase in juvenile perch abundance in 2006 and 2007 and may mean the fishery is recovering. Yellow perch populations in Ontario waters have continued to support an active fishery. Stock status in these lakes thus ranges from healthy in areas like Saginaw Bay to poor but recently improving in Les Cheneaux Islands. In the near future, cormorant control strategies may help stabilize populations, but more rigorous stock assessment is needed to truly determine an overall status for yellow perch in Lake Ontario and Lake Huron.

Status of Wild Stocks Rank (based on Lake Erie stocks):

Lake Erie:

Healthy 🟩 Moderate/Rebuilding 🟨 Poor 🟥 Critical ⬛

Lake Huron, Lake Ontario:

Healthy 🟩 **Moderate/Rebuilding** 🟨 Poor 🟥 Critical ⬛

Criterion 3: Nature and Extent of Bycatch

Seafood Watch® defines sustainable wild-caught seafood as marine life captured using fishing techniques that successfully minimize the catch of unwanted and/or unmarketable species (i.e., bycatch). Bycatch is defined as species that are caught but subsequently discarded (injured or dead) for any reason. Bycatch does not include incidental catch (non-targeted catch) if it is utilized, accounted for, and managed in some way.

The Canadian yellow perch commercial fishery in Lake Erie uses small-mesh gillnets. No systematic study of yellow perch gillnet catches is available that details quantity of bycatch relative to perch catches, but one study was undertaken to determine the occurrence of yearling walleye catches in commercial nets during the Coordinated Percid Management Strategy (CPMS) between 2001 and 2003. At the time, walleye populations were undergoing substantial declines, and the impact of immature walleye bycatch in the small mesh yellow perch gillnet fishery was investigated. The Ontario Ministry of Natural Resources estimated that in the year 2000, approximately 200,000 immature walleye were netted as bycatch in the yellow perch fishery, a small proportion of the total number of yellow perch caught (<5% of the total catch). However, this represents only a single data point, and the importance of this bycatch is still being evaluated (LEC 2004). Gillnetting is used to target yellow perch in some US waters of the Great Lakes as well, but concerns about salmon and lake trout bycatch in this gear is leading to increased use of trap nets, which have much lower incidence of bycatch than gillnets.

Synthesis

The trap nets used in most US commercial and tribal fisheries have low incidence of bycatch mortality, so any non-target species can be easily released. Gillnets, on the other hand, which are a primary gear in Canadian commercial fisheries, have the potential to have substantial bycatch impacts, as they have low selectivity and high mortality. One study has shown that yearling walleye bycatch occurs in the yellow perch small mesh fishery in Lake Erie, though the significance of the quantity caught is still to be determined. In general, more information is needed on the bycatch impacts of this near-shore, small-mesh gear. Because of its potential, and the high uncertainty associated with its use in the yellow perch fishery, the bycatch associated with the largest yellow perch catches (those from Canadian Lake Erie waters) are of moderate conservation concern.

Nature of Bycatch Rank:

Low 🟩 **Moderate** 🟨 High 🟥 Critical ⬛

Criterion 4: Effect of Fishing Practices on Habitats and Ecosystems

Habitat Effects

Both the gillnets and trap nets used in the Great Lakes yellow perch fisheries are stationary gear, but are bottom set. Bottom-set gear in marine fisheries is considered to cause moderate habitat damage. No systematic study of these impacts have been made in the Great Lakes, however, thus the habitat effects of these gillnet fisheries are considered of moderate conservation concern. Great Lakes bottom substrates are generally soft, however, and do not have extensive complex structures and are therefore resilient to damage.

Ecosystem Effects

The yellow perch position at an intermediate trophic level increases the number of potential interactions it has with both native and invasive species. At different points in its life cycle, it competes for resources with exotic alewife, white perch, and dreissenid mussels, primarily via competition for zooplankton, and also interacts with other forage (alewife, white perch, and other yellow perch can consume yellow perch larvae) and predatory fish (e.g., walleye). The maintenance of adequate yellow perch stocks will be crucial to rebuilding a strong percid community in lake areas where walleye and yellow perch once dominated. Perch abundance will be particularly important to walleye and other predators if alewife and smelt populations continue to collapse.

The imbalance of predators-to-prey in many Great Lakes waters, and in particular in Lake Huron, where large-scale stocking of non-native predators occurs, may put a strain on native forage species like yellow perch should non-native forage stocks collapse (MIDEQ 2002). It will ultimately rest on management of the predator stocks to prevent this imbalance from impacting yellow perch and other valuable native forage stocks. Of more immediate concern is the competition between the commercial fishery and cormorant populations. Because of their rapidly expanding populations, cormorants are seen as a nuisance species that take too many yellow perch annually. This is a valid concern in the context of protecting yellow perch spawning populations, as cormorants take a substantial number of young (age-2) and possibly immature perch (Burnett et al. 2002). However, large-scale cormorant control could harm the sustainability of cormorant populations, which have only recently emerged from endangered status in the Great Lakes Region (Weseloh and Collier 2005). On the other hand, the combined pressure of fishing and cormorant predation may be driving yellow perch populations in areas of high cormorant density towards over-exploited status; the impacts of this combined mortality on current population levels merit further study. The techniques currently used to control cormorants in Lake Ontario and Lake Huron, including egg oiling and nest disruption, are recognized as localized, temporary control measures that in the long run do not affect the size of the adult cormorant population, as this adaptable bird species will continue breeding throughout the season and will attract new nesting pairs to colonies as needed (Kortanfy et al. 1997). Therefore, in areas where cormorants have been shown to negatively impact species such as yellow perch, which figure prominently in the cormorant diet in a number of lakes, these control strategies may be warranted.

Synthesis

Stationary bottom-set gear such as the gillnets and trap nets used in yellow perch Great Lakes fisheries are of moderate conservation concern, due to unknown effects on Great Lakes bottom habitat. In addition, there is the potential for some substantial ecosystem effects from these fishing practices. While the yellow perch occupies an intermediate trophic position and is not generally thought to be a “keystone” species in the region, its importance to the food webs of Lake Erie, Lake Huron, and Lake Ontario may increase should the current declining trend in exotic forage species—in particular rainbow smelt and alewife, both currently important prey species for the region’s predators—continue. Additionally, the disruption of cormorant breeding, although not a direct fishing practice, is directly related to the yellow perch fishery and is of some concern, as these birds only recently emerged from precipitous declines that occurred in the 1960s and 1970s. Though their populations have undergone dramatic expansion, they may not yet have reached equilibrium and further disruption could have unexpected consequences, particularly if their prey base (which includes rainbow smelt and alewife, invasive forage species whose expansion aided cormorant population growth by providing increased food supply) destabilizes. A recent long-term study of cormorant colonies has shown that their growth is density dependent; per capita rate of change in colony size decreases with increasing colony size, and as of 2003 cormorant colonies in Lake Huron appeared to have stabilized at site-specific carrying capacity, but was subject to change as prey fish abundance was in decline (Ridgway et al. 2006). Decline in food availability changes the carrying capacity of a site for cormorants, and should lead to declines in cormorant abundance. Therefore, cormorant control strategies should operate with caution and respond to these density- and prey-dependent changes in colony size. Considering these different factors, the effects of yellow perch fishing practices are considered of moderate conservation concern, and caution is warranted in any ongoing management of related species, including non-native forage competitors (alewife, rainbow smelt) and predators (double crested cormorant).

Effect of Fishing Practices Rank:

Benign 🟩 [✓ **Moderate** 🟨] Severe 🟥 Critical ⬛

Criterion 5: Effectiveness of the Management Regime

The Great Lakes Fishery Commission (GLFC) is the primary, binational, interjurisdictional management body for fisheries in the Great Lakes region. Under its auspices, a set of lake committees operate to manage individual fisheries in each lake.

Lake Erie

The Lake Erie Committee (LEC) is a bi-national group comprised of senior members from several state and provincial agencies, including the Michigan Department of Natural Resources (MDNR), the New York State Department of Environmental Conservation (NYSDEC), the Ohio Department of Natural Resources (ODNR), the Ontario Ministry of Natural Resources (OMNR), and the Pennsylvania Fish and Boat Commission (PFBC). The Committee manages yellow perch on an annual quota basis, and quotas are developed on the basis of extensive survey and modeling activity.

Fishery independent surveys of yellow perch stocks began in Lake Erie in 1989. By 1998, estimates of gillnet selectivity were being used to calibrate individual populations surveys (Belore et al. 2005), and estimates of recruitment and age-specific stock projections are updated yearly. Data from annual harvests, interagency trawl and gillnet surveys and length- and weight-at-age data are used to forecast catch for the following year, in an attempt to keep exploitation rates relatively constant from year to year (as percentage of total age 3 and older stock) (Fig. 16).

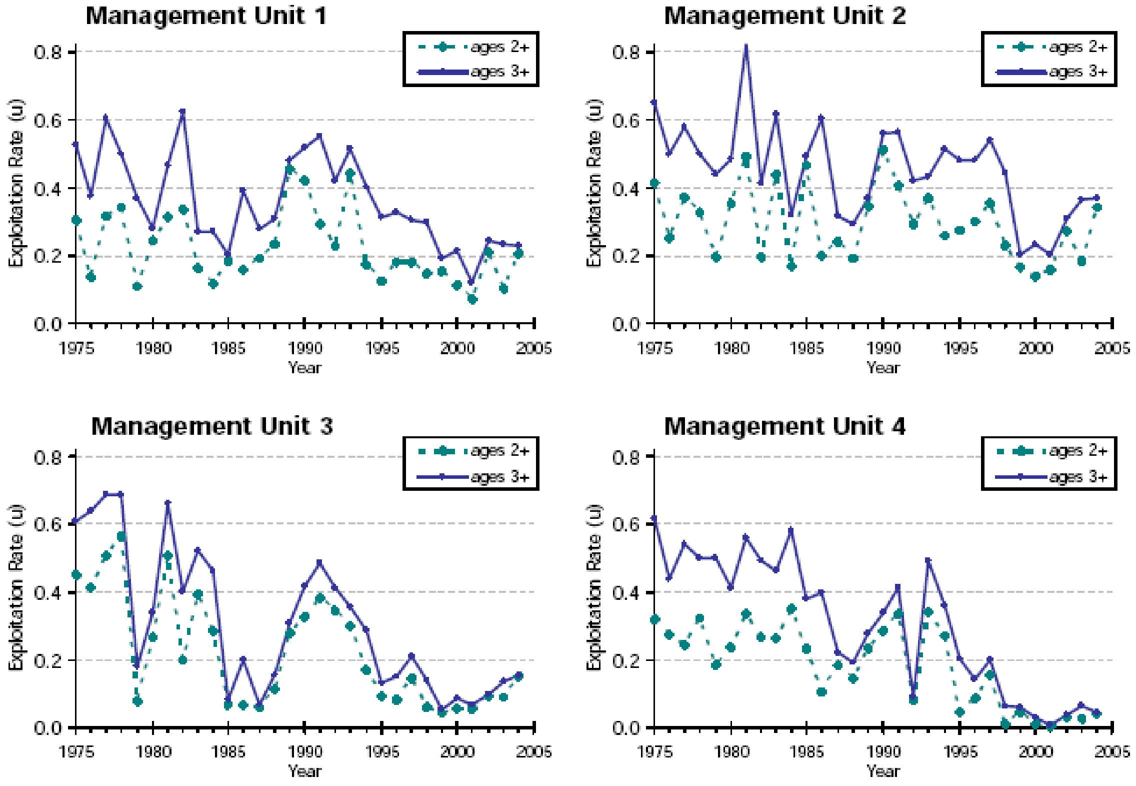


Figure 16: Age-specific exploitation rates in Lake Erie management units, 1975-2005 (Figure from Belore et al. 2005).

Between 2001 and 2003, the LEC instituted the Coordinated Percid Management Strategy (CPMS), a conservative strategy meant to halt and reverse declining trends in walleye and yellow perch populations observed in the late 1990s. Under this strategy, the Committee updated many of its practices to provide more up-to-date, scientifically accurate and effective stock assessment and management. Population models were updated to statistical catch-at-age models that incorporated more fishery independent data (surveys) and included longer-term data series (LEC 2004). An independent review of these changes asserted that this strategy was a substantial improvement over previous stock assessment methods.

In addition to LEC surveys, the US Geological Survey's Lake Erie Biological Station (USGS LEBS) conducts summer and fall assessments of fish populations in western Lake Erie each year. These surveys include abundance of native and invasive forage fish, yellow perch diets, and zooplankton abundance, and give important insight into the status of the predator-prey balance and the health (abundance) of the forage base in Lake Erie (Bur et al. 2007).

The CPMS also began to incorporate environmental variables into growth and stock size models, an important feature that helps to anticipate the large-scale variability in year class strength and recruitment seen in yellow perch stocks over the past two decades. At the same time, however, the TAC set by the LEC was exceeded in a number of Lake Erie's management units during the CPMS. At that time, yellow perch populations were expanding and TACs were being increased; however, catches exceeding TAC in at least one management unit over all three years of the CPMS indicates the limits may not have been properly set during these years and, more importantly, were not strictly enforced. Management action in 2007 has moved in a positive direction to conserve yellow perch populations and for the first time since the CPMS was instituted, the yellow perch TAC in Lake Erie has been decreased, a reduction of more than 5 million pounds (from 16.48 million pounds in 2006 to 11.4 in 2007) in spite of a record yellow perch catch in 2006. The decrease was instituted to protect the weak 2002 and 2004 year classes currently recruiting to the fishery. Overall, interagency management activity aimed at reducing exploitation and protecting the spawning yellow perch population has succeeded in rebuilding yellow perch numbers and maintaining commercial catch at steady rates. In addition, a number of strong year classes have been produced since the steep declines observed in the 1990s (Ryan et al. 2003).

Lake Ontario

Management of Lake Ontario's yellow perch fishery is based on a quota system. As a "premium" species, the yellow perch is one of the few species in Canada's Lake Ontario fishery to be regulated on a quota basis. Individual allocations in the fishery are determined independently by the Ontario Ministry of Natural Resources in Canada and the New York State Department of Environmental Conservation (NYSDEC) in the US. Yellow perch catches in Lake Ontario in recent years have been well short of the quota and may indicate that quotas are currently higher than stocks are able to support (Hoyle et al. 2007). The effectiveness of management varies depending on location and is confounded with impacts from double-crested cormorant and alewife abundance. However, cormorant control programs (e.g., egg oiling) appear to be having a positive effect on yellow perch abundance in areas of high cormorant density. In general, the stock assessment process is less well developed and occurs less regularly here than in Lake Erie, where the yellow perch fishery is much larger.

Lake Huron

The Lake Huron Committee (LHC) consists of members from Michigan DNR, Ontario MNR, and the Chippewa-Ottawa Treaty Resource Authority. The established Fish Community Objective (FCO) for yellow perch in Lake Huron is 1.1 million pounds/year. However, there has historically been no concerted assessment of sport catch in Lake Huron, which makes true catch estimates difficult. To better determine yellow perch abundance, fishery independent survey methods have been instituted. Currently, the Lake Huron Committee has suggested that percid fish community objectives should be reformulated according to sustainable abundance, rather than desired catch levels (Ebener 2005), indicating that management is making a positive move toward more sustainable fishery management. New survey methods combined with cormorant population controls should serve to improve the effectiveness of Lake Huron's yellow perch stock assessment and management.

Table 3. Commercial catch management measures for the yellow perch fishery.

Management Jurisdictions & Agencies	Total Allowable Landings	Size Limit	Gear Restrictions	Trip Limit	Area Closures	Sources
Lake Erie: LEC, NYSDEC, ODNR, OMNR, MDNR, PFBC	TAC set annually.	Minimum size limit set to increase spawning potential.	Mesh size restrictions.	None.	None.	Hartman et al. 1980; LEC 2004; LEC 2007
Lake Ontario: OMNR, NYSDEC	TAC set annually.	Size limit for recreational catch, gear limit for commercial.	Mesh size restrictions.	None.	None.	Stewart et al. 1999; Hoyle et al. 2007
Lake Huron: MDNR, OMNR, CORA	TAC set annually.	7 inches for sport fishery.	Mesh size restrictions.	None.	None.	DesJardine et al. 1995; Ebener 2005

Synthesis

Management of the Lake Erie yellow perch fishery has improved substantially in recent years, due largely to the population declines that occurred in both yellow perch and walleye during the 1990s. These declines prompted the implementation of the Coordinated Percid Management Strategy, a three-year period of conservative management, primarily for walleye, and intensive research and improvement of stock assessment practices for both yellow perch and walleye. Through this strategy, the Lake Erie Committee increased the amount of fishery independent data collected, and incorporated environmental factors affecting yellow perch recruitment and growth into population models, thereby improving their ability to monitor and control yellow perch populations. Total allowable catch (TAC), which is determined each year based on both fishery dependent and independent data, has changed each year since the CPMS began in 2001. In 2007 for the first time the TAC was substantially reduced in order to protect the weak 2002 and 2004 year classes currently recruiting to the fishery, a positive management action illustrating a commitment to a sustainable fishery. The maintenance of a well-developed commercial fishery over the past seven years, despite some variability in year class strength and recruitment, has shown that Lake Erie's yellow perch management has been highly effective.

The yellow perch fisheries in Lake Ontario and Lake Huron are much smaller than in Lake Erie, and management in these lakes is not as well developed. Stock status of yellow perch in these lakes is highly variable, with populations increasing in some regions but decreasing in others. This seems to be correlated with the presence of cormorants in some regions, and cormorant control strategies have seen some success, particularly in Lake Ontario. However, substantial predation by cormorants coupled with an incomplete stock assessment means that it is currently difficult to tell whether current fishery exploitation rates are appropriate. The overall effectiveness of the yellow perch management regimes in these lakes can be considered moderate, as steps are being taken to reverse declining trends, but substantial improvements need to be made in the amount and type of data collected, and TACs need to be evaluated in the face of concurrent cormorant predation.

Effectiveness of Management Rank:

Lake Erie:

[✓ **Highly Effective** 🟩] Moderately Effective 🟨 Ineffective 🟥 Critical ⬛

Lake Huron, Lake Ontario:

Highly Effective 🟩 [✓ **Moderately Effective** 🟨] Ineffective 🟥 Critical ⬛

4-IV. Overall Evaluation and Seafood Recommendation

The yellow perch is characteristic of the type of species currently flourishing in the Great Lakes fisheries. It is an adaptable species tolerant of a variety of environmental conditions, occupies an intermediate trophic position, and has a flexible diet that can adapt to ecosystem changes. Its resilience is illustrated by its continued ability to rebound from population decline, despite having a number of pressures acting against it, including fishing, predation by increasing cormorant populations, and interaction with a number of invasive species, including those with which is competes directly (e.g., white perch, alewife) and those that restructure its environment (e.g., dreissenid mussels). Its resilience is a function of, and aided by, its rapid growth, low age at maturity, and high fecundity.

In Lake Erie, management of the yellow perch population by annual stock assessment and TAC allocation, coupled with an environment well suited to temperate species and mesotrophic conditions, have resulted in healthy perch populations able to sustain a substantial commercial fishery in spite of some variability in year class strength largely due to environmental conditions. Yellow perch fishery management, led by the Lake Erie Committee, uses modern scientific methods to incorporate large amounts of both fishery dependent and independent data in their population models, and modify TAC allocations from year to year in order to protect weak year classes and ensure a sufficient spawning stock size.

Despite these management improvements, there still exists great uncertainty and concern surrounding the fishing gear impacts in the Lake Erie yellow perch fishery, as small mesh gillnets are still used, particularly in the Canadian fishery. This gear is known to be of low species selectivity and high mortality, and as such can pose a substantial bycatch problem.

However, no systematic study of bycatch has been made in the Great Lakes. Some limited data has shown that immature walleye can be captured in yellow perch nets, which may be of concern as walleye populations are still in recovery from 1990s declines. In addition, other forage fish populations, which provide important food for Lake Erie’s top predators, are also in decline. Any bycatch of these species could therefore also be of concern. Though further study is warranted to ensure that bycatch and ecosystem/habitat damage are not substantial in this fishery, in all other respects the Lake Erie yellow perch fishery is a healthy one that has had success in maintaining stock abundance, and is therefore recommended as a “**Best Choice**.”

Yellow perch catches in Lake Ontario and Lake Huron are minor compared to Lake Erie, and as such stock assessment in these fisheries is less frequent and less sophisticated, and the stock status varies greatly from region to region. In some cases this is due to a region simply being better suited to yellow perch, as in Saginaw Bay, where perch populations were always high and have remained at historic levels. In other regions, population declines are linked to increased cormorant predation and management must verify that the combined pressure of this “natural” predator and of fishing has not led to overexploitation of perch. Uncertainty remains high in both stock status and in the ecosystem effects of the fisheries removing forage species, particularly in the predator-heavy environment of Lake Huron. These smaller yellow perch fisheries are therefore recommended as a “**Good Alternatives**.”

Table of Sustainability Ranks for Yellow Perch

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability	√			
Status of Stocks	√ Lake Erie	√ Lake Huron, Lake Ontario		
Nature of Bycatch		√		
Habitat & Ecosystem Effects		√		
Management Effectiveness	√ Lake Erie	√ Lake Huron, Lake Ontario		

Overall Seafood Recommendation for Yellow Perch

Lake Erie:

[✓ **Best Choice** 🟩] Good Alternative 🟨 Avoid 🟥

Lake Huron, Lake Ontario:

Best Choice 🟩 [✓ **Good Alternative** 🟨] Avoid 🟥

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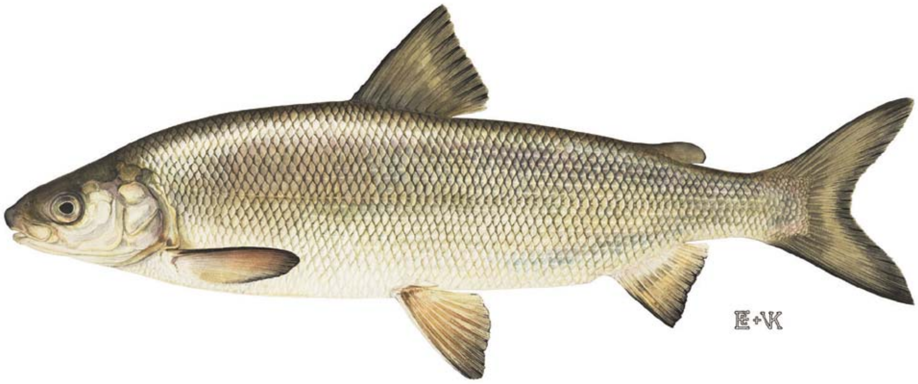
Chapter 5: Lake whitefish

Coregonus clupeaformis



(Image courtesy of the New York State Department of Environmental Conservation)

5-I. Executive Summary

Lake whitefish (*Coregonus clupeaformis*) is an epibenthic, coldwater species that has been commercially important in the Great Lakes fishery for over a century. It is broadly distributed throughout the northern United States and Canada, and is now the dominant deepwater epibenthic fish in the Great Lakes, as other deepwater species, such as the deepwater ciscoes, underwent severe declines and have not recovered. Lake whitefish available in US markets may come from Canadian and US Great Lakes catches or from sources in northwestern Canada (Manitoba, Saskatchewan, and the Northwest Territories produce sizeable whitefish exports). This report focuses on Great Lakes sources exclusively and in particular on catches from Lake Michigan (>50% of the US catch), Lake Huron (>30% of US catch, >80% of Canadian catch), Lake Superior (20% of the US catch), and Lake Erie (>10% of the Canadian catch). The remainder comes from US catches in Lake Erie and Canadian catches in Lake Superior and Lake Ontario, but is too small to influence overall recommendations, which will be driven by the status of stocks in Lake Huron, Lake Michigan and Lake Superior.

Lake whitefish is a schooling fish, a behavior that increases their vulnerability to fishing pressure, but is also widely migratory. Stocks commingle during the year in deeper waters but separate into distinct populations during spawning season in the fall when they return to their original nursery grounds. Their patchy and variable distribution greatly complicates stock assessment and subsequent fishery management, introducing uncertainty into predictions of abundance, mortality, and recruitment.

During the middle of the 20th century, a combination of overfishing, habitat degradation, eutrophication, and interaction with invasive species such as the sea lamprey (*Petromyzon marinus*), alewife (*Alosa pseudoharengus*), and rainbow smelt (*Osmerus mordax*) reduced lake whitefish populations to remnant levels in many areas of the Great Lakes. The period of restoration that followed, which included nutrient abatement, invasive species control, and fishery limitations, led to population growth that in some cases produced lake whitefish catches well above historical means. In most lakes this resurgence in whitefish abundance peaked in the mid-1990s, when the arrival of new invasive species, the zebra and quagga mussels (*Dreissena polymorpha* and *D. bugensis*), caused *Diporeia* spp. (hereafter, Diporeia), an amphipod and preferred lake whitefish prey, to nearly disappear in Lake Michigan, Lake Huron, Lake Ontario, and Lake Erie. No such decline was evident in Lake Superior. In lakes where only less energetically favorable prey were available, whitefish populations underwent substantial declines in condition, including decreased size-at-age, decreased weight-at-age, and increased age at first maturity. In Lake Erie, an abundance of chironomid larvae allowed lake whitefish conditions to remain stable; however, current yields are approximately half the long-term (1909-1953) commercial catch size.

Although condition, growth, recruitment, and catch rates have been highly variable across the lake whitefish fisheries, whitefish populations are generally abundant relative to long-term means. In Lake Michigan, catches from Wisconsin waters are at historic highs, and abundance is above historic values in the rest of the lake, though size-at-age, a measure of condition, has decreased in recent years, either due to a density-dependent response or decreasing abundance of high-energy zooplankton prey. In Lake Huron, catch rates have been variable, as have condition and recruitment. However, catch rates are either stable or increasing, and in many cases remain above historic means. Therefore, despite some concerns around condition and recruitment, stocks in both Lake Michigan and Lake Huron appear healthy. In Lake Superior, biomass of lake whitefish did not undergo the same declines observed in other lakes, and stocks have remained at historic levels. Lake Superior's lake whitefish stocks are also healthy. Finally, stocks from Lake Erie have remained stable, but with declining recruitment in recent years and an increasing age structure that gives cause for moderate conservation concern.

In the Great Lakes, whitefish are caught in pound nets, trap nets, and gillnets, with gillnets and trap nets being the dominant gear and pound nets having limited use only in the Wisconsin fishery. Canadian whitefish fisheries use gillnets almost exclusively, while US efforts are more evenly divided with gillnets used more frequently in tribal fisheries and trap nets more commonly used in state-licensed fisheries. However, trap net use has also been increasing in tribal fisheries over the last decade so that they now represent more than 75% of the gear used in tribal whitefish fisheries. Bycatch in pound nets and trap nets is minimal, and in gillnets is controlled by limits on effort, placement, and mesh size, such that bycatch is not of substantial conservation concern in this fishery.

Whitefish management is generally effective with catches remaining well below total allowable catch (TAC) levels, but stock assessment methodology for these highly migratory stocks is still under development to build more reliable stock description and TAC recommendations. Management of lake whitefish stocks is shared among the Ontario Ministry of Natural Resources (OMNR), Michigan, Wisconsin, and Minnesota Departments of Natural Resources, and two tribal management agencies, the Chippewa-Ottawa Resource Authority (CORA) and the Great Lakes Indian Fish and Wildlife Commission (GLIFWC).

Lake whitefish stocks in the Great Lakes have recovered to levels well above mid-20th century lows, and despite some variability in recruitment and a general decline in condition (most notably size-at-age), populations continue to sustain large commercial yields. Recruitment and year-class-strength since 2002 have also been strong, and in general lake whitefish from the Great Lakes have healthy stocks and are well managed. However, gillnet fisheries remain of moderate concern due to unknown bycatch management and possible habitat impacts of bottom-set gear. Therefore, lake whitefish from trap net fisheries in Lake Michigan, Lake Huron, and Lake Superior are considered a "**Best Choice**," while those from their gillnet counterparts or from Lake Erie are recommended as a "**Good Alternative**."

Table of Sustainability Ranks for Lake Whitefish

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability		√		
Status of Stocks	√ Lake Michigan, Lake Huron, and Lake Superior	√ Lake Erie		
Nature of Bycatch	√ Trap Nets	√ Gillnets		
Habitat & Ecosystem Effects		√		
Management Effectiveness	√ Lake Michigan, Lake Huron, and Lake Superior	√ Lake Erie		

About the Overall Seafood Recommendation:

- A seafood product is ranked **Best Choice** if three or more criteria are of Low Conservation Concern (green) and the remaining criteria are not of High or Critical Conservation Concern.
- A seafood product is ranked **Good Alternative** if the five criteria "average" to yellow (Moderate Conservation Concern) OR if the "Status of Stocks" and "Management Effectiveness" criteria are both of Moderate Conservation Concern.
- A seafood product is ranked **Avoid** if two or more criteria are of High Conservation Concern (red) OR if one or more criteria are of Critical Conservation Concern (black) in the table above.

Overall Seafood Recommendation for Lake Whitefish

Lake Superior, Lake Huron, and Lake Michigan trap net fisheries:

Best Choice 🟩 Good Alternative 🟨 Avoid 🟥

Lake Erie and gillnet portion of Lake Superior, Lake Huron, and Lake Michigan:

Best Choice 🟩 **Good Alternative** 🟨 Avoid 🟥

5-II. Introduction

Lake whitefish (*Coregonus clupeaformis*) has long been one of the most valuable species in the Great Lakes commercial fishery, and a dominant epibenthic fish in the cold, deep waters of the Great Lakes basin. As with most Great Lakes species, whitefish populations underwent large-scale fluctuations during the 20th century, and substantial declines in historic biomass were associated with habitat degradation, overfishing, and interactions with invasive species. The period of lowest population density occurred between 1950 and 1970, when exploitation, negative interactions with non-indigenous species such as the sea lamprey, alewife, and rainbow smelt, and loss of spawning habitat drove many populations to remnant levels (Fig. 1).

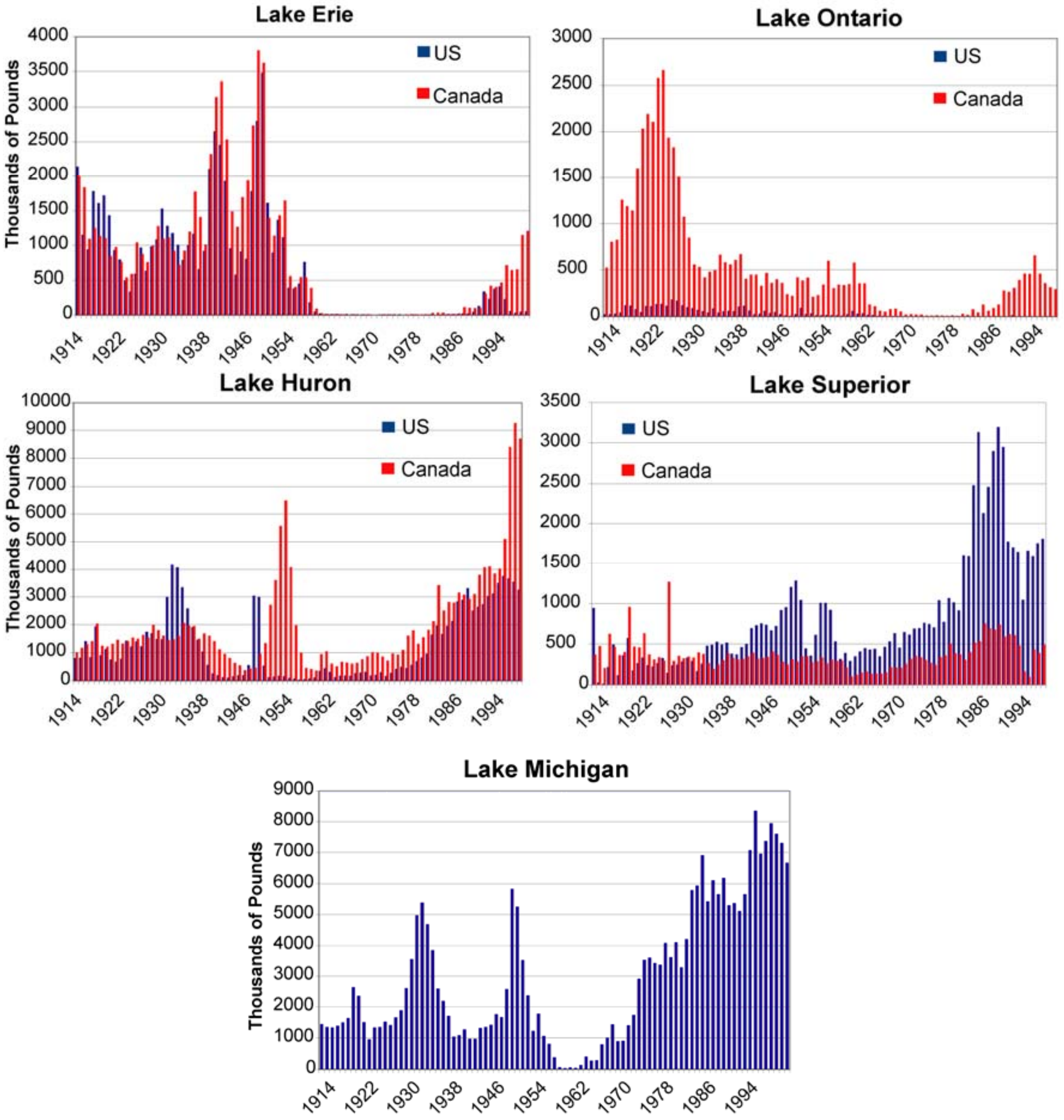


Figure 1. Historic trends in Great Lakes commercial lake whitefish catches (Figure from Baldwin et al. 2002).

In contrast to other deep-water Great Lakes species such as lake sturgeon and lake trout, whitefish underwent a period of highly successful recovery following the implementation of restoration efforts in the 1970s that included nutrient reduction, sea lamprey controls, reductions in alewife and smelt abundance by predator stocking, and restrictions on fishing. The success of whitefish populations under this management regime has increased their importance to the commercial fishery as other species have declined or disappeared (Fig. 2). Above-average harvests were achieved in Lake Michigan and Lake Huron by the 1990s, and whitefish remains one of the few Great Lakes species fished commercially from all five lakes.

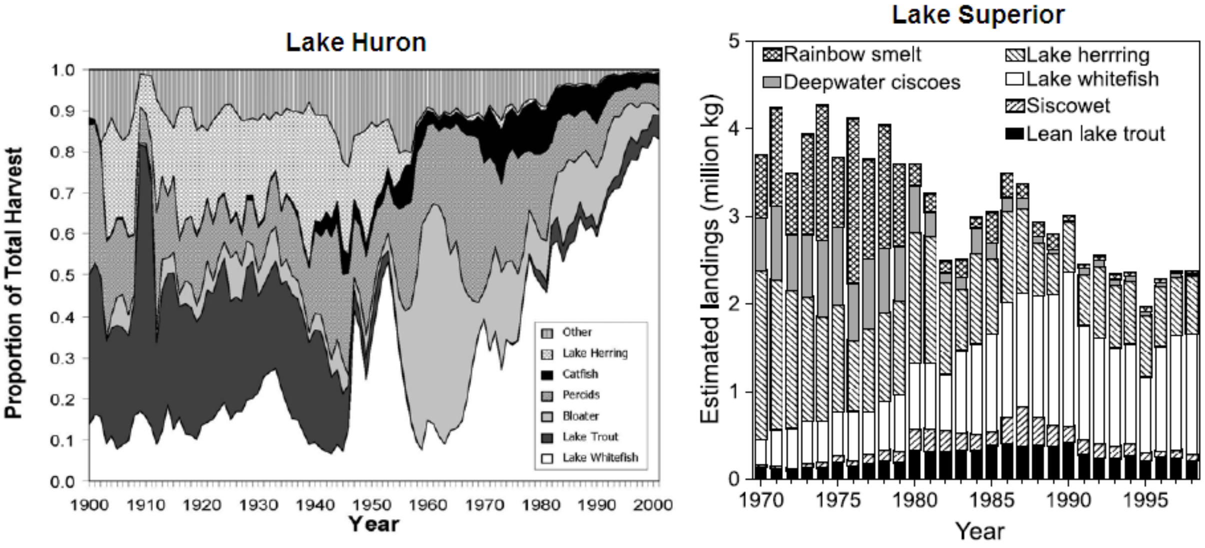


Figure 2. Composition of commercial catches in Lake Huron and Lake Superior showing increasing importance of lake whitefish (Figure from Bronte et al. 2003a).

