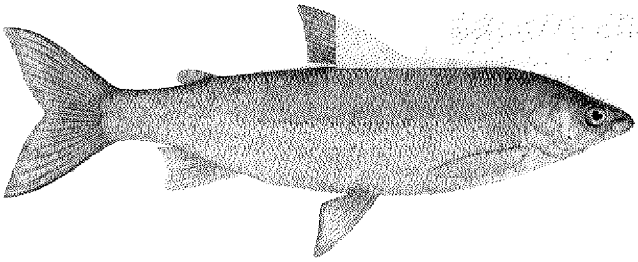
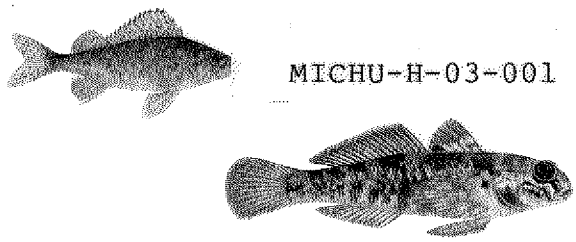
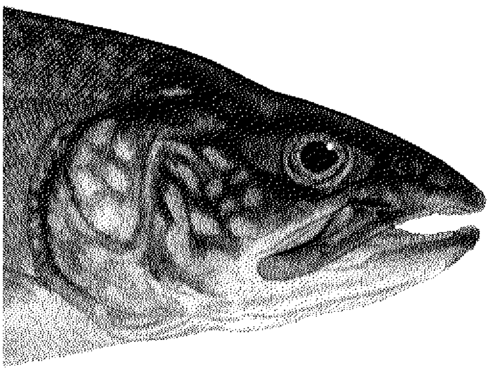
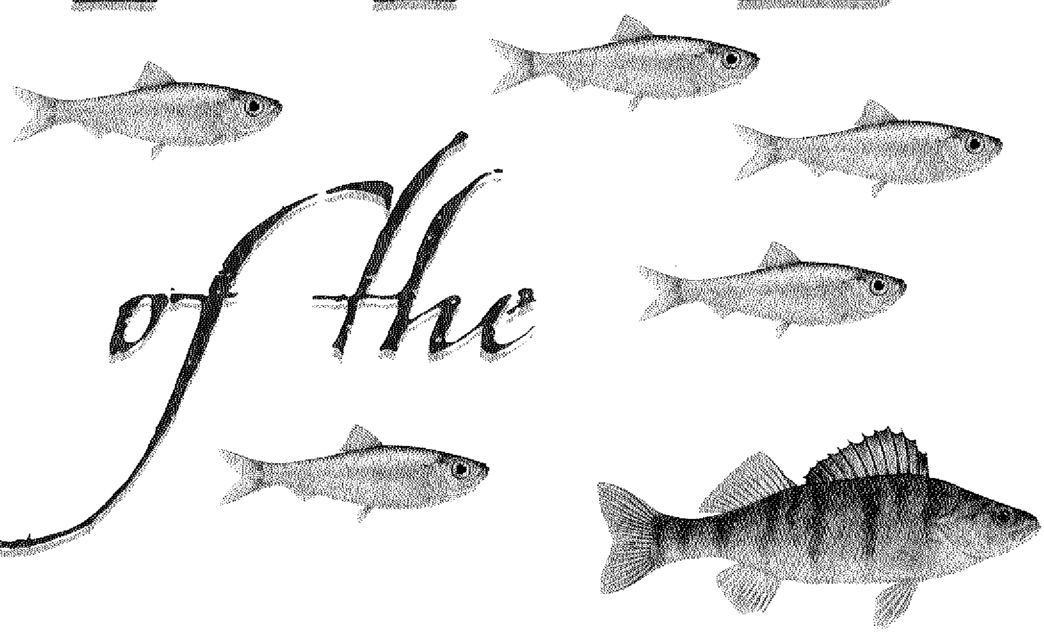


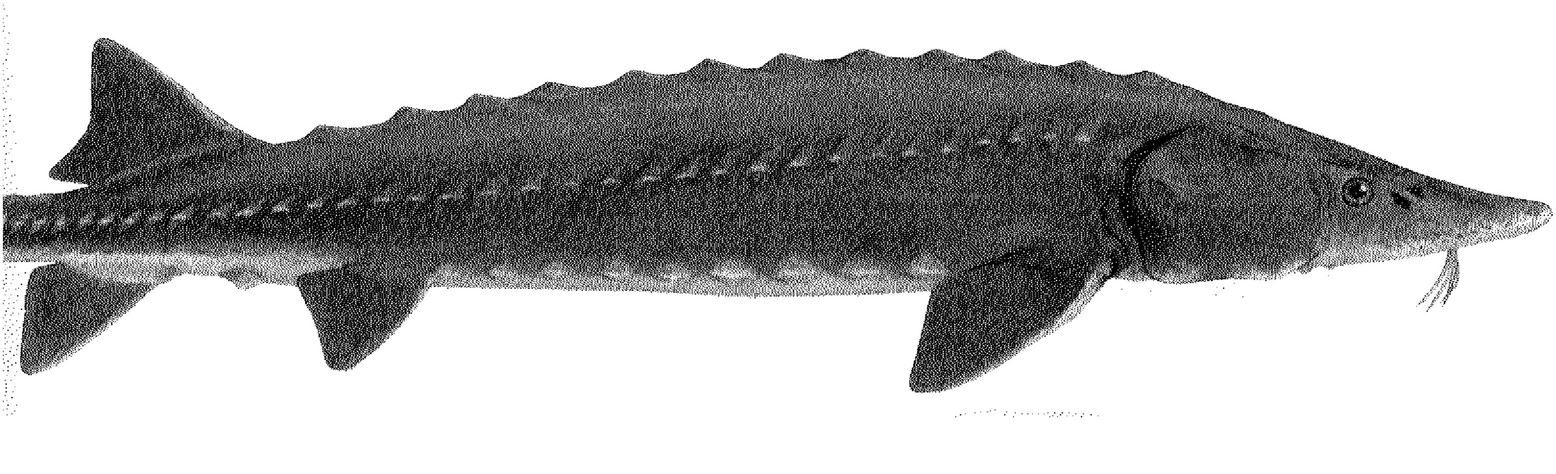


the LIFE of the LAKES





A Guide to the Great Lakes Fishery



Life of the Lakes, *A Guide to the Great Lakes Fishery*

The Life of the Lakes was produced by the Michigan Sea Grant College Program for the Great Lakes Sea Grant Network. Production of this booklet was made possible by a grant from the National Sea Grant College Program of the National Oceanic and Atmospheric Administration (Grant number: NA16RG1145).

First edition, 1993

Editing: *Joyce Daniels*, *Carol Swinehart*
Graphic design: *Dave Brenner*
Creative director: *Elizabeth LaPorte*

Michigan Sea Grant College Program, a cooperative program of the University of Michigan and Michigan State University, supports Great Lakes research and education, (see www.miseeagrant.umich.edu).

ISBN 1-885756-12-7

Library of Congress Control Number: 2003111386

Michigan Sea Grant MICHU #03-400
MSU Extension Bulletin E-2440, 8-2003

the LIFE of the LAKES

A Guide to the Great Lakes Fishery

Shari L. Dann, Ph.D.
and
Brandon C. Schroeder

Department of Fisheries and Wildlife
Michigan State University

Michigan Sea Grant College Program

Sea Grant
Michigan

Contents

Introduction

The Great Lakes provide a home to one of the world's greatest freshwater fisheries. Great Lakes **fisheries** are defined as intricate webs of fish populations, their aquatic environments, and the people who use and enjoy them. These fisheries are important parts of the life of the lakes.

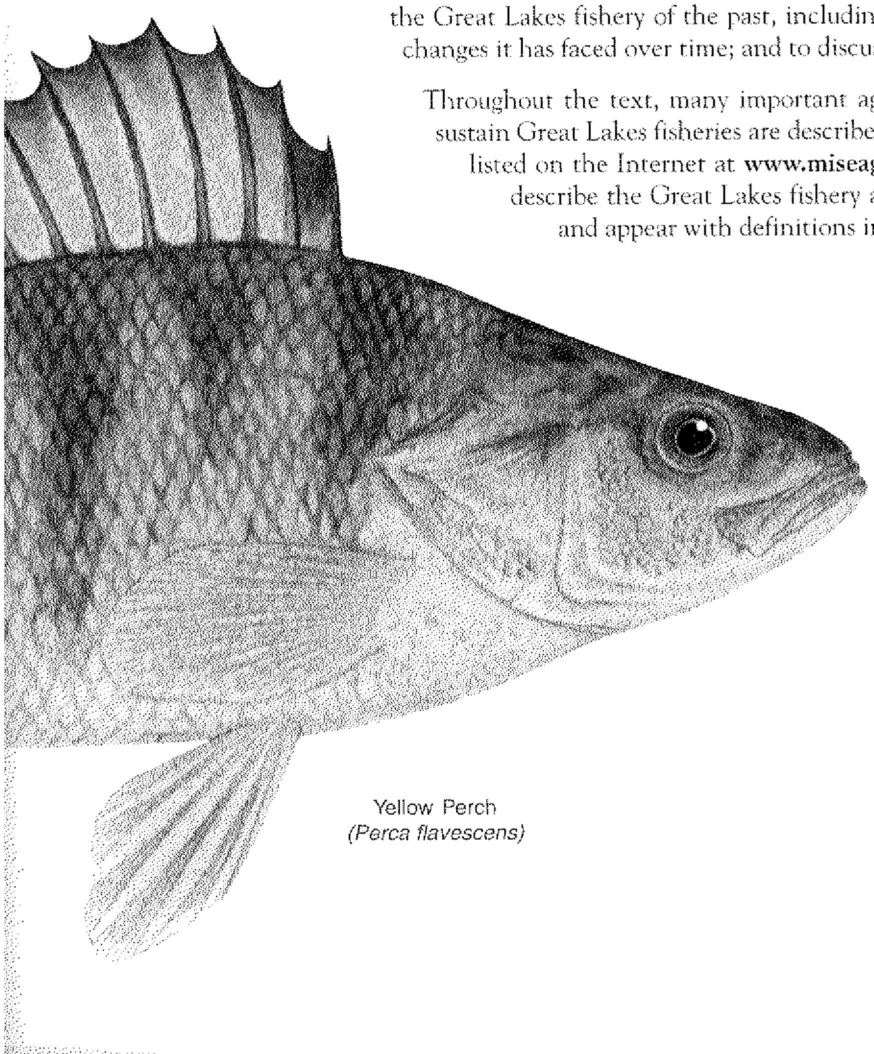
Changes in the life of the lakes reflect the history of the Great Lakes region. Through the history of the fishery, we can understand the way of life of those peoples who have depended directly on the vitality and productivity of the lakes. The story of the fishery reflects the story of various impacts on water quality in the Great Lakes. Fishes serve as valuable indicators of environmental change and environmental health, and fish populations have served as early warning signals of poor environmental quality. Likewise, the fisheries serve as an indicator of resource sustainability. Understanding Great Lakes fisheries helps us better understand what constitutes quality of life.

These vitally important fisheries are ever-changing. The fisheries in the lakes have become established since glacial times, thousands of years ago. Change continued with the arrival of explorers, traders and settlers, with the increased human populations in the Great Lakes basin and with expanded trade and commerce in the region. These changes affected past fisheries and the fisheries of today and will undoubtedly influence the fisheries of the future.