Current commercial yield of lake whitefish is of comparable size in US and Canadian waters, though the proportion by lake varies. In the US, the majority of the whitefish catch is divided among Lake Michigan (45%), Lake Huron (35%), and Lake Superior (20%). Within these lakes, catches are divided more or less evenly between state-licensed and tribe-licensed fisheries, with state-licensed fisheries receiving a somewhat larger allocation than tribal fisheries in Lake Michigan. In Canada, the whitefish catch is overwhelmingly from Lake Huron (81%), with a smaller fraction from Lake Erie (12%). Although the catches from Canadian waters of Lake Superior and Lake Ontario are close to one million pounds each, they represent a relatively minor proportion of the total Great Lakes catch. Overall, Lake Ontario has the smallest share of the commercial whitefish catch, and is therefore excluded from the analysis in this report, and recommendations for Lake Superior are driven by the status of lake whitefish in US waters, which produce a much larger commercial catch.

Fishery management of whitefish populations has on balance been highly successful in the Great Lakes following a steep decline in the middle of the 20th century. At present it is not overexploitation but an ongoing change in the structure of the Great Lakes biological community that currently poses the greatest threat to lake whitefish success. Over the past ten years, the disappearance of one of the most important whitefish prey items, the amphipod Diporeia, has triggered declines in whitefish condition, delayed maturity, and in some lakes led to reproductive failure. In lakes where equivalent high-energy prey was unavailable, declines in condition and recruitment success have been substantial. Only Lake Superior and Lake Erie populations have been relatively unaffected. The loss of Diporeia throughout the Great Lakes appears to be linked to the proliferation of invasive dreissenid (zebra and quagga) mussels, which became abundant in the basin in the mid-1990s. The exact causative links between zebra mussel presence and Diporeia abundance are still unknown. Whitefish are currently adjusting to this change in prey availability with shifts in diet and spatial distribution. The long-term impacts of this major ecological change are yet to be realized, and each lake is at a slightly different stage of response, depending on the timing of zebra mussel arrival, the timing and severity of Diporeia decline, and the availability of alternative resources.

Scope of the analysis and the ensuing recommendation:
This report focuses on lake whitefish stocks from the US waters of Lake Michigan, Lake Huron, and Lake Superior. In addition, because whitefish are a major export stock for Canadian fisheries and much of this export is to the United States, Canadian whitefish stocks from Lake Huron and Lake Erie will also be considered (Fig. 3).

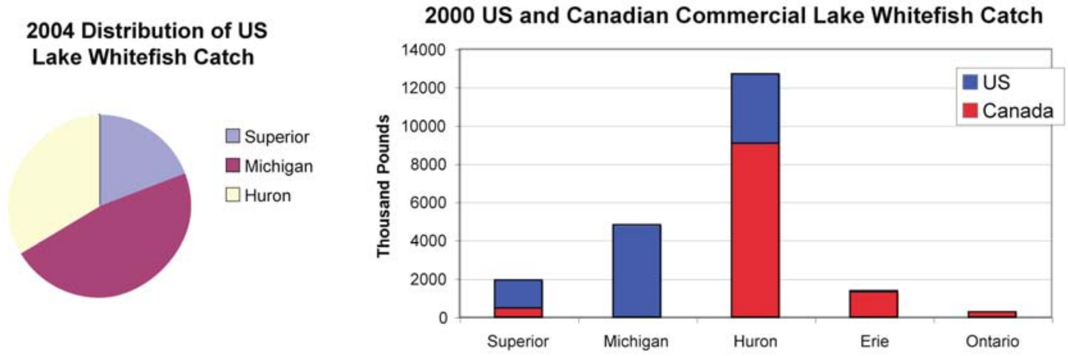


Figure 3: Distribution of lake whitefish catches in the US and Canada by lake (Figures adapted from Baldwin et al. 2002 and Kinnunen 2003b).

Canadian exports from lakes north and west of the Great Lakes basin, particularly from the Northwest Territories and Saskatchewan, are also a substantial portion of US whitefish imports, but will not be treated here as this report focuses on Great Lakes sources exclusively. Recommendations for lake whitefish will be driven primarily by stock status and management in Lake Huron and Lake Michigan, as these lakes support the largest fisheries. Catches from Lake Ontario, US catches from Lake Erie, and Canadian catches from Lake Erie are all relatively minor, and will not be considered in this analysis.

Availability of Science

The lake whitefish has long been a commercially important species in the Great Lakes and as such has been monitored closely since at least the 1970s and in some jurisdictions as far back as the 1930s. Therefore, a large body of literature is available, consisting of commercial fishery records, management reports from the Great Lakes Fishery Commission, individual state Departments of Natural Resources and the Ontario Ministry of Natural Resources, as well as peer-reviewed scientific research papers.

Market Availability

Common and market names:

Lake whitefish is also known as common whitefish, Sault whitefish, whitefish, eastern whitefish, Great Lakes whitefish, inland whitefish, gizzard fish, grande coregone (French), and Attikumaig (Chippewa).

Seasonal availability:

Whitefish supply is seasonal, with the bulk of fresh whitefish available in the fall and spring. To prevent flooding of the market during these periods, large quantities are routinely frozen to support the market during the off-season (Daniels 2003).

Product forms:

Whitefish is available fresh or frozen as whole dressed fish or fillets. New value-added products growing in market share include frozen vacuum-packed fillets and prepared foods such as spreads. Lake whitefish roe is also successfully marketed as “golden caviar.” Canadian whitefish catches from outside the Great Lakes are marketed by the Freshwater Fish Marketing Corporation (FFMC), which produces three main whitefish products: minced block, whole fresh, and whole frozen whitefish.

Import and export sources and statistics:

The largest exports of whitefish from Canada are from the Northwest Territories, Manitoba, Saskatchewan, and Alberta. Great Lakes catches traditionally focused on domestic wholesale markets but competition from Canadian wholesalers from northwest regions of Canada are driving prices down and increasing competition with Great Lakes fish. As a result the lake whitefish market is currently exploring better branding and value-added products.

Lake whitefish is one of the three largest freshwater exports, by both weight and value, from Canada (Fig. 4). Approximately 50% of total Canadian freshwater fish exports come from Ontario, almost entirely from the Great Lakes region. These fish are primarily sold in US markets.

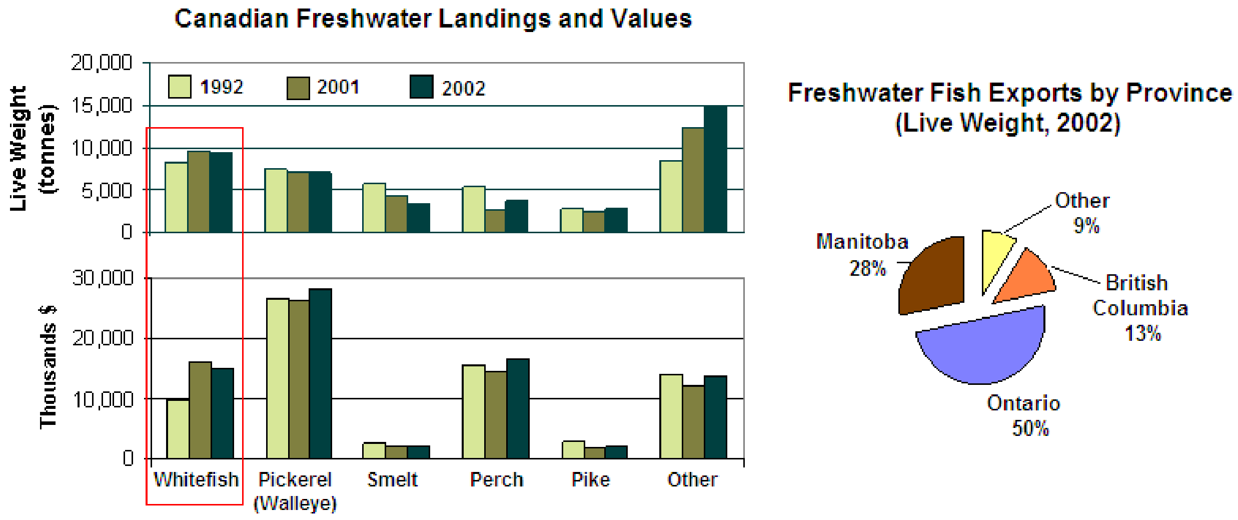


Figure 4. Freshwater fish exports from Canada (Figure fromFAO 2002).

5-III. Analysis of Seafood Watch® Sustainability Criteria for Wild-caught Species

Criterion 1: Inherent Vulnerability to Fishing Pressure

Lake whitefish are a cool-water, demersal species, preferring temperatures between 52ºF and 63ºF (Lasenby et al. 2001). They school in deep waters (>40 ft) and can move to depths greater than 200 ft in the summer in search of colder water (Downs et al. 2002; Froese and Pauly 2007).

Whitefish growth rates can vary with prey availability, degree of exploitation, and population density. They regularly live longer than 20 years, with maximum age listed as 50 years. Total adult length in the Great Lake is typically 18-25 inches, and weights range from 1.5 to 5 pounds. However, unexploited populations of lake whitefish have slower growth rates and attain larger sizes (Mills et al. 2005). Historically, lake whitefish were known to reach 20 lbs, and the largest recorded was 42 lbs, caught off Isle Royale in Lake Superior in 1918.

In the Great Lakes, whitefish mature at 4 to 6 years, depending on growth rate and condition (Mohr and Ebener 2005; Woldt et al. 2006). Spawning occurs in the fall, when temperatures reach 46ºF. Populations that intermingle in the summer exhibit homing behavior, separating into distinct spawning stocks that return to their shallow (<25 ft) nursery habitats to reproduce (Cook et al. 2005; Woldt et al. 2006). Spawning occurs over hard substrates such as cobble, boulders, or honeycomb limestone, or over sand. Fecundity is substantially correlated with female whitefish size, with the average clutch size per female ranging from 8,000 to 24,000 eggs. After hatching, juvenile whitefish leave the spawning grounds in early summer, moving into deeper, cooler waters. Adults typically feed on benthic invertebrates (particularly amphipods) and insect larvae, and may become increasingly planktivorous if benthic prey is scarce.

The schooling behavior of whitefish increases their vulnerability to fishing pressure to some degree, though pressure is lessened in the summer when they move into much deeper waters. Of greater importance to current and historic whitefish population status are habitat quality and food web interactions. Because whitefish spawn in near-shore areas, habitat degradation was an important factor in whitefish population declines from 1900 to 1970, particularly in Lake Erie, where eutrophication was a major issue between the mid-1950s and the mid-1970s (Cook et al. 2005). Restoration put into effect during the latter part of the 20th century reversed many of these effects and helped support substantial recovery throughout the lakes. All populations of lake whitefish in the Great Lakes are naturally reproducing.

More recently, changes in the biological structure of Great Lakes food webs, brought on by the invasion of dreissenid mussels in the early to mid-1990's, has initiated substantial declines in condition and abundance of a number of lake whitefish stocks. The zebra mussel (*Dreissena polymorpha*), a native to Eurasia, was first introduced to the Great Lakes via ship ballast transfer in the late 1980s, and had grown abundant by the mid-1990s. The arrival of the zebra mussel, followed quickly by the related quagga mussel, has been linked to the decline of Diporeia, an amphipod that once formed the basis of much of the benthic biomass of deeper Great Lakes environments. Diporeia is the primary prey of lake whitefish, and the Diporeia-whitefish relationship represents a species complex that efficiently transfers benthic production to lake biomass available to both piscivorous fish and humans via the fishery (Nalepa et al. 2005). Soon after the dreissenid invasion, Diporeia began to disappear from areas where it had been most abundant (Fig. 5).

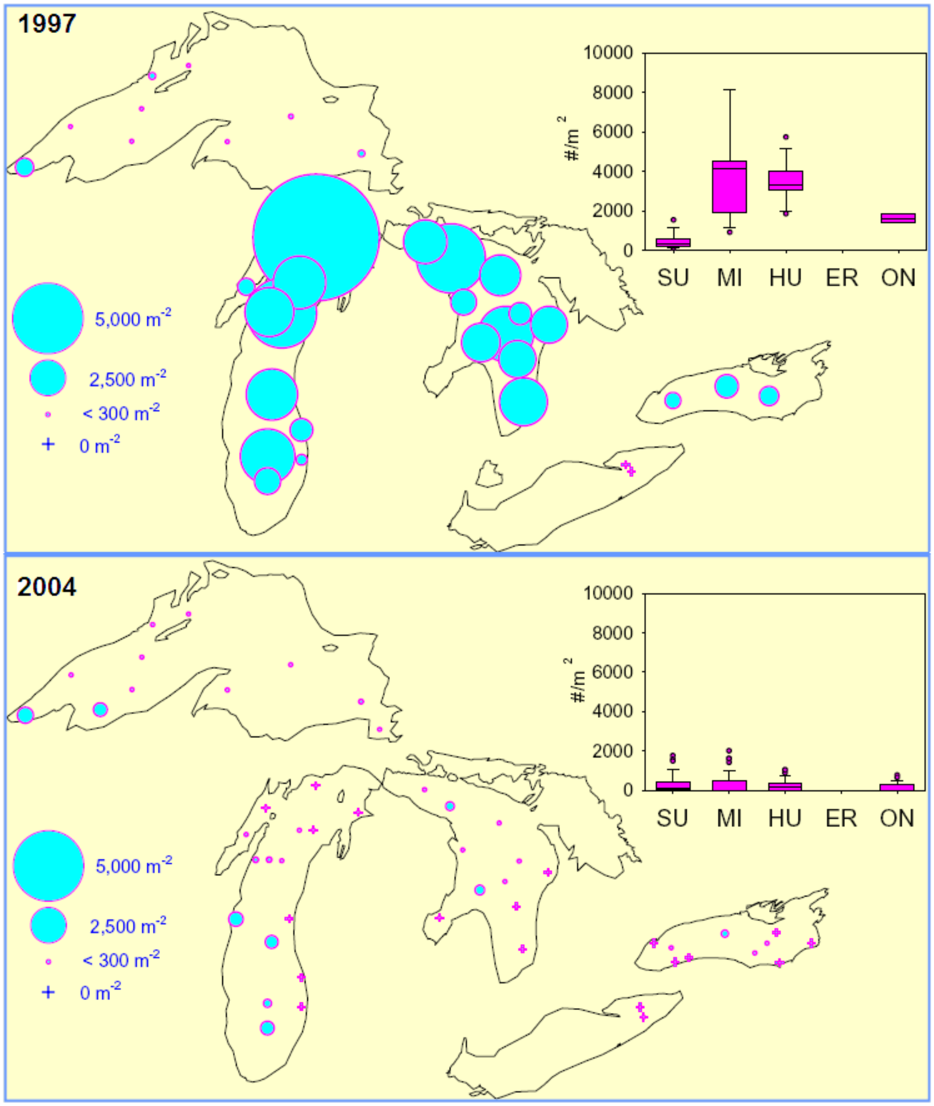


Figure 5. Changing Diporeia abundance in the Great Lakes, 1997-2004 (Figure from Rockwell et al. 2006).

The loss of this major food source has likely caused a reduction in lake carrying capacity (Kratzer et al. 2007; Wright and Ebener 2007), and reductions in the condition, growth, and reproductive success of lake whitefish has been observed in Lake Ontario, Lake Huron, and Lake Michigan. In Lake Superior, comparable Diporeia declines have not occurred, and in Lake Erie the abundance of alternative prey, particularly large densities of insect larvae, have buffered the condition of whitefish populations (Fig. 6). In Lake Michigan, Lake Ontario, and Lake Huron, where only less energetically favorable or less abundant prey, such as mussels and sphaeriids, were available, whitefish distributions first shifted to deeper water, possibly following Diporeia into areas less habitable to dreissenid mussels, and then adjusted to include zebra mussels as a substantial proportion of their diet. This change in diet, however, has resulted in declining condition; in Lake Michigan, a 53% decline in lake whitefish body condition, K (K=weight $x10^5/length^3$) (Fig. 6), has been attributed to the virtual disappearance of Diporeia (Nalepa et al. 2005).

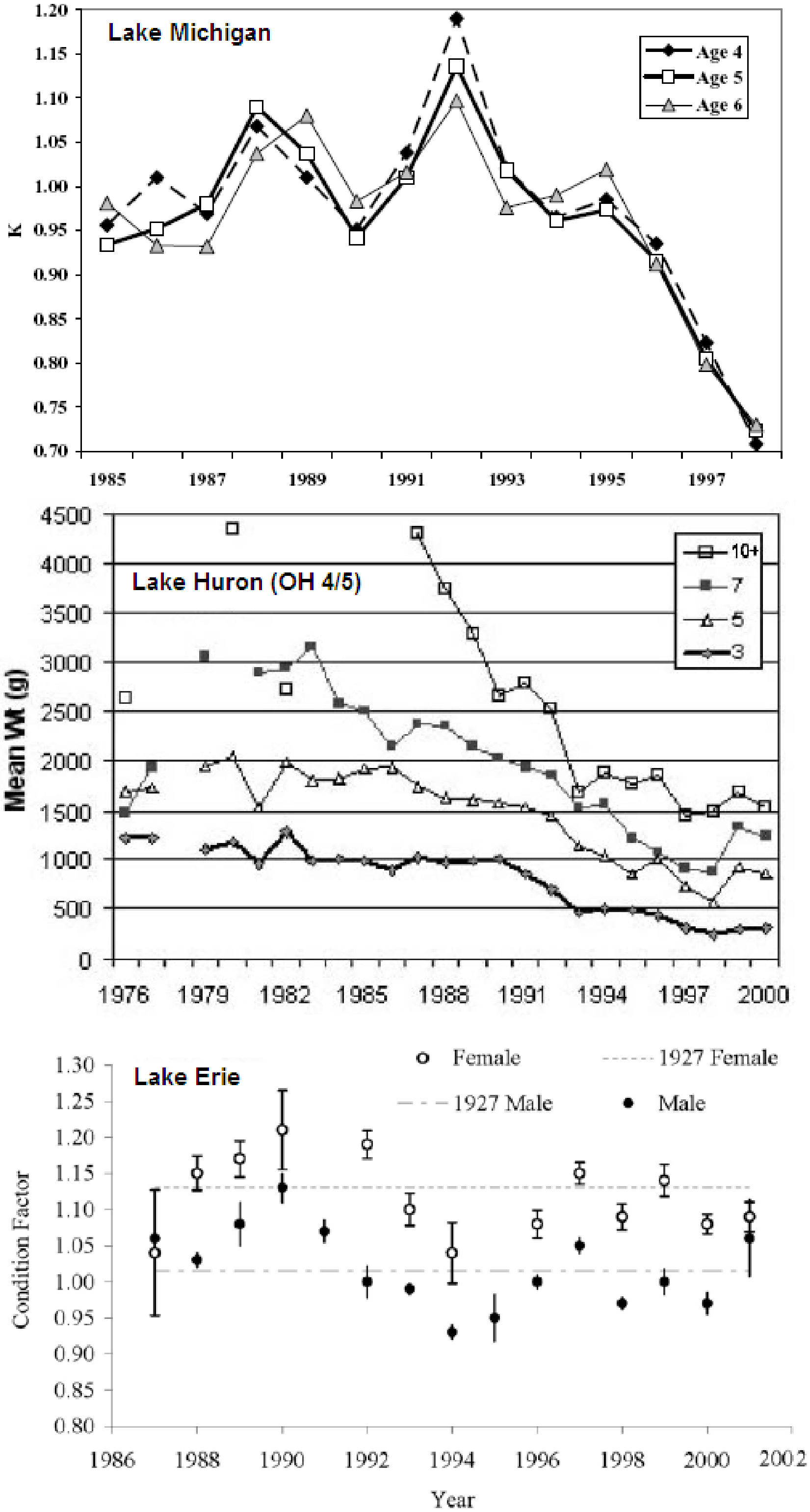


Figure 6. Declining lake whitefish condition in Lake Michigan and Lake Huron, as measured by condition factor (K=Weight x10^5/Length^3) or mean weight-at age. Whitefish populations in Lake Erie, where chironomids larvae (alternate prey) are plentiful, have shown relatively stable condition indices over the same time period (Figures from Cook et al. 2005; Mohr and Ebener 2005; Schneeberger et al. 2005).

Table 1. Life history characteristics of lake whitefish.

Intrinsic Rate of Increase (r)	Age at Maturity	Growth Rate	Max Age	Max Size	Fecundity	Species Range	Special Behaviors	Sources
0.05-0.15	4-6 years	K=0.15-0.35	20 years	25 inches	8,000-24,000 eggs/female	Broad	Schooling, spawning site fidelity.	Downs et al. 2002; Cook et al. 2005; Woldt et al. 2006; Froese and Pauly 2007

Synthesis

Lake whitefish is a schooling, deep-water fish that grows moderately quickly, reaching maturity in as early as 4 years. Its preferred habitat is plentiful in the Great Lakes region, particularly in the northern lakes, where it is broadly distributed. As evidenced by their recovery after steep declines in the middle of the past century, whitefish populations can rebound quickly from low abundance once stress is removed. Their habitat is generally in good condition in the Great Lakes, but biotic interactions currently inhibit whitefish health; the invasion of the zebra and quagga mussels in the 1990s caused a substantial reduction in the abundance of the preferred prey of lake whitefish, Diporeia. The loss of this energetically rich food source has caused declines in lake whitefish condition, particularly in lakes where similarly energy-rich prey is not readily available. However, this loss of condition has not directly caused an increase in their vulnerability to fishing pressure—in many areas, whitefish are now recruiting to the fishery at older ages. Recent (since 2002) increases in abundance and catch per unit effort indicate that whitefish may be adjusting to the loss of Diporeia by changing their distribution or diet; however, changes in the food web structure of the Great Lakes may have changed the carrying capacity for lake whitefish (Kratzer et al. 2007; Wright and Ebener 2007), and some caution is warranted. The ongoing effects of Diporeia loss on whitefish condition should be monitored, as when condition becomes particularly low, fecundity and recruitment can be affected, causing declines in abundance. These concerns, balanced with moderate growth rate and early age at first maturity, results in a rank of moderate vulnerability to fishing pressure for lake whitefish.

Inherent Vulnerability Rank:

Resilient 🟩 **Moderately Vulnerable** 🟨 Highly Vulnerable 🟥

Criterion 2: Status of Wild Stocks

Lake Michigan

About 45% of the total US lake whitefish catch comes from Lake Michigan, where whitefish is the most important commercial stock. Currently about 60% of the allowable catch is allocated to state-licensed fisheries, and 40% to tribal operations (Fig.7).

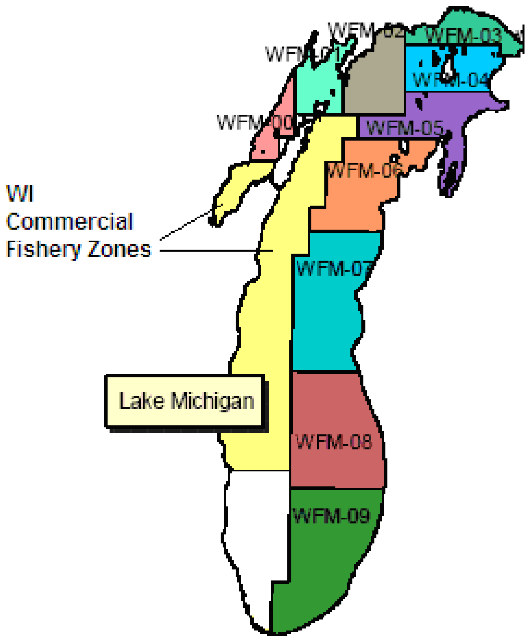


Figure 7. Wisconsin commercial fishery zones and whitefish management zones (WFM) in Lake Michigan (Figure from Woldt et al. 2006).

During the 1990s, Lake Michigan produced nearly 60% of the total whitefish catch across all of the Great Lakes. Over the history of the fishery, whitefish abundance has fluctuated over a wide range in response to a variety of stresses. Prior to 1900, overfishing had already reduced local stocks; however, whitefish, lake-wide, still yielded 1,000 metric tons annually from 1900 to 1950 (Fig. 8). Two distinct peaks can be seen in this time period, attributable to two strong year classes moving through the fishery (Fig. 8, panel I). Increasing fishing pressure, predation on larval whitefish by invasive alewife and rainbow smelt and the invasion of the sea lamprey, which preyed on whitefish more intensely when lake trout became scarce, led to a population low in the mid-1950s of only 11 metric tons, a nearly 99% decrease from 19th century yields (Schneeberger et al. 2005).

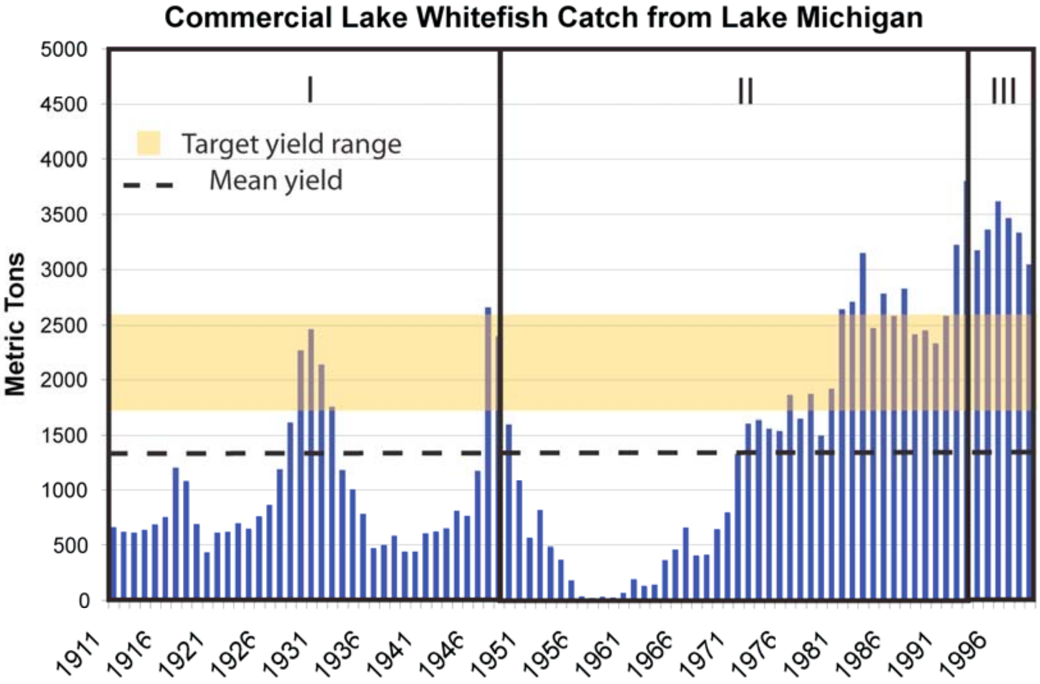


Figure 8. Lake whitefish commercial catch relative to target yields in Lake Michigan, 1911-2000 (Figure adapted from Baldwin et al. 2002 and Schneeberger et al. 2005).

By the mid-1960s, a number of management efforts, including chemical control of sea lamprey populations, stocking of salmonids to control alewife and rainbow smelt abundance, and reduced fishing pressure, were put into place. This resulted in a rapid rehabilitation of the whitefish population, such that by the mid-1970s commercial catches were once again at historic levels. Commercial catches have since met or exceeded the target yield of 1,800-2,700 metric tons (4-6 million pounds) per year set by the Lake Michigan whitefish Fish Community Objective (Eshenroder et al. 1995; Schneeberger et al. 2005) (Fig. 8, panel II).

During the 1990s, lake whitefish condition and growth began to decline. Length-at-age fell by 4-7% while weight-at-age decreased by 36-47%. This decline in condition has been attributed to two primary factors: a density-dependent growth mechanism; and the loss of Diporeia as a major food source. Authors of recent lake whitefish diet studies have argued that the latter is the more influent factor in large observed decreases in whitefish condition; in the absence of Diporeia, dreissenid mussels make up a large proportion of the whitefish diet but are much less energy-dense, leading to decreased condition. However, declines in lake whitefish condition were already being observed in Lake Superior, Lake Huron, and Lake Michigan prior to the arrival and proliferation of dreissenid mussels and subsequent loss of Diporeia from whitefish diets (Ebener et al. 2007; Kratzer et al. 2007). It is therefore more likely that declines that had been initiated by density-dependent mechanisms within the lake whitefish population were further exacerbated by the ecosystem effects of the dreissenid mussel invasion in the late 1980s.

Between 1996 and 2002, fishery yield declined for many Lake Michigan whitefish stocks (Fig. 8, panel III). Decreases in catch per unit effort (CPUE) observed over this same period in both tribe- and state-licensed commercial fisheries (Fig. 9) have been attributed at least in part to the redistribution of whitefish stocks as a response to the proliferation of dreissenid mussels in near-shore areas and the decline of Diporeia. Increases in the maximum depth permitted for trap netting in the mid-1990s and again in 2002 led to some short-term increases in CPUE (Peeters 2003).

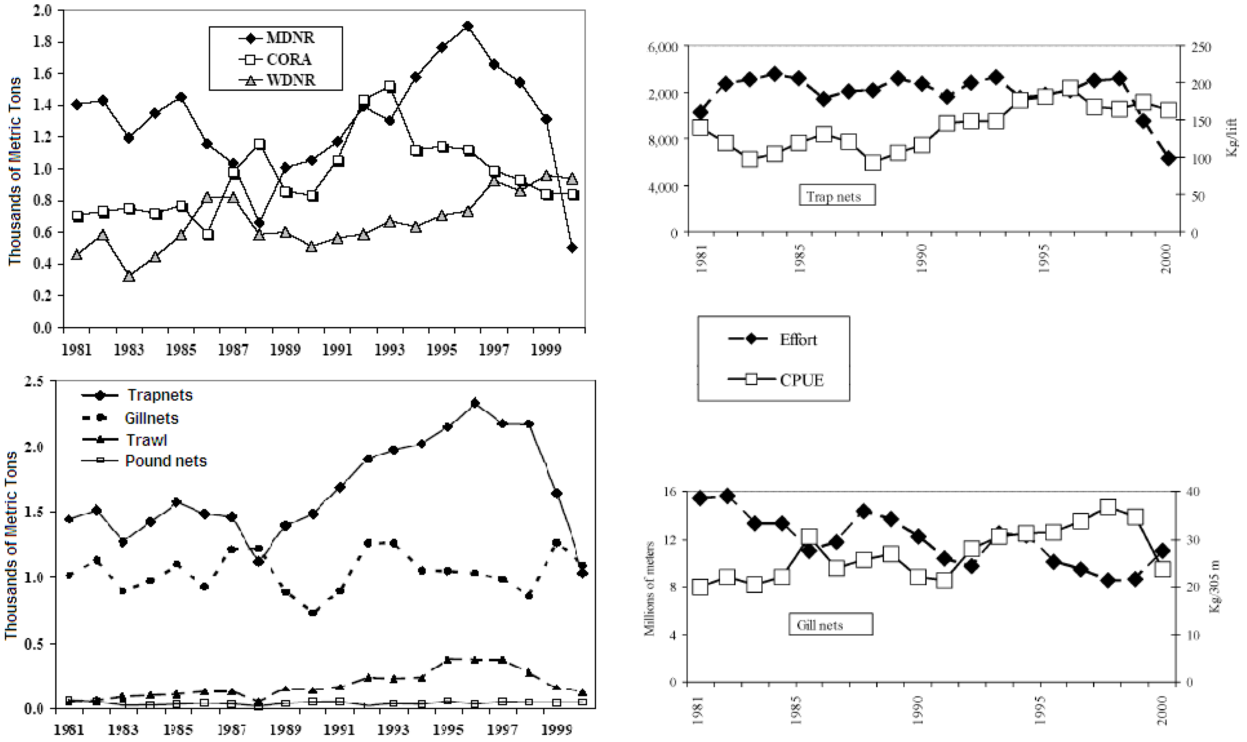
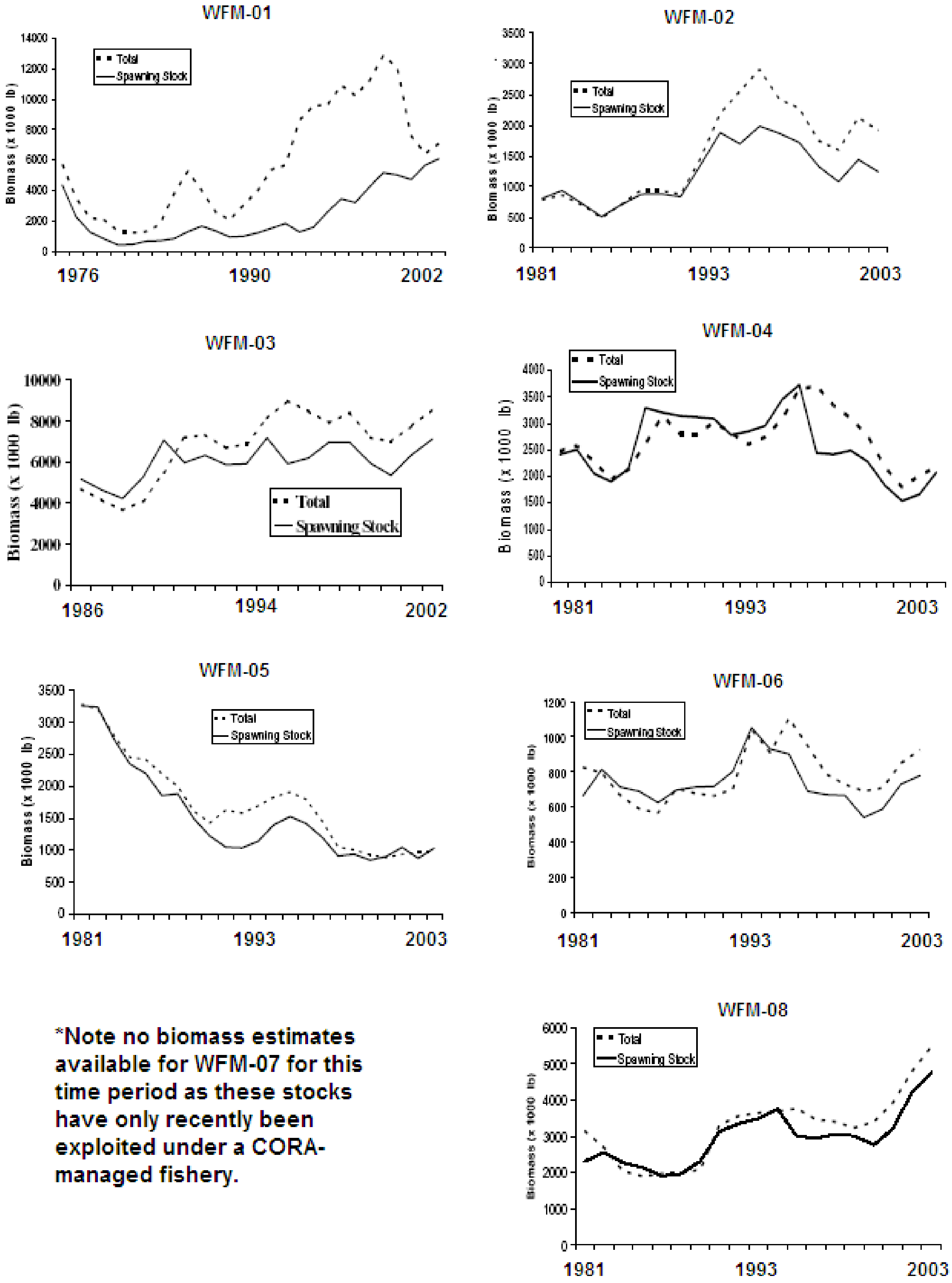


Figure 9. Lake whitefish commercial yield and catch per unit effort in tribe- and state-licensed (Michigan and Wisconsin) fisheries in Lake Michigan (Figure from Peeters 2003).

The substantial decrease in trap net effort and Michigan commercial yield in 2000 reflects the redistribution of whitefish allocation and effort following the 2000 Consent Decree which reasserted the 1836 Treaty rights of tribal fisheries. A decrease in tribal gillnet effort soon followed. Following yield declines from the mid-1990s to about 2000, whitefish abundance stabilized or began to increase, and growth and condition also improved in many management areas (Fig. 10). It is possible that by 2002 whitefish had begun adjusting to the loss of Diporeia.



*Note no biomass estimates available for WFM-07 for this time period as these stocks have only recently been exploited under a CORA-managed fishery.

Figure 10. Lake whitefish total and spawning stock biomass in tribe-licensed waters of Lake Michigan (Figure from Woldt et al. 2006).

In general, growth and condition in Lake Michigan whitefish were stable, albeit in most cases at lower levels than those of the mid-1990s. Similar increases are reflected in the increase in total catch between 2002 and 2006, which remained within the target sustainable yield of 4-6 million pounds set by the Fish Community Objectives in 1995 (Breidert et al. 2007) and began to reverse an overall decline observed between 1997 and 2002 (Fig. 11).

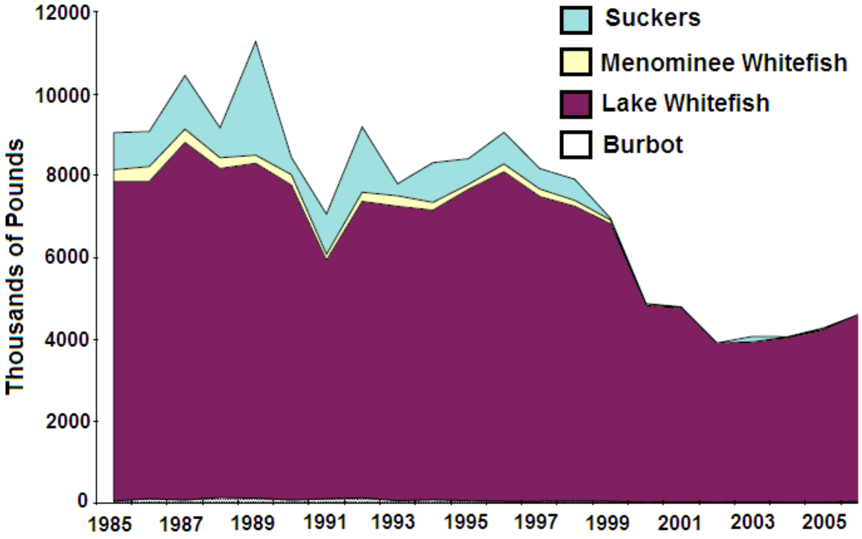


Figure 11. Catch of benthivore fish from Lake Michigan, 1985-2006 (Figure from Breidert et al. 2007).

The major spawning stock for Wisconsin and Michigan commercial fisheries has grown in recent years, leading to an increase in the total allowable catch. Current catches are now higher than any whitefish catch in the history of these fisheries (Peeters 2001). However, despite populations that are stable at levels well above the mid-19th century lows, the loss of condition that occurred over the past two decades has led to reduction in mean length at age (Fig. 12). This decline has resulted in an increase in the age at which whitefish recruit to the fishery (attain legal size), from 4 years to nearly 7 years (Peeters 2006).

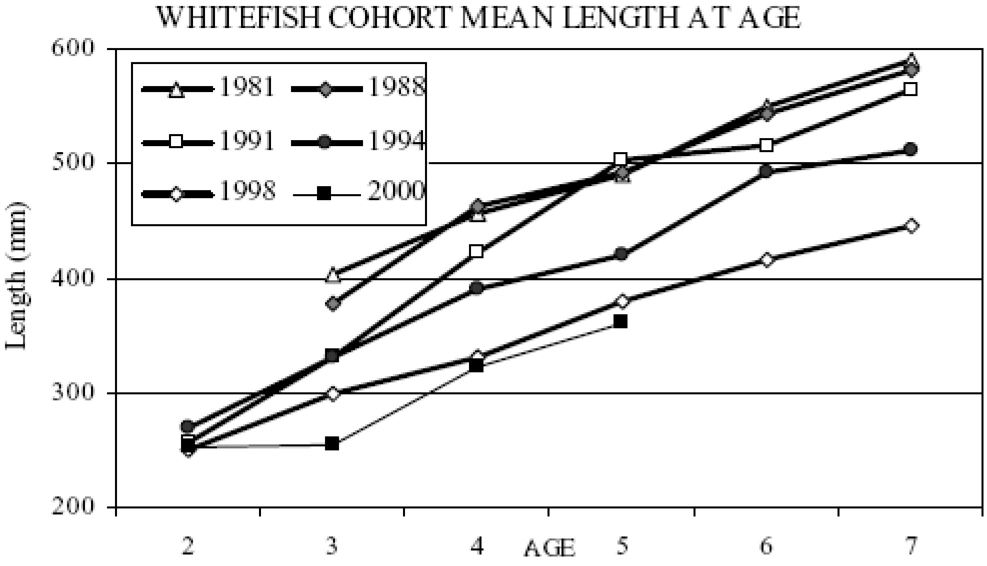


Figure 12. Decline in mean length-at-age of whitefish caught in Wisconsin waters of Lake Michigan, for the 1981-2000 year classes captured between 1984 and 2005 (Figure from Peeters 2006).

Synthesis – Lake Michigan

Approximately 45% of the US commercial whitefish catch comes from Lake Michigan, where abundance is well above historical levels and consistently above the maximum sustainable yield. In Wisconsin waters, whitefish catches are the largest in the history of the fishery, indicating that stocks are healthy. The recent decline in condition of Lake Michigan lake whitefish has been some cause for concern, as it can affect not only the age at which fish recruit to the fishery, but also affect recruitment. However, it appears that whitefish have been redistributing in the lake as a response to decreased abundance of Diporeia, and though this has led to variable and in some cases decreasing catch per unit effort, it indicates that whitefish are adjusting to the loss of a formerly important prey item. Catch rates have increased again as of 2002, and the Lake Michigan whitefish stock is therefore considered healthy according to Seafood Watch® criteria.

Lake Huron

Commercial catch of lake whitefish in Lake Huron accounts for 35% of the US catch and more than 80% of the Canadian catch. Within the US, the catch is allocated evenly among state- and tribe-licensed fisheries (Fig. 13).

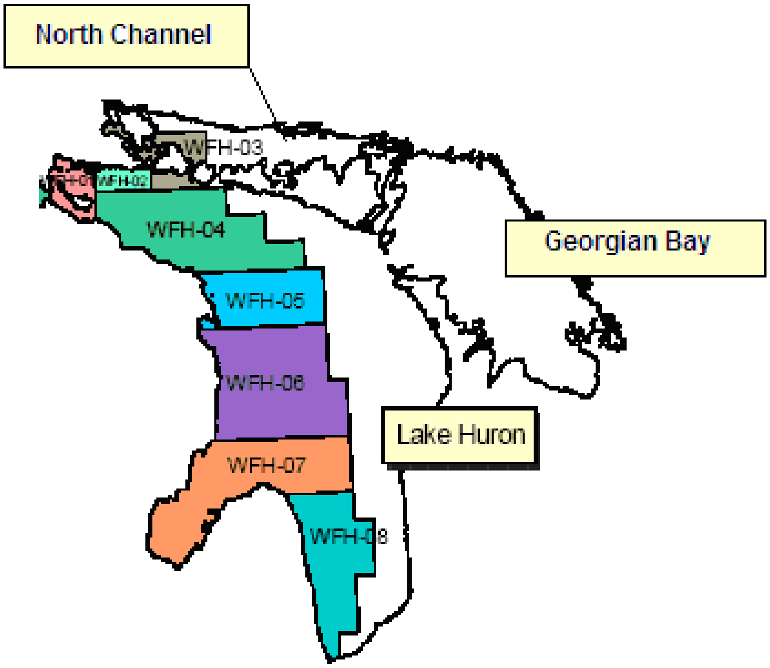


Figure 13. Lake whitefish management units in US waters of Lake Huron (Figure from Woldt et al. 2006).

Yields of lake whitefish in Lake Huron declined substantially beginning in the 1930s, reaching a low in 1958. Populations then remained depressed until the mid-1970s, when a steady increase in commercial fishery catch per unit effort (CPUE) indicated increasing abundance through the mid-1990s (Fig. 14). Restoration efforts resulted in commercial yields that were well above the target sustainable catch of 8.36 million pounds per year set by the Lake Huron Fish Community Objectives in 1995. Catches have remained above this target since 1993, but with a peak in the late 1990s (Mohr and Ebener 2005). More recently, CPUE throughout Lake Huron has been variable in recent years. In tribe-licensed (CORA) fisheries, CPUE has been variable with no long-term trend. In Canadian waters (main basin), CPUE has recently declined, though it remains above 1980s levels. In Georgian Bay and North Channel gillnet fisheries, CPUE continues to increase. Trap net CPUE increased until the mid-1990s and has recently decreased but remained well above that of the 1980s (Fig. 14, right panel).

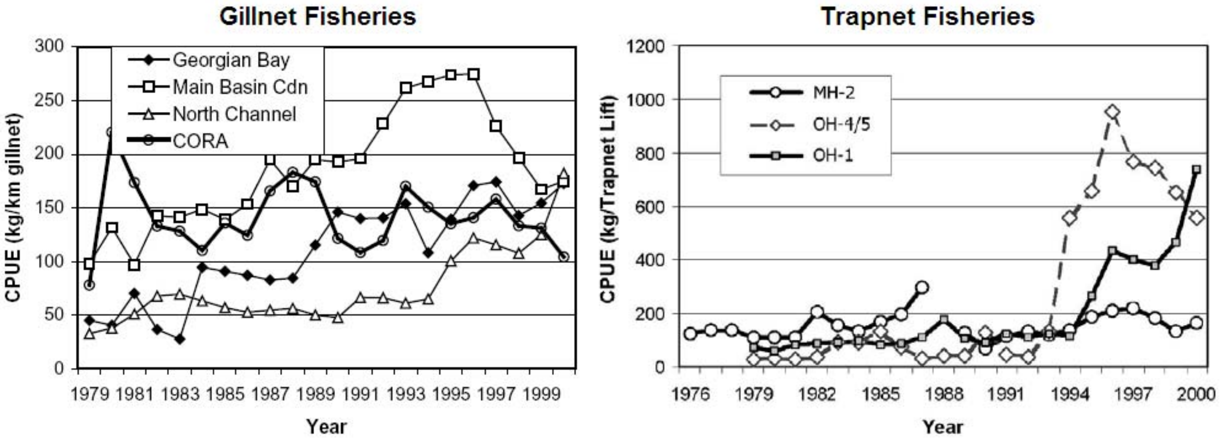


Figure 14: Catch per unit effort (CPUE) in the lake whitefish fisheries of Lake Huron (Figure from Mohr and Ebener 2005).

Strong whitefish year classes were produced between 1992 and 1997 but recruitment has generally been variable in the past 20 years. Weaker year classes are currently recruiting to the fishery (Fig. 15).

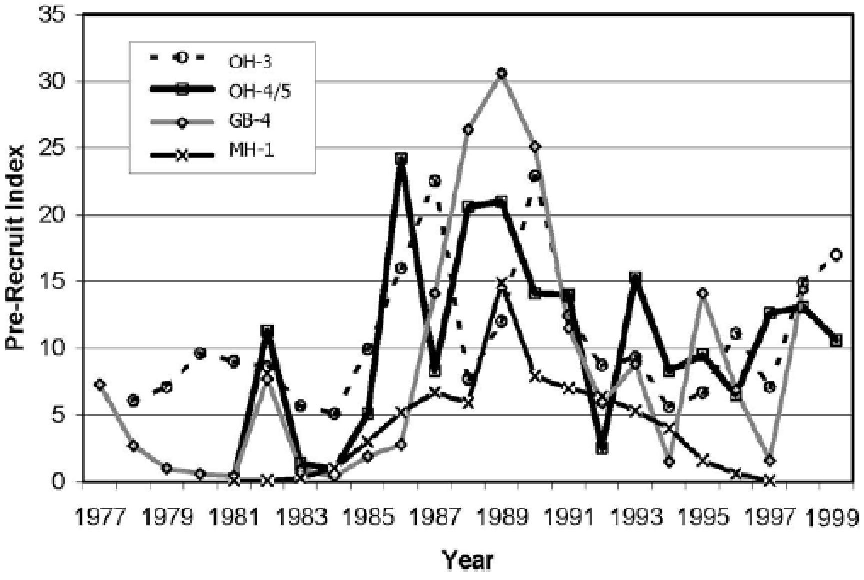


Figure 15. Lake whitefish year class strength in Lake Huron (Figure from Mohr and Ebener 2005).

In tribe-licensed waters, whitefish biomass peaked in the mid-1990s and has since either stabilized at lower levels or decreased (Fig. 16), though fishing mortality remains well below target limits (i.e., catch remains at sustainable levels). However, mortality attributed to the sea lamprey, a predator that typically prefers lake trout, has been increasing, particularly in WFH-03.

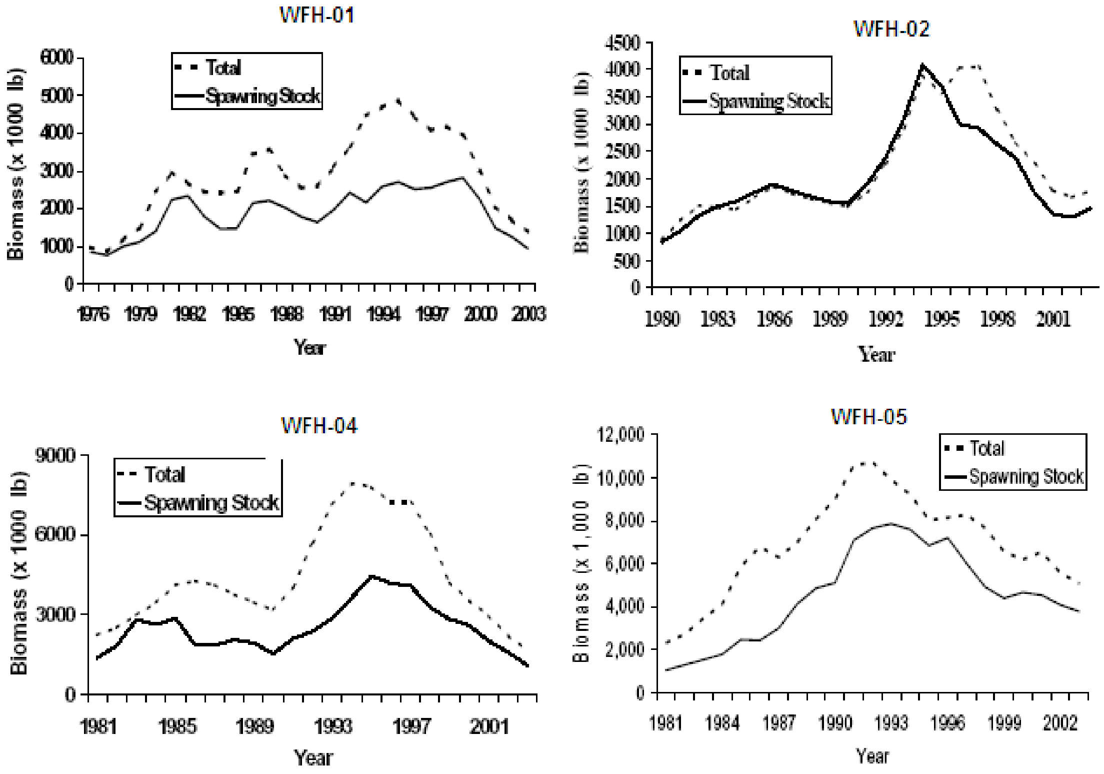


Figure 16. Estimated whitefish biomass in Lake Huron management units managed by CORA for tribe-licensed fisheries. Note no biomass estimates are available for WFH-03, where results have been too variable. Recruitment in WFH-03 has been similar to WFH-02 (Figure from Mohr and Ebener 2005).

The age structure of Lake Huron stocks has improved since populations plummeted in the late 1970s to early 1980s, with the mean age of catches increasing from a low of 2-3 years of age in 1983 to 6-7 years of age in 2000. Mean age at maturity has also increased as growth declines. Growth and condition have not changed uniformly in Lake Huron, with steeper declines evident in the main basin and southern districts while no decline has been observed in Georgian Bay or the North Channel. Diporeia declines were first observed in near-shore areas of southern Lake Huron in 2000, and together with density-dependent mechanisms have resulted in reduced biomass and decreased whitefish condition. However, Diporeia remain abundant in deeper waters and a recent shift in fishery effort offshore suggests that whitefish are shifting their distribution to follow their preferred benthic prey (Mohr and Ebener 2005).

Synthesis – Lake Huron

Approximately 35% of the US and 80% of the Canadian lake whitefish catches are from Lake Huron. Although catches in this lake have generally remained above historic long-term means, abundance varies substantially among jurisdictions. The Canadian fisheries appear to have the healthiest stocks; in the North Channel and Georgian Bay in particular catch per unit effort (CPUE) is increasing, and there has been no decline in growth or condition. Within Canadian waters of the main basin CPUE had declined but is now stabilizing. In contrast, within most tribe-licensed management units (WFH-01, WFH-04, and WFH-05) (Fig. 13), CPUE has declined. Only WFH-02 has seen a stabilization or slight increase in catch per effort. In state-licensed management units in US waters of Lake Huron, CPUE is variable but stable or increasing more than decreasing. Age at maturity within US waters has increased, but at the same time so has the age at which fish recruit to commercial gear. Consequently, increased catches of immature fish are not of great concern. Lake whitefish biomass from US waters of Lake Huron within tribe-licensed fisheries have undergone recent short-term declines after peaking in the mid-1990s (Fig. 16), though populations are still strong relative to mid-20th century lows, and are therefore considered of only moderate conservation concern. As Canadian whitefish catches from Lake Huron are much larger, and Canadian stocks are considered the healthiest of the stocks in Lake Huron, the overall status of lake whitefish stocks from Lake Huron is healthy.

Lake Superior

Lake whitefish have been the primary commercial species caught in Lake Superior since the late 1980s (Horns et al. 2003), and account for 20% of the total US catch. This catch is equally divided between state- and tribe-licensed fisheries (USGS 2007b), with allocation shared in management units WFS-01 through WFS-05, but exclusive to tribal fisheries in WFS-06 through WFS-08 (Fig. 17).

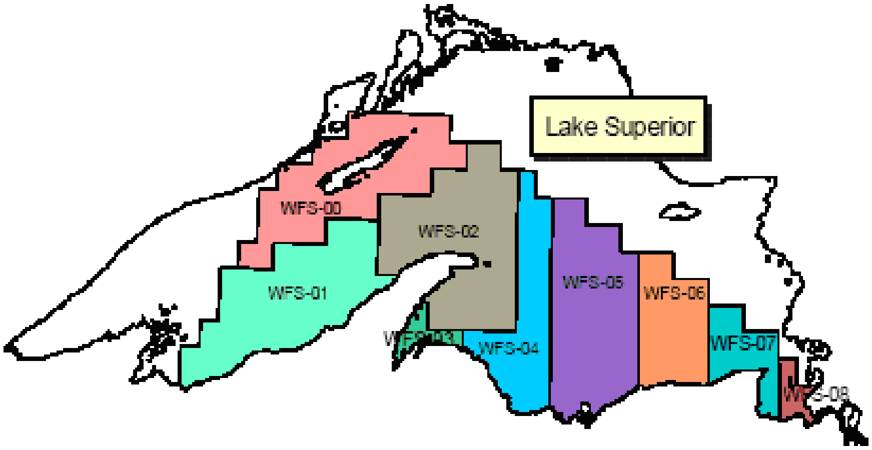


Figure 17. Lake whitefish management zones in US waters of Lake Superior (Figure from Woldt et al. 2006).

In the early part of the 20th century, overfishing and habitat degradation seriously depleted whitefish stocks in Lake Superior, but stocks have increased substantially since that time, producing annual catches since 1983 that have exceeded any historic yields. Over the last two decades the whitefish populations have continued to expand, and in recent years mean biomass has remained stable, though year class strength has varied; the 2003 class was much stronger in US waters than in Canada, for example, but substantially lower than the 2002 year class in both jurisdictions (Stockwell et al. 2005) (Fig. 18).

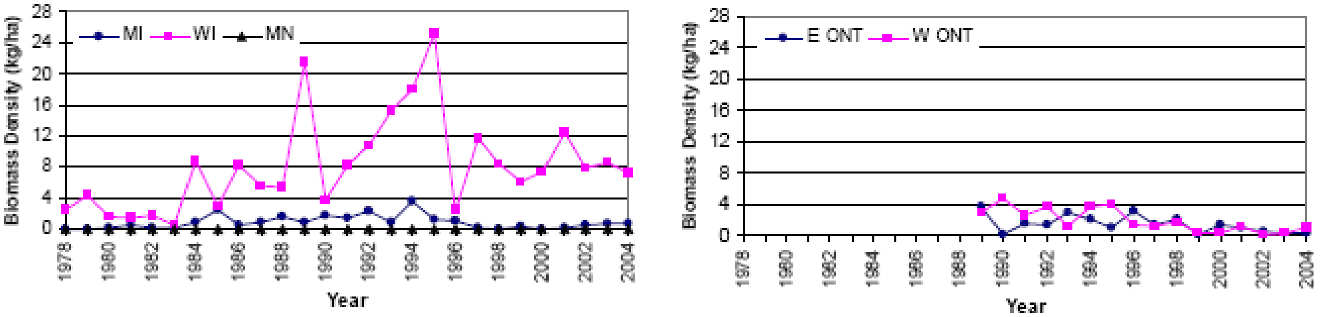


Figure 18. Lake whitefish biomass in US and Canadian waters of Lake Superior, 1978-2004 (Figure from Stockwell et al. 2005).

Whitefish catches in Treaty-ceded waters remain below maximum sustainable levels, and total and spawning biomass, which peaked in the mid-1990s, have been generally stable. In WFS-07, where key tribal fisheries operate, biomass has stabilized to levels equivalent to those observed in the 1980s (Fig. 19).

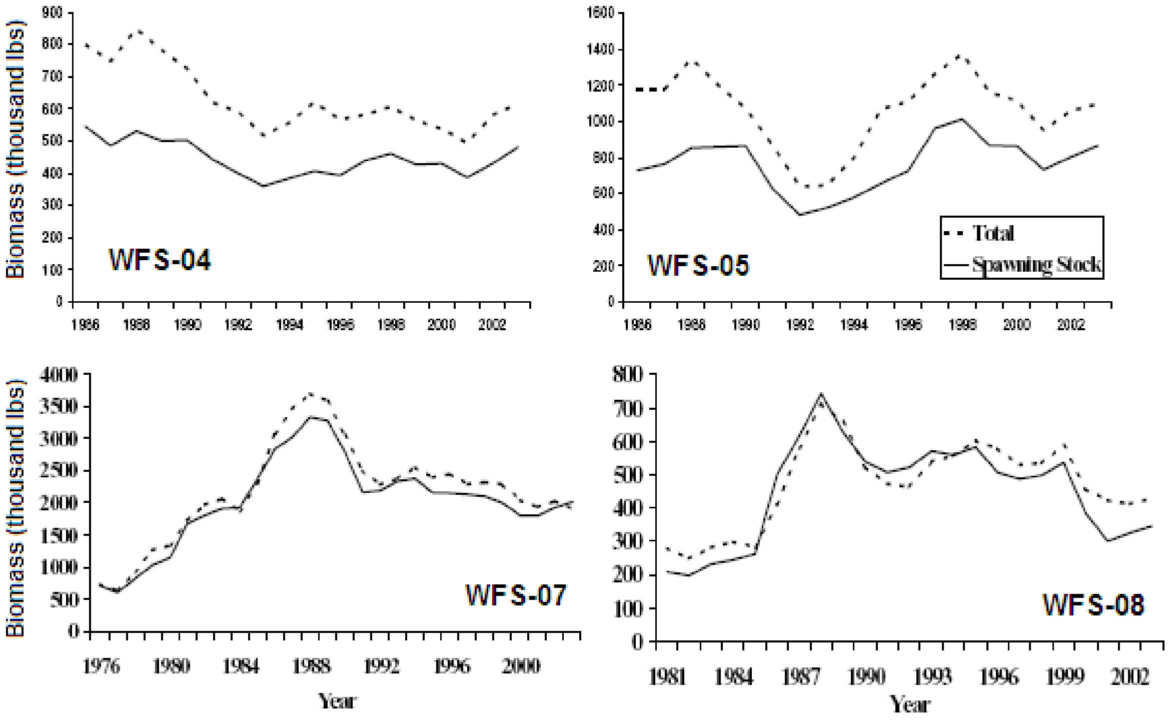


Figure 19. Total and spawning stock biomass estimates for Lake Superior management units where tribal fisheries operate. Note no biomass estimates were available for WFS-06 (Figure from Woldt et al. 2006).

Synthesis – Lake Superior

Approximately 20% of the US lake whitefish catch is from Lake Superior. In contrast to stocks in Lake Huron and Lake Michigan, Lake Superior whitefish abundance did not decline in the mid-1990s. The Diporeia declines that impacted those other stocks did not occur in Lake Superior, probably because it lacks suitable dreissenid mussel habitat. Consequently, lake whitefish biomass has remained stable and above long-term means in Lake Superior. In Wisconsin waters in particular catches are at record levels. In tribe-licensed fisheries, where catches generally peaked in the mid-to-late 1980s, biomass has been relatively stable over the past decade, if somewhat lower than peak values. Because there was no Diporeia decline in Lake Superior, decreasing lake whitefish condition has not been an issue. Therefore, stocks from Lake Superior are considered healthy.

Lake Erie

In Lake Erie, whitefish have been a part of the commercial fishery since the early 1800s. In the early days of the fishery, exceptional year-classes were produced in 1926, 1936, and 1944, and lake-wide yield peaked in 1949 with 7.04 million pounds, supporting substantial fisheries in Ontario, Ohio, Pennsylvania, New York, and Michigan. In the 1950s, as happened to many other species and in many of the Great Lakes, the whitefish stocks collapsed, and remained low for decades (Cook et al. 2005).

After restoration efforts reduced nutrient loading and began to control populations of invasive species such as sea lamprey, alewife, and rainbow smelt, the Lake Erie whitefish population began to rebound, producing a very strong year class in 1984. The abundance of whitefish in Lake Erie led Canadian fisheries, which had been catching whitefish as incidental bycatch in their gillnet fisheries, to target whitefish beginning in 1997. Gillnets were prohibited in US waters of the Great Lakes, and, despite Pennsylvania and Ohio having once had sizeable whitefish fisheries, by 2001 Canada was taking 96% of the lake-wide whitefish catch. Ohio trap net fisheries caught the remaining 4% (Fig. 20).

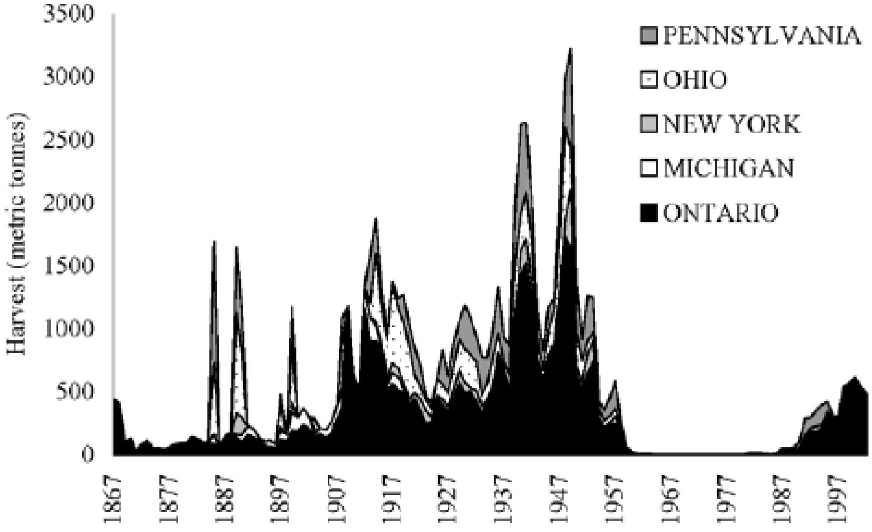


Figure 20. Distribution of lake whitefish harvests in Lake Erie by jurisdiction (Figure from Cook et al. 2005).

Currently, lake whitefish primarily inhabit the eastern basin of Lake Erie, which has the deepest, coolest water of the three basins, and their habitat is often limited to this basin during summer when the central basin stratifies. In the fall, whitefish redistribute among the lake’s three basins to spawn. The majority of the stock is migratory, though some remain in the eastern basin to spawn (Cook et al. 2005). This movement, coupled with large inter-basin variability, makes it difficult to monitor trends in whitefish abundance. Catch rates in the eastern basin appeared to have declined in recent years, but increased substantially in 2004 (Fig. 21). The central basin currently accounts for 52% of the commercial catch, and the western basin accounts for 47% (Markham et al. 2005). Catch averages over the past two decades are less than half the long-term pre-crash (1909-1953) mean, suggesting the lake's carrying capacity for whitefish has changed (Cook et al. 2005).

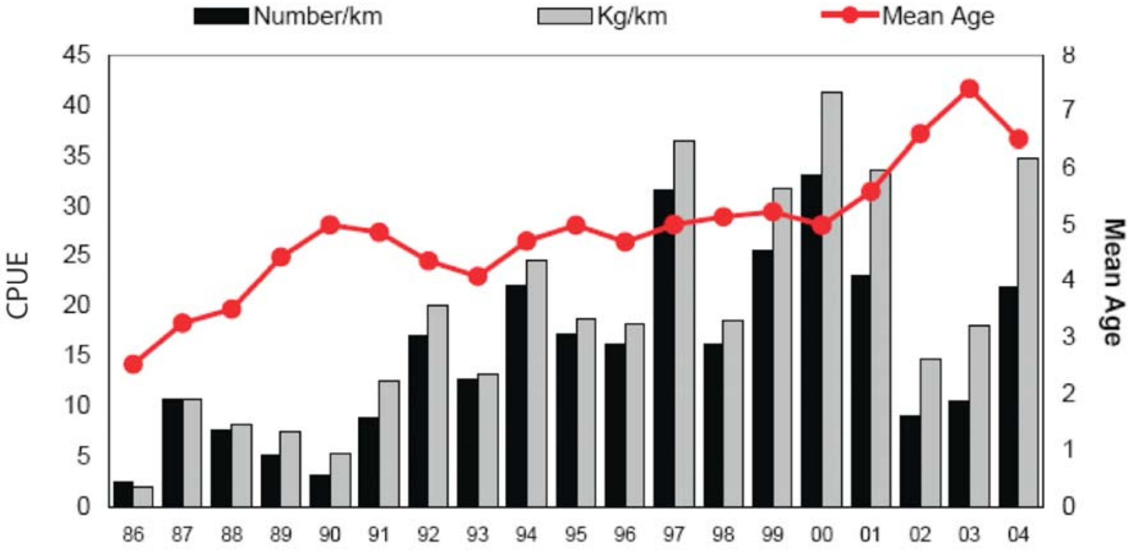


Figure 21. Catch per unit effort of lake whitefish in Ontario waters of Lake Erie (Figure from Cook et al. 2005).

Whitefish growth rates are similar to what they were before the stocks crashed in the 1950s (Nalepa et al. 2005), and condition has remained stable, in contrast to most other lakes (Fig. 5). Although Diporeia declined in Lake Erie as in Lake Michigan and Lake Huron, sufficient alternate prey (chironomid larvae, in particular) were available to buffer whitefish populations from this food web change (Cook et al. 2005). However, trends in the age composition of catches suggest that recruitment has declined since the mid-1990s (Fig. 22).

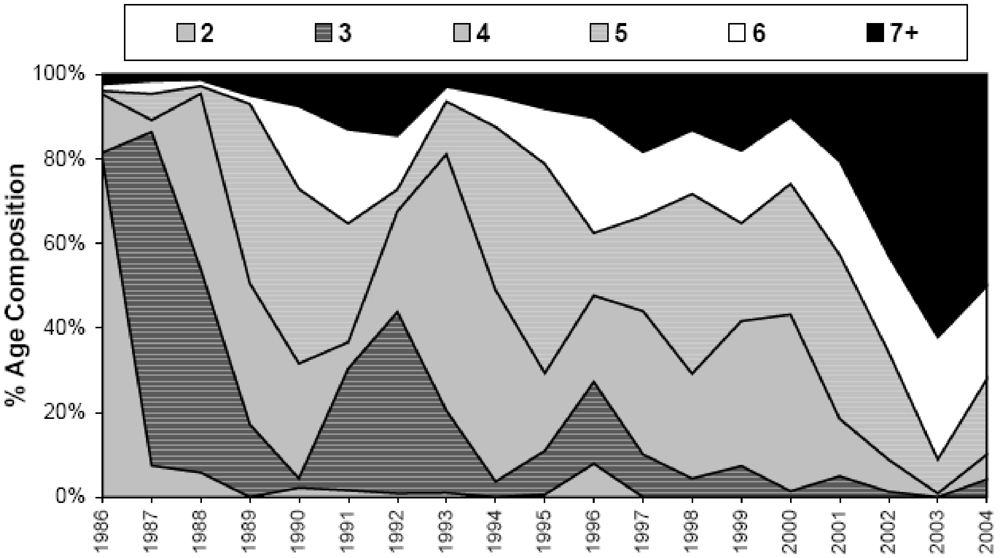


Figure 22: Age composition of lake whitefish from fall Ontario commercial gillnet catches (Figure from Markham et al. 2005).

Synthesis – Lake Erie

Approximately 10% of the Canadian commercial whitefish catch is from Lake Erie. Stock assessment is difficult in Lake Erie as whitefish stocks are highly migratory and their patchy distribution among the three basins can confound assessment catch rates. CPUE has been variable in recent years, with a low in 2002 followed by substantial increases in 2004 and 2005 that brought catch rates close to the mid-1990s peak. Condition of stocks in Lake Erie has been stable, as the Diporeia declines that affected stocks in other lakes had less impact due to the abundance of suitable alternative prey (chironomid larvae). However, recruitment appears to have declined in recent years, as evidenced by an age structure that is skewing to fish age 7+. Given the short-term variability in whitefish abundance, particularly with the substantial decline in 2002, and the uncertainty associated with stock distribution and status across the lake's three basins, Lake Erie's stocks are considered to be of moderate conservation concern.

Table 2. Stock status of lake whitefish.