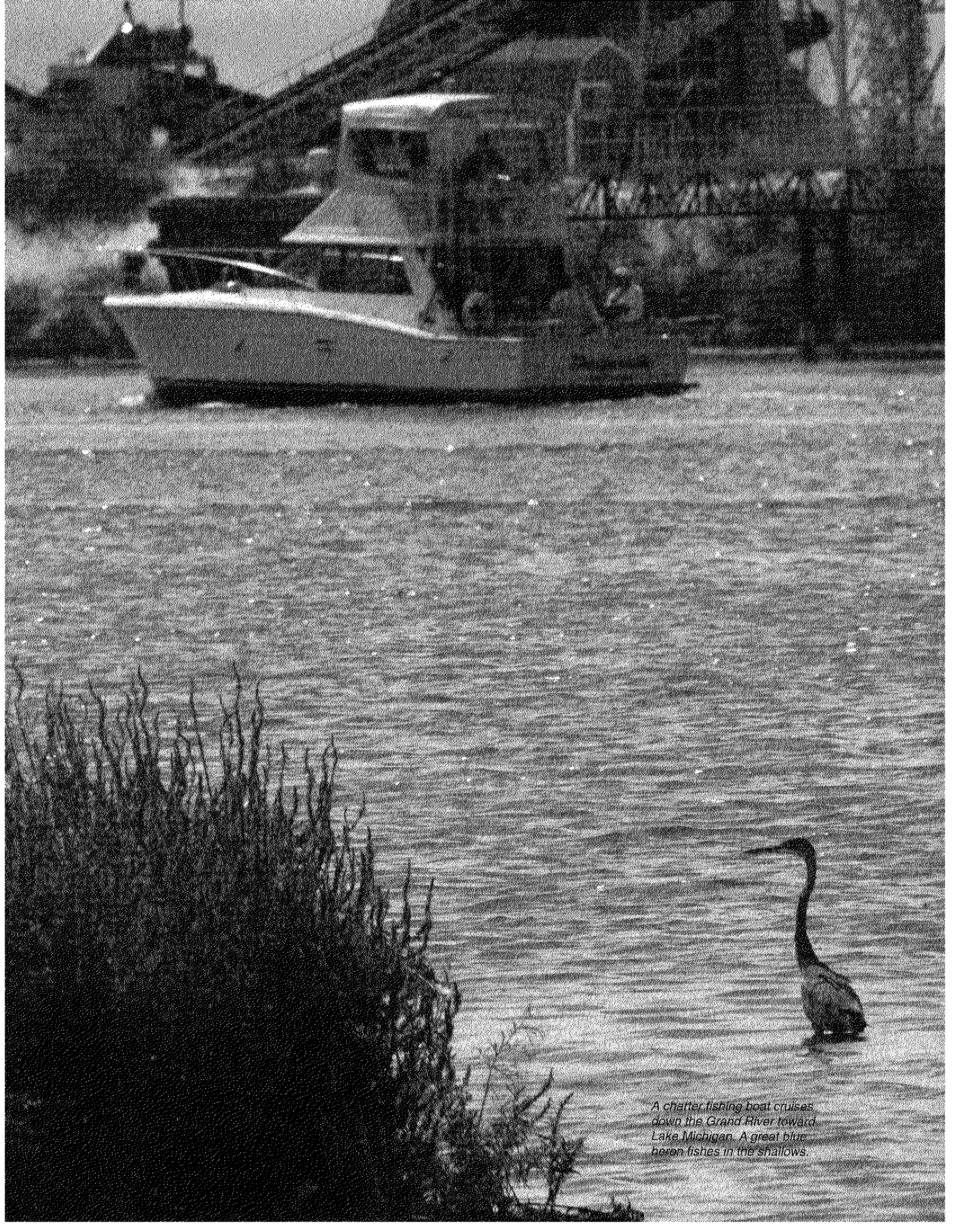
The cultural importance of the fisheries still echoes from the names of places along the coasts of each of the Great Lakes: Fish Creek, Whitefish Point, Siskiwit ("fat trout") Bay, Menominee, Sturgeon Bay, Fish Point, Salmon River, Troutburg, Bass Island, Pike Bay, Carp River. Today, the influence of Great Lakes fisheries has spread widely. We depend upon the lakes as sport anglers, as visitors to historic fishing and coastal villages, and as consumers who eat Great Lakes fish.

The purpose of this publication is to describe the current status of the Great Lakes fishery; to outline the Great Lakes fishery of the past, including the social, technological and environmental changes it has faced over time; and to discuss fisheries issues expected in the future.

Throughout the text, many important agencies and organizations working together to sustain Great Lakes fisheries are described; details on contacting these organizations are listed on the Internet at **www.miseagrant.umich.edu/fisheries**. Also, terms used to describe the Great Lakes fishery are shown in bold throughout this publication, and appear with definitions in the Glossary.



Yellow Perch
(Perca flavescens)



A charter fishing boat cruises down the Grand River toward Lake Michigan. A great blue heron fishes in the shallows.

Ecology of the Great Lakes

The Great Lakes are a geologically young system compared to the world's oceans. The present day lakes began to form 18,000 to 15,000 years ago. Glaciers last retreated from the region 9,000 years ago, leaving a relatively short time for fishes to evolve or move into the region's lakes. As the glaciers receded, the Great Lakes shorelines changed greatly. Water levels fluctuated as the land rebounded (lifted up) when the heavy glaciers retreated northward. As the shorelines and rivers around the Great Lakes changed over thousands of years, so also did the avenues for movement of fishes into and throughout the region.

Some parts of the Great Lakes region are cold and are so far north that the climate provides only a short growing season. Other parts of the region are warmer and have a longer growing season. In spite of their harsh surroundings, the Great Lakes are productive. They form one of the largest surface freshwater systems in the world, and their sheer size means that these bodies of water can support an abundance of life. Together, the Great Lakes cover more than 94,000 square miles (244,000 square kilometers) of surface area, larger than the states of New York, New Jersey, Connecticut, Rhode Island, Massachusetts, Vermont and New Hampshire combined. They contain 6 quadrillion gallons (22.7 quadrillion liters) of freshwater, almost one-fifth of the world's surface supply.

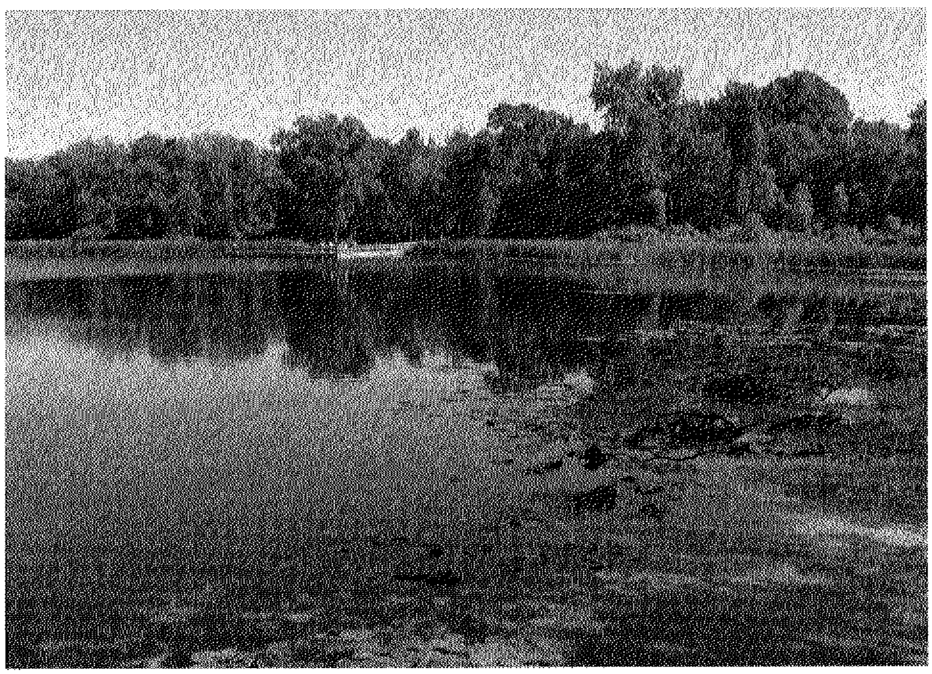
The **abiotic** (nonliving) features of the lakes interact with the **biotic** (living) organisms to affect the amount and type of life that can be supported. **Ecology** is the study of the interaction between abiotic and biotic factors. Because of their size and varied geography, geology and ecology, the Great Lakes are comprised of sub-regions that vary in climate, sunlight, temperature, depth, nutrients, chemical composition (such as oxygen concentrations), water movements, shoreline, and other physical and biological characteristics. This variation means that some areas of the lakes are more productive than others.

The intricate shorelines of the lakes (including the shores of many islands) total about 11,000 miles (17,700 km). Bays, rocky **reefs** and the sheltered areas around islands provide the shallows that many fishes depend upon at some time in their life cycles.

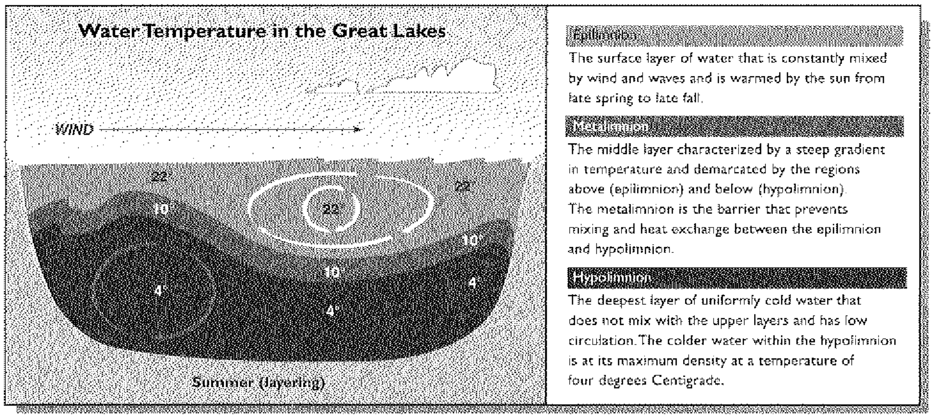
Streams and rivers drain over 295,000 square miles (767,000 square kilometers) of the heart of North America, forming the Great Lakes **watershed**. These **tributaries**, rivers and streams flowing into the lakes, provide habitat where some fishes, such as salmon, migrate to **spawn** (breed). Other river-spawning fishes include steelhead, rainbow smelt, suckers, lake sturgeon, white bass and walleye.

Wetlands, with their warm, shallow, nutrient-rich waters, support a rich growth of aquatic plants, which in turn harbor small aquatic life. These conditions provide food and shelter for fishes. Coastal wetlands provide valuable spawning areas for some fishes and nurseries for juvenile (young) fishes. Waves and currents carry nutrients and energy from wetlands into offshore areas, enriching them enough to support more life.

The Great Lakes have a variety of bottom types including mud, silt, sand, rock and gravel. Some organisms, called **benthic** organisms, prefer to live in this bottom zone. Here, in the **sediments** or among the different bottom materials, live bacteria, which help decompose dead plants and animals, and **detritivores**, small animals that feed on decomposing matter. Some fishes (such as lake sturgeon) prefer to feed on small benthic organisms.



Tobico Marsh, a wetland connected to Saginaw Bay, supports a rich growth of aquatic plants and a diversity of fish and wildlife.