Status	B/B_{MSY}	Occurrence of Overfishing	F/F_{MSY}	Abundance Trends/ CPUE	Age/Size/Sex Distribution	Degree of Uncertainty in Stock Status	Sources	SFW Rank
Lake Michigan Not listed	>100%	None	Fishing mortality within target levels.	CPUE variable but increasing	Skewed.	Low to moderate.	Peeters 2001; Schneeberger et al. 2005; Peeters 2006; Woldt et al. 2006; Breidert et al. 2007	**Healthy**
Lake Huron Not listed	>100%	None	Fishing mortality within target levels.	CPUE up or stable in CA, variable in CORA/US	Skewed.	Low to moderate.	Mohr and Ebener 2005; Woldt et al. 2006	**Healthy**
Lake Superior Not listed	>100%	None	Fishing mortality within target levels.	Increasing/ stable.	Normal.	Low to moderate.	Horns et al. 2003; Stockwell et al. 2005; Woldt et al. 2006	**Healthy**
Lake Erie Not listed	Unknown	Unknown	No target level set.	Variable CPUE.	Skewed	Moderate.	Cook et al. 2005; Markham et al. 2005; Nalepa et al. 2005	**Moderate**

Status of Wild Stocks Rank:

Lake Superior:

Healthy 🟩 Moderate/Rebuilding 🟨 Poor 🟥 Critical ⬛

Lake Erie, Lake Michigan, Lake Huron:

Healthy 🟩 **Moderate/Rebuilding** 🟨 Poor 🟥 Critical ⬛

Criterion 3: Nature and Extent of Bycatch

Seafood Watch® defines sustainable wild-caught seafood as marine life captured using fishing techniques that successfully minimize the catch of unwanted and/or unmarketable species (i.e., bycatch). Bycatch is defined as species that are caught but subsequently discarded (injured or dead) for any reason. Bycatch does not include incidental catch (non-targeted catch) if it is utilized, accounted for, and managed in some way.

Great Lakes whitefish fisheries use a combination of pound nets, trap nets and gillnets. In state-licensed commercial fisheries, trap nets are more common, whereas in tribal fisheries gillnets have traditionally dominated but are now being gradually replaced by trap nets, as a result of the implementation of the 2000 Consent Decree.

Gillnet mesh size determines the size of fish targeted, and can be further tuned by seasonal and spatial considerations, but selectivity is low when target and non-target species are of similar size. Lake trout have higher selectivity than whitefish for this gear as their toothy mouth is more easily entangled in mesh. Gillnets can kill via suffocation or damage to gills, and have a very high rate of mortality. In Lake Superior, gillnets account for only 35% of the whitefish catch but 96% of mortality (of all whitefish caught in gill and trap nets, 96% of those that were dead came from gillnets), whereas trap nets catch 60% of the whitefish but kill only 3%. Gillnets are still often preferred, however, particularly in smaller fisheries, because of simplicity of use and the ability to deploy them from smaller boats, therefore lowering overall costs (Johnson et al. 2004b).

In the mid-1960s, as lake trout restoration efforts were underway, inspections of gillnets in Lake Michigan revealed more than 70,000 lake trout had been taken as incidental bycatch to the whitefish fishery. Given that whitefish catches from Lake Michigan at the time were quite low, averaging only about 200,000 pounds per year, this would have corresponded to a greater than 100% bycatch rate, conservatively assuming lake whitefish caught weighed only 3 to 4 pounds per fish. This high incidental catch of an important and depleted fish stock led to a ban on gillnets in many areas of the Great Lakes in 1977. However, tribal fisheries are exempt from this ban, though the 2000 Consent Decree instituted much tighter regulations on gillnet use and an overall dramatic reduction in effort. State-licensed whitefish fisheries in Lake Michigan also employ gillnets at about the same frequency as trap nets, although gillnet effort is decreasing while trap net effort increases (Peeters 2001). Most Canadian commercial fisheries also employ gillnets.

A recent study on gillnet use in Northern Lake Huron has shown that lake trout bycatch in whitefish gear can be as high as 30% of the total catch. However, use of gillnets in Treaty waters are permitted only where lake trout are commercially landed along with whitefish, thereby reducing impacts as the bycatch is not discarded. Furthermore, the use of gillnets in lake trout refuges is strictly prohibited, and incidental bycatch of other species (excluding juvenile whitefish and lake trout) accounts for only about 10% of the catch and includes no species of special concern (Johnson et al. 2004a). In Lake Michigan, the most common incidental catches in the commercial whitefish fishery are lake trout and Chinook salmon. However, the incidence of bycatch in this fishery, though slightly up in the past decade, remains well below historical levels and makes up less than 10% of the total whitefish catch (Peeters 2001).

Pound nets are a passive gear similar to trap nets, trapping live catches and therefore having a very low incidence of bycatch mortality. They are typically restricted to waters less than 90 feet deep.

Synthesis

Gillnets can have substantial negative effects on non-target species, as they are highly efficient but have low selectivity and cause high mortality. However, restrictions in place in the Great Lakes that regulate gillnet effort, mesh size, and location, substantially reduces these effects. Trap nets, which are the primary gear used in US commercial fisheries, have very low incidental mortality rates and are therefore considered to have low bycatch impacts. Pound nets, which have much more limited use, also have low bycatch impacts, as fish are caught live and any incidental catches can be released with minimal mortality.

Nature of Bycatch Rank:

Pound/Trap Nets:

[✓ **Low** 🟩] Moderate 🟨 High 🟥 Critical ⬛

Gillnets:

Low 🟩 [✓ **Moderate** 🟨] High 🟥 Critical ⬛

Criterion 4: Effect of Fishing Practices on Habitats and Ecosystems

Habitat Effects

The gillnets, trap nets, and pound nets used in the whitefish fishery are all stationary gear, but they are bottom set, which is generally considered to cause moderate habitat damage in marine systems. There has been no systematic study of the impacts of these gears in the Great Lakes, however, and Great Lakes substrates are expected to be highly resilient to gear effects. Nonetheless, in the absence of a systematic study these gears are considered have moderate habitat effects in the Great Lakes fisheries.

Ecosystem Effects

The lake whitefish occupies a unique position as a deepwater benthivore that is not a major prey item for other piscivorous fish. Although it can be consumed, when at a small size, by predators such as northern pike, walleye, or lake trout, these predators tend to concentrate on other preferred prey (Conner et al. 1993; Ray et al. 2007). Additionally, the decline of Diporeia and associated expansion of dreissenid mussels may have altered the Great Lakes ecosystem to better support near-shore benthic systems, reducing the Lakes' carrying capacity for fish such as the lake whitefish. Removal of this species by the commercial fishery is thus unlikely to have substantial impacts on its associated ecosystems.

Synthesis

Removal of lake whitefish is not expected to have substantial impacts on associated ecosystems, nor is the gear used in catching lake whitefish expected to have severe impacts on lake habitats. However, there has been no study of the impacts of gillnets and trap nets on Great Lakes ecosystems, calling for a rank of moderate effects for this fishery.

Effect of Fishing Practices Rank:

Benign 🟩 [✓ **Moderate** 🟨] Severe 🟥 Critical ⬛

Criterion 5: Effectiveness of the Management Regime

Management of lake whitefish fisheries in the Great Lakes is shared by the Ontario Ministry of Natural Resources (OMNR), individual state Departments of Natural Resources (DNRs), and the Chippewa-Ottawa Resource Authority (CORA). The agencies determine catch quotas based on assessment surveys and statistical modeling, and then manage enforcement of allocations internally. In CORA-managed fisheries, the 2000 Consent Decree established that within shared management zones lake whitefish yields are to be regulated by setting catch limits to at most 65% of the total annual mortality. This is determined annually through assessments and statistical modeling with a one year lag. Deviations between catch limits and actual catch rates are monitored, with deviations greater than 25% triggering management action. However, under the 2000 Consent Decree tribal fisheries are not required to abide by established TACs.

Lake Michigan

Management of commercial lake whitefish fisheries in Lake Michigan is complex because of the way distinct stocks intermix and are shared among jurisdictions. Fish may spawn within one jurisdiction but be caught from another depending on season, and stocks in general have a wide geographical range around the lake (Schneeberger et al. 2005).

Stock assessment efforts in Lake Michigan include data collected on commercial yield, effort, and biological data such as length-at-age, weight-at-age, and recruitment. Such data have been collected by the Chippewa-Ottawa Resource Authority (CORA), the Michigan Department of Natural Resources (MDNR), and the Wisconsin Department of Natural Resources (WIDNR), since at least the mid-1970s. These parameters are monitored at 13 locations in Lake Michigan (Fig. 23).

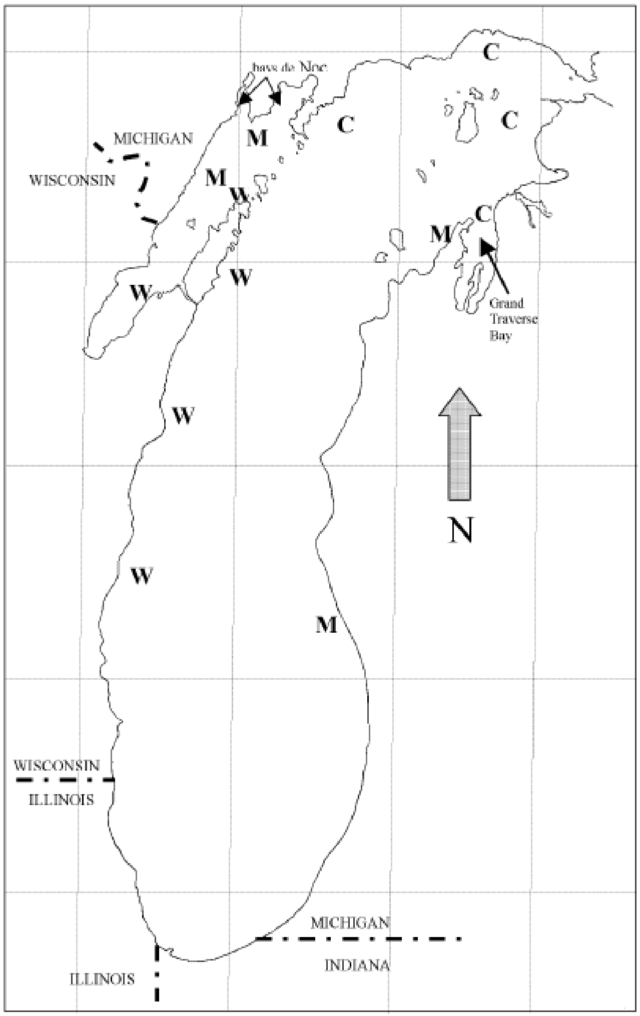


Figure 23. Location of whitefish monitoring sites in Lake Michigan managed by WIDNR (W), MDNR (M) and CORA (C) (Figure from Schneeberger et al. 2005 in Technical Report 66).

In addition, assessment netting is conducted on lake whitefish, among other species, and creel surveys provide information on the recreational fishery. Management agencies use statistical catch at age models to estimate abundance and mortality in order to project catch limits each year. Allocations are then decided among agencies. Catches have remained within the total allowable catch (TAC) in recent years (Fig. 24 and 25).

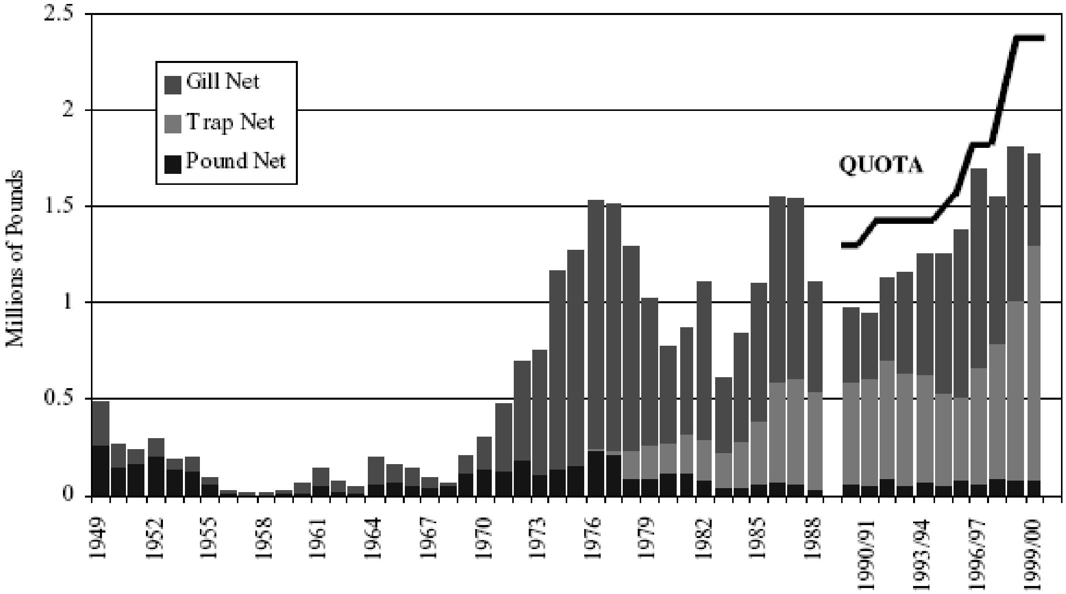


Figure 24. Commercial catch relative to quota in Wisconsin waters of Lake Michigan (Figure from Peeters 2001).

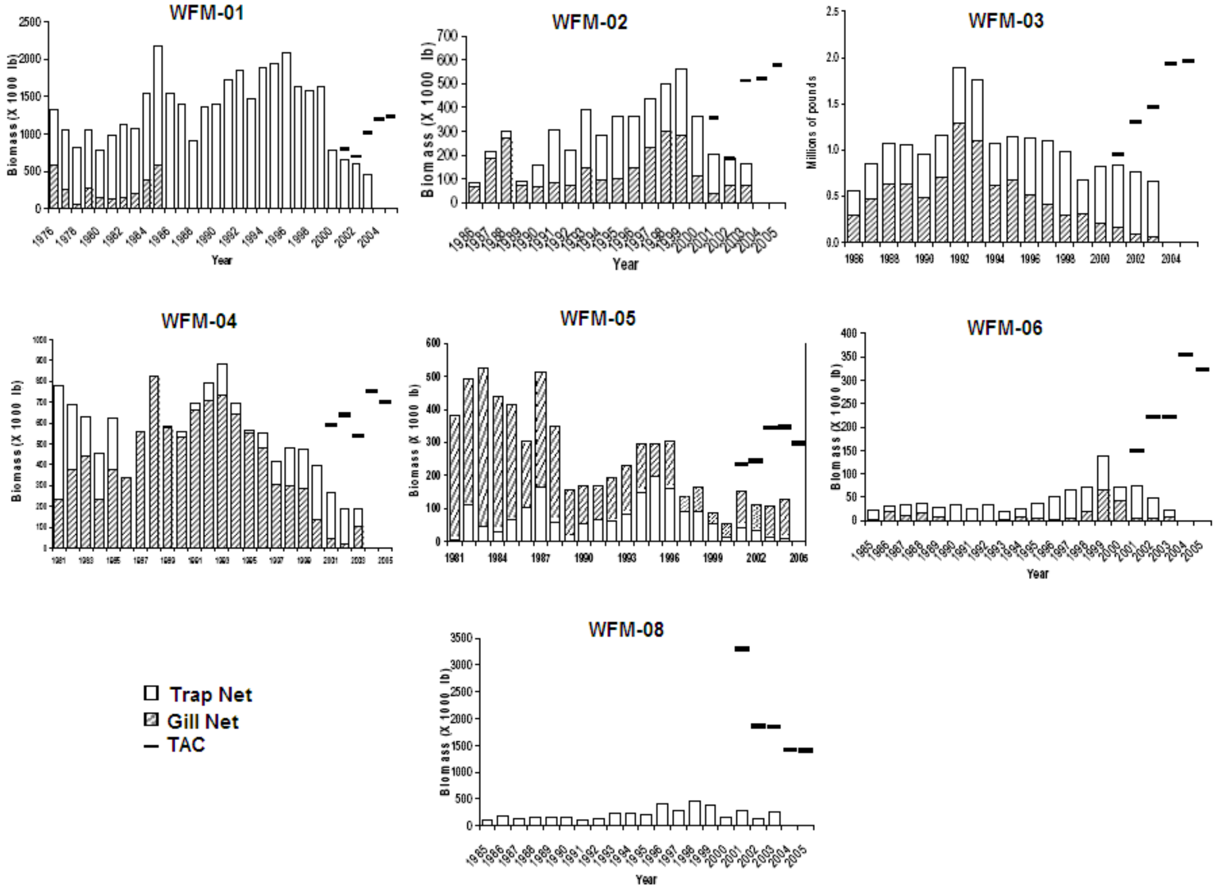


Figure 25. Commercial lake whitefish catch relative to total allowable catch (TAC) in Lake Michigan's tribal fisheries (Figures from Woldt et al. 2006).

Synthesis – Lake Michigan

The management regime in Lake Michigan has a long record of collecting both fishery dependent and independent data on lake whitefish stock status, allowing them to monitor changes in abundance despite the complexity of stock distribution and intermixing among the lake's management units. This comprehensive stock assessment has allowed them to set catch quotas that have maintained stock productivity even in the face of declining condition and variable recruitment following the loss of Diporeia in some areas of the lake. Furthermore, commercial catches have remained well within total allowable catch (TAC), indicating that management has implemented successful enforcement measures. Overall, the Lake Michigan whitefish management regime is thus deemed highly effective.

Lake Huron

The commercial fishery in Lake Huron has undergone substantial changes over the past thirty years. During the 1960s, a period of severe decline in many Lake Huron species, the Michigan Department of Natural Resources (MDNR) reduced the total amount and distribution of fishing in US waters. In 1984 the Canadian commercial fishery changed as the Ontario Ministry of Natural Resources (OMNR) worked with commercial fishing companies to modernize the fishery, changing how catch and effort were managed. In 2000, the Consent Decree further changed the distribution and type of gear utilized in Lake Huron waters as Native American and First Nations asserted their Treaty rights to fishing grounds in the Great Lakes (Mohr and Ebener 2005).

Assessment of fishing stocks has a long history in Lake Huron, with commercial catch records, consisting of daily effort and catch reports reported monthly to the MDNR by commercial fishermen, going back as far as 1929. In Canadian waters, monthly effort and catch reports were replaced in 1990 by daily catch reports, which are required to be submitted after each trip before any fish may be landed. In addition to these fishery dependent statistics, MDNR, OMNR and the Chippewa-Ottawa Resource Authority (CORA) conduct index netting to provide population-specific measures of maturity, mortality, recruitment, growth, condition, and age composition. These management agencies also sample commercial catches to monitor these biological parameters as well as assess catch-at-age for the purposes of mortality and abundance estimates.

The implementation of these fishery independent measures is still under development, however, particularly in CORA-managed waters of Lake Huron, where data are not available for all management units. In WFH-07, for example, no commercial fishing occurred from 1981-2000, and little data exist with which to formulate an allowable catch limit without large uncertainty. This high uncertainty is also of concern given the declining condition and recruitment of whitefish in parts of Lake Huron. Although total mortality levels remain within guidelines, catches have exceeded TAC in the recent past and current catch levels may not be sustainable in the near future (Fig. 26). Plans were undertaken in 2004 to initiate mark-recapture studies of lake whitefish populations in Lake Huron in order to reduce uncertainty about population distribution and whitefish stock movements.

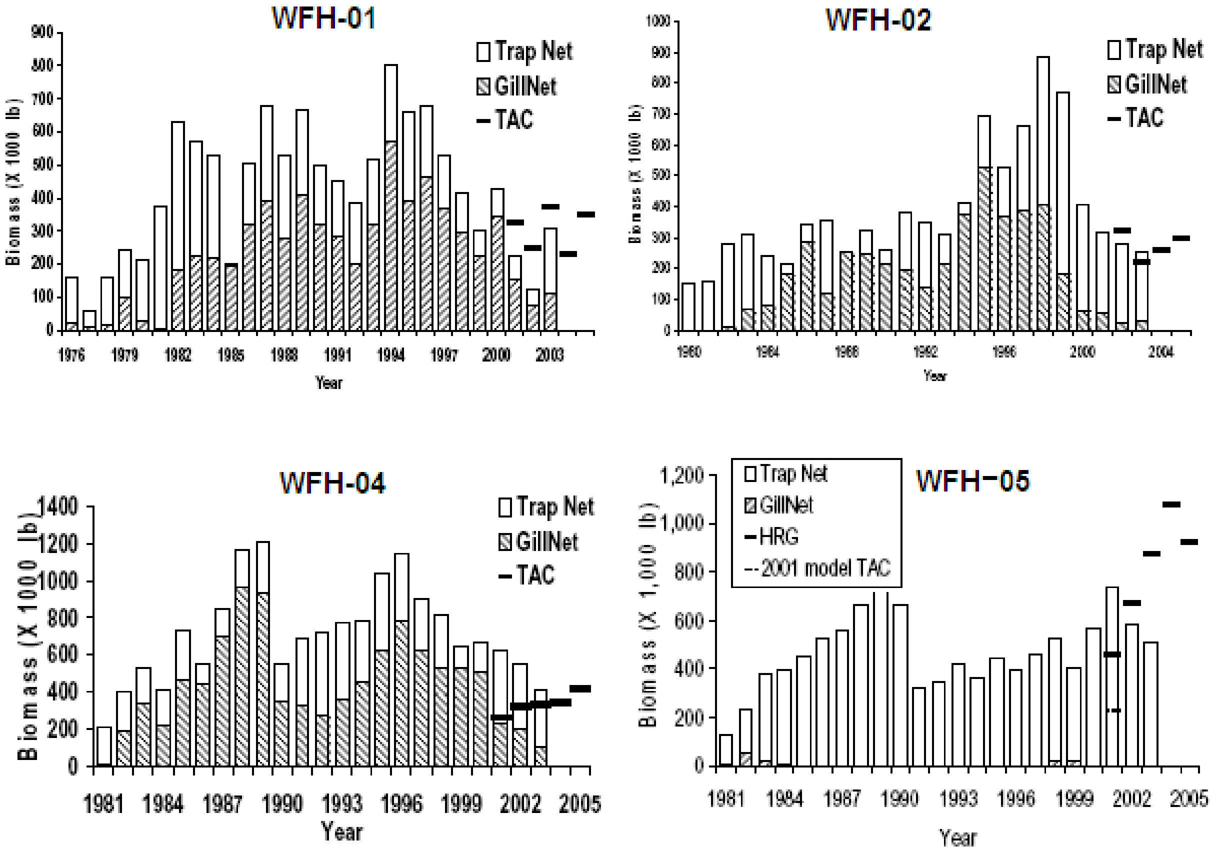


Figure 26. Commercial lake whitefish catch from Lake Huron (tribal fishery waters) relative to total allowable catch or catch regulation (Figures from Woldt et al. 2006).

Statistical catch-at-age models have been developed for five whitefish populations in the US waters of Lake Huron and for six populations in Canadian waters. In addition, cohort analysis has been used to study the Canadian populations since 1994 (Mohr and Ebener 2005).

Synthesis – Lake Huron

Management of lake whitefish stocks in Lake Huron is not as uniformly well developed as in Lake Michigan. Although catch records for the US and Canadian fishery go back as far as 1929, stock assessment in tribal fisheries is still being developed. In these fisheries, not all management units have been able to set a solid catch quota, as abundance data are lacking. In other CORA-managed areas, TACs have been exceeded a number of times in recent years, which indicates that either TACs are unreasonably set, poorly enforced, or both. However, management throughout the lake is moving towards more comprehensive stock assessment and a better understanding of how Lake Huron's carrying capacity for whitefish may be changing in response to ecosystem changes, so as to make better catch quota determinations in the future. Given that Canadian catches far exceed US catches in Lake Huron, and have a solid track record in terms of stock assessment and enforcement, the overall lake whitefish fishery in Lake Huron is considered effectively managed, though the portion of the fishery operating in tribe-licensed waters are of greater conservation concern due to lack of data in some areas and the recent short-term declining trend. However, stocks in these areas are still largely above long-term means and improved stock assessment is underway. Therefore, management in these fisheries is deemed moderately effective.

Lake Superior

Lake Superior whitefish stocks are also managed by a number of agencies including OMNR, state Departments of Natural Resources, CORA, and the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), which also has enforcement powers over tribal fisheries. In tribal fishery waters, TACs are set using target mortalities or the maximum mortality a population can sustain without declining. This is derived by determining what level of fishing mortality will result in a spawning stock biomass per recruit (SSBR) that is 20% of that in an unexploited population. This high level of spawning stock biomass reduction reflects a belief that whitefish are generally resilient to fishing pressure.

Management of whitefish in Lake Superior can be challenging due to the migratory nature of the stock. There are nine lake whitefish management units in Michigan waters and 21 in Ontario waters, but little information exists on how stocks in these units are distributed, due to the fact that stocks may return to widely separated areas to spawn and intermingle during the year.

In Michigan and Ontario whitefish catches are managed on the basis of total allowable catch (TAC). In Wisconsin waters, the reduction of lake trout bycatch is the key goal, and therefore the fishery is managed by controlling gillnet effort. Lake whitefish catches have generally remained well below TACs in recent years, and total mortality is lower than the target rate (Fig. 27).

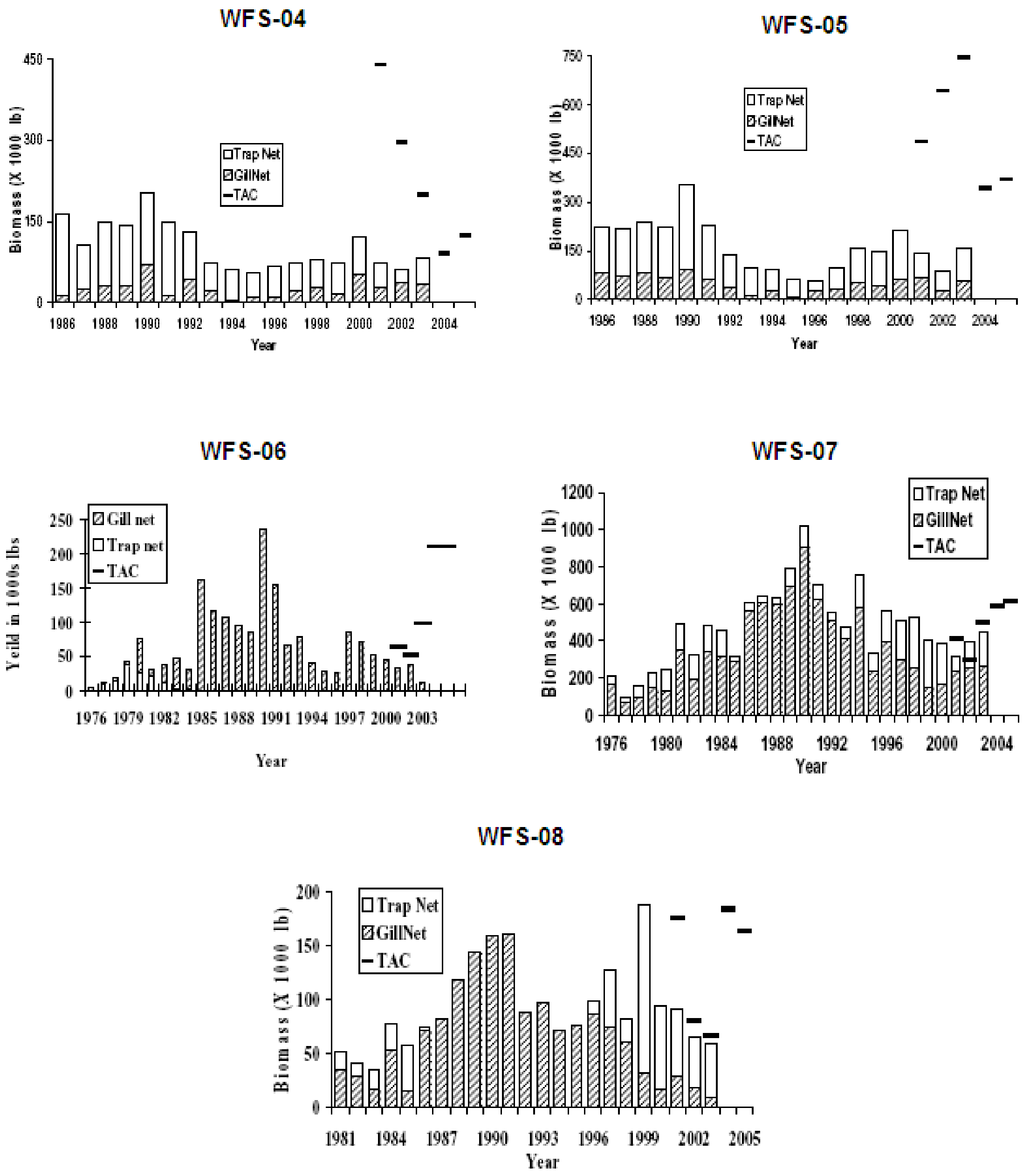


Figure 27. Lake whitefish catches relative to total allowable catch in US waters of Lake Superior (Figure from Woldt et al. 2006).

Synthesis – Lake Superior

Management of lake whitefish stocks in US (state-licensed) and Canadian waters of Lake Superior has generally been effective, maintaining productivity in the fishery and catches in almost all occasions well below the TAC (TAC was exceeded in WFS-07 in 2002) (Fig. 27). In Wisconsin waters, catch limits are based on reducing lake trout bycatch and are therefore based on restricting gillnet effort. In tribe-licensed fisheries, on the other hand, the TAC is calculated based on maintaining a spawning stock biomass per recruit (SSBR) index that is only 20% of that in an unexploited population. This has been determined under the assumption that whitefish populations are very resilient to fishing pressure, and though 20% is a small fraction this assumption appears to be supported by the fact that spawning stock biomass has remained stable within Lake Superior waters where tribe-licensed fisheries operate (Fig. 19). Therefore, management of the lake whitefish fishery throughout Lake Superior is deemed effective.

Lake Erie

Whitefish populations are monitored in Lake Erie by the Coldwater Task Group, under the auspices of the Great Lakes Fishery Commission's Lake Erie Committee. The Task Group collects information on the abundance, age structure, and condition of lake whitefish in Lake Erie; however, no allowable catch limits are set by the Lake Erie Committee (Markham et al. 2005). In general, large inter-basin variability in whitefish abundance, recruitment, and catch per unit effort, coupled with the large-scale seasonal movement of both the species and the fishery effort makes monitoring, modeling, and predicting the trajectory of whitefish stocks difficult.

Synthesis – Lake Erie

The high uncertainty around stock status in Lake Erie, coupled with a lack of catch limits and evidence that recruitment success may be declining (an increasingly unbalanced age structure) (Fig. 22) indicate that Lake Erie's whitefish management is at best only moderately effective. Stock assessment methods and procedures for setting effective TACs must be further developed for this fishery.

Table 3. Commercial catch management measures for the lake whitefish fishery.

Management Jurisdictions & Agencies	Total Allowable Landings	Size Limit	Gear Restrictions	Trip Limit	Area Closures	Sources
Lake Michigan: MI DNR, WI DNR, CORA, GLIFWC	Vary by jurisdiction.	None.	Limits on gillnet effort and mesh size. Limits on depth of trap and pound nets.	None.	No fishing within designated lake trout refuges.	Peeters 2001; Cook et al. 2005; Mohr and Ebener 2005; Schneeberger et al. 2005; Peeters 2006; Schneeberger 2006; Woldt et al. 2006
Lake Huron: MI DNR, OMNR, CORA	Vary by jurisdiction.					
Lake Superior: OMNR, WI, MI and MN DNR, CORA and GLIFW	Total allowable catch set only in MI and ON waters; tribal fisheries use mortality limits, WI controls total effort.					
LEC Cold-water Task Group	No limit set.					

Effectiveness of Management Rank:

Lake Michigan, Lake Huron, Lake Superior:

[✓ **Highly Effective** 🟩] Moderately Effective 🟨 Ineffective 🟥 Critical ⬛

Lake Erie:

Highly Effective 🟩 [✓ **Moderately Effective** 🟨] Ineffective 🟥 Critical ⬛

5-IV. Overall Evaluation and Seafood Recommendation

Long a part of the commercial Great Lakes fishery, lake whitefish has proven to be a resilient member of the deepwater fish community. Though in most lakes (excluding Lake Superior) lake whitefish stocks underwent a period of steep decline in the middle of the 20th century, its life history traits, which include a broad distribution, high intrinsic rate of increase, and low age at maturity, have allowed it to rebound quickly after removal of pressure. More recently, the loss of a preferred, energy-rich prey, catalyzed by the proliferation of an invasive species, led to a decline in the condition and recruitment success of lake whitefish stocks. Once again, however, it appears to have adapted to the shift in its ecosystem by changing its distribution to deeper waters where its preferred prey is more plentiful or, in the case of Lake Erie, exploiting alternate suitable prey.

Stocks in Lake Michigan, Lake Huron, and Lake Superior are deemed healthy; in some cases, such as in the Wisconsin waters of Lake Michigan, abundance is at historic highs. In Lake Huron the outlook is more variable, with stocks from Canadian waters in better shape than those in US state-licensed fisheries, where stocks are merely stable, or in US tribe-licensed fisheries, where CPUE has decreased or reached stable lower levels in recent years. Lake Superior has not had a problem with Diporeia declines so stocks from this lake, in addition to maintaining productivity, have also remained in good condition. In Lake Erie, the movement of whitefish among the lake's three basins makes stock assessment difficult, and uncertainty is too high to accurately rate the stock status, so stocks from this lake are considered to be of moderate conservation concern.

Whitefish in the Great Lakes are captured using a combination of gillnets and trap nets. Gillnets are more common in Canadian commercial fisheries and in tribal fisheries, though in the latter the proportion of gillnets used is decreasing as stipulated in the 2000 Consent Decree that reasserted tribal fishery rights in the Great Lakes. In state-licensed US fisheries, trap nets are the predominant gear. Though gillnets are typically considered a low selectivity, high mortality gear their bycatch and ecosystem impact in the whitefish fishery is reduced by limiting effort (as in state-licensed Wisconsin fisheries), placement (restricting use of gillnets in refuge areas), and mesh size. Their use in the whitefish fishery is therefore of moderate conservation concern, though bycatch of lake trout has been of concern in the past, and any continuing interaction with the whitefish fishery should be monitored. Bycatch in trap nets in the Great Lakes is considered benign. Habitat and ecosystem impacts from these fishing gears have not been studied in the Great Lakes and are thus deemed to be a moderate conservation concern.

Management effectiveness in the Great Lakes whitefish fishery falls along the same lines as stock status. In general, management in Lake Michigan, Lake Huron, and Lake Superior has been effective in maintaining stock productivity and keeping catches below total allowable catch (TAC), although tribe-licensed fisheries from Lake Huron have exceeded TAC on several occasions in the past decade. This indicates that management in these regions is only moderately effective. However, tribal fisheries represent a relatively minor part of the catch and generally the management of whitefish stocks in Lake Huron has been effective. Finally, management in Lake Erie is very limited. Although data for stock assessment are regularly collected, the uncertainty in stock status makes it impossible to set catch quotas, so no TAC exists. Management in Lake Erie is therefore only moderately effective.

Overall, the lake whitefish fishery in the Great Lakes is well-managed, maintaining appropriate stock abundance, and having limited negative impacts on the ecosystem. Lake whitefish from trap net fisheries in Lake Michigan, Lake Huron, and Lake Superior are recommended as a "**Best Choice**," while those from gillnet fisheries are "**Good Alternatives**." Because of gillnet use and uncertainty surrounding stock status and management efficacy of Lake Erie stocks, lake whitefish from Lake Erie is also recommended as a "**Good Alternative**." Lake Michigan accounts for 45% of the total US fishery, Lake Huron accounts for 35%, and Lake Superior 20%. Canadian catches are primarily from Lake Huron (80%) and Lake Erie (10%) with the balance from small catches in other lakes.