Ecological Zones

The Great Lakes provide a variety of **habitats**, areas where fishes can find their life requirements such as food, water conditions, shelter and space. More specifically, habitats can be described in terms of how they differ in the amount of sunlight they receive, in the amount of nutrients present, and in water temperature. Generally, the lake can be divided into **off-shore** and **near-shore** (also called **in-shore**) habitats. The near-shore (in-shore) habitats closest to the edge of the lake have the greatest light penetration, and due to their proximity to land, they receive the most run-off of nutrients and other materials from the watershed (the land area drained by a system of streams and rivers). Off-shore habitats include the uppermost portions of the open water of the lake, as well as the depths.

The **benthic** zone includes the entire bottom of the lake. In off-shore areas, the benthic zone receives no light. However, near-shore, the benthic life may benefit from light that reaches bottom.

The aquatic life present in the Great Lakes depends upon the amount of sunlight reaching portions of these large bodies of water. Light can penetrate water only to a depth of about 300 to 600 feet (about 100 to 200 meters). Some wavelengths of light energy can penetrate farther than others. The degree of light penetration into the water varies greatly among lakes, among regions within a lake, and seasonally.

Generally speaking, the zone of a lake where light can penetrate is called the **limnetic** or **photic** zone. In contrast, the deepest portion of the lake, where light energy cannot penetrate, is called the **profundal**, or the **aphotic** zone. At the shallow edges of the lake, is the **littoral** zone, shallow enough so that light can penetrate the water, reach the bottom and support the growth of rooted vegetation. The littoral zones, which include coastal wetlands, are very valuable for Great Lakes fisheries because they provide areas for spawning and feeding. In protected areas, rooted plants provide shelter and habitat for fishes and other life.

The **pelagic** zone is the open-water area of a lake, away from the littoral zone. In the pelagic zone, the uppermost portion of the water is within the limnetic zone, where light can penetrate and foster growth of algae and other forms of open-water plants and life. Some adult fishes, such as salmon and lake herring, spend much of their time in the colder regions of the pelagic zone. Other species, such as smallmouth bass, prefer to spend their lives in the slightly warmer littoral zones.

Ecological Processes

Nutrient and chemical composition of the Great Lakes can vary tremendously by location and over a period of time. Large areas of the Great Lakes are considered **oligotrophic**, or low in nutrients, and tend to be deep and cold. Other areas are **eutrophic**, warmer and richer in nutrients than the oligotrophic portions of the lakes. **Mesotrophic** regions have moderate amounts of nutrients and biological productivity. The nutrient levels found in Great Lakes habitats affect both the number and type of fishes and other aquatic life. In the late 1960s, Lake Erie was feared "dead," devoid of much fish life due to over-enrichment (or human-induced **eutrophication**) of water due to nutrient run-off from land.

Seasonal changes also affect fish habitats. In the summer, portions of the lakes undergo **thermal stratification** — a process that results in layers of water of different temperatures. Warm water near the surface forms the **epilimnion**. Colder, bottom water forms the **hypolimnion**. The two layers are separated by a thin **metalimnion** (also called a **thermocline**), in which the water temperature drops markedly. At certain times of the year, shallow, nearshore water can heat more rapidly than the deeper portions of a lake. This can create a thin, vertical transition zone, called a **thermal bar**, sandwiched between the warmer nearshore waters and colder waters offshore.

Each species of fish in the Great Lakes has a preferred range of water temperature and other water conditions. Some species, such as salmon and lake trout, are coldwater fishes, generally found in deep waters. Others, such as walleye and perch, are coolwater fishes and thrive in waters that are slightly shallower and warmer.

In the fall, as Great Lakes surface waters cool and become heavier, they sink, causing waters to mix. During winter, ice may cover some areas of lakes Erie and Ontario, and larger areas of the upper three Great Lakes—Superior, Michigan and Huron. In spring, cold surface water is heated by the sun to about 39.2° F (4° C), the point at which water is densest and heaviest, and sinks. Turnover (mixing) occurs once again.

Turnover and movement of nutrients and materials are not uniform across any given lake. Strong winds can play a role in the turnover process, and an early spring can mean early productivity in the lake. At certain times of the year, wind and changes in water temperature can also cause **upwellings**, in which strong winds can cause warm water at the surface to move laterally so that cold water from the deeper layers moves up toward the surface. Likewise, **downwelling** of Great Lakes water can be caused by temperature changes and wind-created water movements. Certain patterns in wind speed, surface water movement, and up- and downwelling lead to the creation of streaks, or as anglers call them "scum lines," areas where algae and zooplankton can collect and be moved toward the water surface. Fish sometimes then move to these streaks for feeding.

Circulation of water in the lakes and from one lake to another, in combination with wave action, creates littoral or longshore currents, carrying nutrients and materials along the shore and throughout the lakes. This action changes with the intensity of weather patterns and with the seasons. This variety and mixing is important for fishes, because seasonal turnovers, upwellings, downwellings, and littoral currents and other water movements cause oxygen and nutrients to be mixed throughout the lakes. These water movements also transport larval fish long distances, a process important for fostering recruitment of fish in habitats far from their hatching areas.

Diversity of Fishes in the Great Lakes

Since the retreat of glaciers, the Great Lakes basin has been connected with the Mississippi drainage system and to waterways reaching the Atlantic Ocean. All of the basin's original lifeforms evolved in the Great Lakes or invaded from one of three directions—from the Susquehanna River and Hudson River drainages of the Atlantic Coastal Plain, the Mississippi River drainage basin or the Yukon basin of Alaska. In more recent years, species have moved into or out of the lakes through the Erie Canal, the Welland Canal and the Chicago Sanitary and Ship Canal. New species have also arrived unintentionally from across the world via ships' ballast water, have been unintentionally transferred by humans from one area to another or have been intentionally introduced by humans.

At least 179 species of fishes are found in one or more of the Great Lakes, their tributaries, the connecting waterways (St. Marys River, St. Clair River, Lake St. Clair, Detroit River and Niagara River). Lake Michigan has the greatest number of fish species (136); Lake Erie has the second highest number of fish species (129). Lake Superior has fewer fish species than the other lakes (83), but this northernmost lake has three unique varieties of one species—the lake trout—including the "siscowet," an extremely fatty subspecies. Lake Ontario has more fishes from the Atlantic drainage than any of the other lakes. Lakes Superior, Ontario and Erie, with an east-west orientation, have more species in their southern tributaries than in their northern streams and rivers. This is probably because many fishes invaded the region from the south, as glaciers melted and the climate of the region warmed.

Lake Superior is unique in its collection of fishes, in part because it is located the farthest upstream and north of the other lakes. Together lakes Superior, Huron and Michigan are commonly known as the upper Great Lakes since they are farther upstream than lakes Erie and Ontario. Lakes Huron and Michigan contain very similar fish species. Because they are at the same elevation and are connected through the Straits of Mackinac, they might be considered as one lake were it not for slight differences in physical and chemical characteristics. Lakes Ontario and Erie have many fishes in common with each other because they are farther south than the other lakes, are shallower in comparison, and are closely connected through the Welland Canal. Each lake's set of fish inhabitants is closely tied to the whole set of living and nonliving lake components—collectively called the **ecosystem**.

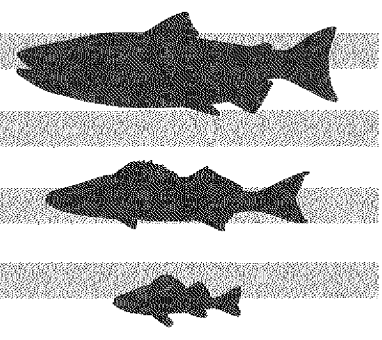
Great Lakes Food Webs

Aquatic diversity in the Great Lakes depends upon the availability and abundance of food. A **food chain** is a linkage of a predator to its prey. In reality, many different food chains interact in the Great Lakes to form diverse, complex **food webs**, through which energy is passed from one group of organisms to others. Each energy level is called a **trophic level.**

Plants form the base, the first trophic level, of the Great Lakes food chains. They convert and store the sun's energy and available nutrients into living **biomass**, which is then available to other organisms in the food chain. For this reason, plants are called **producers**. In the Great Lakes, most of these producers are microscopic floating plants called **phytoplankton**. Examples of phytoplankton are **diatoms**—tiny, single-celled plants with hard shells of silica. They may cling to each other in groups or in loose filaments or may cling to underwater objects. Other phytoplankton in the Great Lakes include green **algae**, blue-green algae (cyanobacteria), and dinoflagellates (plants with hair-like structures that allow them to move). Peaks in phytoplankton growth occur twice a year, the first in spring (mostly diatoms) and the second in the fall (diatoms and blue-green and green algae). These bursts of phytoplankton growth are called **algal blooms** and follow spring and fall turnover. Large rooted plants, called **macrophytes**, are another prominent type of producer. Mac-

Number of Fish Species Found in the Great Lakes Basin*

Basin	Number of fish species
Erie	129
Ontario	119
Huron	117
Michigan	136
Superior	83
Lake Nipigon	39
St. Lawrence River	105
Total 5 lakes and tributaries	172
Total basin	179



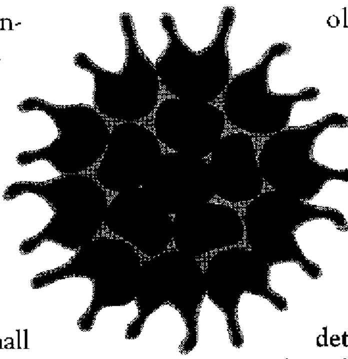
Source: Coon 1999 in Taylor and Ferreri 1999 *Includes tributaries rophytes grow in areas where light reaches the lake bottom. Macrophytes support different animal life than do phytoplankton.

The next trophic levels are made up of tiny or even microscopic floating or somewhat mobile animals called **zooplankton**. These are the first level of **consumers** in the Great Lakes. These animals have a great variety of forms with unique life cycles. The most numerous type of zooplankton found in the Great Lakes are protozoans (microscopic one-celled animals such as amoebae and paramecia). Other common types include rotifers, cladocerans (water fleas such as *Daphnia*), which are numerous in the summer months, and copepods (such as *Cyclops*).

Zooplankton abundance varies throughout the spring, summer and fall. Their numbers are influenced by food availability, which in turn is affected by such things as an early spring, winds, seasonal mixing of water layers, upwellings, and productivity of the water.

Another trophic level consists of **macroinvertebrates** (larger animals lacking backbones). Different types live in deep areas and shallow areas of the Great Lakes. Deepwater life is dominated by two unique small animals: *Diporeia* spp., which is an amphipod or "sideswimmer" (sometimes mistakenly called a freshwater shrimp) and opossum shrimp, *Mysis oculata relicta*. Some zooplankton such as opossum shrimp migrate dozens of meters (many thousands of times their body length) vertically, up and down in the water daily. Their movements are affected by light levels, season, temperature, and mating behaviors. These organisms move nutrients and energy between shallow and deep regions of the lakes. Also found in deep waters are oligochaetes (freshwater worms) and chironomids (larvae of midges).

The small animals found in shallow, protected waters of the Great Lakes are similar to those found in cold, inland lakes—leeches, clams, zebra mussels, snails, and larvae of mayflies, dragonflies and caddisflies. The average density of these small benthic animals, some of which are burrowing and others associated with vegetation, may reach hundreds of animals per square meter. Some areas of the Great Lakes may be even more productive, with tens of thousands of small animals per square meter.