Table of Sustainability Ranks for Lake Whitefish

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability		√		
Status of Stocks	√ Lake Michigan, Lake Huron, and Lake Superior	√ Lake Erie		
Nature of Bycatch	√ Trap Nets	√ Gillnets		
Habitat & Ecosystem Effects		√		
Management Effectiveness	√ Lake Michigan, Lake Huron, and Lake Superior	√ Lake Erie		

Overall Seafood Recommendation for Lake Whitefish

Lake Superior, Lake Huron, and Lake Michigan trap net fisheries:

Best Choice 🟩 Good Alternative 🟨 Avoid 🟥

Lake Erie and gillnet portion of Lake Superior, Lake Huron, and Lake Michigan:

Best Choice 🟩 **Good Alternative** 🟨 Avoid 🟥

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Chapter 6: Lake Herring

Coregonus artedii

(Image courtesy of the New York State Department of Environmental Conservation)

6-I. Executive Summary

Lake herring (*Coregonus artedii*) is a long-lived, large-bodied, deepwater prey fish related to the lake whitefish, which once dominated the diets of native Great Lakes predators such as lake trout. Its life history characteristics, such as high fecundity and moderate population growth rates, impart moderate resilience to fishing pressure. Its resilience is evidenced by its persistence throughout the Great Lakes basin in spite of overfishing and competition with or predation from invasive species, such as alewife, through a greater than 100-year history in the Great Lakes commercial fisheries. Lake herring do, however, have some behaviors that increase their vulnerability to fishing pressure, including aggregating in schools, particularly during spawning season in the fall when some populations move to shallower waters.

Lake herring populations throughout the Great Lakes experienced dramatic declines between 1930 and 1960, and remain at low levels in most lakes. A short-lived increase in biomass during the 1980s through the early 1990s resulted from management actions to protect the fishery, but recruitment remains highly variable and populations have not fully recovered. Commercial fishing continues only in Lake Superior and in very limited quantities in Lake Huron. Since about 1990, lake herring commercial catch in Lake Superior has been declining, and catch per unit effort (CPUE) has been extremely variable or declining. Very strong year classes have been interspersed with periods of very low recruitment, and the density dependent and independent factors that control lake herring population growth are still not well understood.

Lake herring are caught in Lake Superior primarily using suspended gillnets, and some are also caught in spring and winter using bottom-set gillnets. Control of net placement, mesh size, and season minimizes bycatch concerns in these fisheries. In addition, there is negligible habitat impact from these fisheries due to the suspended nature of the nets. Removal of herring from the ecosystem is not currently of great concern, as predatory fish, which switched to consuming rainbow smelt and alewife when these species invaded and proliferated in the Great Lakes ecosystem, have not yet reverted to consuming lake herring as a preferred prey. This is despite marked declines in rainbow smelt and alewife abundance throughout the Great Lakes. As these food sources decline, herring may once again come to dominate predator diets, and management will have to adjust to both support the commercial fishery and sustain balanced populations of predators and prey.

Management effectiveness for lake herring is growing, but a number of uncertainties remain. Better scientific understanding of habitat requirements for all herring life stages is needed, as are better estimates of fishing mortality by both commercial and recreational fisheries. Control of invasive species populations that have the ability to negatively impact herring stocks, such as rainbow smelt and zebra mussel, will remain important as will the prevention of new invasions that could have unforeseen consequences.

Overall, lake herring is a moderately resilient species but is facing some challenges that limit its recovery from the steep declines that occurred in the middle of the 20th century. These include competition with and predation from invasive species such as rainbow smelt, a balance of fishing pressure and predatory pressure that is likely to change in the near future and is still not well understood, and a management regime that still requires better scientific understanding of lake herring characteristics and needs. However, management agencies are currently engaged in a number of fishery dependent and independent assessment programs that are growing in breadth and sophistication, and have recognized the importance of lake herring as a key prey species native to the Great Lakes ecosystem. Commercial fishery management is generally conservative and fishing practices benign, resulting in a "**Good Alternative**" recommendation for lake herring from Lake Superior.

Table of Sustainability Ranks for Lake Herring

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability		√		
Status of Stocks		√		
Nature of Bycatch	√			
Habitat & Ecosystem Effects		√		
Management Effectiveness		√		

About the Overall Seafood Recommendation:

- A seafood product is ranked **Best Choice** if three or more criteria are of Low Conservation Concern (green) and the remaining criteria are not of High or Critical Conservation Concern.
- A seafood product is ranked **Good Alternative** if the five criteria "average" to yellow (Moderate Conservation Concern) OR if the "Status of Stocks" and "Management Effectiveness" criteria are both of Moderate Conservation Concern.
- A seafood product is ranked **Avoid** if two or more criteria are of High Conservation Concern (red) OR if one or more criteria are of Critical Conservation Concern (black) in the table above.

Overall Seafood Recommendation for Lake Herring

Best Choice 🟩 **Good Alternative** 🟨 Avoid 🟥

6-II. Introduction

Lake herring (*Coregonus artedii*) was once part of a large species complex of ciscoes that formed the native forage base for Great Lakes piscivores. These prey fish formed an important link between crustaceans and predatory fish, efficiently utilizing lake productivity not accessible to planktivorous species (Fitzsimons and O'Gorman 2004).

Of seven original cisco species—lake herring, bloater, kiyi, shortnose cisco, shortjaw cisco, blackfin cisco, and deepwater cisco—lake herring is the only species still present in all of the Great Lakes, though its population is much reduced. Its persistence in this range indicates that herring may be the most resilient member of the cisco complex, and therefore presents an ideal candidate for the restoration of natural predator-prey dynamics among predator and forage fish in the Great Lakes (Schreiner et al. 2006).

Lake herring populations, which had supported a large and valuable commercial fishery during the first half of the 20th century, entered a period of steep decline between the 1930s and 1950s, with declines occurring first in Lake Erie and last in Lake Superior (Fig. 1). By 1970, many lake herring populations had reached remnant levels. The collapse of commercial fisheries throughout the Great Lakes has been attributed to overfishing and interactions with invasive species, particularly alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*), non-indigenous planktivores that feed on larval fish and compete with many juvenile native fish for food (Horns et al. 2003).

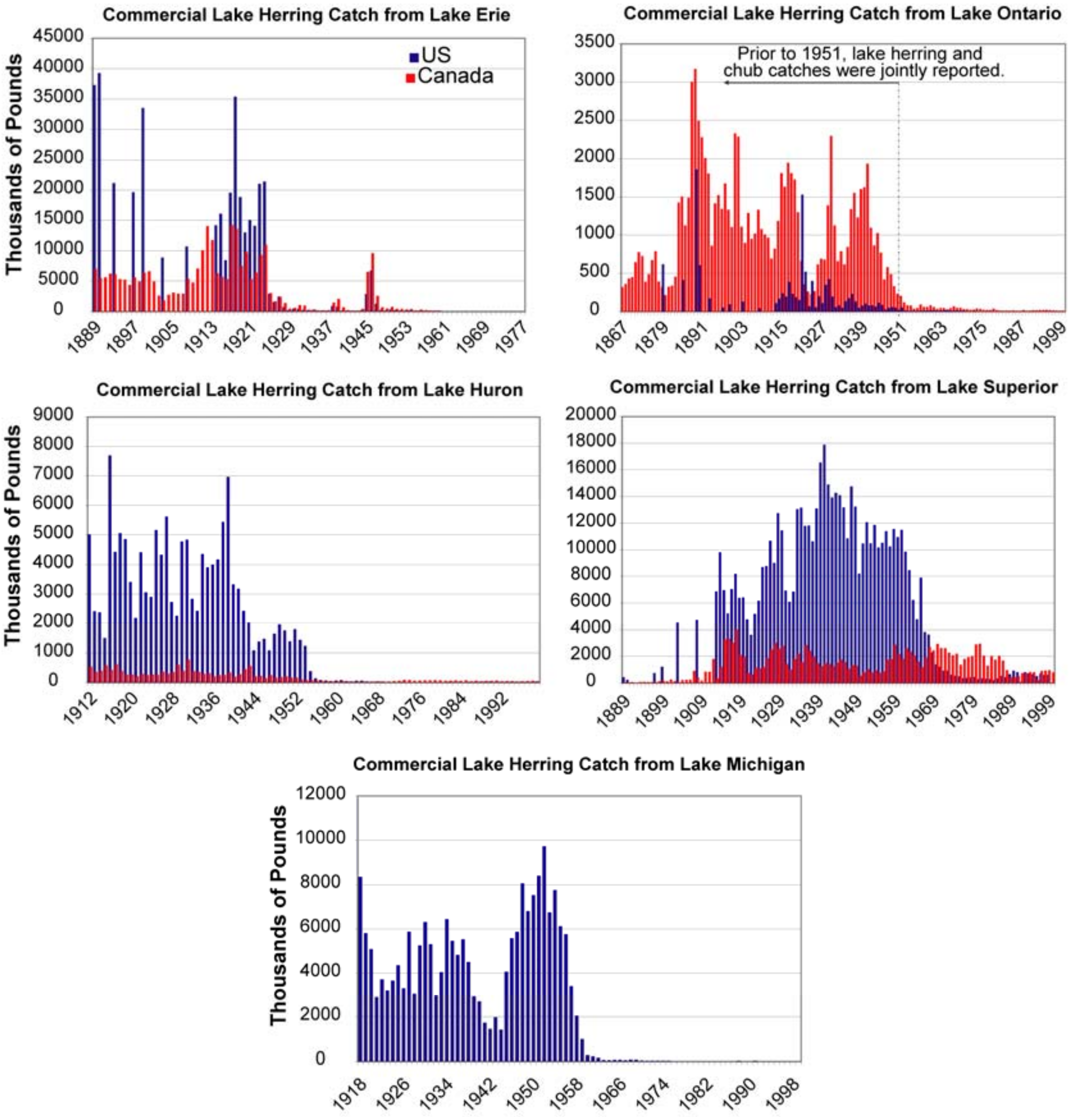

Figure 1. Commercial lake herring catch in the Great Lakes, 1867-2000 (Figure from Baldwin et al. 2002).

In Lake Erie, the large annual commercial yield of the early 20th century led to dramatic declines by the 1920s, and left small populations with fishery yields fluctuating around the same low value until the 1950s. The period of intense eutrophication that followed pushed herring populations to remnant levels in the lake, and lake herring remain rare in Lake Erie.

In Lake Ontario, commercial catches of lake herring first peaked in 1917, then underwent a brief period of decline before remaining relatively stable through the 1930s. In the 1940s, a dramatic decline led to very low fishery yields by the 1950s, and despite a very brief resurgence in biomass in the 1990s, commercial catch dwindled to near zero by the end of the century. Small populations currently persist only in the Bay of Quinte and in the eastern basin of the lake near Sodus Bay. No commercial fishing for lake herring occurs today in Lake Ontario.

In Lake Huron, commercial yield of lake herring was high, if variable, until 1940, but underwent declines between 1950 and 1960, such that by the 1960s commercial catches were insubstantial. The fishery shifted to targeting other cisco species, and there is evidence that lake herring populations in Lake Huron then recovered to some degree. Stocks in the North Channel, Georgian Bay, and northern Michigan waters, in particular, are now above their pre-1994 means.

Lake Michigan herring catches fluctuated widely for the first half of the 20th century, peaking in 1950 and then declining to near zero in the 1960s. Populations remain low despite a small increase after 1994, having returned to near zero levels by 2002.

In Lake Superior, commercial catches peaked in 1941 and remained high through the early 1960s, after which time they declined sharply. Commercial fishing regulations were put into effect in most lake jurisdictions during the 1970s. Between 1980 and 2000, commercial yield averaged less than 10% of the peak value; however, Lake Superior has had the most success in maintaining and recovering lake herring abundance. Lake herring have remained a dominant part of the community, though their biomass has fluctuated widely, with year-class-strength varying by as much as 4,000-fold between 1978 and 2002 (Fitzsimons and O'Gorman 2004). Lake Superior supports the largest commercial herring fishery in the Great Lakes (a small fishery also operates in Lake Huron) (Kinnunen 2003b; USGS 2007b), and has had the most success of all of the Great Lakes in restoring the native predator-prey complex.

Scope of the analysis and the ensuing recommendation:
This analysis will focus on US lake herring stocks from Lake Superior. Although Canadian catches in this lake are substantial, herring is not a major export from Canada to the US; therefore, the analysis will focus on lake herring catches from US waters only, which are primarily from Wisconsin and Minnesota waters.

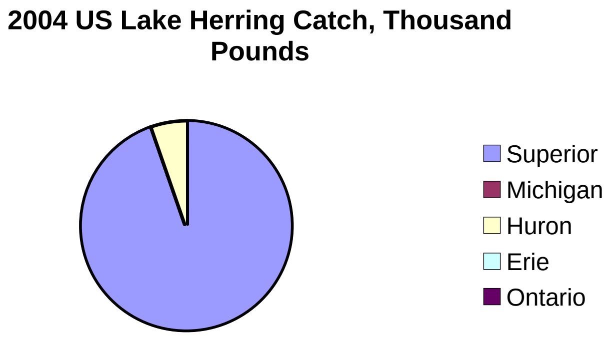

Figure 2. Lake herring commercial catch from US waters (Figure from USGS 2007b).

Availability of Science

Lake herring is a member of the original complex of prey species in the Great Lakes, and was at one time a valuable commercial species as well. Though the commercial fishery only holds a fraction of its historic value, there is a growing recognition that the restoration of lake herring stocks may be essential to the continued success and rehabilitation of major predator stocks in the Great Lakes, which currently drive both commercial and recreational fisheries in the region (Kitchell et al. 2000; Horns et al. 2003; Fitzsimons and O'Gorman 2004; Schreiner et al. 2006; USEPA 2006; Stockwell et al. 2007b). As a result, there is a growing body of literature on lake herring life history characteristics, stock status, and prominence in predator diets. Stock assessment for this species is still fairly new, and there are a number of important species traits, such as habitat requirements, natural age, and sex structure, as well as density-independent recruitment factors that are still not well understood. Plans are underway to increase the accuracy and breadth of this scientific knowledge as Great Lakes management agencies work to restore natural predator-prey dynamics within the basin.

Market Availability

Common and market names:
Lake herring is also known as northern cisco and tullibee (Canada).

Seasonal availability:
Lake herring is available year-round, although some fisheries are closed during the spawning season (October-December). Herring roe, on the other hand, is collected only during the spawning season.

Product forms:
Lake herring is marketed as head-on, dressed whole fish, often smoked, and may also be available as a minced, frozen block. Herring roe is also sold and may represent a substantial part of the market value.

Import and export sources and statistics:
In the Great Lakes, lake herring are caught in substantial numbers exclusively from Lake Superior. There is only a very minor import of frozen minced block herring from Canadian waters to the US, however, and Great Lakes catches are primarily sold to area restaurants and markets (DFO 2006c), as commercial yield remains relatively small.

6-III. Analysis of Seafood Watch® Sustainability Criteria for Wild-caught Species

Criterion 1: Inherent Vulnerability to Fishing Pressure

Lake herring (*Coregonus artedii*) is a coldwater species related to the lake whitefish. It is part of the cisco complex, a group of seven species that once dominated the native Great Lakes forage fish base and formed an important benthic-pelagic link between invertebrates and pelagic predators. This complex was widely distributed throughout North America, from the upper Mississippi basin through the Great Lakes region and into Canada as far north as Labrador. Of the seven species, lake herring inhabited the shallowest habitat. Overfishing, interaction with invasive species, and habitat disruption decimated cisco stocks, such that at present lake herring is the only species remaining in all of the Great Lakes (Table 1). Lake herring is therefore considered the most resilient member of the cisco complex (Fitzsimons and O'Gorman 2004).

Table 1. Current distribution of cisco species in the Great Lakes.

Species	Common Name	Current Distribution in Great Lakes
Coregonus artedii	Lake herring	All (low abundance)
Coregonus hoyi	Bloater	Huron, Michigan, Superior
Coregonus kiyi	Kiyi	Huron, Superior
Coregonus reighardi	Shortnose cisco	Huron
Coregonus zenithicus	Shortjaw cisco	Superior
Coregonus nigripinnis	Blackfin cisco	Eliminated from Great Lakes
Coregonus johannae	Deepwater cisco	Eliminated from Great Lakes

Lake herring is a pelagic schooling fish, which inhabits open lake waters, moving to shallower waters in the fall as the temperature drops. Herring spawn in late fall, typically late November to early December. They form large spawning schools, which in coastal areas spawn over hard substrates; open-water populations, on the other hand, may spawn in the pelagic zone, releasing their eggs 30-40 feet below the surface in waters greater than 200 feet deep (MIDNR 2007a). Females produce 20,000-30,000 eggs, depending on size. Fishing pressure on spawning populations can be high, as herring roe is highly valued (Schreiner et al. 2006).

The relationship between spawning stock size and year class strength is highly variable, and strong year classes can be followed by weak ones and vice versa, as strong year classes are sometimes produced from very small standing stocks. The mechanism behind this variability is still not well understood, but appears to be a feature of lake herring populations across the Great Lakes. Inter-lake synchrony in recruitment patterns suggests it is a density independent phenomenon and may be linked to lake productivity and other environmental factors (Stockwell et al. 2007a).

Female lake herring live longer and may attain larger sizes than males, though both grow at similar rates. They typically attain lengths between 14 and 17 inches, weigh 0.5-1 lb, and can live longer than 20 years. Lake herring are consumed by lake trout, northern pike, yellow perch and walleye, while adult herring consume crustaceans and small aquatic insects and lake herring fry consume primarily zooplankton. In the Great Lakes, Diporeia and *Mysis relicta* are the primary invertebrate prey of lake herring (Fitzsimons and O'Gorman 2004). This is of some concern given that Diporeia populations are declining throughout the region (with the exception of Lake Superior), possibly as a result of interaction with non-indigenous zebra and quagga mussels (*Dreissena polymorpha* and *D. bugensis*). In addition, exogenous impacts from habitat loss and interactions with invasive species have greatly increased the vulnerability of the remaining stocks of herring in the Great Lakes. The primary factors currently limiting lake herring recovery in the Great Lakes are the size of spawning stocks (most populations outside Lake Superior are reduced to remnant levels), interactions with non-native species (primarily alewife, dreissenid mussels, and predators) and the loss of genetic diversity, which resulted from loss of individual stocks as populations declined in the latter half of the 20th century (Fig. 3).

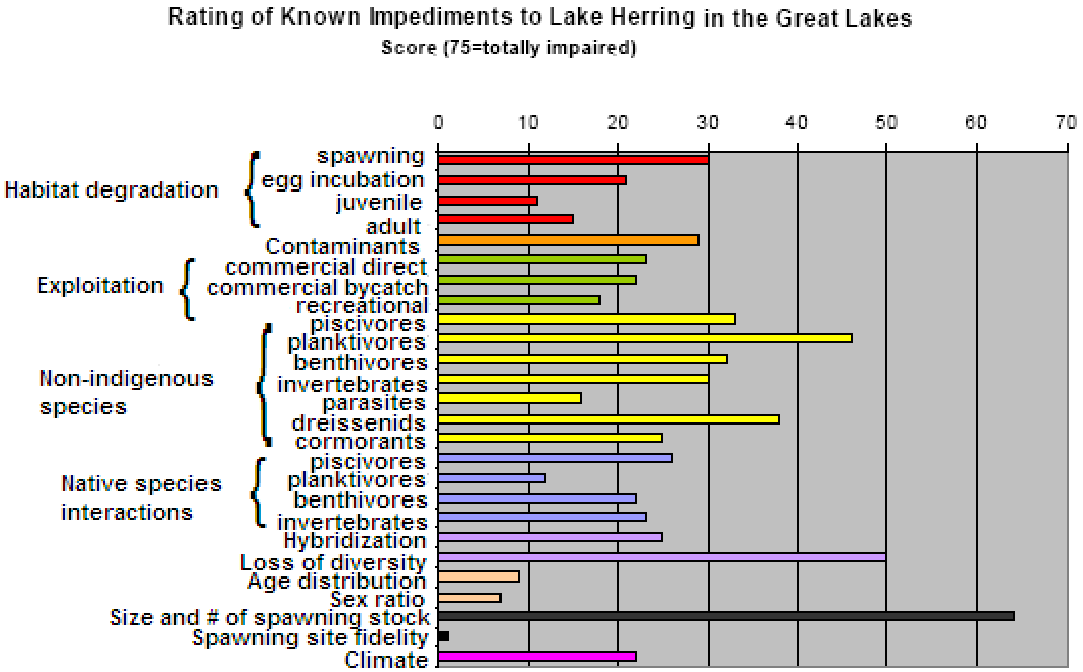

Figure 3. Factors hindering lake herring rehabilitation in the Great Lakes (Figure from Fitzsimons and O'Gorman 2004).

The least controllable of these factors is the interaction with invasive species. Lake herring compete for food with, and larval herring are consumed by, alewife and to a lesser extent rainbow smelt, both non-indigenous planktivores. Increasing predator density both from non-indigenous stocked salmonids and recovering native lake trout and walleye is also increasing predation mortality on younger lake herring (adults are too large to be consumed by many piscivorous fish, though lake trout can consume herring of all sizes), particularly in the light of decreasing stocks of alewife and rainbow smelt. Finally, dreissenid mussels are leading to reduced pelagic productivity in many lakes as a result of their enormous filtering capacity, and are also linked to the basin-wide decline of Diporeia, an important native prey of lake herring. As Diporeia abundance decreases, herring are becoming more dependent on two non-indigenous crustacean species: *Bythotrephes cederstroemi*, the spiny water flea; and *Cercopagis pengoi*, the fishhook water flea. The fitness of these prey for supporting healthy lake herring populations is not yet known (Schreiner et al. 2006).

Table 2. Life history characteristics of lake herring.

Intrinsic Rate of Increase (r)	Age at Maturity	Growth Rate	Max Age	Max Size	Fecundity	Species Range	Special Behaviors	Sources
0.05-0.15	4-5 years	K=0.06-0.27	20 years	17 inches	High: 20,000 to 30,000 eggs/female.	Broad: throughout Great Lakes, but only remnant populations persist in some lakes.	Congregate to spawn. Primary prey, Diporeia, is declining in Great Lakes. Predator-prey imbalance as rainbow smelt and alewife decline, leading to increased predation mortality.	Fitzsimons and O'Gorman 2004; DFO 2006c; Froese and Pauly 2007; MIDNR 2007a

Synthesis

The life history characteristics of lake herring, such as high fecundity and moderate population growth rates, lend the species moderate resilience to fishing pressure, as evidenced by their success in persisting throughout the Great Lakes basin where other ciscoes underwent more dramatic declines. The species does exhibit some behaviors, however, that increase their vulnerability to fishing pressure, such as aggregating in schools, particularly in the fall during spawning season when some populations move to shallower waters. Lake herring also have naturally variable recruitment, which leads to a cyclical nature in lake herring abundance and can increase their vulnerability to both fishing pressure and other external stresses, such as adverse climatic conditions.

Interactions with invasive species are also of particular concern with lake herring, as they appear to be impeding lake herring recovery within the Great Lakes. Competition with and predation by non-native planktivores (alewife and rainbow smelt), the reduction in food availability associated with proliferation of filter-feeding dreissenid mussels (zebra and quagga mussels), and increasing predation pressure from both native (lake trout) and stocked fish (salmon) as exotic planktivores decline, are all affecting lake herring stocks to different degrees and increasing herring vulnerability to fishing pressure. Lake herring are therefore considered to be moderately vulnerable to fishing pressure under Seafood Watch® criteria.

Inherent Vulnerability Rank:

Resilient 🟩 **Moderately Vulnerable** 🟨 Highly Vulnerable 🟥

Criterion 2: Status of Wild Stocks

Commercial lake herring fisheries operate almost exclusively in Minnesota, Michigan, Wisconsin, and Ontario waters of Lake Superior (Fig. 4). As Canadian catches are not imported to the US in large quantities, only catches from US waters are considered here. Of the 2005 US catch, 63% was from Minnesota waters (300,624 lbs), 36% from Wisconsin waters (174,841 lbs), and only 1% from the tribe-licensed commercial fishery in Michigan waters (3,996 lbs)

(USGS 2007b). Analysis of stock status will therefore focus primarily on herring populations in Minnesota and Wisconsin waters.

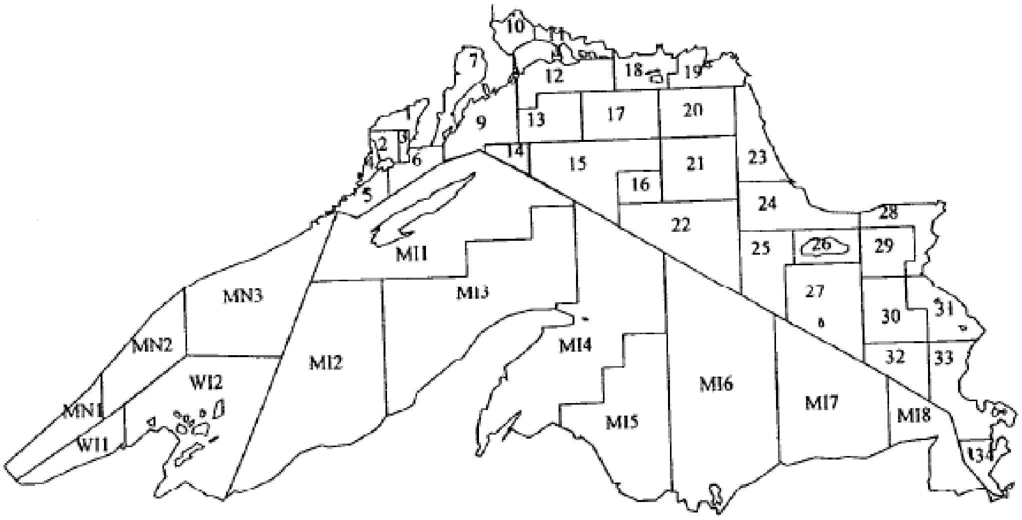

Figure 4. Lake Superior management units in Wisconsin (WI1-2), Michigan (MI1-8), Minnesota (MN1-3), and Ontario (1-34) (Figure from USGS 2007).

Lake herring is one of six primary prey species in Lake Superior, which also includes bloater, slimy and deepwater sculpins, ninespine stickleback, and rainbow smelt. Of these, lake herring was historically dominant, serving as both the primary prey for lake trout and targeted by the commercial fishery. The collapse of lake herring stocks in the mid-1960s has been attributed to overfishing (Selgeby 1982) and interactions with the non-indigenous rainbow smelt, which proliferated in Lake Superior from the 1930s through the 1950s. During this time, rainbow smelt overtook herring as the predominant prey fish in the lake and remained so until the 1980s, when rainbow smelt stocks in US waters underwent a steep decline (Horns et al. 2003).

Herring began to recover in 1978, following the recruitment of a very strong 1977 year class, and further strong year class production resulted in a moderate-to-large biomass of spawning herring by the late 1980s. Recruitment remains variable, however, showing signs of both density dependent effects (low recruitment when stocks are very high) and density independent (primarily climate-related) controls on biomass.

Currently, only western Ontario lake herring stocks are higher than long-term (1978-2006) means. This abundance is still well below pre-decline levels, however. Herring are currently most abundant in Wisconsin waters, followed by western Ontario and Michigan stocks. Eastern Ontario and Minnesota stocks are only at remnant levels; in 2006, no herring were collected in the USGS spring trawling survey in these waters (Fig. 5). Michigan stocks are 48%, Wisconsin stocks 54%, and eastern Ontario stocks 13% below their respective long-term averages (Stockwell et al. 2007b).

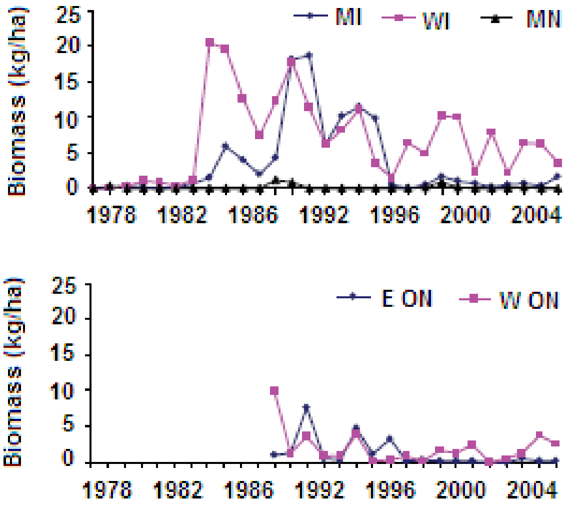

Figure 5. Relative biomass of age-1 and older lake herring in Lake Superior, 1978-2006 (Figure from Stockwell et al. 2007b).

Lake herring age structure in Lake Superior illustrates the effect of strong year-classes on herring abundance, showing a bimodal distribution. The large 2005 year class dominated the bottom trawl survey catch in 2006, accounting for 52% of the mean relative density, while strong cohorts from the 2002 and 2003 year classes accounted for 14% and 24% of the catch, respectively (Fig. 6).

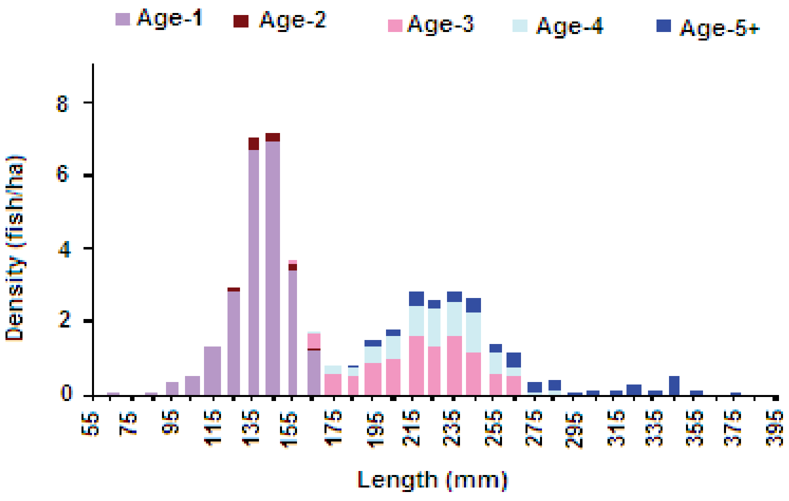

Figure 6. Age-specific relative density of lake herring in Lake Superior in 2006 (Figure from Stockwell et al. 2007b).

There is still substantial uncertainty about the natural age distribution of lake herring populations, and comparing current assessments to historic data is problematic, as in the past herring were aged using scales, a method that is now known to underestimate age in older fish. Currently herring larger than 300 mm are aged using otoliths, which is more accurate but precludes comparison with historic data (Fitzsimons and O'Gorman 2004). It is therefore difficult to say whether the distributions of herring age, size, and sex are “functionally normal,” particularly given that these fish may have naturally cyclical populations that can bias age structures.

Management agencies throughout Lake Superior are continuing to limit commercial lake herring catch in order to minimize mortality.

Minnesota Stocks

The commercial fishery for lake herring in Minnesota waters of Lake Superior dates back to 1875. Yields peaked around 1920 at over 9 million pounds, and maintained a long-term average of around 6 million pounds until 1940, when catches declined drastically. This downward trend persisted until 1985, when herring catches began to increase again, but remained at levels well below historic yields (Fig. 7) (Schreiner et al. 2006).

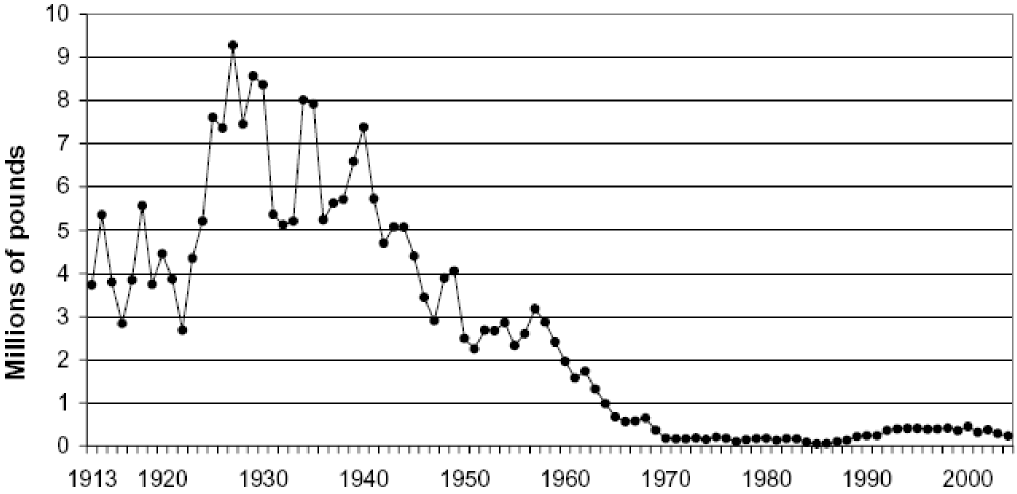

Figure 7. Historic commercial lake herring catch from Minnesota waters of Lake Superior (Figure from Schreiner et al. 2006).

Following the long-term decline from 1940 to 1985, commercial catches of lake herring began to increase again through the 1980s and 1990s, reaching a peak of over 400,000 lbs in 2000. Although only a fraction of the historic average, this was well above the average annual yield since 1970 (Fig. 8). Catch then gradually declined to 240,000 lbs in 2004, and rose to just over 300,000 in 2005. Catch per unit effort (CPUE), which provides a better estimate of abundance, has mirrored commercial catch trends and is likewise decreasing.

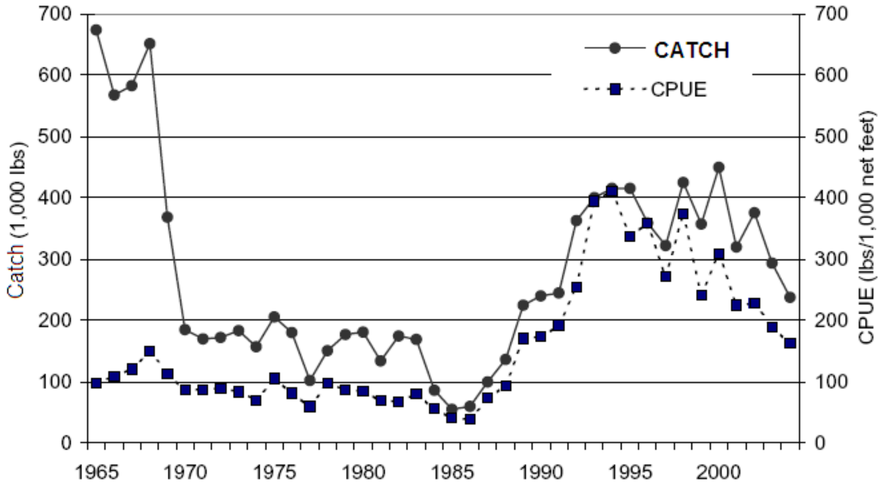

Figure 8. Lake herring commercial catch and catch per unit effort (CPUE) in Minnesota waters of Lake Superior, 1965-2004 (Figure from Schreiner et al. 2006).

Fishable biomass for lake herring in Lake Superior increased in 2005 (Fig. 5), showing the effect of strong year classes in 2002 and 2003 (Stockwell et al. 2005). The commercial fishery for lake herring in Minnesota waters generally represents a relatively small source of mortality for lake herring. Predator consumption reduces mid-aged fish by some degree, but of greatest concern is the lack of consistently strong recruitment, as evidenced by the skewed age structure of herring in Minnesota waters of Lake Superior (Fig. 9). Lake herring biomass is dominated by age-17+ fish, with distinct peaks at age-18 (1989 year class) and age-23 fish (1984 year class).