Zooplankton and macroinvertebrates provide the basis for fishes at the next trophic levels in Great Lakes ecosystems. Some fishes, such as alewife, various shiners and lake herring, feed mainly on zooplankton and are called **planktivorous** (plankton-eating) fishes. The alewife and other planktivorous fishes have specialized structures, called gill rakers, which sift out food as water passes over their gills.

Generally, the juveniles of large or medium-sized Great Lakes fishes, such as salmon, lake trout and yellow perch, feed mainly on zooplankton and macroinvertebrates until they grow large enough to eat small, young-of-the-year fish. Fishes that eat other fish are called **piscivorous**.

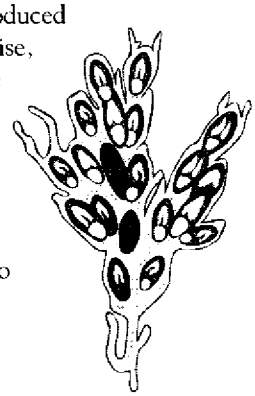
Small fishes that provide food for larger fish are called **forage fishes**. Forage fish include bloaters, lake herring, sculpins, shiners, alewife, gizzard shad, rainbow smelt and juveniles of other species.

Consumers of Great Lakes fishes include amphibians (such as mudpuppies), birds (such as bald eagles, herons, osprey, cormorants, mergansers and loons) and mammals (such as mink, river otters, and of course, humans). It is important to remember that the chain does not end with these consumers. As all organisms die, whether they are the larger animals or the microscopic **plankton**, decomposers such as bacteria and fungi begin their work. As they feed on dead material (**detritus**), organic materials are broken down and nutrients then again become available to the **producers** (plants) at the start of the food chain. Some of these organisms are found in the sediment at the bottom of the lakes, even in deep regions. For example, *Diporeia* spp. and oligochaetes burrow into sediments and feed on detritus. Other small organisms, such as rotifers, feed in midwater on the **detrital rain**, the dead algae and zooplankton that sink down from upper layers of water. These decomposers and **detritivores** play an important role in the Great Lakes. By recycling nutrients, they allow even deep areas of the Great Lakes to be productive and to support life.

Each link in Great Lakes food chains strongly influences other links. For example, zooplankton may play a role in limiting the standing crop of phytoplankton. Fish can affect the size and species composition of zooplankton by visually searching out and eating larger plankton. In turn, the size of zooplankton and forage fishes eaten can influence the predator's growth rates. When the non-native alewife arrived in the Great Lakes, its effects were felt both up and down the food chain.

The lakes can support only a finite amount of life. This **carrying capacity** and the overall productivity of an area within a lake are determined by a variety of factors acting collectively. At each trophic level, some energy is used by the organisms for growth, reproduction or movement, and some energy is lost in the form of heat.

Many organisms in the Great Lakes feed on more than one type of food; in fact, some can readily switch food types if a regular food supply is depleted. This complex ecology of the Great Lakes is shown by a food web. **Pelagic food webs** have their basis of productivity from floating algae, whereas **littoral food webs** are based on energy produced by macrophytes. Likewise, **benthic food webs** are based on energy and nutrient flow from organisms that make use of the detritus floating down from above and settling into the sediments.

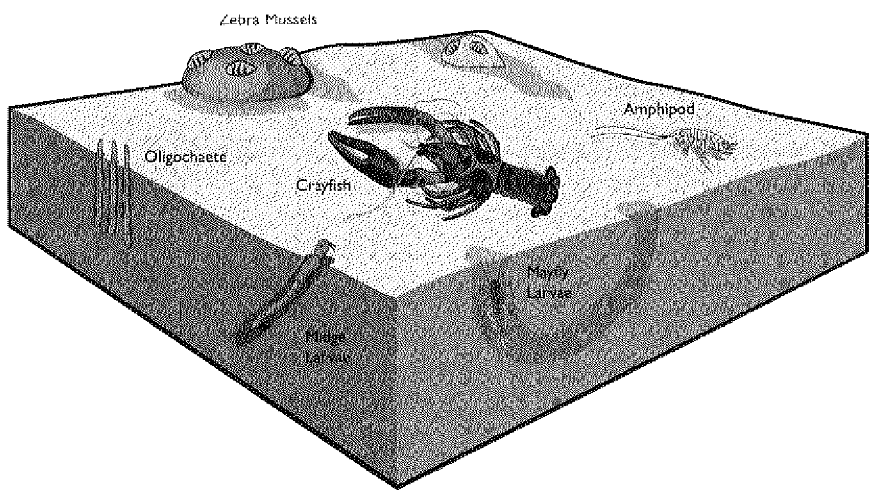


Great Lakes food webs are dynamic and complex. Some of the members of food webs have arrived in the Great Lakes relatively recently, causing significant changes that ecologists call **food web disruption**. The zebra mussel and sea lamprey are examples of such invasive species. Species living outside the area where they evolved are called **nonindigenous** species. These include species such as the zebra mussel, sea lamprey, alewife and spiny water flea that have arrived accidentally. All non-native species, whether intentionally or unintentionlly introduced, have effects on Great Lakes food webs.

Over time, some members of Great Lakes food webs have declined in numbers due to combinations of factors such as over-fishing, poor environmental quality, or parasitism by the sea lamprey. Atlantic salmon in Lake Ontario probably declined because of habitat loss from early logging and dam building. Lake sturgeon, which grow and mature slowly, were affected by damming and overfishing. Lake trout declined due to factors such as sea lamprey predation, habitat degradation, overfishing and decline of its foods. When **predators** such as lake trout disappear, the effects are noticed throughout the food web. In some cases, fisheries managers intentionally introduced some members of the Great Lakes food web, both to assist in limiting numbers of other organisms and to provide fishing opportunities. For example, Chinook and coho salmon were introduced to reduce alewife populations and to provide sportfishing opportunities.

Understanding Great Lakes ecology requires studying the interactions between life cycles and habitats of organisms, and population fluctuations or cycles over time. Nearly all Great Lakes fishes can be found in shallow water during part of their life cycles. Many species use shallow waters of lakes or rivers as spawning habitat either in the spring or the fall. Spring spawners include steelhead, lake sturgeon, various suckers, channel catfish, bullheads, yellow perch, walleye, northern pike, and smallmouth bass. Fall spawning fishes include lake trout, lake whitefish, lake herring, Chinook and coho salmon.

Benthic Life in the Great Lakes



Description: microscopic to small animals that live on the lake bottom. Includes animals from the following groups:

Anelida: Oligochaetes (aquatic "mud" worms) and Leeches (*Hirudinea*) – members of segmented worm group; most under 5 cm.

Crustaceans: Decapods (crayfish) – cylinder-shaped body with heavy shell and five pairs of walking legs; claws.

Amphipods (including *Diporeia spp.*) – sometimes called freshwater shrimp, scuds, or sideswimmers; no shell, gills at base of legs, slightly compressed (flattened side-to-side). (Note: *Diporeia* was called *Pontoporeia* until the 1980s)

Native mollusks – mussels, clams, fingernail clams, snails, etc. - majority have a shell covering internal organs, such as mouth and digestive tract, gills or lung, and a muscular "foot" used for locomotion.

Insect larvae: Chironomids (midge larvae) – long, cylinder-shaped; some have anal gills. *Hexagenia* (mayfly nymph) – long, slender body with feather-like gills along sides of abdomen; three tails at posterior and a pair of tusks at mouth.

Aquatic adult insects (waterstriders) – limited to the nearshore (littoral) zones.

Adult Diet: scavengers/omnivores – decaying plant and animal debris (detritus), bacteria, algae; some feed on crustaceans or insect larvae; crayfish and midge larvae mainly herbivorous, but also detritivores.

Habitat/Behavior: benthic; many benthic organisms build burrows or seek cover under rocks or debris. Oligochaetes build tubes and bury themselves head first, leaving the tail end with gills up in the water. Midge larvae may construct small tubes of algae, silt or sand. Mayfly nymphs of the genus *Hexagenia* burrow into soft sediments in areas high in oxygen. *Diporeia* is historically the most important of the benthic organisms in the diet of Great Lakes fish. During the day it lives close to or even buried in the sediments; by night it migrates upward into the hypolimnion (areas high in oxygen). Since the arrival of zebra mussels, *Diporeia* populations have been in decline throughout large regions of the Great Lakes (except for Lake Superior), including areas not directly infested by the mussels. *Diporeia* breed from December through April and release their young from a brood pouch in the spring.

Fish species prefer certain habitat types for spawning and for early development of their **fry**, or newly hatched young. Some, such as northern pike, prefer wetlands with aquatic vegetation; others such as lake whitefish, prefer shallow reefs, which provide rich areas for food items and some rocky structure (cover) to retain the eggs and in which the fry can hide from predators. Much remains to be learned about the early-life histories of Great Lakes fishes.

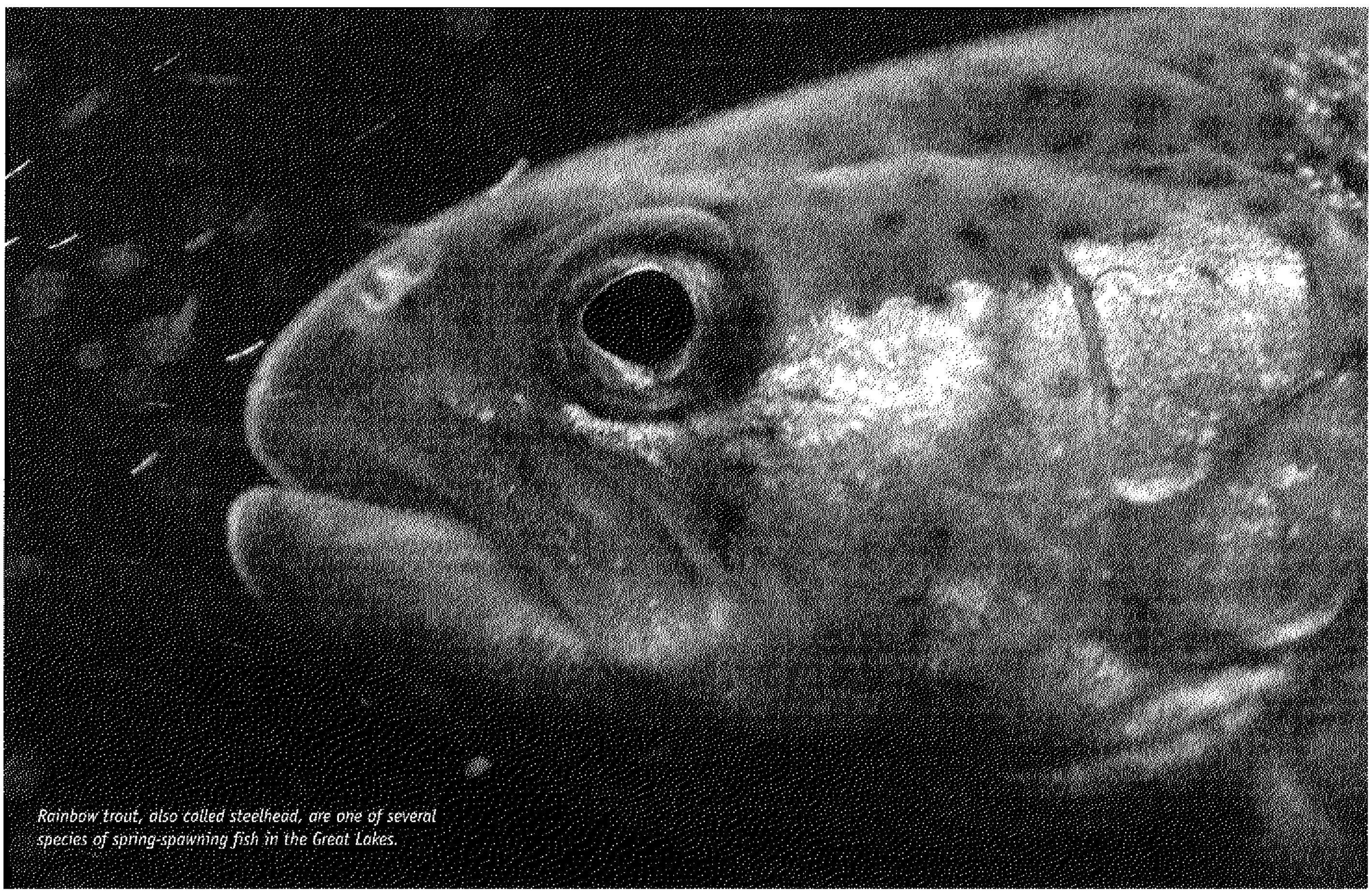
Whatever their course of development, the success of fishes depends on the match between the organisms and their environment. The genetics of the species and the individual fish determine what environmental features are important to that fish. In addition, genetics determine the range of tolerance of a particular fish. For example, lake trout are genetically adapted to cold, clear, highly oxygenated waters; they grow best in waters around 10.5° C (50.9° F); temperature extremes may be deadly. The genetics of a fish, combined with the actual characteristics of the fish's environment, work together to affect that fish's reproduction, growth and survival. Whereas some fishes, including salmon, spawn after only three or four years (then die), some groups of fishes, such as lake sturgeon, reproduce at an older age and live much longer—up to an estimated 100 years. For most fishes, growth rates are greatly affected by the quality and the amount of food sources and by water temperatures. The result of all of these factors is **fish production**, the amount of new biomass produced by a given species in a particular area over a period of time.

Learning about this web of life in the Great Lakes is crucial to understanding the history of its fisheries, current fisheries issues, and environmental quality issues. Understanding the biological basis for these fisheries is also important when decisions are made about allocating or dividing fisheries resources among various resource-user groups. Today, fisheries scientists and managers, as well as many other professionals and citizens, are involved in making such decisions.

Fisheries Science and Management

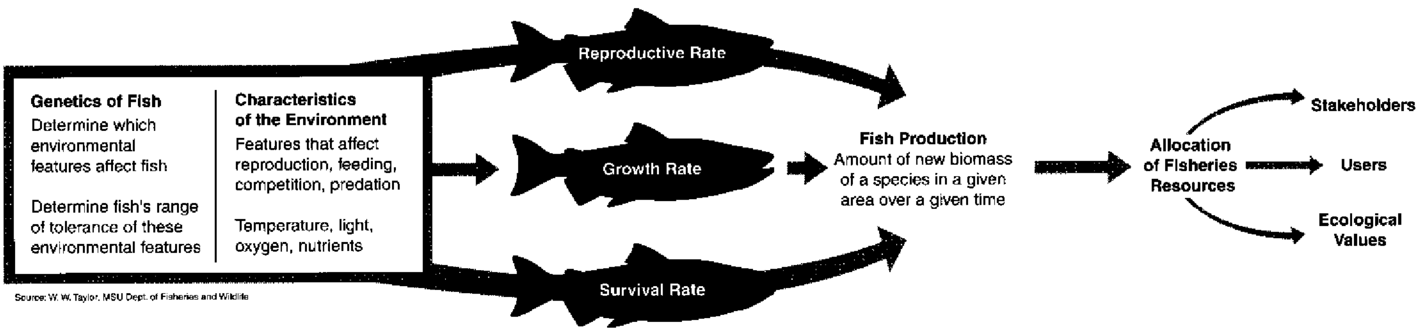
Fisheries science is the systematic study of fishes, aquatic (water-related) resources, and their uses and users. This science involves understanding the structure, dynamics, and interactions of habitat, aquatic organisms and humans. **Fisheries management** is a branch of fisheries science. Fisheries management is the translation of information about people, aquatic populations and habitats into efforts to reach the goals humans desire for particular aquatic populations or **ecosystems**.

Great Lakes fishes are known as **common property resources**, resources held in trust for everyone. Governmental agencies are responsible for caring for these "public trust" resources on the peoples' behalf, keeping both human and resource needs in mind. These agencies are also responsible for allocating fishery resources, dividing them among resource-user groups and ensuring a healthy population in future years. In the U.S., states and tribes have the primary responsibil-



Rainbow trout, also called steelhead, are one of several species of spring-spawning fish in the Great Lakes.

Fish Production and Resource Allocation



Source: W. W. Taylor, MSU Dept. of Fisheries and Wildlife

ity for fisheries management, working with U.S. federal agencies. However, because the Great Lakes are situated on an international border, state and tribal agencies must manage the resource as partners with provincial government agencies and the stakeholders of Ontario as well as the national government of Canada. Because of this complexity, both in the biological and in the human systems in the Great Lakes region, the potential for conflict is great—as is the opportunity to cooperate to solve complicated fisheries issues.

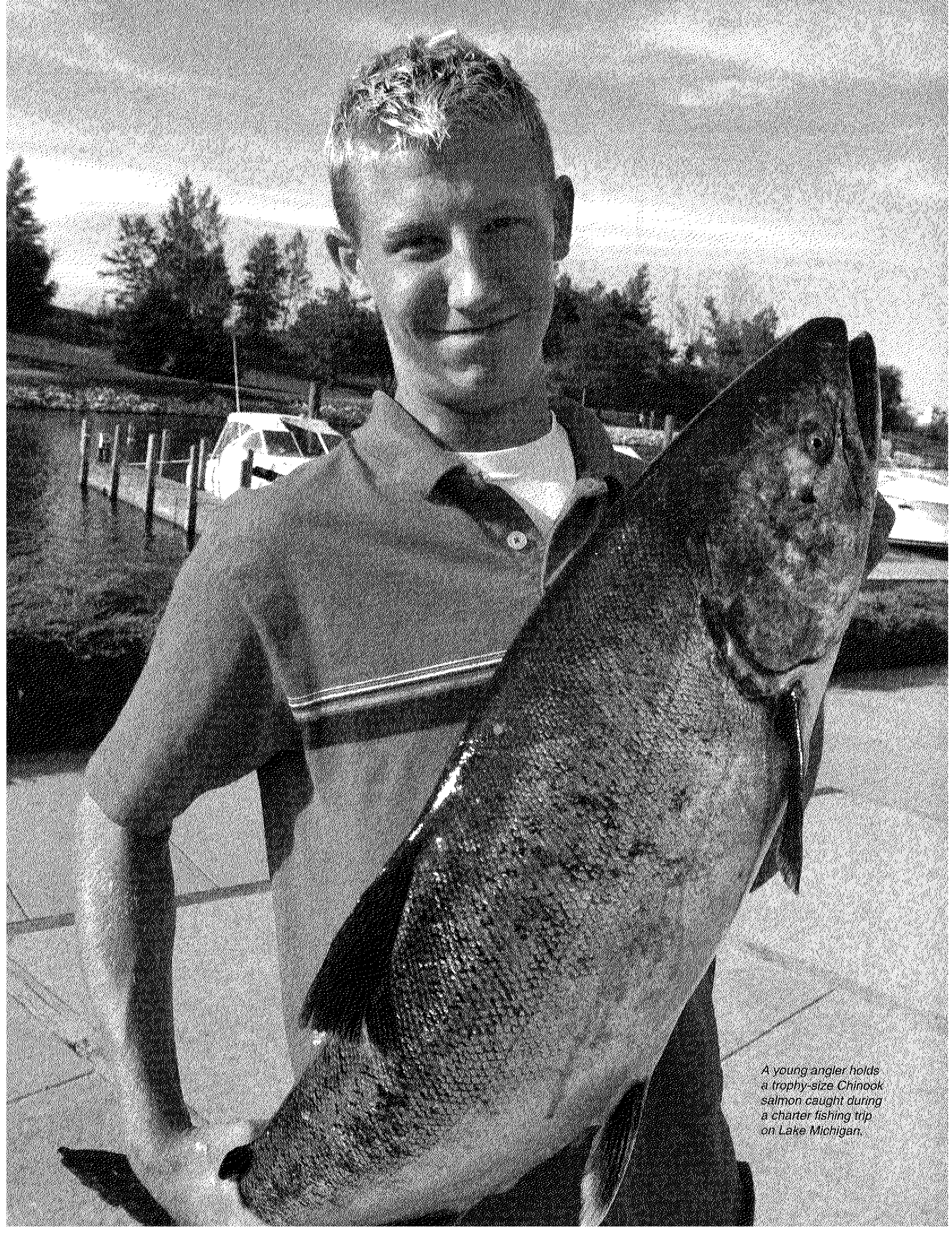
Fisheries management today involves all of the region's fisheries stakeholders. To apply the most current scientific information to decision-making, Great Lakes scientists, fisheries managers and representatives of many organizations come together through two commissions—the Great Lakes Fishery Commission and the International Joint Commission—as well as through many professional societies such as the American Fisheries Society, the Society of Environmental Toxicology and Chemistry, and the International Association for Great Lakes Research. Sea Grant College Programs throughout the Great Lakes states also provide a network for managers, research scientists and stakeholders to be involved directly in fisheries management.

Many organizations are partners with fisheries managers in making decisions about Great Lakes fisheries. Tribal fishers belong to individual tribes that have organized management agencies including the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), the Chippewa Ottawa Resource Authority (CORA) and the Anishinabek/Ontario Fisheries Resource Center (A/OFRC). These groups take part and lead efforts in fisheries resource planning, habitat improvement, law enforcement, and stocking. State and provincial licensed commercial fishermen also have organizations, as do charter fishing operators. Commercial and tribal fishers and charter operators help collect data and keep records about fish resources to assist resource management agencies.

Sport anglers have provided information to assist Great Lakes fisheries managers for a long time. Concerns about declining fish populations and citizen interest in Great Lakes fisheries led to the formation of a variety of fishing and conservation organizations. Examples of national organizations include Trout Unlimited and B.A.S.S. (Bass Anglers' Sportsmen's Society). Regional, provincial and state groups also focus on the fisheries; these include the Great Lakes Sport Fishing Council, the Ontario Federation of Anglers and Hunters, Michigan United Conservation Clubs and many others throughout the region. Interest groups focused on commercial and tribal fisheries also exist. Today, all of these organizations cooperate with fisheries agencies in resource management activities such as artificial reef and habitat improvement projects, in hatchery and pen-rearing projects and in raising funds to sponsor fisheries research and conservation. Some also assist management agencies by volunteering their time for fisheries research, collecting data or responding to surveys.

At the national level, many resource management and environmental agencies collaborate with each other and with states to accomplish fisheries goals. Several branches of the National Oceanic and Atmospheric Administration (NOAA) are involved. The Great Lakes Environmental Research Laboratory is a part of NOAA. The Environmental Protection Agency, the U.S. Fish and Wildlife Service, Environment Canada, and the Canadian Department of Fisheries and Oceans are all active in research and decision-making regarding the Great Lakes.