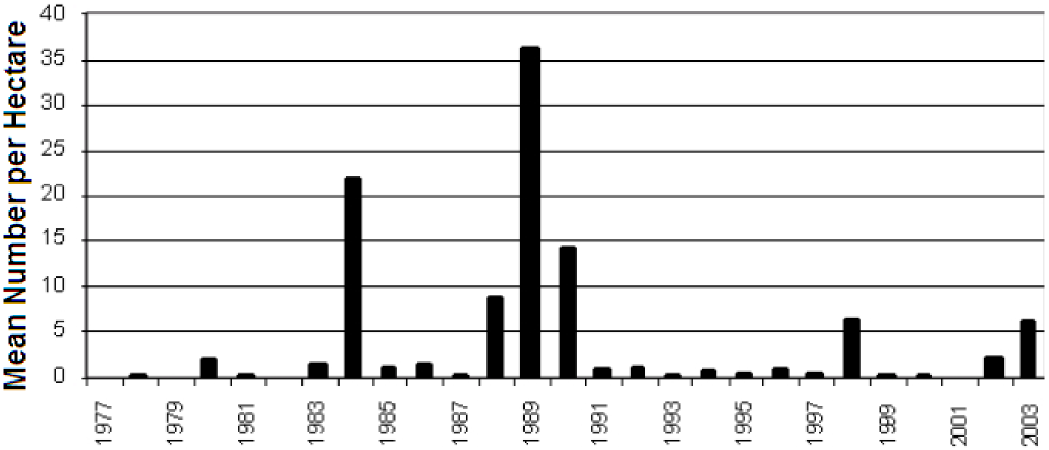

Figure 9. Age-specific relative biomass of lake herring in Minnesota waters of Lake Superior (Figure from Schreiner et al. 2006).

In contrast, there is a paucity of fish aged 5 to 16 years, with the exception of the moderately strong age-9 cohort (1998 year class). Although recent years have produced some strong year classes, no long-term trend has yet been established.

Wisconsin Stocks

In Wisconsin waters of Lake Superior, historic catches peaked in 1940 at over 5 million pounds, and then stabilized at high levels until a steep decline began in the 1960s. It is believed that many individual stocks crashed by the early 1960s, though their sequential depletion was masked in the commercial catch data as more remote stocks were targeted (Selgeby 1982). Since this decline, commercial catches, though variable, have remained near 200,000 lbs (Yule et al. 2005).

CPUE of lake herring in gillnet assessment surveys (occurring each odd-numbered year in WI-1 and each even-numbered year in WI-2) have been highly variable but above 1970-1990 means. Peak CPUEs occurring between 1992 and 2000 show the effect of strong year classes in Wisconsin waters of Lake Superior (Fig. 10).

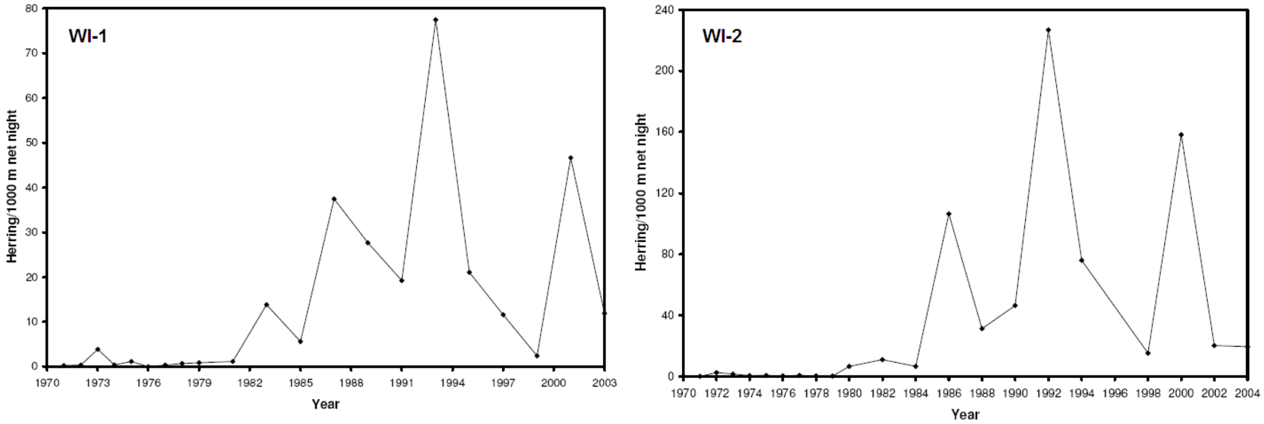

Figure 10. Catch per unit effort (CPUE) of lake herring in WI-1 and WI-2 survey netting, 1970-2004 (Figure from WIDNR 2005c).

The Wisconsin fishery targets female lake herring, typically large female herring, during spawning season, as herring in this fishery are currently caught primarily for their roe (Fig. 12) (Yule et al. 2005). This raises concerns that fishing activity may be skewing the sex structure of herring populations; however, midwater survey trawls conducted in 2004 revealed herring catches were 47% female and 53% male. Furthermore, of lake herring greater than 10 inches in length, 94.5% were females. This probably stems from females being more consistently pelagic during spawning season (therefore being more susceptible to midwater trawls), while males during this time are largely benthic (Yule et al. 2006b), and also living longer and attaining larger sizes than males (Yule et al. 2005; MIDNR 2007a).

A spawning stock assessment conducted by Yule et al. (2004) made some of the first estimates of lake herring fishing mortality available for Wisconsin waters of Lake Superior. They found that the spawning season fishery accounted for only about 2% of the mortality of all female lake herring (Yule et al. 2006b), similar to the fishing mortality estimated for lake herring in Minnesota waters (Fig. 11).

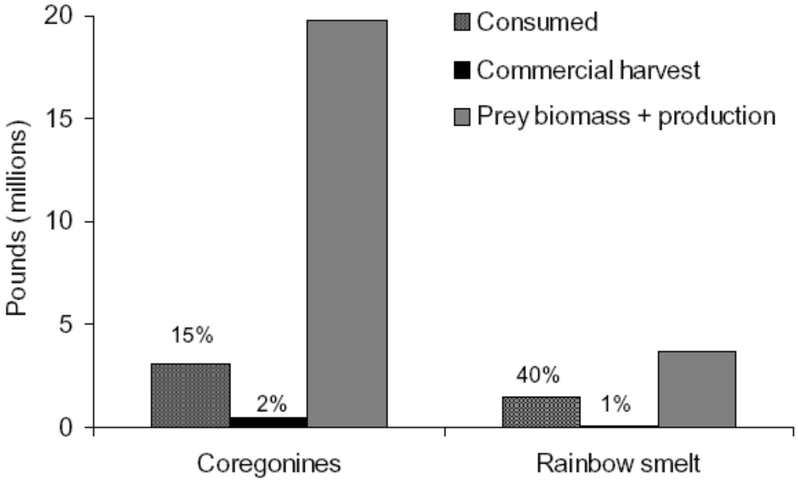

Figure 11. Estimated sources of mortality for coregonines and rainbow smelt in Minnesota waters of Lake Superior (Figure from Schreiner et al. 2006).

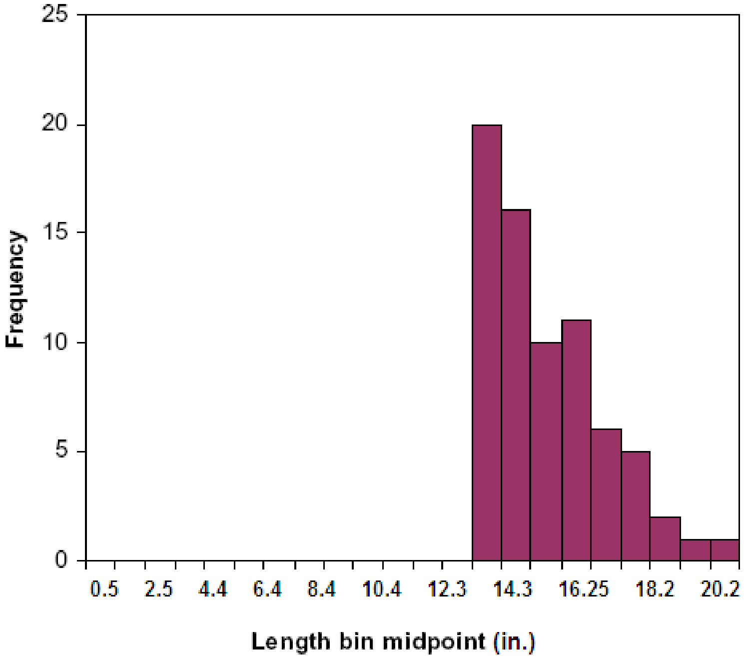

Figure 12. Distribution of female lake herring lengths from commercial fishery catch in Wisconsin waters of Lake Superior (Figure from Yule et al. 2005).

The actual lake herring population in Wisconsin waters, as assessed by graded mesh gillnet surveys during summer and fall of 2004, has a relatively even length distribution (Fig. 13). Assessment of lake herring population characteristics can be difficult, as fish schools show both seasonal and depth dependent changes in distribution, such as separation of male and female populations during spawning and a tendency for mean age of schooling fish to decrease with depth (larger, older fish are more often found in shallower waters), but recent advances in acoustic methods, such as described by Yule et al. (2006), are improving the accuracy of abundance measures.

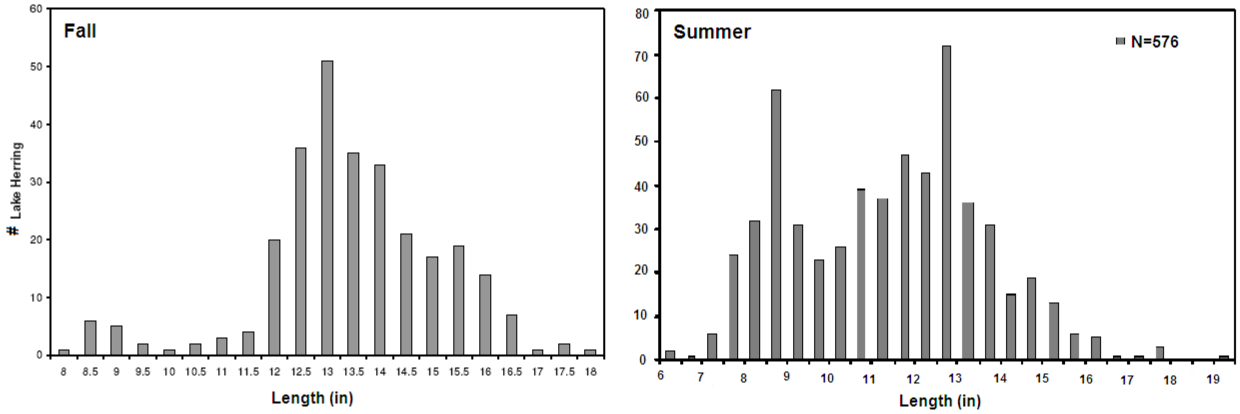

Figure 13. Length frequency of lake herring in fall and summer assessment surveys in Wisconsin waters of Lake Superior (Figure adapted from WIDNR 2005a and WIDNR 2005c).

Table 3. Stock status of lake herring.

Status	**B/B_{MSY}**	**Occurrence of Overfishing**	**F/F_{MSY}**	**Abundance Trends/CPUE**	**Age/Size/ Sex Distribution**	**Degree of Uncertainty in Stock Status**	**Sources**	**SFW Rank**
Not listed as threatened	Current biomass estimates well below historic fishery yields—when stocks were overfished	MN fishery based on season rather than TAC, so no level of overfishing officially determined. Commercial catches in MN and WI are small.	Fishing mortality low: ~2%.	CPUE in MN waters increased in 1990s but now in steady decline. CPUE in WI waters highly variable at levels above long-term (post-decline) means.	Age structure skewed.	High—No long-term systematic assessment of fishing mortality. No TAC set in MN waters. Highly variable years make determination of future long-term stock trends difficult.	Stockwell et al. 2007; Schreiner et al. 2006; Stockwell et al. 2005; Yule et al. 2005; WI DNR 2005a; WI DNR 2005b	Moderate

Synthesis

After a period of dramatic decline beginning in the 1960s, lake herring populations experienced a short-lived increase in biomass during the 1980s through the early 1990s. However, since about 1990, lake herring commercial catch in Lake Superior has again been declining. In Minnesota waters, where the majority of lake herring is caught, both commercial yield and catch per unit effort (CPUE) has been decreasing steadily. There have been some strong year-classes that have led to short-term increases in fishable lake herring abundance, but the trend in yield continues to be down and the age structure of herring is highly skewed as strong year classes have been interspersed with periods of very low recruitment, particularly between 1991 and 2001. In Wisconsin waters of Lake Superior, CPUE has been extremely variable, but with peaks well above 1970-1990 means. In Wisconsin waters the size structure of fish is also more uniform. Throughout the Great Lakes, the status of wild lake herring stocks is therefore deemed moderate.

Status of Wild Stocks Rank:

Healthy 🟩 **Moderate/Rebuilding 🟨** Poor 🟥 Critical ⬛

Criterion 3: Nature and Extent of Bycatch

Seafood Watch® defines sustainable wild-caught seafood as marine life captured using fishing techniques that successfully minimize the catch of unwanted and/or unmarketable species (i.e., bycatch). Bycatch is defined as species that are caught but subsequently discarded (injured or dead) for any reason. Bycatch does not include incidental catch (non-targeted catch) if it is utilized, accounted for, and managed in some way.

Lake herring are caught in Lake Superior primarily using suspended gillnets. Although no study of bycatch in the lake herring fishery is currently available, midwater surveys using graded mesh gillnets have shown that in the midwaters where lake herring are found the predominant species are rainbow smelt (~80%) and lake herring (~19%), with bloater chubs, ninespine stickleback, and sculpins representing only about 1%. In addition, rainbow smelt are much smaller in size than targeted lake herring, and it is therefore likely that the commercial gillnets used, which target fish larger than 12 inches, are highly selective for lake herring. Although bycatch effects are highly uncertain given the lack of a detailed study, the restrictions on size, placement, and season for lake herring gillnets are likely to result in a low incidence of bycatch (WIDNR 2005a; WIDNR 2005c; Yule et al. 2005).

Nature of Bycatch Rank:

[✓ **Low** 🟩] Moderate 🟨 High 🟥 Critical ⬛

Criterion 4: Effect of Fishing Practices on Habitats and Ecosystems

Habitat Effects

As the gillnets used in the lake herring fishery are suspended and stationary, they have minimal effects on benthic habitat.

Ecosystem Effects

Lake herring was historically an important forage species for native Great Lakes piscivores such as walleye and lake trout. However, alewife and rainbow smelt, exotic planktivores that invaded the Great Lakes during the first half of the 20th century, have largely replaced lake herring and other native forage as the preferred prey of Great Lakes predatory fish (Fitzsimons and O'Gorman 2004). In Lake Superior, where alewife is rare, rainbow smelt has become the primary forage. In fact, studies have shown that despite their declining abundance, rainbow smelt are actively chosen by both lake trout and walleye above lake herring (Cox and Kitchell 2004; Krueger and Hrabik 2005). This shift in predator-prey dynamics has to some extent aided the recovery of herring stocks, as they are both released from predation pressure and from competition with rainbow smelt by recently increasing populations of lake trout and walleye.

Given that native predators are currently more dependent on alternate prey, the removal of lake herring from the food web does not pose immediate concern for predator fish stocks. However, in terms of ecosystem stability and sustainability, the lake herring is a more ideal prey for native Great Lakes predators than either alewife or rainbow smelt, as it provides a better link to the available Lake Superior productivity due to its more efficient transfer of energy from invertebrate prey, its larger size (allowing predators to attain larger sizes), and lack of high levels of thiaminase found in the exotic planktivores (Fitzsimons and O'Gorman 2004; Schreiner et al. 2006). Consumption of prey high in thiaminase leads to the development of thiamine-deficient eggs in predatory fish, resulting in early mortality syndrome (EMS). EMS is currently seen as a bottleneck to lake trout recovery in particular.

In the long term, effective management of Lake Superior fish stocks will entail replacing rainbow smelt and alewife with lake herring both in terms of lake biomass and in predator diets. Once lake herring have reassumed their position as preferred prey of important predator species such as lake trout and walleye, fishing pressure may need to be readjusted to balance both fishery and predator demand.

Synthesis

The lake herring fishery has low habitat impacts, as the suspended gillnets used do not contact the lake bottom, but its ecosystem impacts are not currently well known. As such, the effects of fishing practices in the lake herring fishery are rated moderate.

Effect of Fishing Practices Rank:

Benign 🟩 [✓ **Moderate** 🟨] Severe 🟥 Critical ⬛

<u>Criterion 5: Effectiveness of the Management Regime</u>

Minnesota Stocks

The commercial fishery for lake herring in Minnesota waters of Lake Superior is managed by the Minnesota Department of Natural Resources (MN DNR), with assessment and planning support from the Lake Superior Technical Committee (LSTC), under the auspices of the Great Lakes Fishery Commission (GLFC), and the USGS Great Lakes Science Center (USGS GLSC), which monitors prey fish status lake-wide.

The Minnesota commercial fishery is limited to 50 licenses sharing a total of 100,000 feet of suspended nets. Lake herring management in Minnesota waters began in the early 1970s, after the strong mid-century decline, with the institution of near-shore refuges, a temporary stocking program in Duluth that lasted from 1975 to 1986, and the closing of the commercial fishery from November to early December to protect spawning fish. The closed season persists to the modern commercial fishery, though it has become controversial, but no such closure and no bag limits exist for the sport fishery. Lake Superior fisheries in other waters operate primarily during herring spawning season, as they are targeted at roe rather than whole fish. The recent Fisheries Management Plan for the Minnesota waters of Lake Superior suggests that the lake herring fishery should transition from its current seasonal management to one that is based on a total allowable catch (TAC) and is open during spawning season (Schreiner et al. 2006). It has been estimated that fishing mortality accounts for only 2% of total mortality for coregonines in

Minnesota waters of Lake Superior, and a TAC-based fishery during spawning season would not unduly stress stocks.

Commercial fishers are required to submit monthly catch reports for lake herring. In addition, fishery independent monitoring is conducted by both the MN DNR and USGS. The DNR conducts gillnet surveys in Minnesota waters, while the USGS uses spring trawls to evaluate prey fish populations throughout Lake Superior (both US and Canadian waters). Beginning in 1996, acoustic surveys have been used to augment trawl and net catches. Surveys collect data on year-class strength (YCS), size structure, length-at-age, biomass, and catch per unit effort (CPUE) trends and predator diets.

Wisconsin Stocks

In Wisconsin waters, the USGS data provide information on lake herring biomass, CPUE trends, predator diets, and year class strength, as it does for Minnesota. In addition, the Wisconsin Department of Natural Resources (WI DNR) has conducted summer index surveys and fall spawning assessments.

Spawning assessments are particularly important for the Wisconsin fishery as it operates primarily during spawning and targets larger females for their roe. Prior to the pilot spawning stock assessment conducted in 2004, little was known about the fishing-induced mortality in female lake herring stocks in the Wisconsin fishery. The 2004 study combined graded gillnet assessments and acoustic surveys to estimate the proportion of spawning females and lake herring eggs caught by the commercial fishery, and found that mortality in the overall population from the fishery was low (2%).

In addition to the spawning assessment, summer index surveys are conducted at 19 stations in WI-1 on odd-numbered years, and at 39 stations in WI-2 on even-numbered years (WIDNR 2005c). Total length is measured, and presence of fin clips (on lake trout) or sea lamprey marks are noted for all fish. Live fish are then released, while dead fish are weighed and otoliths removed for aging. Stomach contents of dead predatory fish are also examined.

The Wisconsin fishery is limited to using only suspended gillnets between November 1 and December 15 when targeting lake herring. Nets may have a maximum 3 inch stretch, and must be placed a minimum of two fathoms from the bottom.

General Management Concerns

Compared to other Great Lakes fisheries (e.g., yellow perch, lake trout), lake herring management is still fairly new and under development. Thus, a number of key uncertainties still exist. The habitat requirements of most of the life stages of lake herring, for example, are unknown, though degradation of habitat is known to affect spawning populations outside of Lake Superior. Site fidelity in lake herring is also not well understood, and there is little historic data available on what “healthy” or “normal” age and size structures should be (Schreiner et al. 2006). The impacts of the recreational fishery also need to be better understood, as there are currently no limits in the sport fishery and its contribution to total fishing mortality of lake herring is unknown. Finally, the naturally variable nature of lake herring recruitment (very large year classes followed by very small ones and vice versa) makes them particularly vulnerable to external stresses, such as environmental effects (e.g., climate or fishing pressure). Although fishing mortality remains low, conservative management should continue until lake herring dynamics, and its relationship to environmental conditions, are better understood.

Table 4. Commercial catch management measures for the lake herring fishery.

Management Jurisdictions & Agencies	Total Allowable Landings	Size Limit	Gear Restrictions	Trip Limit	Area Closures	Sources
Minnesota Stocks: MN DNR, USGS, Lake Superior Technical Committee	No limit, but TACs currently being developed.	No size limit.	Suspended nets only.	Limited number of licenses.	Fishery closed during spawning season (Nov-Dec).	Schreiner et al. 2006
Wisconsin Stocks: WI DNR, USGS, Lake Superior Technical Committee	TAC instituted.	No size limit.	Suspended nets, no more than 3" mesh size, at minimum of 2 fathoms from bottom.	None.	None.	WNRB 2005; Yule et al. 2005

Synthesis

Management effectiveness for the lake herring fishery is growing, but a number of uncertainties remain. The short-term increase in lake herring abundance illustrated the effectiveness of initial management actions to curb overfishing and manage competing invasive species; however, current abundance trends, based on both fishery dependent (CPUE) and independent (gillnet and trawl surveys) data indicate that lake herring populations are either declining or highly variable within the Minnesota and Wisconsin fisheries. Truly effective management will require better understanding of lake herring needs through its various life stages, better estimates of fishing mortality by both commercial and recreational fisheries, and better control of invasive species populations that have the ability to negatively impact lake herring stocks, such as rainbow smelt and zebra mussels. Given the challenges and uncertainties currently facing the herring fishery, and the need for improved stock assessment, the management for both Minnesota and Wisconsin waters is ranked moderately effective.

Effectiveness of Management Rank:

Highly Effective 🟩 **Moderately Effective** 🟨 Ineffective 🟥 Critical ⬛

6-IV. Overall Evaluation and Seafood Recommendation

Lake herring is a moderately resilient fish, with high fecundity and moderate growth rates, and as such has withstood substantial overfishing and negative interactions with a number of non-indigenous species throughout its long history in the Great Lakes fishery. Stocks from Lake Superior show promise for recovery, particularly in light of the recovery of the natural predator-prey structure in this lake (e.g., lake trout and other predator stocks recovering and reproducing naturally, invasive species such as the rainbow smelt in decline), which has progressed to a greater degree here than in any of the other Great Lakes. The fishery also has low bycatch, due to restrictions on the use of suspended gillnets, and has negligible habitat impacts, though the ecosystem effects of removing lake herring is unknown and thus considered moderate. Current management is reasonably conservative and effectively regulates the habitat and ecosystem impacts of the fishery; however, both stock assessment and understanding of herring ecology must expand in order to better design effective management of lake herring stocks and balance demands for herring biomass from both the commercial fishery and piscivorous fish. Lake herring stocks from Lake Superior have undergone some of the most dramatic recovery from historic lows, but to ensure continued growth, management of these stocks should proceed cautiously. Lake herring is therefore recommended as a "**Good Alternative**."

Table of Sustainability Ranks for Lake Herring

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability		√		
Status of Stocks		√		
Nature of Bycatch	√			
Habitat & Ecosystem Effects		√		
Management Effectiveness		√		

Overall Seafood Recommendation for Lake Herring

Best Choice 🟩　　**Good Alternative** 🟨　　Avoid 🟥

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Chapter 7: Round whitefish

Prosopium cylindraceum

(Image courtesy of New York Sate Department of Environmental Conservation)

7-I. Executive Summary

Round whitefish (*Prosopium cylindraceum*) is a coregonid species that forms part of the native forage base of the Great Lakes. It is found in all the Lakes except Lake Erie, and is rare in Lake Ontario. It is a bottom-dwelling species that feeds primarily on insect larvae, crustaceans, and fish eggs. It is sometimes consumed by piscivorous fish, such as lake trout, but is not the preferred prey of any of the major Great Lakes predatory fish.

Round whitefish populations are resilient, reaching maturity in as few as three years, with a high reproductive potential and a moderately long lifespan, reaching a maximum age of thirteen years. They are available to the fishery seasonally as they move to shallow waters in the fall to spawn and become more vulnerable to fishing.

Round whitefish has played only a minor role in the history of the Great Lakes fisheries, as it has long been considered an “alternate” or “incidental” catch. As such, it is not well studied and little data exist on its stock status, age and size distribution, and habitat quality. Currently, round whitefish are caught primarily by tribe-licensed fisheries in Lake Huron and Lake Michigan, and a smaller catch comes from Wisconsin waters of Lake Michigan.

There are no catch limits set for round whitefish, and no biomass estimates have been made, so it is unknown whether overfishing is occurring. Regulation of fisheries restrict the type, effort, and placement of commercial fishing gear in the Great Lakes, which helps management for round whitefish remain moderately effective even in the face of so much uncertainty in the round whitefish fishery.

Due to so many uncertainties, round whitefish is currently recommended as a “**Good Alternative**,” but subject to revision should additional data on stock status and management effectiveness become available.

Table of Sustainability Ranks for Round Whitefish

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability	√			
Status of Stocks		√		
Nature of Bycatch		√		
Habitat & Ecosystem Effects	√			
Management Effectiveness		√		

About the Overall Seafood Recommendation:

- A seafood product is ranked **Best Choice** if three or more criteria are of Low Conservation Concern (green) and the remaining criteria are not of High or Critical Conservation Concern.
- A seafood product is ranked **Good Alternative** if the five criteria "average" to yellow (Moderate Conservation Concern) OR if the "Status of Stocks" and "Management Effectiveness" criteria are both of Moderate Conservation Concern.
- A seafood product is ranked **Avoid** if two or more criteria are of High Conservation Concern (red) OR if one or more criteria are of Critical Conservation Concern (black) in the table above.

Overall Seafood Recommendation for Round Whitefish

Best Choice 🟩 [✓ **Good Alternative** 🟨] Avoid 🟥

7-II. Introduction

Round whitefish (*Prosopium cylindraceum*) is a temperate, demersal (bottom-dwelling) fish native to the Great Lakes. It is widely distributed throughout the northern regions of North America, from Alaska through the Northwest Territories and Quebec, and in the south in the Great Lakes region, where it is present in all lakes except Lake Erie, and is relatively rare in Lake Ontario (Fig. 1).

Figure 1. Distribution of round whitefish in North America (Figure from Hebert 2002).

Round whitefish is part of the native prey species complex in the Great Lakes, and is consumed by lake trout and other large piscivores. In the Great Lakes commercial fishery, it has long been considered an “alternate catch” as round whitefish have never been as valuable as other species such as walleye, yellow perch, and lake trout. However, it has been fished consistently in Lake Huron and Lake Superior since the beginning of the 20th century. In Lake Michigan, there was a single record-breaking catch in 1993 (Fig. 2), after which by the year 2000, round whitefish accounted for only 0.35% of the commercial catch by weight (Kinnunen 2003b).

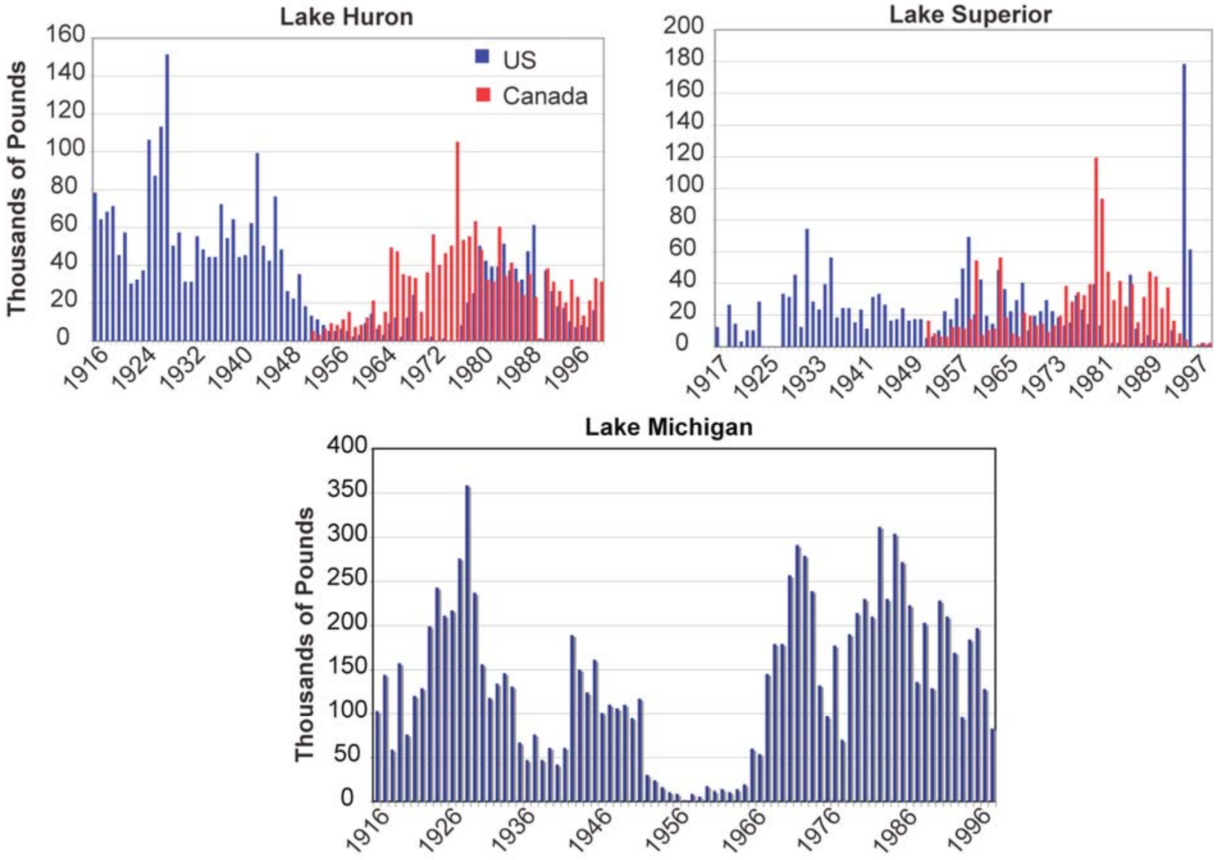

Figure 2: Commercial catches of round whitefish in the Great Lakes (no record of commercial catches in Lake Erie or Lake Ontario), 1916-2000 (Figure from Baldwin et al. 2002).

Commercial fishing for round whitefish currently occurs primarily in Lake Huron and Lake Michigan, and is dominated by tribal fisheries. Approximately 76% of the commercial round whitefish catch is from tribe-licensed fisheries in Michigan waters of Lake Huron, and 24% is from Lake Michigan. In Lake Michigan, 64% of the catch is from tribe-licensed fisheries in Michigan waters and 36% is from state-licensed fisheries in Wisconsin waters (USGS 2007b).

Round whitefish populations declined during the middle of the 20th century, in line with declines of many other Great Lakes species; however, commercial catch records do not provide a reliable measure of round whitefish stock size, as catches were often combined with other species, particularly lake whitefish (Downs et al. 2002).

Because the round whitefish is an alternate fishery target (Spangler and Collins 1980) and is not considered a key prey species for important lake predators (when compared to lake whitefish, lake herring, and invasive alewife and rainbow smelt), round whitefish fisheries are not regulated with total allowable catch (TAC), season, or size limits (WNRB 2005). Only restrictions that are generally applied to tribal and state fisheries, such as allowable gear type, effort, and number of licenses, regulate the catch of round whitefish.

Scope of the analysis and the ensuing recommendation:
Round whitefish is caught commercially in substantial numbers from fisheries in Lake Huron and Lake Michigan, and thus the following analysis will focus on these lakes alone.

Availability of Science

Very little scientific or management assessment data are available for round whitefish. In some limited regions, such as in the state of New York where it is considered endangered, more research is being initiated on round whitefish distribution and population structure. As the fishery is largely unregulated, it is also difficult to assess the impact of fishing practices on round whitefish stock status and overall sustainability.

Market Availability

Common and market names:
Round whitefish, *Prosopium cylindraceum*, is also known as menominee whitefish, pilot fish, frost fish, and round-fish.

Seasonal availability:
Round whitefish are available seasonally, and are caught primarily in the fall.

Product forms:
Round whitefish is available whole, as dressed fish or fillets, fresh or frozen.

Import and export sources and statistics:
Round whitefish are an "alternate" target for fisheries. They are neither exported from the US nor imported, as markets are small and local.

7-III. Analysis of Seafood Watch® Sustainability Criteria for Wild-caught Species

Criterion 1: Inherent Vulnerability to Fishing Pressure

Round whitefish (*Prosopium cylindraceum*) is broadly distributed throughout North America, and in the Great Lakes can be found in Lake Huron, Lake Superior, and Lake Michigan. The species is not present in Lake Erie and rare in Lake Ontario.

Round whitefish spend most of the year in mid-to-deep water (50-100 feet in depth), but return to shallow water in April to May and then again to spawn between October and December (depending on latitude). Round whitefish found in shallow waters around northern Lake Michigan and Lake Huron are referred to locally as "menominees." Spawning occurs over shallow gravel bottoms at lake shores, river mouths, and occasionally within rivers (Fig.3).

Figure 3. Round whitefish spawning and nursery grounds in Lake Huron (Figure from Goodyear et al. 1982).

Round whitefish has an early age at maturity, around 3-6 years and 12 inches in length, and relatively high fecundity; a female typically produces between 1,000 and 10,000 eggs, depending on size and condition. Eggs are consumed by burbot, bullheads, and yellow perch. Juvenile round whitefish can grow to 3-5 inches by the end of their first year. Adult whitefish feed primarily on invertebrates, insect larvae, small mollusks, and the eggs of other fish including lake trout. Round whitefish can grow to nearly 20 inches, though typical sizes are between 10 and 15 inches, and weigh 1-2 pounds. They commonly live to 13 years, and can live as long as 22 years (Normandeau 1969; Hebert 2002; Froese and Pauly 2007; MIDNR 2007c; NYSDEC 2007).

Round whitefish is listed as endangered in New York, where commercial fishing ended before 1950. It had at one time been common in Adirondack lakes, but a combination of loss of spawning sites, siltation, lake acidification, overfishing, and predation on round whitefish eggs by introduced yellow perch led to a dramatic decline, and populations have not recovered (NYSDEC 2007). The poor condition of these stocks indicates that round whitefish can be vulnerable to habitat conditions and invasive species interactions.

Table 1. Life history characteristics of round whitefish.

Intrinsic Rate of Increase (r)	Age at Maturity	Growth Rate	Max Age	Max Size	Fecundity	Species Range	Special Behaviors	Sources
Unknown	3-6 years	0.05-0.15	13-22 years	20 inches	1,000 – 10,000 eggs per female	Broad: northern North America, all Great Lakes except Erie, rare in Lake Ontario.	Spawning aggregations, interactions with invasive species, habitat.	Normandeau 1969; Hebert 2002; Froese and Pauly 2007; MIDNR 2007c; NYSDEC 2007

Synthesis

Round whitefish has an early age at maturity and moderate-to-high fecundity, and is broadly distributed in the Great Lakes, except Lake Erie. In Lake Erie the species is listed as endangered, and its decline in this lake points to vulnerabilities to habitat alteration (lake acidification is thought to have affected round whitefish populations in New York) and negative interactions with invasive species that prey on whitefish eggs. Broad distribution, fecundity, and the health of the majority of its habitat, however, makes round whitefish resilient to fishing pressure.