Funding for fisheries management comes from several sources. About one-third of the funds comes from sportfishing licenses, while about half is from governmental general funds from states, the Province of Ontario, and the U.S. and Canada. Another portion of funding comes from federal excise taxes on fishing equipment and taxes on motorboat gasoline. In the U.S., these excise taxes are collected under the Federal Aid in Sport Fish Restoration Program (through what is commonly called the Wallop-Breaux Trust Fund and what was known as the Dingell-Johnson Act). More than $51 million (one-fifth of the U.S. total) of Wallop-Breaux revenues was returned to Great Lakes states in 2001 for their fisheries management programs. Altogether, tens of millions of dollars are spent on Great Lakes fisheries management each year. Hundreds of millions of dollars are also spent each year on managing the entire Great Lakes basin for issues such as water quality that benefit fisheries directly or indirectly.



A young angler holds a trophy-size Chinook salmon caught during a charter fishing trip on Lake Michigan.

Today's Great Lakes *fisheries*

Sport and commercial fisheries are the major fisheries in the Great Lakes. These fisheries are defined by fish species sought (game fish or commercial species), their aquatic habitats and those who harvest them. Within these fisheries are sub-groups of sport and commercial fishermen who hold licenses issued by a state, provincial or tribal authority. Each license reflects a different set of governing regulations. The Great Lakes also support a small subsistence fishery, encompassing those who rely on fish as a supplemental food source.

Sport and commercial fisheries of the Great Lakes differ in significant ways, primarily in the fish sought, fishing procedures and gear, management regulations, and the fishing culture, values and purpose of those involved (stakeholders). For example, sportfishing might be viewed as primarily recreationally oriented and commercial fishing primarily as a business venture. However, these fisheries also have some similarities. The sportfishery has an economic or "business" component. Many communities depend on tourism and the revenue generated in their areas through sportfishing. Charter fishing operators are sport anglers, but also must work to build and maintain markets for their services. The commercial fishery is similar to the sportfishery in that its cultural history and fish products may influence tourism in some areas. Tourists dine on fresh fish in coastal communities and visit old fishing villages such as Fishtown in Leland, Michigan. The most striking similarity is that each fishery depends on a healthy Great Lakes ecosystem that supports a diversity of high-quality and healthy fish.

Great Lakes fisheries provide a wealth of values:

Nutritional value: Great Lakes fish are an excellent source of protein with less fat and fewer calories than other meats.

Economic value: Various studies and estimates place the total economic impact of the sport and commerical food fishery on the Great Lakes regional economy between $4 and $7.4 billion per year.

Social value: Countless people enjoy fishing and related activities, participate in fishing organizations and attend events such as fishing festivals or tournaments.

Historical and cultural value: Many commercial fishing families, including state-, province- and tribe-licensed, maintain a way of life similar to their ancestors. Others learn about Great Lakes fisheries history by visiting historic fishing villages and Great Lakes museums.

Educational and scientific value: Fisheries provide educational opportunities that encourage people to learn about ecosystems and their processes and to help monitor the quality of aquatic environments.

Ecological value: Fisheries are a critical component of a healthy, functioning Great Lakes ecosystem. Fish support healthy wildlife populations, fill ecological niches that help maintain predator-prey relationships and keep the Great Lakes ecosystem in balance.

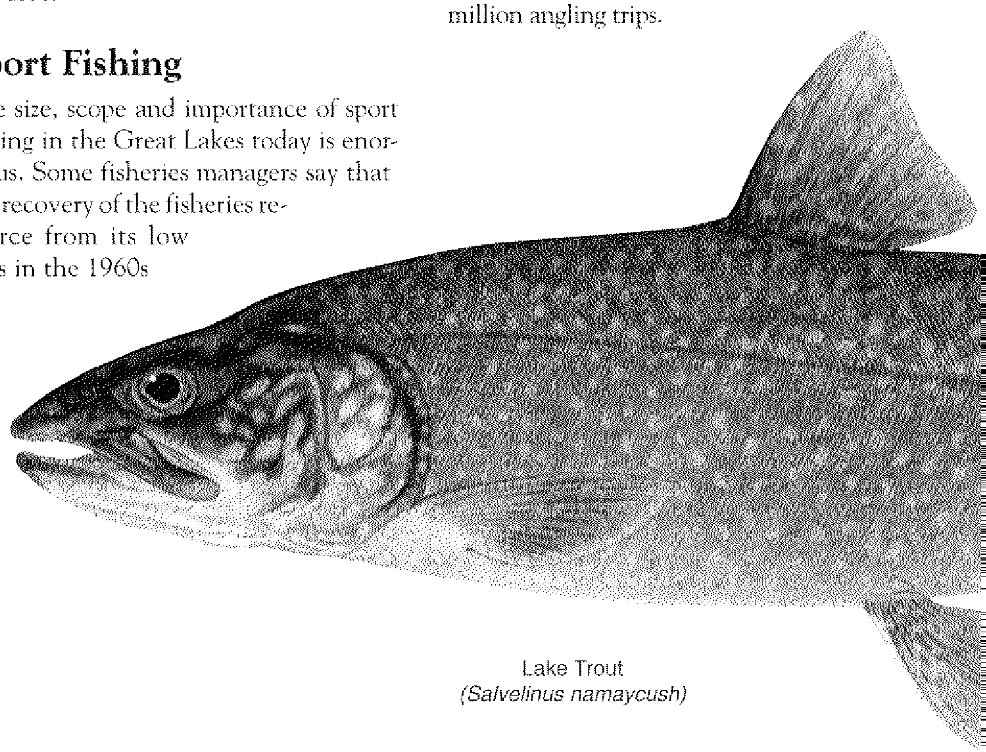
Future value: A sustainable Great Lakes fishery helps ensure the long-term protection of Great Lakes natural resources.

Sport Fishing

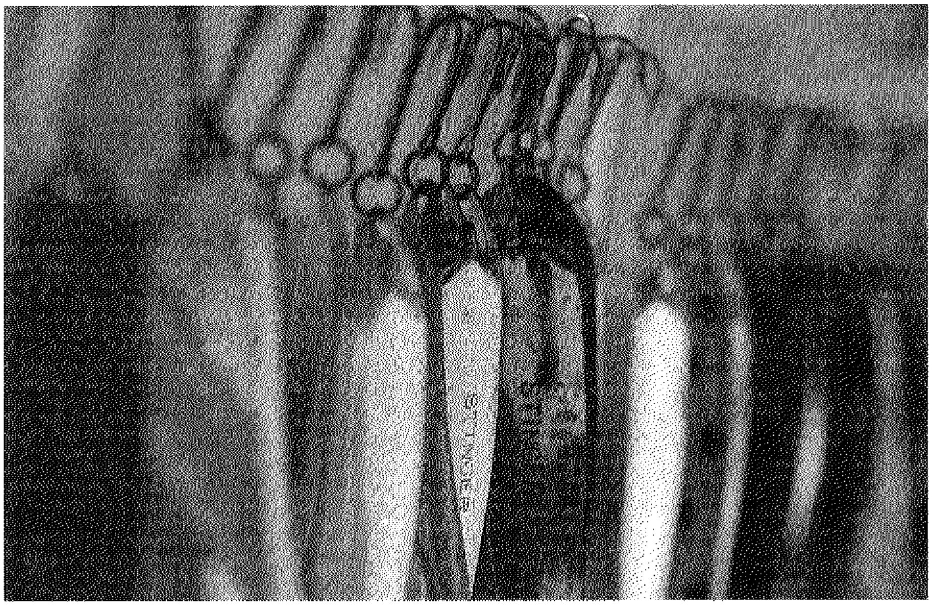
The size, scope and importance of sport fishing in the Great Lakes today is enormous. Some fisheries managers say that the recovery of the fisheries resource from its low days in the 1960s to the sport fishery of the early to mid-1980s (and continuing through today) is nothing short of a resource management miracle. Managers and economists agree that sportfishing governed by size limits, creel limits, seasons and gear restrictions and regulations for specific species has increased the value of the sportfishery. This has been accomplished by managing several different sport fish populations to diversify opportunity, alleviate angler pressure on individual species and allow additional anglers to participate in the fishery. Fisheries managers measure the health and success of sport fishing by taking into account angler days (the total of all days spent angling), number of angling trips, catch rates, species targeted, and surveys about angler attitudes and satisfaction.

Angling Effort

Surveys conducted every five years by the U.S. and Canadian governments, while not perfect, are good indicators of sportfishing activity and trends. Recent surveys show that more than 1.8 million anglers spent more than 23 million days fishing U.S. waters of the Great Lakes in 2001. These U.S. anglers made a total of nearly 16 million angling trips.



Lake Trout
(Salvelinus namaycush)



Bait and tackle shops are common in Great Lakes coastal communities.

In Canadian waters of the Great Lakes, nearly half a million anglers fished more than 5.3 million days in 2000. More than 60 percent of Canadian anglers fished from boats and more than 30 percent fished from shorelines; a small percentage opted for ice fishing.

Recent surveys also show that in the United States sport fishing is most popular on Lake Erie and Lake Michigan. These two lakes had the largest number of anglers and the greatest angling effort (number of days spent angling). Similarly, Lake Huron boasts the greatest number of anglers, as well as the greatest number of days spent angling on Canadian waters of the Great Lakes. Notable numbers of Canadian anglers also spent a similar amount of days on lakes Erie and Ontario. Within the United States, the state of Michigan had the most anglers and the most days spent angling in 2001, followed by Ohio and New York.

Sportfish Species

The diversity of Great Lakes sport fishing ranges from warm- and cool-water species such as bluegill, bass, yellow perch, walleye, pike, and muskellunge of the shallower bays and nearshore areas, to coldwater fishes such as lake trout or salmon found in deeper, open waters. The methods anglers use to take Great Lakes sport fishes vary widely from area to area and include shore or pier fishing, wading, boat fishing, and ice fishing.

The most popular fish species sought by U.S. and Canadian anglers in the Great Lakes region is yellow perch, followed by large- and smallmouth bass and walleye. Sunfishes and rock bass, or other panfish, are also highly valued sportfish, especially in Canadian waters.

Other sport fish sought particlarly in U.S. waters include cold-water species such as lake trout and several salmon species such as Chinook, coho, and pink salmon. Brown trout and rainbow trout (known as steelhead) are also popular. Great Lakes salmon and steelhead are two of many species caught in Great Lakes tributaries.

Smelt are also frequently caught with dip nets (and seines in Canada) during spring spawning runs throughout the region. Northern pike and muskellunge round out the primary list of popular sport fish species noted in both U.S. and Canadian surveys.

Economic and Cultural Impact

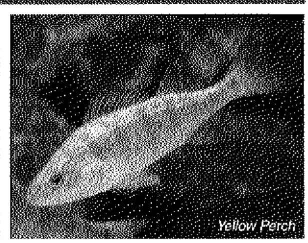
Economists estimate that, as of 1985, the annual economic impact of sport fishing within the Great Lakes region was at least $4 billion (U.S. dollars). Some experts estimate the value of the sportfishery to be much higher, exceeding $7 billion (U.S. dollars). Great Lakes anglers spend $2-3 billion per year for bait, tackle, food, gasoline, boats, and charter services. In the U.S. anglers spent between $1.3 and $2.5 billion in 2001. In Canada, it is estimated that anglers spend more than $415 million (CDN) yearly on

Popularity of Fish Species for Anglers in U.S. Waters of the Great Lakes 2001

Species	Anglers	Days spent angling
Yellow Perch	693,000	6,597,000
Bass	589,000	6,355,000
Walleye	571,000	5,521,000
Salmon	516,000	3,985,000
Lake Trout	349,000	3,605,000
Steelhead	338,000	3,698,000

Fish Species Caught by Anglers in Canadian waters of the Great Lakes 2000

Species	Fish caught
Yellow Perch	6,462,593
Bass	4,734,876
Walleye	2,581,995
Sunfish/Rock Bass	4,570,376
Smelt	1,666,235
Pike	1,665,515



Yellow Perch

Sources: U.S. Dept of Interior, U.S. Fish and Wildlife Service and U.S. Dept. of Commerce, 2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation/ Dept. of Fisheries and Oceans, Canada, 2003 equipment, supplies and direct services related to fishing, such as fishing gear, boating equipment, travel, lodging and licenses.

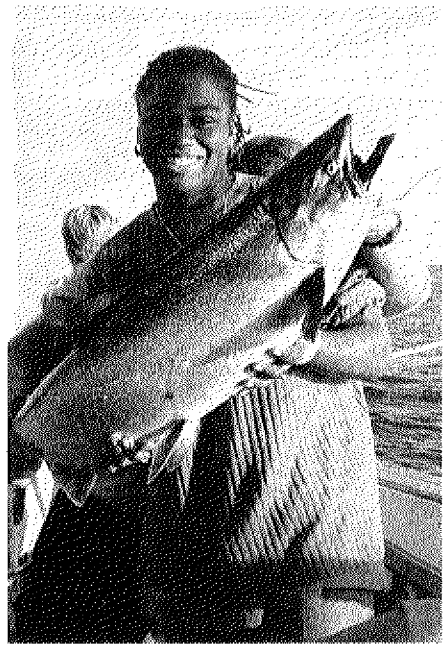
The sportfishing industry has brought new life to many coastal towns. Some communities have developed their shorelines with sport anglers in mind. Bait and tackle shops and other support industries are commonplace in coastal communities. Some develop and build fishing gear, such as lures marketed and used worldwide. Fishing gear such as the **downrigger** was developed in this region to meet the needs of Great Lakes anglers.

The Great Lakes region has taken on a sportfishing identity, and tourism has been touted as an economic development alternative to heavy industry. Some communities have organized popular fishing festivals and sportfishing tournaments to attract visitors and to celebrate their Great Lakes fisheries resource heritage. Steelhead runs in spring, fall and winter draw anglers to traditional, favorite fishing areas on tributaries. Likewise, spawning runs of salmon, smelt, and other fishes offer predictable opportunities for fishing with family and friends. Great Lakes tributaries or river systems allow anglers opportunities to enjoy Great Lakes fisheries far inland.

Charter Fishing Industry

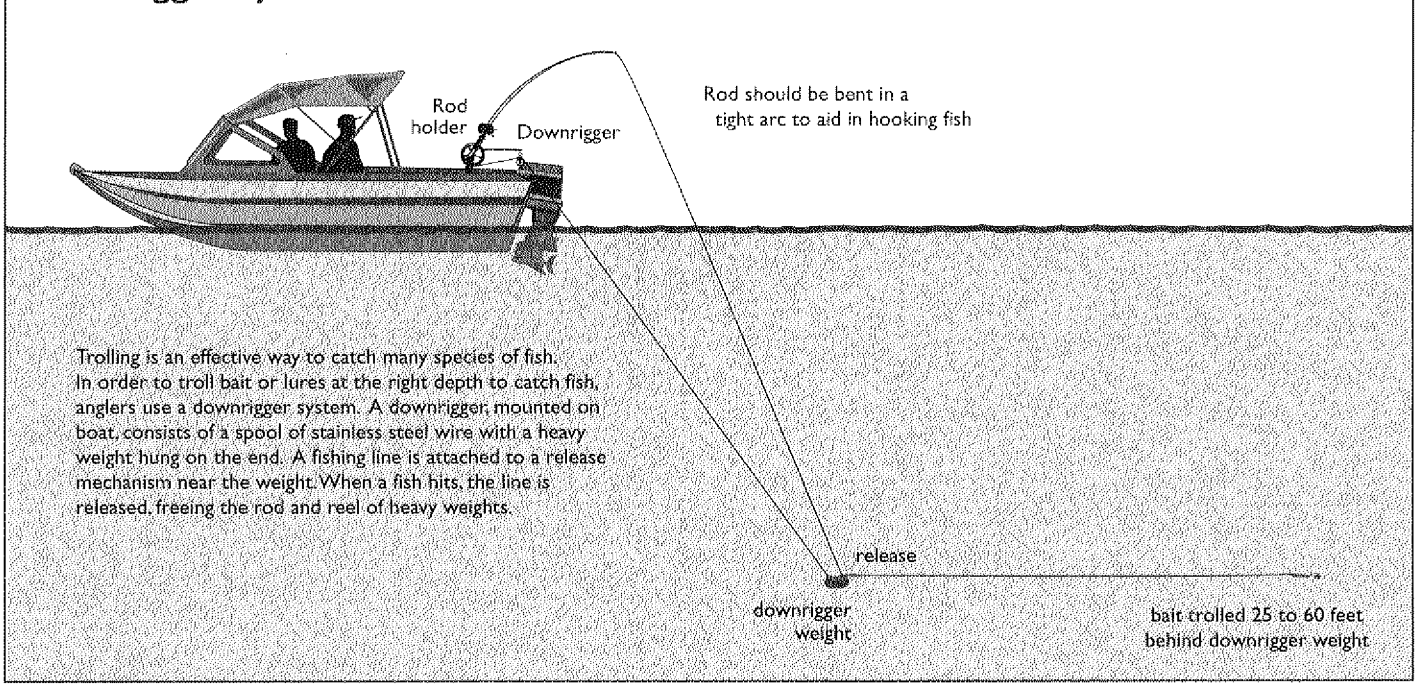
The charter fishing industry grew tremendously in the region during the 1970s and 1980s. The number of charter fishing boats in the U.S. grew from several hundred in 1975, peaking at more than 3,000 boats in 1988. Trip expenditures by charter fishing anglers also peaked in the late 1980s, with Michigan charter anglers alone spending a total of more than $59 million. The charter fishing industry, primarily in the upper Great Lakes, began experiencing difficulties in the early 1990s due to factors such as declines in Chinook salmon stocks and their prey (alewife), economic downturns and concern over contaminants in fishes. Similarly, Lake Erie charter operations declined along with walleye populations through the late 1990s and early 2000s.

Declines in Lake Michigan Chinook salmon or Lake Erie walleye forced Great Lakes anglers and the charter industry to focus on different species, such as steelhead. Fisheries managers began to recognize the importance of managing for a diverse and sustainable sportfishery. As fish populations tend to fluctuate in cycles, some species, such as the Chinook salmon, rebounded in the 1990s, and fisheries managers now work to manage such fluctuations for more sustainable



Salmon are among the most popular sportfish in U.S. waters of the Great Lakes.

Downrigger System



Number of Anglers Fishing in U.S. Waters of the Great Lakes

Lake/Waters	Anglers	Days spent angling
Erie	645,000	7,748,000
Huron	155,000	1,171,000
Michigan	561,000	4,836,000
Ontario	241,000	3,560,000
Superior	93,000	601,000
St. Clair	96,000	524,000
St. Lawrence	111,000	905,000
Tributaries	284,000	3,331,000

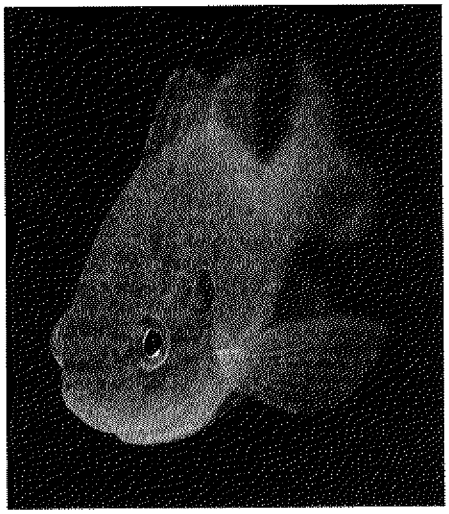
State	Anglers	Days spent angling
Illinois	120,000	756,000
Indiana	45,000	721,000
Michigan	680,000	7,002,000
Minnesota	60,000	603,000
New York	368,000	6,324,000
Ohio	430,000	4,241,000
Pennsylvania	80,000	1,406,000
Wisconsin	198,000	2,085,000

Source: U.S. Dept. of Interior, U.S. Fish and Wildlife Service and U.S. Dept. of Commerce, 2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation

Days Angling in Canadian Waters of the Great Lakes

Lake/Waters	Days spent angling	Anglers
Erie	719,029	99,878
Huron	2,497,249	218,806
Ontario	1,308,991	110,418
St. Clair	415,476	39,958
St. Lawrence	188,131	27,332
Superior	202,695	27,332
Great Lakes	5,331,571	469,128

Source: Department of Fisheries and Oceans, Canada 2000



Sunfish are a popular sportfish in the Canadian waters of the Great Lakes.

numbers of fish. Likewise, the charter industry, while not as large as in the past, still continues to provide productive economic returns to the Great Lakes region.

Sportfishery Trends

The U.S. Fish and Wildlife Service reports over 2.9 million angler licenses sold in Great Lakes states in 2001, nearly 30 percent of all licenses sold in the United States that year. However, recent trends indicate declines in angler license sales. Surveys indicate that numbers of sport anglers in U.S. waters declined 28 percent between 1991 and 2001, and similar declines have been noted among Canadian sport anglers. Yet angler attitudes, values, and use of Great Lakes fisheries resources have become increasingly diverse.

Researchers and managers are just beginning to understand the diversity of preferences and interests of Great Lakes anglers. This understanding of angler values and attitudes is necessary to help predict the future demand for fisheries resources and to allocate the fisheries resources available today. Some are concerned that urbanization and other factors may cause fewer people to participate in fishing in the future, while others are concerned about angling pressure in certain areas. Some anglers gain satisfaction from releasing their prized catch (catch-and-release fishing), and management for trophy fish has increased in popularity. Others enjoy harvesting fish for the purpose of a good meal. Whether to keep or release a fish is a question left to each person's individual values and decisions about their participation in the fishery. Angler values and ethics are increasingly important in maintaining a high quality, sustainable Great Lakes sport fishery.

Commercial Fishing

Commercial fishing, when managed properly, can provide an important and sustainable food source from the Great Lakes. Creative commercial fishing operations also find ways to maximize value of their harvest through marketing the uniqueness of Great Lakes fish. The commercial fishery is important to tourism and to communities along the Great Lakes shoreline, as it supplies such regional favorites as yellow perch, walleye, lake whitefish, smelt, and smoked fish. Families and communities throughout the region have developed their own variations of the "fish fry" for smelt and perch, and the fish boil is a Great Lakes regional specialty. Planked whitefish is also a traditional Great Lakes delicacy. Preparing smoked whitefish, suckers, bloater (chubs), lake herring and other fishes is often a family project and also offers distinctive regional fare for visitors to coastal towns.

The contribution of the state-, province- and tribe-licensed commercial fisheries in the Great Lakes region today is substantial. Many people in the basin depend on commercial fishing for their livelihood. About 9,000 worker-years were spent in the commercial Great Lakes food fishery in 1985 (the most recent year for which comprehensive commercial fishing economic statistics are available), with occupations ranging from fishing to processing, wholesaling, and marketing.