Inherent Vulnerability Rank:

[✓ **Resilient** 🟩] Moderately Vulnerable 🟨 Highly Vulnerable 🟥

Criterion 2: Status of Wild Stocks

Not much is known about the status of round whitefish stocks in Lake Huron and Lake Michigan, as they are not routinely monitored by Great Lakes management agencies. In Lake Huron, round whitefish historically accounted for less than 1% of the total coregonine catch (which is dominated by lake whitefish, *Coregonus clupeaformis*). Between 1912 and 1940, a period of relatively high yields for the Great Lakes commercial fishery, an average of about 60,000 pounds of round whitefish was caught in Lake Huron each year. The catch then fluctuated due to both market demand and changes in population size, showing no real trend, from 1960-1980. In the 1990s, commercial yields began to decline and shift from US waters almost entirely to Canadian waters; however, by 1992 the balance was even once again (Ebener 2005).

Currently, no round whitefish catch limits have been set in Lake Huron. In Lake Michigan, a target catch range was set in 1995 at 40,000-100,000 pounds. The commercial catch in 1992-1993 from Wisconsin waters had been 16,000 pounds and this target was considered reasonable. The total round whitefish catch from Lake Michigan in 2005 was below 5,000 pounds (WIDNR 1995). This suggests the targets set in the early 1990s are not possible, given the current state of the lake and cormorant predation rates. However, catch rates are strongly influenced by market demand, which has been declining in recent years, so abundance status cannot be directly inferred from catch rates.

Table 2. Stock status of round whitefish.

Status	B/B_{MSY}	Occurrence of Overfishing	F/F_{MSY}	Abundance Trends/ CPUE	Age/Size/ Sex Distribution	Degree of Uncertainty in Stock Status	Sources	SFW Rank
Listed as endangered in New York.	Unknown	Unknown	Unknown	Long-term trends are down.	Unknown	High	WIDNR 1995; Ebener 2005	Moderate

Synthesis

Very little is known about the health of round whitefish stocks in Lake Huron and Lake Michigan, as the commercial fisheries they support are small and there is no program for stock assessment. It is clear that a decline in abundance has occurred, but it remains unclear what the impact of the fishery is on this species, whether any recovery has occurred, or what stresses (e.g., habitat loss, overfishing, or invasive species interactions) are impacting the status of round whitefish populations. The uncertainty about the overall stock status of round whitefish is high, thus stock status is considered of moderate conservation concern.

Status of Wild Stocks Rank:

Healthy 🟩 **Moderate/Rebuilding** 🟨 Poor 🟥 Critical ⬛

Criterion 3: Nature and Extent of Bycatch

Seafood Watch® defines sustainable wild-caught seafood as marine life captured using fishing techniques that successfully minimize the catch of unwanted and/or unmarketable species (i.e., bycatch). Bycatch is defined as species that are caught but subsequently discarded (injured or dead) for any reason. Bycatch does not include incidental catch (non-targeted catch) if it is utilized, accounted for, and managed in some way.

Although there is almost no information available about the round whitefish fishery, the impacts of the fishing practices can be assessed from related tribal- and state-licensed commercial fisheries in Lake Huron and Lake Michigan, which use a combination of trap net and gillnet gear. Round whitefish are often incidental bycatch to the lake whitefish and chub fisheries, which have been monitored for bycatch since the 1960s, and round whitefish catches are generally low. Of greater concern in these fisheries, which may also be of concern in targeted round whitefish fisheries, is the incidental bycatch of important predator species such as lake trout and coho salmon (Toneys 2000). However, onboard monitoring of the Wisconsin lake whitefish and chub fisheries show that incidental bycatch of this species is low compared to total catch (in 1999, fewer than 30,000 lake trout were caught with a total catch in Wisconsin of nearly 2 million pounds of chubs). Targeted round whitefish fisheries may be expected to have similar bycatch statistics, but without scientific monitoring bycatch status remains uncertain, and thus is ranked as a moderate conservation concern in the round whitefish fishery.

Nature of Bycatch Rank:

Low 🟩 [✓ **Moderate** 🟨] High 🟥 Critical ⬛

Criterion 4: Effect of Fishing Practices on Habitats and Ecosystems

Habitat Effects

The stationary gear used in commercial fisheries for round whitefish in the Great Lakes causes minimal habitat damage.

Ecosystem Effects

The effect of removing round whitefish from the ecosystems/food webs of Lake Huron and Lake Michigan has not been studied. However, it is known that this species is not the preferred prey of high-valued predator fish such as lake trout. In addition, since round whitefish consume the eggs of lake trout, their removal may be beneficial for this important native predator, which is currently recovering in the Great Lakes (Downs et al. 2002). Although there is high uncertainty around the impact of round whitefish removal, it is concluded that the impacts of the fishery on the ecosystem are likely benign and therefore of low conservation concern.

Effect of Fishing Practices Rank:

[✓ **Benign** 🟩] Moderate 🟨 Severe 🟥 Critical ⬛

Criterion 5: Effectiveness of the Management Regime

For state- and tribe-licensed fisheries in Lake Michigan and Lake Huron, the relevant management agencies are the Wisconsin Department of Natural Resources (WI DNR), the Chippewa-Ottawa Resource Authority (CORA), and the Great Lakes Indian Fish and Wildlife Commission (GLIFWC). Currently, there is no assessment of round whitefish health in Lakes Huron and Michigan, and no total allowable catch (TAC) limits have been set for the fishery. However, catches remain very small compared to other targeted fish and the round whitefish does not appear to be a keystone species in Great Lakes food webs.

Gear restrictions that have been put in place to protect other species, including limitations on the use of gillnets, seasonal closures, and restriction of fishing in protected areas such as lake trout refuges, help minimize the impacts of the round whitefish fishery. The management of round whitefish stocks and of ecosystem effects of the fishery is therefore deemed moderately effective.

Table 3. Commercial catch management measures for the round whitefish fishery.

Management Jurisdictions & Agencies	Total Allowable Landings	Size Limit	Gear Restrictions	Trip Limit	Area Closures	Sources
WI DNR, CORA, GLIFWC	None set	None	General restrictions apply to the use of gillnets and placement of all commercial fishing gear.	None.	None.	Spangler and Collins 1980; WNRB 2005

Effectiveness of Management Rank:

Highly Effective 🟩 [✓ **Moderately Effective** 🟨] Ineffective 🟥 Critical ⬛

7-IV. Overall Evaluation and Seafood Recommendation

The round whitefish fisheries in Lake Michigan and Lake Huron are not well-monitored. Though this fish species has resilient life history characteristics, including early age at maturity and relatively high fecundity, there is high uncertainty about the status of round whitefish stocks. The management regime is effective insomuch as it is regulated by general Great Lakes fisheries restrictions on gear type, placement, and effort. Without further scientific study and management assessment of round whitefish populations it is difficult to draw reliable conclusions as to the sustainability of these fisheries. Round whitefish is therefore recommended as a "**Good Alternative,**" but this recommendation is subject to revision when more assessment data become available. Caution is warranted in concluding that current management and fishing practices are sustainable.

Table of Sustainability Ranks for Round Whitefish

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability	√			
Status of Stocks		√		
Nature of Bycatch		√		
Habitat & Ecosystem Effects	√			
Management Effectiveness		√		

Overall Seafood Recommendation for Round Whitefish

Best Choice 🟩 [✓ **Good Alternative** 🟨] Avoid 🟥

7-V. References

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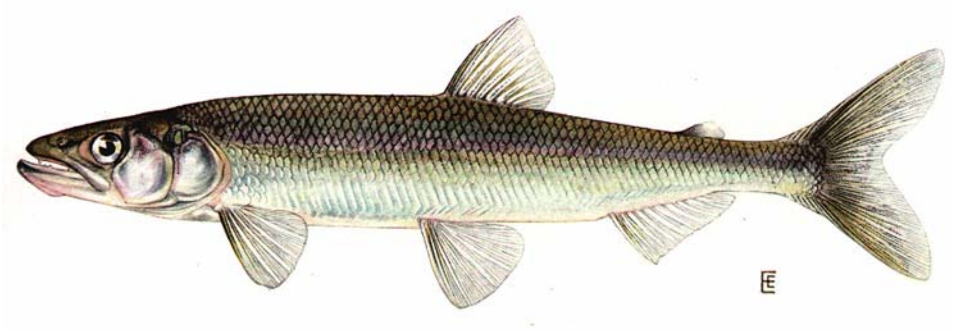
Chapter 8: Rainbow Smelt

Osmerus mordax



(Image courtesy of New York State Department of Environmental Conservation)

8-I. Executive Summary

Rainbow smelt (*Osmerus mordax*) is a small forage fish with a broad native range that spans the Atlantic coast from New Jersey north to Newfoundland and Labrador, and the Pacific coast from the Pacific Northwest through Alaska to the Arctic coast. The species was introduced to the Great Lakes in the 1930s and quickly grew in abundance, replacing the native forage community of lake herring and other deepwater ciscoes that had declined due to overfishing, decreased water quality, and competition from both rainbow smelt and another invasive forage fish, the alewife (*Alosa pseudoharengus*). At one time rainbow smelt was commercially fished from all Great Lakes, but fisheries are currently limited to Lake Erie, Lake Michigan, and Lake Superior. The Lake Erie fishery is the largest, and had surpassed the formerly dominant Atlantic rainbow smelt fishery by 1960.

Rainbow smelt is a naturally resilient species with a high rate of increase, high fecundity, and a short lifespan. However, smelt in the Great Lakes has experienced a number of substantial biomass declines due to introduction of non-indigenous parasites (1970s), increased predation by stocked predator fish and recovering native predator populations (1970s-present), and reductions in overall lake productivity associated with the proliferation of dreissenid mussels (1990s). Commercial catch rates and biomass surveys in Lake Erie indicate a pronounced decline in the abundance of rainbow smelt since the mid-1980s and highly variable year class strength. In Lake Michigan, rainbow smelt abundance is also substantially lower than the long-term mean, though populations have increased over the past three years and may be recovering from 1990s lows. In Lake Superior, abundance trends are highly variable but generally lower than long-term means. Due to limited catch regulation and stock assessment, the long-term trajectory of the rainbow smelt population remains highly uncertain but it is doubtful that populations will recover to pre-1980s highs.

Bycatch mortality in the rainbow smelt fishery is highly uncertain, as there is no systematic study of discarded incidental catches. The most commonly reported incidental catches include alewife and bloater chubs, and it is likely that unreported catches of rainbow smelt below marketable size may be substantial. In addition, ecosystem impacts of forage fish removal, given the large biomass of predator fish in the Great Lakes, may be substantial. General forage abundance has declined throughout Lake Erie, Lake Michigan, and Lake Superior, and current forage biomass may be insufficient to support the naturally reproducing and stocked predator fish populations in these lakes.

Because it is not native to the Great Lakes ecosystem and can impede the recovery of native forage species through predation and competition for zooplankton resources, rainbow smelt is generally regarded as an undesirable species. Its removal is seen as a part of the restructuring of Great Lakes communities, restoring the native predator-prey balance to sustainable, self-regulating levels. Because of this, smelt fisheries are relatively unregulated. Catch quotas are in place only in Lake Michigan. There is high uncertainty throughout the fisheries around whether overfishing is occurring, and whether the combined biomass of the forage base (rainbow smelt, alewife, and bloater chubs, all with highly variable year-to-year abundance) will be sufficient to support the current biomass of predator fish in the Great Lakes.

The sustainability of rainbow smelt in the Great Lakes thus represents a complex and unique issue. Rainbow smelt stocks are valued as a commercial species and important forage prey for predator fish such as lake trout, walleye, and introduced salmonids; however, the presence of rainbow smelt impedes the recovery of native forage fish populations and it is therefore considered an undesirable species. The removal of rainbow smelt is likely to cause a short-term decrease in the carrying capacity of the Great Lakes predator species, but should in the long-term aid in the recovery of native forage species and the promotion of native self-regulating populations. Article 8(h) of the Convention on Biological Diversity (CBD) states that "Contracting parties to the Convention should, as far as possible and appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" (Hansson 2002). The trajectory of rainbow smelt stocks in the Great Lakes, given the limited stock assessment and regulations surrounding the fishery, is currently highly uncertain; however, the motivation to remove this species from the ecosystem makes it a "**Good Alternative**," provided that conservative management remains ineffective and populations decline.

Table of Sustainability Ranks for Rainbow Smelt

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability	√			
Status of Stocks		√	√	
Nature of Bycatch		√		
Habitat & Ecosystem Effects		√		
Management Effectiveness		√		

About the Overall Seafood Recommendation:

- A seafood product is ranked **Best Choice** if three or more criteria are of Low Conservation Concern (green) and the remaining criteria are not of High or Critical Conservation Concern.
- A seafood product is ranked **Good Alternative** if the five criteria "average" to yellow (Moderate Conservation Concern) OR if the "Status of Stocks" and "Management Effectiveness" criteria are both of Moderate Conservation Concern.
- A seafood product is ranked **Avoid** if two or more criteria are of High Conservation Concern (red) OR if one or more criteria are of Critical Conservation Concern (black) in the table above.

Overall Seafood Recommendation for Rainbow Smelt

Best Choice 🟩 **Good Alternative** 🟨 Avoid 🟥

8-II. Introduction

Rainbow smelt (*Osmerus mordax*) is a planktivorous marine fish with a wide native distribution along the Atlantic and northern Pacific coasts, but not including the Great Lakes. It has long supported a commercial Atlantic fishery but was not caught commercially in the Great Lakes until the latter half of the 20th century, decades after its introduction to the region. It was first introduced intentionally to inland Michigan lakes as forage for stocked salmonids in 1906 (FAO 2002), and then escaped to Lake Michigan and the rest of the Great Lakes by the 1930s (Downs et al. 2002).

In many lakes, the rainbow smelt population expanded quickly to fill the niche vacated by the lake herring crash between 1920 and 1940 (Cornelius 2000). Peak rainbow smelt abundance coincided with a period when the non-indigenous alewife was also proliferating in the Great Lakes, and their combined populations had several negative ecosystem impacts. Alewife was subject to massive die-offs as a result of sensitivity to extreme temperatures, washing up onto lakeshores and causing unsanitary conditions. Consumption of large quantities of zooplankton and/or predation on larval native fish by both smelt and alewife also drove native fish species, such as lake herring and other deepwater ciscoes, into dramatic declines. Several management actions were soon put into place to mitigate the negative effects of these invasive forage species on the native fish communities, and by the mid-1950s, smelt had become part of a large commercial forage species fishery destined for both human consumption and animal feed (Fig. 1).

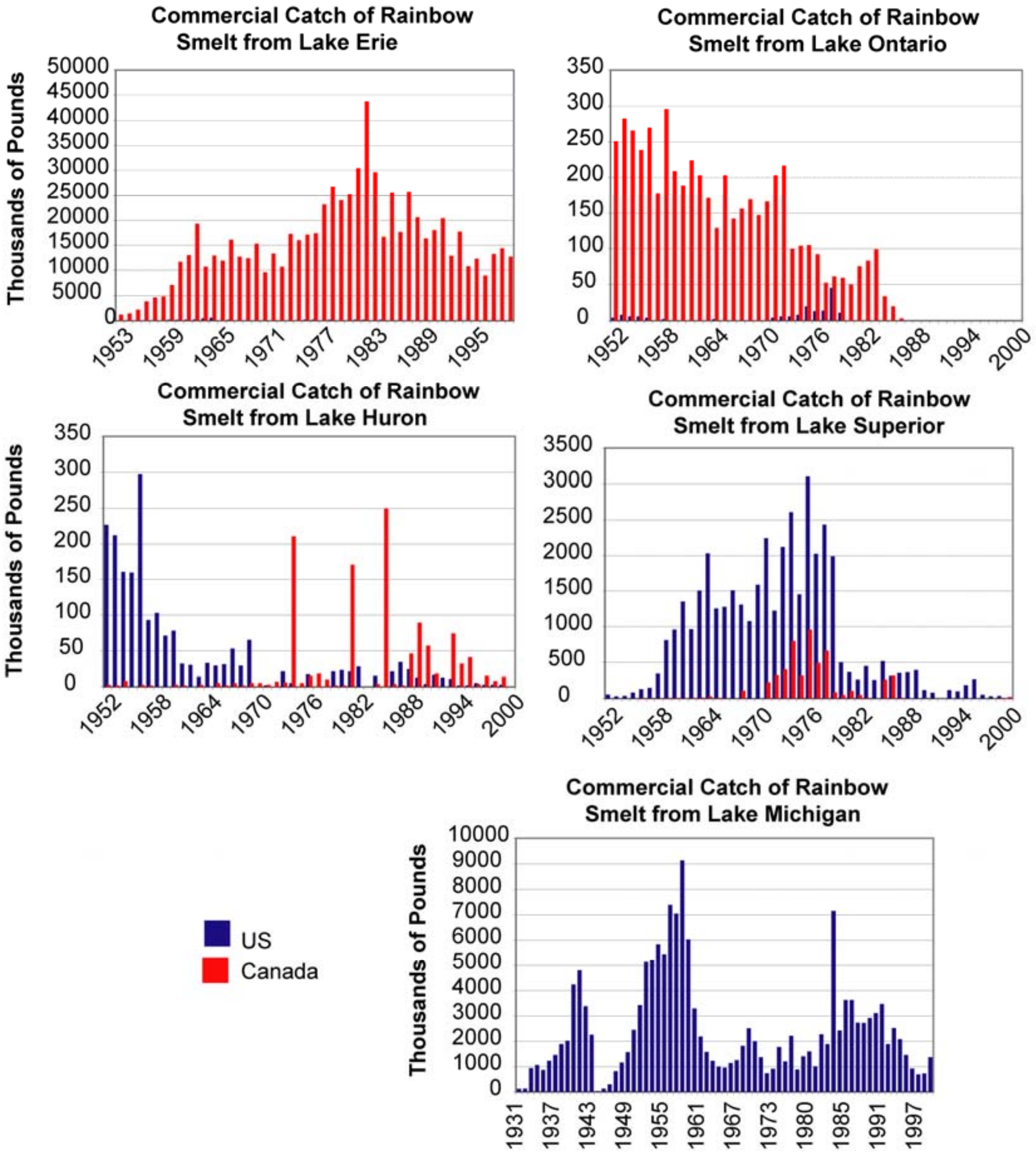


Figure 1: Commercial catch of rainbow smelt from US and Canadian waters of the Great Lakes, 1930-2000 (Figure from Baldwin et al. 2002).

In addition to the commercial fishery for rainbow smelt, a large-scale predator stocking program was initiated to control non-indigenous forage populations, which soon grew to support a number of lucrative sport fisheries. Rainbow smelt thus became important in the maintenance of sport fisheries for predators initially introduced to eradicate them, setting up fundamental conflicts in the management of commercial smelt and recreational sport fisheries.

The predator stocking program was highly successful and led to substantial reductions in rainbow smelt abundance in most lakes through the 1970s. The invasion of the zebra and quagga mussels in the early 1990s led to further declines, as the pelagic productivity of lakes decreased and substantial restructuring of lower levels of the food web occurred (Lantry and Stewart 2000). By this time other restoration efforts occurring throughout the Great Lakes, including the implementation of the Great Lakes Water Quality Agreement, had led to the recovery of a number of native piscivores, including walleye and yellow perch, and many lakes had initiated programs aimed at recuperating native lake trout populations through intensive stocking. The concurrent increase in predator abundance and decline in non-native forage species that had largely replaced their native counterparts then resulted in an imbalance in the predator-prey dynamic throughout the Great Lakes. Further declines in smelt abundance may result in a reduced carrying capacity for predator species (Hrabik et al. 2004), but the current predator density is not “natural”; it consists largely of introduced species that in many cases must be supported by stocking. Removal of non-native forage and an overall reduction in predator biomass may be a necessary step in reestablishing self-sustaining native populations.

Commercial rainbow smelt fisheries are currently limited to Lake Erie, Lake Michigan, and Lake Superior (Kinnunen 2003b; USGS 2007b). The Lake Erie catch is from a Canadian trawl fishery, and is the largest at around seven million pounds. It is now substantially larger than the Canadian Atlantic smelt catch, which was once dominant (DFO 2006b). The bulk of the US rainbow smelt catch is from Wisconsin waters of Lake Michigan, which is the most tightly regulated of the Great Lakes smelt fisheries. The rainbow smelt catch in Lake Michigan has declined substantially since general forage trawls were conducted in the 1960s. The catch is primarily from Wisconsin waters, with a smaller proportion coming from state-licensed Michigan fisheries. The Wisconsin catch currently averages under 400,000 pounds per year, down from a high of nearly two million pounds in 1990 (Hogler and Surendonk 2007). The US Lake Superior fishery is relatively minor, with a catch of only 11,000 pounds in 2005 (USGS 2007b), and is restricted to pound nets.

Scope of the analysis and the ensuing recommendation:
Rainbow smelt are caught within both marine (primarily Atlantic) and freshwater (Great Lakes and northern Canada) fisheries. Although marine rainbow smelt are generally seen as higher quality, the volume of freshwater rainbow smelt catches from the Great Lakes is larger. This report focuses on the sustainability of non-anadromous populations of rainbow smelt from Great Lakes waters. Great Lakes commercial catches of rainbow smelt are largely (90%) from Canadian waters of Lake Erie, with US catches from Lake Michigan making up the balance (Fig. 2). The status of the Lake Erie fishery will therefore drive final recommendations for the Great Lakes rainbow smelt fishery.

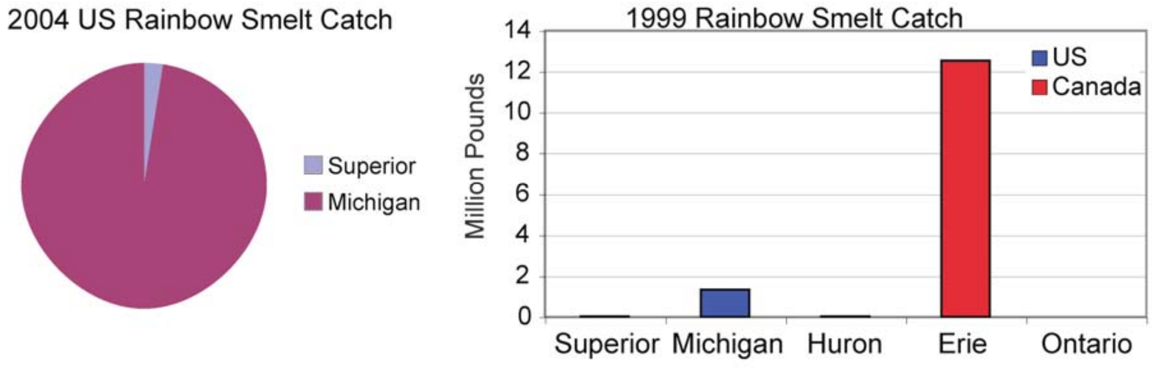


Figure 2. US and Canadian commercial rainbow smelt catches by lake (Figure from Baldwin et al. 2002).

Availability of Science

Rainbow smelt dynamics have been studied in a limited sense due to interest in this species as both an invasive planktivore that competes with native Great Lakes species and as a major forage species in the diets of dominant predator fish in the Great Lakes system, including walleye and lake trout. However, as a relatively low value species in the fishery when compared to predator fish, there is not as extensive a body of literature available. In particular, systematic monitoring of the abundance and distribution of this species is relatively new to the Great Lakes system, and is not practiced in the commercial Canadian fishery in Lake Erie. Since no reliable estimate of abundance exists, there is no recommendation available on the sustainability of catch levels. This suggests caution is warranted in monitoring the status of the rainbow smelt fishery.

Market Availability

Rainbow smelt are commercially harvested from both anadromous Atlantic stocks and land-locked Great Lakes stocks. Great Lakes rainbow smelt are caught in larger quantities than Atlantic smelt, but demand a lower price, as anadromous smelt are perceived as a higher quality product (DFO 2006b).

Common and market names:
Rainbow smelt is also known as American smelt, leefish, freshwater smelt, and frost fish.

Seasonal availability:
Rainbow smelt caught by trawling in the Great Lakes are available year-round. Rainbow smelt are available more widely from coastal fisheries (including recreational fisheries) in the spring (primarily April).

Product forms:
Rainbow smelt can be found on the US market as fresh or frozen whole fish.

Import and export sources and statistics:
Great Lakes rainbow smelt are the third largest Canadian freshwater fish export by weight and fourth or fifth by value (Fig. 3). The majority of Canadian-caught freshwater smelt are exported frozen to Japan, with some going to the US. A portion of the Lake Erie catch is also exported fresh to the US (FAO 2002).

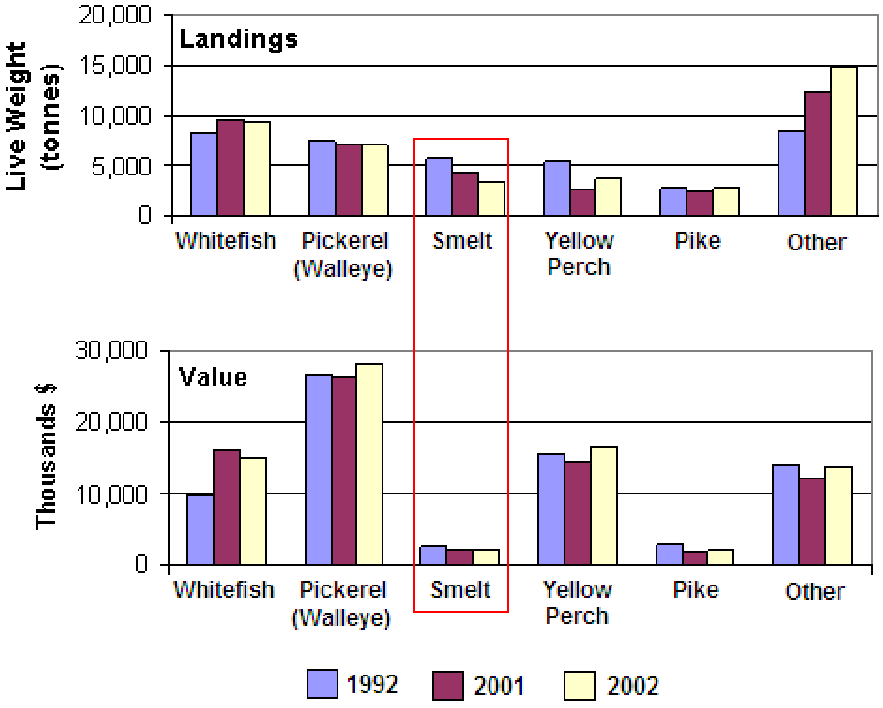
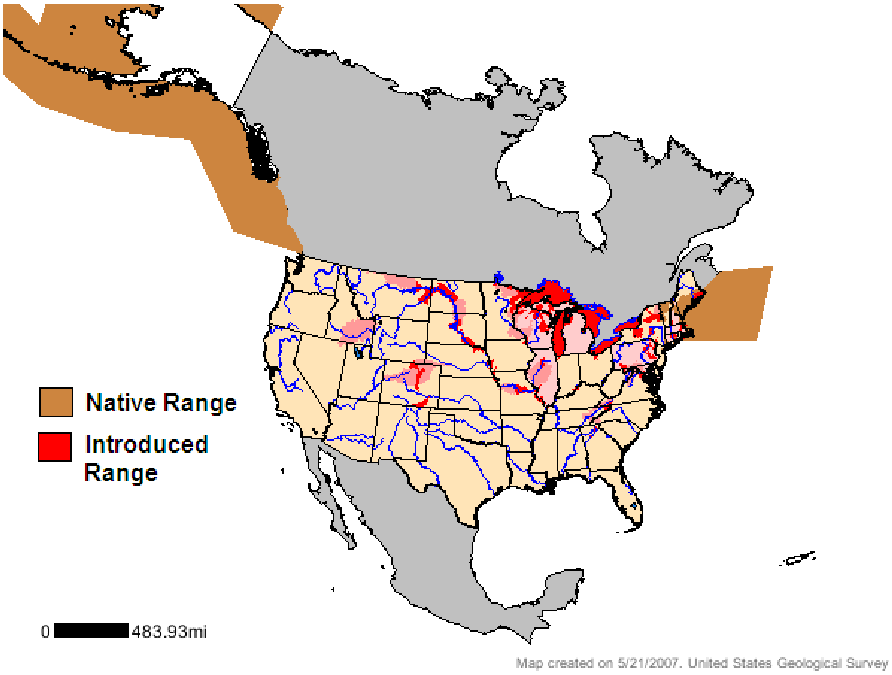


Figure 3. Value of Canada's Great Lakes rainbow smelt catch, 1992-2002 (Figure from FAO 2002).

8-III. Analysis of Seafood Watch® Sustainability Criteria for Wild-caught Species

Criterion 1: Inherent Vulnerability to Fishing Pressure

Rainbow smelt (*Osmerus mordax*) is an anadromous fish native to the Atlantic coast, which, like other marine species such as alewife (*Alosa pseudoharengus*) and sea lamprey (*Petromyzon marinus*), has successfully adapted to inland freshwater environments. In addition to its native range, which spans the North American Atlantic coast from New Jersey in the south to Newfoundland and Labrador in the north, and the Pacific coast from Vancouver Island to Alaska and east along the Arctic coast (DFO 2006b), rainbow smelt is now found in many inland water bodies including all of the Great Lakes (Fig. 4).



Map created on 5/21/2007. United States Geological Survey

Figure 4. Range of rainbow smelt in US drainages (Figure from USGS 2007a).

In the Great Lakes, rainbow smelt school in both coastal and central lake areas. Though their preferred habitat is typically at the middle depths of lakes, they are sensitive to both light and temperature, and are therefore often found near the bottom during the day. Rainbow smelt prefer temperatures between 7ºC and 16ºC (Downs et al. 2002).

Female rainbow smelt grow faster and attain larger sizes than males. Rainbow smelt typically grow to 6-9 inches and reach only about 1/3 of a pound. The typical lifespan of a rainbow smelt is 6 years, with maturity occurring by age 2. Spawning appears to be controlled by photoperiod rather than by temperature. In southern reaches of its range, rainbow smelt spawn in late winter or early spring, while in northern reaches spawning occurs mid-spring. Rainbow smelt typically spawn at night over hard substrates such as gravel. A female rainbow smelt can produce from 7,000 to more than 75,000 eggs, depending on size, but landlocked populations are less fecund than anadromous ones, and average around 30,000 eggs per female. Hatching is more successful at low density when eggs can remain well-aerated; at high densities hatching success drops from 4% to only 0.03%. This can be of particular concern when obstructions in rainbow smelt habitat prevent populations from accessing sufficient suitable spawning grounds, and multiple rainbow smelt are forced to spawn over a limited area. Rainbow smelt are also particularly vulnerable to infection, and the introduction of exotic pathogens has caused massive die-offs of rainbow smelt in the past. For example, infection by the parasite *Glugea hertwigi* is thought to have caused extensive mortality of young rainbow smelt in Lake Erie in 1969 (Dechtiar 1972).

Juvenile rainbow smelt are planktivorous, but as they grow they switch to consuming invertebrates, such as amphipods and mysids, as well as any small fish available (DFO 2006b). The reliance of juvenile rainbow smelt on zooplankton has made them particularly vulnerable to ecosystem changes in the Great Lakes that occurred after the invasion of the zebra and quagga mussels (*Dreissena polymorpha* and *D. bugensis*) in the late 1980s. The high filtration rates of these non-native mussels substantially reduced lake productivity by both direct removal of zooplankton and by increased oligotrophication.

In Lake Erie, in particular, *Dreissena* have had a dramatic effect on the lower levels of the food web. Lake Erie, the most productive of the Great Lakes, had substantial eutrophication problems in the mid-1970s. At that time, total phosphorous levels in the lake often exceeded 20 µg/L. The Great Lakes Water Quality Agreement established a target level of 10 µg/L in Lake Erie, which was achieved in 1987 following implementation of phosphorous abatement programs. Zebra mussels arrived in Lake Erie in 1989, and by 1998 total phosphorous had been reduced to 4.4 µg/L. This decline in productivity was correlated with decreased zooplankton abundance, from 120 µg/L in 1970 to 60.8 µg/L in 1987 to less than 24 µg/L by 1994 (Parker et al. 2000).

Ecosystem impacts of dreissenid mussels are greatest in the near-shore zone, which contains habitat important to juvenile rainbow smelt. Adult rainbow smelt, on the other hand, feed primarily on opossum shrimp, *Mysis relicta*, and other invertebrates. In addition, adult smelt have been implicated as important predators of larval Great Lakes fish, including other rainbow smelt, burbot (*Lota lota*), lake whitefish (*Coregonus clupeaformis*), and lake herring (*Coregonus artedii*). They also provide important forage to predator fish such as walleye, lake trout, and non-native salmonids; smelt mortality due to predation can be very high. The combined effects of reduced food availability, which can reduce rainbow smelt condition and lead to post-spawn die-offs, and predation by abundant stocked predator fish, led to annual mortalities in excess of 90% in Lake Erie during the late 1990s (Cornelius 2000). Such imbalances in the predator-prey dynamics within the Great Lakes suggest that current relative densities of predator and forage fish may be unsustainable.

Table 1. Life history characteristics of rainbow smelt.

Intrinsic Rate of Increase (r)	**Age at Maturity**	**Growth Rate**	**Max Age**	**Max Size**	**Fecundity**	**Species Range**	**Special Behaviors**	**Sources**
0.15-0.5	2-3 years	K=0.31	6 years	14 inches	7,000 to 75,000 eggs/female (Great Lakes average: 30,000)	Broad—Atlantic coast from New Jersey to Newfoundland, Pacific Coast from Vancouver to Alaska and Arctic Ocean, widely introduced to inland North America	Schooling. Susceptible to infection. Habitat disruption by zebra mussel invasion and predation by stocked predator fish have led to population instability.	Froese and Pauly 2007

Synthesis

Rainbow smelt is a naturally resilient species with a high intrinsic rate of increase, high fecundity, and a short lifespan. However, their susceptibility to infection, the reduction of food availability for juvenile rainbow smelt in the Great Lakes due to the dreissenid mussel invasion, and extremely high predation pressure from stocked and recovering wild predator fish has led to an unstable outlook for rainbow smelt stocks. More importantly, this translates to an unstable outlook for both native and introduced predator stocks as well. Therefore, though this species is inherently resilient to fishing pressure, the instability of predator-dominated food webs in the Great Lakes warrant caution in the management of the rainbow smelt fishery.

Inherent Vulnerability Rank:

[✓ **Resilient** 🟩]   Moderately Vulnerable 🟨   Highly Vulnerable 🟥

<u>Criterion 2: Status of Wild Stocks</u>

Lake Erie

The Canadian waters of Lake Erie account for nearly all of the sizeable commercial catch of freshwater rainbow smelt in Canada (Baldwin et al. 2002), and Lake Erie catch continues to exceed the commercial catch of Atlantic rainbow smelt. Prior to the proliferation of rainbow smelt in the Great Lakes, Atlantic catches dominated, averaging 8 million pounds per year, but a unique reversal occurred beginning in the middle of the century. By the early 1960s Great Lakes catches had risen to nearly 19 million pounds per year and in 1982 the peak catch of over 43 million pounds of rainbow smelt far exceeded any Atlantic catch (Baldwin et al. 2002; DFO 2006b).

In the past, landings of both Atlantic and Great Lakes rainbow smelt have been regulated more by market demand than by availability (DFO 2006b). Commercial catch records from this period are therefore poor metrics for rainbow smelt abundance. In recent decades, however, the catch has been decreasing and recent surveys of forage fish biomass in Lake Erie suggest that rainbow smelt abundance has declined dramatically.

The majority of the Canadian commercial catch comes from Ontario waters of Lake Erie in the easternmost central basin and the eastern basin. The catch from this region has shown a pronounced downward trend since the mid-1980s (Fig. 5), and biomass remains well below long-term averages (Cornelius 2000; Witzel et al. 2005). No long-term systematic assessment of rainbow smelt abundance occurs in Canadian waters of the eastern and central basins, making reliable predictions of stock trends impossible; however, interagency prey fish surveys in US waters of Lake Erie have recently expanded to include Canadian waters as well, and current trends in smelt abundance revealed by these surveys indicate that current total mortality (fishing mortality and predation mortality combined) may be unsustainable (Markham et al. 2005; Bur et al. 2007)..

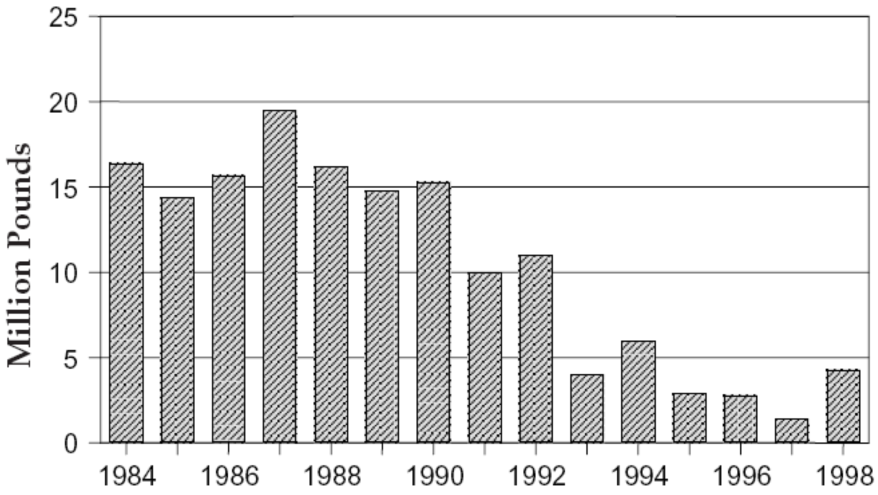


Figure 5. Commercial catch of rainbow smelt from Ontario waters of Lake Erie (eastern central basin and eastern basin) (Figure from Cornelius 2000).

In New York waters of the eastern basin in Lake Erie, trawl and hydroacoustic surveys conducted by the New York State Department of Environmental Conservation (NYSDEC) showed that the density of age-0 rainbow smelt decreased in 2004, while size-at-age increased. Yearling and older (YAO) rainbow smelt abundance, in contrast, was the highest in the history of the survey—nearly 3,000 fish per hectare, as compared to the 11-year average of 440 fish per hectare—while size-at-age decreased. This increase was based on record high year-class-strength in 2003, despite the previous trends in alternating cycles of abundance that suggested rainbow smelt abundance would decrease in 2004.

In the central basin of Lake Erie, recruitment of all forage species declined between 2003 and 2004, but was still above long-term means. The strong 2003 rainbow smelt year-class led to an increase in YAO abundance. In the western basin, rainbow smelt year class strength had been very low since the late 1970s, then the population had one strong class in 1991, and thereafter year class strength remained low until 2005, when abundance increased to more than 50% higher than the 15-year mean (Fig. 6) (Johnson et al. 2005; Bur et al. 2007).

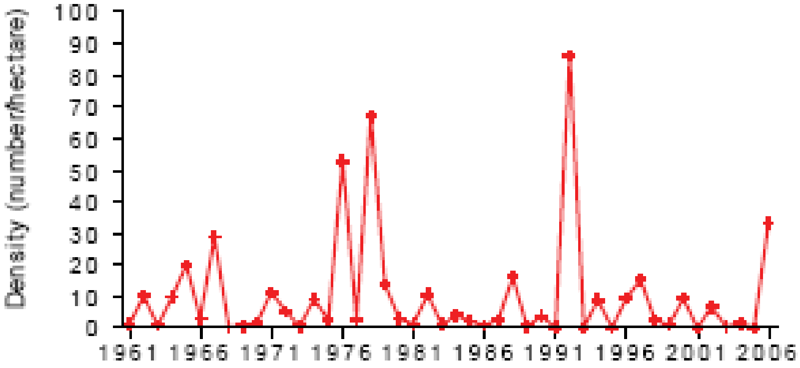


Figure 6. Density of young-of-the-year rainbow smelt in the western basin of Lake Erie (Figure from Bur et al. 2007).

Synthesis – Lake Erie

The commercial rainbow smelt fishery from Canadian waters of Lake Erie is not regulated by catch limits, and only limited stock assessment occurs as a part of lake-wide forage fish surveys. Commercial catch rates and surveys indicate a pronounced decline in the abundance of rainbow smelt since the mid-1980s. Year-class strength has been highly variable, with a very strong class in 2003 and a weaker one in 2004. There is no quota on rainbow smelt in Lake Erie, and there is therefore no estimate of fishing mortality relative to maximum sustainable yield. Due to limited catch regulation and stock assessment, the long-term trajectory of the rainbow smelt population remains highly uncertain but it is doubtful that populations will recover to pre-1980s highs. Because of high uncertainty, rainbow smelt stocks in Lake Erie are of moderate conservation concern, and more comprehensive stock analysis may reveal they are in poor (declining) condition.

Lake Michigan

In Lake Michigan, the deepwater ciscoes that once formed the dominant forage base suffered severe population declines in the first half of the 20th century. Since that time, dominance has been shared, in fluctuating proportions, among non-indigenous alewife and rainbow smelt and, more recently, by bloater chubs (*Coregonus hoyi*), a native deepwater cisco that recovered to short-lived high abundance in the mid-1980s and has since declined to lower levels in an apparent density dependent response (Fig. 7).

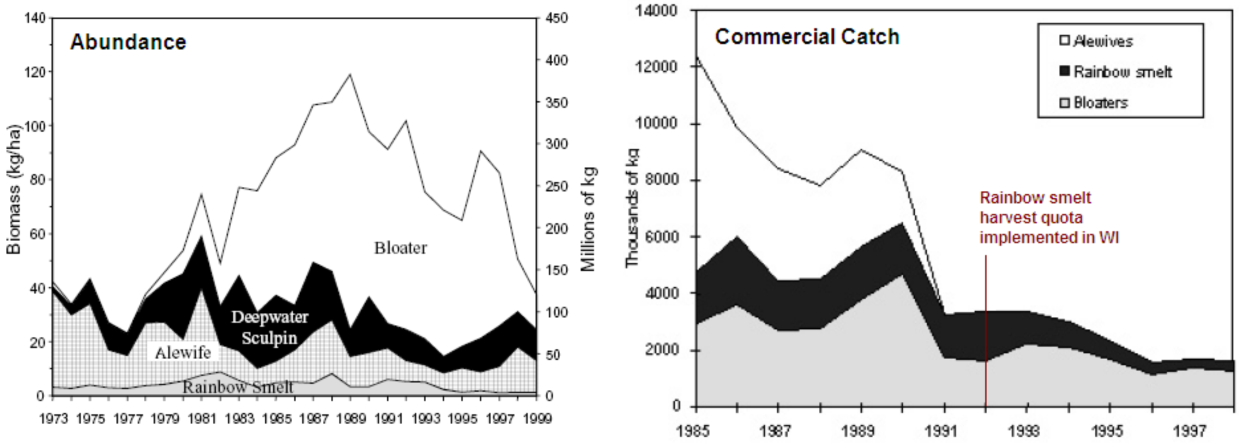


Figure 7. Abundance and commercial catch of forage fish in Lake Michigan, 1973-1999 (Figure from Fleischer et al. 2005).

Rainbow smelt, which have been much less abundant than alewife since the 1960s, declined further in the mid-1990s from a standing stock of 20 kg (44 pounds)/Ha to new low levels lake-wide of only 3 kg (6.6 pounds)/Ha, as measured by acoustic trawls. This has been mirrored by the consistently decreasing contribution of rainbow smelt to predator fish diets in Lake Michigan.

The majority of the commercial rainbow smelt catch in Lake Michigan occurs in Wisconsin waters, excluding Green Bay, where commercial fishing essentially ended in 2003—catches are apparently too small to support a commercial fishery there (Hogler and Surendonk 2007). A general forage trawl was in place until the mid-1980s, when commercial fishing for alewife was prohibited and a targeted rainbow smelt trawl began. Trawl catches have been in decline since the 1990s, decreasing from a high of over 5 million pounds in 1986 to less than 400,000 pounds in 2005. The decline in commercial catch is due to a combination of poor recruitment in the 1990s and the implementation of a catch quota in Wisconsin in 1992 (Fleischer et al. 2005), with a current total allowable catch in Lake Michigan of 1 million pounds (25,000 from Green Bay). Catch rates have been extremely variable since 1997, with highs in 1999, 2004, and 2005, and a record low in 2003 (Fig. 8).

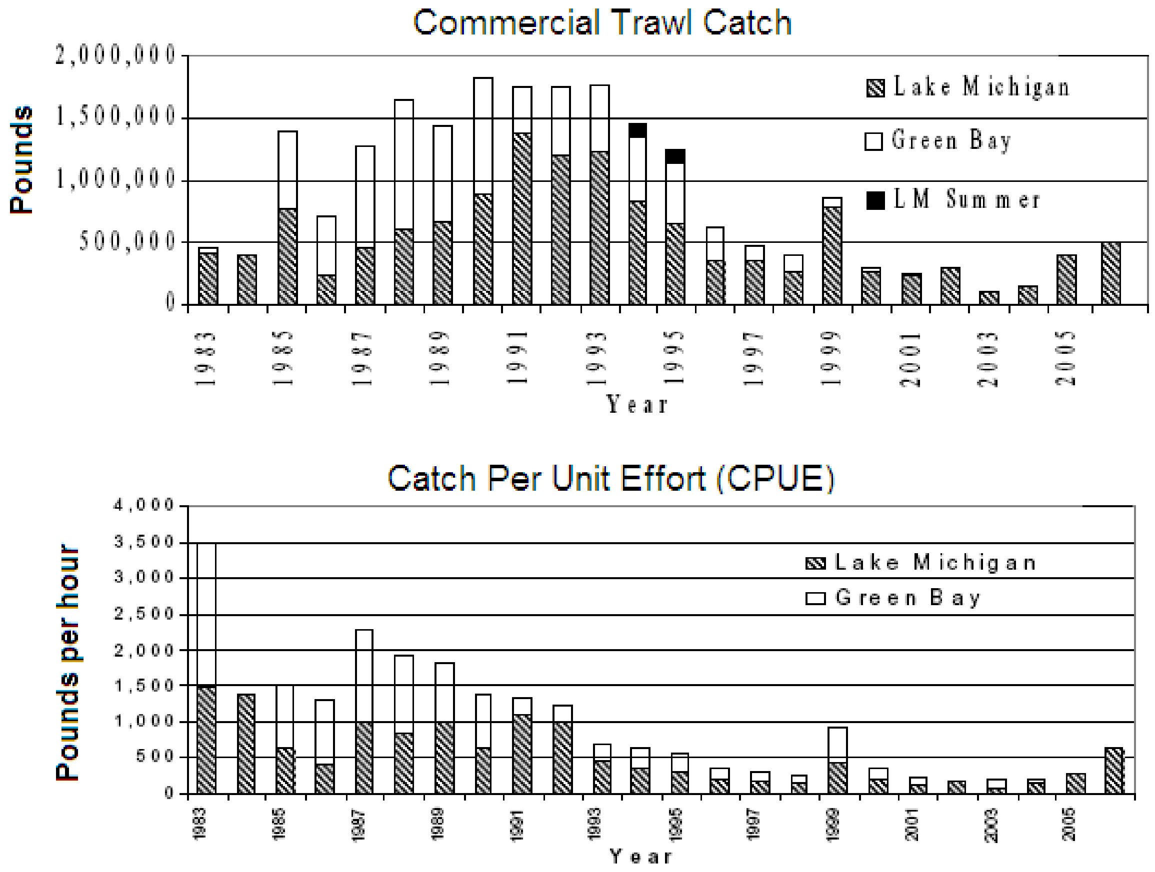


Figure 8. Commercial rainbow smelt catch from Wisconsin waters of Lake Michigan (Figure from Hogler and Surendonk 2007).

Catch per unit effort in 2006 was 616 lbs/hour, up from 281 lbs/hour and the highest since the near-term peak in 1999. Though increasing catch rates and density of young-of-the-year rainbow smelt, as measured by annual survey trawls (Fig. 9), may suggest improving stock status relative to mid-1990s lows (Hogler and Surendonk 2007), in the long term rainbow smelt abundance in Lake Michigan is substantially reduced.

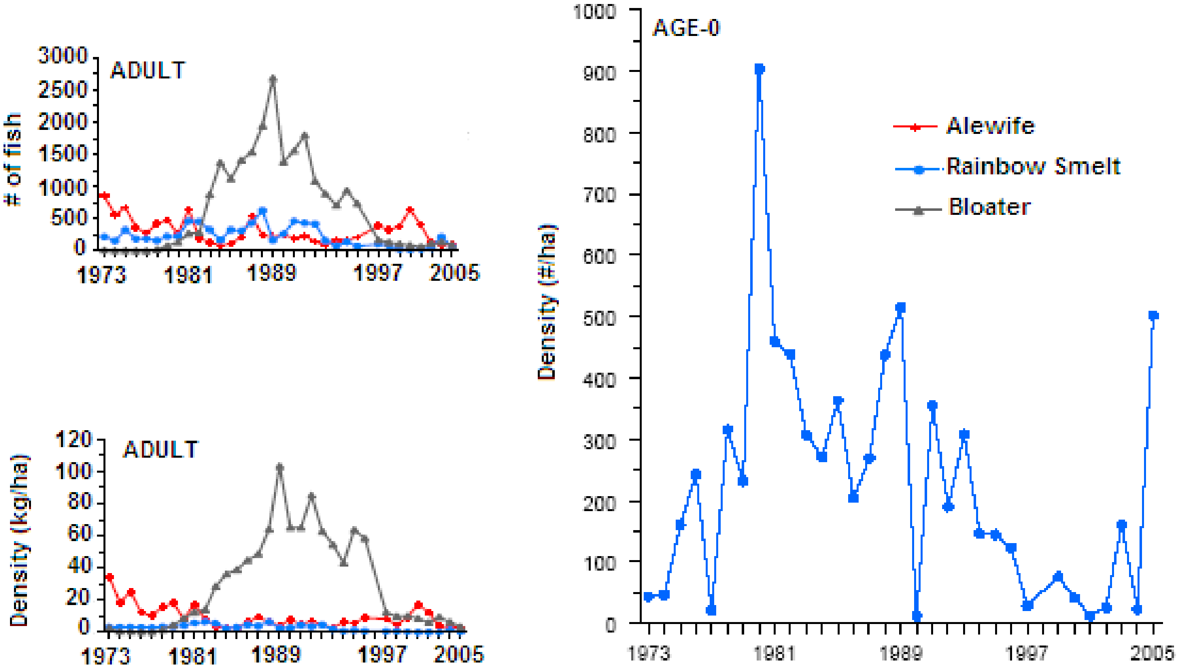


Figure 9. Abundance (number of fish) and biomass (kg/ha) of principal forage species in Lake Michigan, 1973-2005, as measured by bottom trawls along near-shore areas of Lake Michigan (Figure from Bunnell et al. 2007).

Overall rainbow smelt abundance in Lake Michigan from 1994 to 2006 has remained low relative to peak abundance in the mid-1980s. The reasons behind this trend are unclear and will require further research (Bunnell et al. 2007). In Green Bay, in particular, the decline in rainbow smelt abundance has led to attrition in the commercial fishery; although a catch quota is still in effect, no commercial fishing has occurred in the past three years.

Synthesis – Lake Michigan

In Lake Michigan, rainbow smelt abundance is substantially lower than long-term means, though populations have increased over the past three years and may be recovering from 1990s lows. Catches remain well below the annual quota, which is currently set at 1 million pounds; however, the quota may be unrealistic relative to actual rainbow smelt biomass and carrying capacity of the lake. No commercial fishery has operated in Green Bay in the last three years as the abundance of rainbow smelt appear too low to support a viable commercial operation there. All of these trends point to a rainbow smelt stock that is in poor (declining) condition. However, because there is high uncertainty in catches relative to sustainable yield, occurrence of overfishing, and population parameter distributions (size, age, etc.), these stocks are also considered to be a moderate conservation concern.

Table 2. Stock status of rainbow smelt.

Stock	Status	B/B_{MSY}	Occurrence of Overfishing	F/F_{MSY}	Abundance Trends/ CPUE	Age/Size/ Sex Distribution	Degree of Uncertainty in Stock Status	Sources	SFW Rank
Lake Erie	Not listed as endangered.	Lake Erie: Unknown	No TAC set	Unk.	Long term trend is down. Short-term trend is variable.	Skewed size	High	Johnson et al. 2005; DFO 2006b; Bur et al. 2007	Moderate
Lake Michigan	Not listed.	Lake Michigan: <50% current unrealistic B_{MSY}	Catches have remained well below TAC; TAC levels may be unsustainable.	Unk.	Long-term trend is down, but short-term is increasing.	Unknown	Moderate	Surendonk 2003; Hogler and Surendonk 2006; Bunnell et al. 2007; Hogler and Surendonk 2007	Moderate

Status of Wild Stocks Rank:

Healthy 🟩 **Moderate/Rebuilding** 🟨 Poor 🟥 Critical ⬛

Criterion 3: Nature and Extent of Bycatch

Seafood Watch® defines sustainable wild-caught seafood as marine life captured using fishing techniques that successfully minimize the catch of unwanted and/or unmarketable species (i.e., bycatch). Bycatch is defined as species that are caught but subsequently discarded (injured or dead) for any reason. Bycatch does not include incidental catch (non-targeted catch) if it is utilized, accounted for, and managed in some way.

Rainbow smelt are commercially caught in Lake Erie and Lake Michigan by midwater trawl. In marine environments, this gear has been linked to substantial cetacean bycatch (Morizur et al. 1999) but bycatch rates are listed as “low” (FAO 2007). However, no studies are available for bycatch rates relative to catch in the commercial rainbow smelt fisheries of the Great Lakes. Lake whitefish has been reported as an incidental catch in Lake Erie’s rainbow smelt fishery, but it is a marketable commercial species and therefore not discarded as bycatch (Markham et al. 2005). In Lake Michigan, incidental catches reported for the commercial fishery are primarily bloater chub, which are often processed for roe. Non-marketable catches are often unreported, and may include substantial quantities of rainbow smelt under marketable size (Surendonk 2003).

Bycatch impacts may also be qualitatively assessed by determining which species are most likely to be captured with rainbow smelt. In areas where rainbow smelt are surveyed in the Great Lakes, time of trawl (day vs. night), season, and local species composition will determine the profile of species subject to bycatch mortality. In Green Bay, a study of species abundance as a function of trawl depth indicates that rainbow smelt are primarily found at shallower depths (50-

80 feet), where rainbow smelt and alewife are the primary components of the trawl catch. Other species caught at these depths include round goby, trout-perch, lake whitefish, burbot, and sucker (Fig. 10).

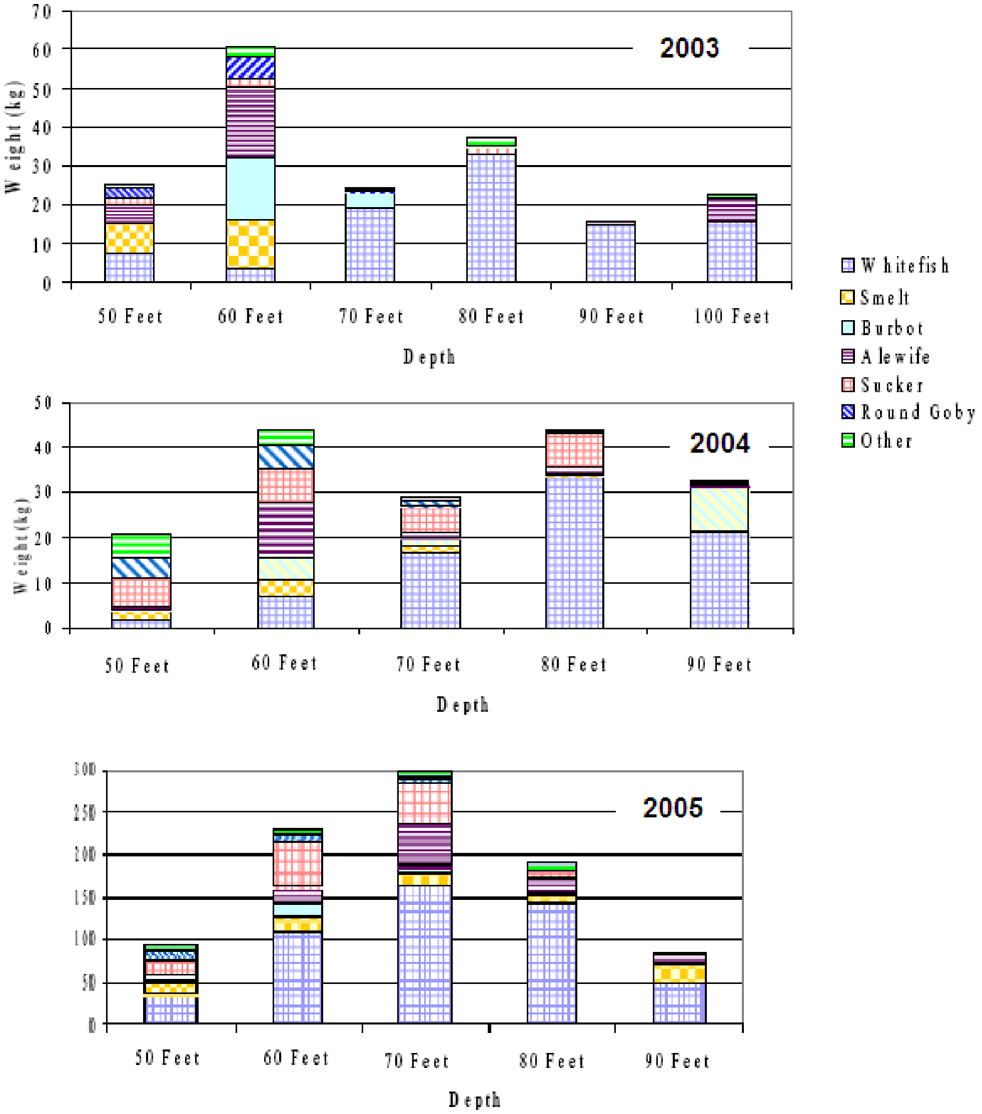


Figure 10. Profile of species in survey trawl catches as a function of depth from Green Bay waters of Lake Michigan (Figure from Hogler and Surendonk 2006).

Of these species, two are non-indigenous (alewife and round goby), and three are native (sucker, whitefish, and burbot). Of the latter group, only lake whitefish are important commercially (a small commercial catch of burbot exists in Lake Michigan). Commercial trawling is limited to depths greater than 60 ft, which should protect alewife (a necessary forage species for predator fish) and shallow water species such as yellow perch.

Synthesis

Bycatch mortality in the rainbow smelt fishery is highly uncertain, as there is no systematic study of discarded incidental catches. Of the incidental catch reported, the majority consists of species regarded as having little commercial value—alewife and bloater chubs; however, the incidental bycatch of juvenile rainbow smelt may be sizeable. Because there are no data available on the percentage of bycatch relative to rainbow smelt catches, bycatch in the commercial rainbow smelt fishery is deemed of moderate conservation concern. Actual impacts, however, may in fact be high.

Nature of Bycatch Rank:

Low 🟩	**Moderate** 🟨	High 🟥	Critical ⬛

Criterion 4: Effect of Fishing Practices on Habitats and Ecosystems

Habitat Effects

In the Great Lakes, commercial trawling is highly restricted and in general does not occur in most US waters. However, trawling is the primary gear used in Wisconsin's commercial rainbow smelt fishery, and is also widely used by Canadian commercial fisheries. Both midwater and bottom trawls are also routinely used by management agencies across jurisdictions to survey fish populations. They are limited to areas with smooth bottom surfaces; in areas with more complex morphology or harder substrate, hydroacoustic surveys are employed (Fabrizio et al. 1997). Soft bottom substrates of the type found in most mid-lake areas of the Great Lakes are thought to be the "most appropriate" surfaces for bottom trawling activity, minimizing potential habitat disruption effects (Stockwell et al. 2006). Although bottom trawling is widely recognized as a high-impact gear that destroys bottom habitat and results in high incidental bycatch mortality (Watling and Norse 1998), midwater trawls, such as are used in rainbow smelt fisheries, have a minimal impact on bottom structures (FAO 2007).

Ecosystem Effects

The removal of rainbow smelt could have substantial impacts on the Great Lakes food webs of which they are a part. In Lake Erie, rainbow smelt are an important prey for walleye, particularly in the central basin (Johnson et al. 2005). In the eastern basin, rainbow smelt is the principal forage species for offshore piscivores like lake trout and burbot, and has been the dominant summer forage prey for walleye since the early 1990s (Witzel et al. 2005). In Lake Michigan, rainbow smelt was historically more important prey for species in the northern and western waters, whereas predator diets in southern waters were dominated by alewife. However, their frequency in the diets of trout and salmon in northern and western Lake Michigan has decreased as their abundance has declined (Fleischer et al. 2005). In Lake Superior, rainbow smelt had been the preferred prey of lake trout and a common prey of siscowet lake trout. As in Lake Michigan, the decline in rainbow smelt abundance appears to be correlated with a decline in their presence in predator diets (Hrabik et al. 2004).

The decline in rainbow smelt abundance, when coupled with the concurrent general decline of forage species in the Great Lakes, brings to question the sustainability of current predator biomass. Rainbow smelt and alewife are both non-native species that have come to dominate Great Lakes food webs as the primary forage species, at the expense of native fish such as lake herring and deepwater ciscoes. This negative effect has led to the classification of rainbow smelt and alewife as "unwanted" species; however, many lakes contain substantial populations of stocked and naturally reproducing predator fish, such as trout and salmon (both native and introduced), which now depend on these exotic species for food. If the forage decline continues, it is likely that the biomass of predators will also decline before reaching sustainable levels. However, rainbow smelt and alewife are not ideal food for the Great Lakes' native predators. They are less energetically efficient than native forage species and also contribute to reduced recruitment in predator populations through early mortality syndrome (EMS), which is associated with thiamine deficiencies in fish that result from consuming rainbow smelt and alewife, which are high in the enzyme thiaminase. On balance, the removal of non-indigenous rainbow smelt and alewife from Great Lakes food webs should result in a healthier predator-prey community, particularly if their absence enhances the rehabilitation of native forage species such as lake herring, which is beginning to show signs of recovery in Lake Superior (Hrabik et al. 2004).

Synthesis
The physical impacts of trawling on soft bottom lake surfaces are generally low when compared to effects on complex hard substrates as observed in marine environments. Pound nets used in Lake Superior have minimal impacts. Of greater importance to the Great Lakes ecosystem is the removal of a substantial fraction of the available forage for predator fish. General forage abundance has declined throughout Lake Erie, Lake Michigan, and Lake Superior, and current forage biomass may be insufficient to support naturally reproducing and stocked predator fish populations in these lakes. However, rainbow smelt are non-native to the Great Lakes and are generally regarded as undesirable. Their removal is therefore seen as a part of the restructuring of Great Lakes communities to restore the native predator-prey balance to sustainable, self-regulating levels.

Effect of Fishing Practices Rank:

Benign 🟩 **Moderate** 🟨 Severe 🟥 Critical ⬛

<u>Criterion 5: Effectiveness of the Management Regime</u>

Lakewide surveys of forage species abundance, including rainbow smelt, alewife, round goby, and chub, are conducted throughout the Great Lakes by each state's Department of Natural Resources, Lake Committees under the auspices of the Great Lakes Fishery Commission, or the United States Geological Service's Great Lakes Biological Station. These surveys monitor changes in the biomass of the forage base, as well as the relative proportions of each forage species within the diets of important predator fish such as walleye, yellow perch, and lake trout. They combine traditional and more sophisticated methods, such as bottom trawls and hydroacoustic surveys, to increase reliability of abundance assessments. However, these surveys are not linked directly to the management of the rainbow smelt fishery, with the exception of the Lake Michigan smelt fishery from Wisconsin waters (Surendonk 2003; Johnson et al. 2005; Hogler and Surendonk 2006; Bunnell et al. 2007; Bur et al. 2007; Hogler and Surendonk 2007; Stockwell et al. 2007b).

The Canadian Lake Erie commercial fishery for rainbow smelt is unregulated and no long-term rainbow smelt stock assessment has occurred that is specific to the Ontario fishery. Lake-wide assessment of forage fish abundance has taken place, however, under the auspices of the Lake Erie Committee (within the Great Lakes Fishery Commission), expanded from an annual survey of New York, Ohio, and Pennsylvania waters in the late 1980s (Johnson et al. 2005). No total allowable catch (TAC) has been determined, and it is therefore unknown whether overfishing is occurring, though declines in rainbow smelt abundance revealed by interagency surveys indicate that the current fishing mortality, when combined with predation mortality, is probably unsustainable (Markham et al. 2005; Bur et al. 2007).

The Lake Michigan rainbow smelt fishery was unregulated until the mid-1980s. Until that time, a "general forage trawl" was in place that caught rainbow smelt, alewife, and bloater chub. While rainbow smelt are typically caught for human consumption, the large catches of alewife and chub were meant primarily for animal feed. Alewife had been targeted since the time of its peak abundance in the 1960s. Substantial declines in alewife abundance subsequently led to a commercial catch quota in 1986, and by 1991 the general forage trawl had been replaced by a targeted rainbow smelt fishery (Fleischer et al. 2005; Hogler and Surendonk 2007). This trawl fishery is restricted by season, area, and time. Trawls may operate during daylight hours only between November 15 and April 20, and at depths greater than 60 feet; nighttime trawls may operate between June 15 and April 20, at depths greater than 65 feet. The current rainbow smelt quota is one million pounds, 25,000 pounds of which may come from Green Bay. However, catches in the past decade have remained well below catch limits, and it is recognized that the original biomass objectives developed for planktivores in Lake Michigan in the late 1980s was based on abundance data from a period of peak productivity for the lake, and are probably unrealistically high for the system in its current state. It is therefore likely that the current, lower levels of forage fish biomass, including rainbow smelt, will persist (Hogler and Surendonk 2007).

In Lake Superior, rainbow smelt are recognized as an "undesirable species" and no fishing regulations are imposed regarding total allowable catch. However, fishing gear is restricted in US waters of Lake Superior for the protection of other species, and the commercial rainbow smelt fishery is therefore limited to pound nets. The decline of rainbow smelt stocks is seen as a part of the rebalancing of the predator-prey community in favor of native forage species and more sustainable population densities of desirable predator species. In line with this position, lake trout stocking has also been limited in Lake Superior to reduce competition for the limited forage base and allow naturally reproducing lake trout populations to increase (USEPA 2006).

Table 3. Commercial catch management measures for the rainbow smelt fishery.

Management Jurisdictions & Agencies	Total Allowable Landings	Size Limit	Gear Restrictions	Trip Limit	Area Closures	Sources
Lake Erie (CA): OMNR	None	None	None	None	None	DFO 2006b
Lake Michigan: Primarily WI DNR	1 million lbs (25,000 from Green Bay)	Minimum size determined by marketability rather than restrictions.	Trawls may be operated in daylight from November 15-April 20 in depths >60 ft and at nighttime from June 15 to Sep 30 at depths >65 ft.	None	None (but see depth limitations under "Gear Restrictions")	Surendonk 2003; Hogler and Surendonk 2007
Lake Superior	None	None	Pound nets only.	None	None	USEPA 2006

Synthesis

Although monitoring of general forage species abundance occurs throughout the Great Lakes and often includes assessments of rainbow smelt biomass, the commercial rainbow smelt fisheries are not strictly regulated. Lake Erie catches are not limited and little stock assessment occurs. In Lake Michigan, the most tightly regulated rainbow smelt fishery in the Great Lakes, total allowable catch may be set at unsustainable levels from a fishery persistence perspective. There is high uncertainty throughout the fisheries regarding whether overfishing is occurring, and whether the combined biomass of the forage base (rainbow smelt, alewife and bloater chubs, all with highly variable year-to-year abundance) will be sufficient to support the current biomass of predator fish in the Great Lakes (both naturally reproducing and stocked populations). However, rainbow smelt is non-indigenous and is generally regarded as an undesirable species that competes with native forage species and provides a poorer food source for predator fish. Its decline is therefore supported by several management agencies. Article 8(h) of the Convention on Biological Diversity (CBD) states that "Contracting parties to the Convention should, as far as possible and appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats, or species" (Hansson 2002, p.306). The rainbow smelt fisheries are not actively managed for elimination of the rainbow smelt; however, the lack of catch regulations in the Lake Erie fishery will encourage the continued decline of this stock. Given a goal of fostering native communities and removing non-native rainbow smelt in order to encourage restoration of natural self-sustaining populations to the Great Lakes, management in this case is deemed moderately effective for both Lake Erie and Lake Michigan.

Effectiveness of Management Rank:

Highly Effective 🟩 **Moderately Effective 🟨** Ineffective 🟥 Critical ⬛

8-IV. Overall Evaluation and Seafood Recommendation

Rainbow smelt is a naturally resilient forage fish that was able to expand into the Great Lakes after its inadvertent introduction to the basin in the 1930s. It utilized the abundant food available in the period of high productivity in the 1960s to fill the niche vacated by a number of native deepwater forage species that had declined due to a combination of overfishing, habitat disruption, and competition with and predation by the invasive alewife. The rainbow smelt continued and exacerbated this latter stress on native forage communities.

Rainbow smelt populations in the Great Lakes are currently in a period of decline, and abundance is well below long-term means. The stocking of predator fish in the 1970s, initially intended to control rainbow smelt and alewife populations and to support a recreational fishery, has reduced the population of forage fish, principally rainbow smelt and alewife, substantially. In addition, the recovery of several native predators such as walleye in the past two decades has increased predation mortality in rainbow smelt populations to levels that are likely to result in continued long-term decline.

The management of rainbow smelt fisheries is generally non-conservative, in some cases (such as in Lake Superior) deliberately so. Although the importance of rainbow smelt to predator diets is well-recognized, there is impetus to allow the decline of rainbow smelt, and the reduction in supportable predator biomass that is likely to follow, to allow the restructuring of Great Lakes communities to a more natural self-sustaining state dominated by indigenous forage species. Article 8(h) of the Convention on Biological Diversity (CBD) states that "Contracting parties to the Convention should, as far as possible and appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" (Hansson 2002). The management of Great Lakes fish populations to promote native communities in the long term, when balanced against the short term fluctuations that are likely to occur as rainbow smelt is removed from Great Lakes food webs, result in a recommendation for Great Lakes rainbow smelt of "**Good Alternative**."

Table of Sustainability Ranks for Rainbow Smelt

	Conservation Concern			
Sustainability Criteria	**Low**	**Moderate**	**High**	**Critical**
Inherent Vulnerability	√			
Status of Stocks		√		
Nature of Bycatch		√		
Habitat & Ecosystem Effects		√		
Management Effectiveness		√		

Overall Seafood Recommendation for Rainbow Smelt

Best Choice 🟩 **Good Alternative** 🟨 Avoid 🟥

8-V. References

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Supplemental Information

Health consumption information on the Seafood Watch® pocket guides is provided by Environmental Defense. Environmental Defense applies the same risk-based methodology as the U.S. Environmental Protection Agency (EPA) to data from government studies and papers published in scientific journals. Environmental Defense has issued consumption advisories for Lake Whitefish, Yellow Perch, and Lake Trout (from all Great Lakes) due to elevated levels of PCBs, and for Walleye due to elevated mercury levels. More detailed information about the Environmental Defense advisories can be found at http://www.environmentaldefense.org/page.cfm?tagID=17694.