Despite these activities, the number of commercial fishing-related jobs in Great Lakes jurisdictions has declined in recent years. As of the early 1990s, there were 300 tribal licenses and fewer than 700 full-time state licenses. Some experts estimate these numbers to be much lower today. In Canadian Great Lakes waters, the numbers of commercial fishing licenses have remained fairly stable since the 1970s, ranging between 1,000 and 1,500.

A management trend in the U.S. waters of the Great Lakes has been to limit the number of commercial fishing operations. The goal of this strategy is to reduce the harvest pressure on the fishery while maintaining ecologically healthy and economically sustainable catch rates for the remaining commercial licensees.

Economic Impact

Commercial fishing in the Great Lakes today continues to provide productive returns from the fishery resources. In 2000, the estimated total catch by commercial state-, province-, and treaty-licensed fishermen was nearly 55 million pounds (24.9 million kilograms). **Landed value** of this harvest was estimated at over $17.8 million (U.S. dollars) for the fish harvested from U.S. waters and approximately $45.8 million (CDN dollars) for the fish taken in Canadian waters. However, the **processed value** of these commercial harvests significantly raises the economic value and benefit of the commercial fishery to the Great Lakes region. For example, in Canada, the processed value of this harvest is estimated to be at least five times the $45.8 million landed value amount.

Throughout the region, the total poundage landed in 2000 was greatest for lake whitefish, yellow perch, walleye, and smelt. Landed value of these four species harvested from U.S. waters was estimated at nearly $14 million (U.S. dollars) and almost $41 million (CDN dollars) for these four species harvested from Canadian waters in 2000. These four species also constitute more than three quarters of the region's total catch by weight, over 41.1 million pounds of fish harvested that year. White bass, lake trout, bloater (chubs), lake herring, and common carp are among the other primary catches in the region by total weight. However, the species of fish taken in the largest quantities varies by lake, by state or province and by country.

Commercial Fish Species

In Lake Superior, nearly 4 million pounds of fish were harvested from both U.S. and Canadian waters in 2000. Approximately half of the total commercial harvest in Lake Superior (by weight) is lake whitefish. Other important species in Lake Superior are lake herring and lake trout (lean and fat—siscowet—forms), which comprise another 44 percent of Superior's commercial harvest.

In Lake Michigan, commercial fishermen harvested more than 7.5 million pounds of mainly lake whitefish, lake trout, yellow perch, chubs and smelt (in Wisconsin and Michigan waters) in 2000. Alewife were once caught commercially from Lake Michigan and sold for animal food, but that activity was curtailed in the 1990s.

In Lake Huron, more than 15 million pounds of fish were harvested commercially in 2000, approximately two-thirds of this harvest from Canadian waters. Lake whitefish make up more than three quarters of the total commercial catch from U.S. and Canadian waters. Other species taken from the U.S. waters of Lake Huron by state-licensed fishers are channel catfish, quillback, herring, round whitefish and common carp. Chinook salmon and lake trout are substantial

Fish processing significantly raises the economic value and benefit of the commercial fishery to the Great Lakes region.

U.S. and Canadian Great Lakes Commercial Fishing Statistics in Great Lakes

Species/Lake	U.S. Total lbs.	U.S. $Value	Canada Total lbs.	CDN $Value	Grand Total lbs.	Grand Total Value*
Lake Whitefish	9,886,310	10,256,122	11,167,000	12,507,040	21,053,310	18,635,838
Yellow Perch	1,169,422	3,034,896	4,004,000	11,771,760	5,173,422	10,921,975
Walleye	22,891	38,851	7,269,000	15,046,830	7,291,891	10,120,227
White Bass	320,895	258,530	127,000	2,908,110	3,447,895	2,206,963
Chubs	1,625,614	1,88,906	300,000	450,000	1,925,614	1,890,406
Smelt	460,842	751,793	7,190,000	1,653,700	7,650,842	1,859,772
Lake Trout	994,087	531,462	563,000	43,430	1,557,087	761,560
Lake Herring	667,584	270,657	793,000	459,940	1,460,584	578,816
Channel Catfish	507,294	299,270	31,000	14,570	538,294	309,031
Pacific Salmon	519,338	262,333	5,000	1,800	524,338	263,539
White Perch	188,275	107,027	313,000	228,490	501,275	260,115
Carp	1,304,048	140,837	197,000	29,550	1,501,048	160,635

Species/Lake	U.S. Total lbs.	U.S. $Value	Canada Total lbs.	CDN $Value	Grand Total lbs.	Grand Total Value*
Erie	3,929,459	3,400,527	23,089,000	30,999,800	27,018,459	24,170,393
Huron	4,819,119	4,517,486	10,472,000	12,270,190	15,291,119	12,738,513
Michigan	7,541,800	7,988,721	0	0	7,541,800	7,988,721
Ontario	70,260	111,401	914,000	1,324,670	984,260	998,929
Superior	2,459,256	1,827,273	1,489,000	1,227,830	3,948,256	2,649,919
Totals	18,819,894	17,845,408	35,964,000	45,822,490	54,783,894	48,546,476

Source: Great Lakes Fisheries Commission, United States Geological Survey, Ontario Commercial Fisheries' Association   *Value in U.S. dollars

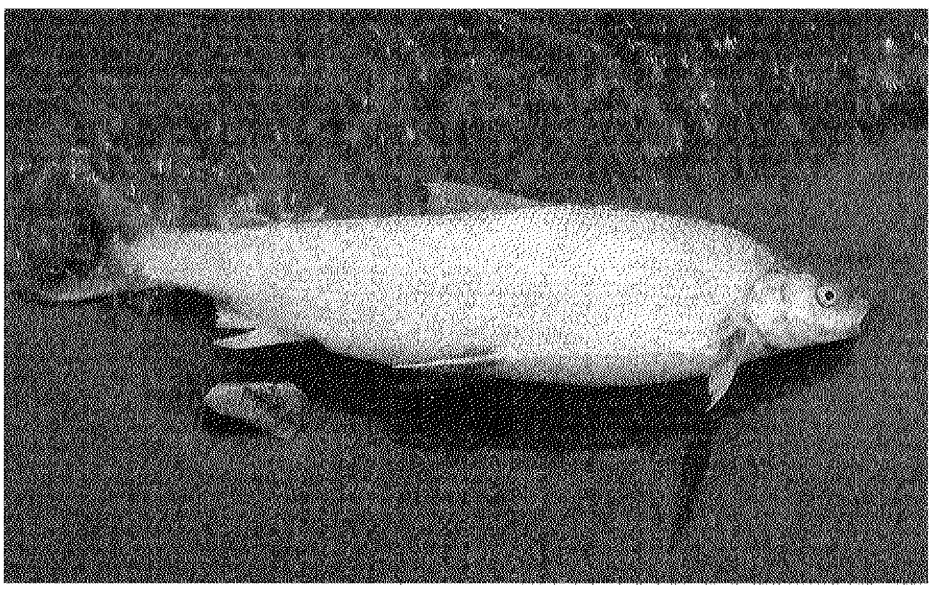
catches of the tribal harvest in U.S. waters. Other popular commercial species in Canadian waters of Lake Huron are lake trout, bloater (chubs), yellow perch, and walleye. In the North Channel of Lake Huron lake trout and lake herring are taken in large numbers, and in Georgian Bay large quantities of lake trout and bloater are harvested.

Lake Erie commercial fishermen harvested more than 27 million pounds of fish in 2000. U.S. commercial fishermen harvested mainly common carp, yellow perch, freshwater drum (sometimes known as "sheepshead"), white bass and channel catfish. Canadian Lake Erie commercial fishermen harvest mostly rainbow smelt, walleye, yellow perch, white perch, white bass and lake whitefish.

Baitfish harvest is an important commercial sector that occurs throughout the Great Lakes waters of both the U.S. and Canada. For example, Pennsylvania commercial fishermen harvest Lake Erie spottail shiners and other minnows that are then sold as bait.

Lake Ontario produced a commercial harvest of nearly 1 million pounds in 2000. Yellow perch constituted more than 80 percent of the U.S. commercial catch (by weight) in Ontario waters; brown bullhead, white perch, rock bass and other sunfishes are also commonly caught species. From Canadian waters of Lake Ontario come lake whitefish, bullheads, sunfishes, freshwater drum, American eel, yellow perch and walleye.

Species such as lake trout, walleye and perch are prized both by sport and commercial fisheries. Managers place great emphasis on shared and multiple uses of



Commercial fishing operations harvested over 21 million pounds of lake whitefish from the Great Lakes in 2000.

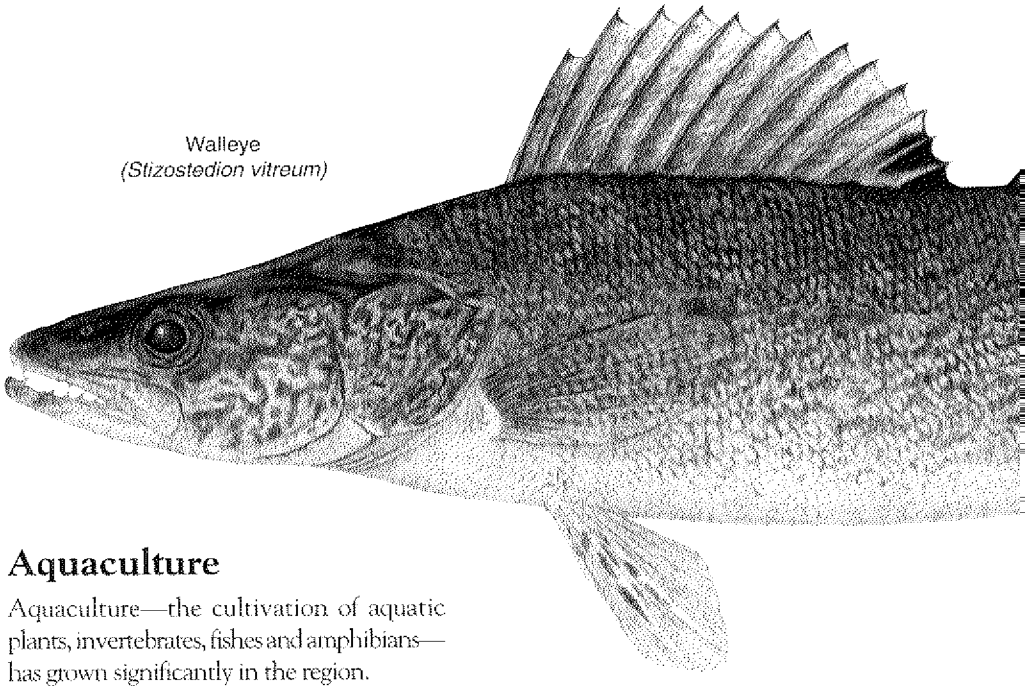
the Great Lakes fishery. In some areas, commercial fishers are restricted according to season, location or fishing gear such as trap nets. Restrictions may also cover the number or amount of nets per operation that can be used to selectively target commercial species and to avoid harvesting species sought by recreational anglers.

In many ways, the life of the commercial fisher is similar to that of the family farmer. The work is hard and sometimes dangerous, and the income uncertain and variable. Often fishing is a family venture, with information, techniques and equipment passed on through generations. In many cases, family members take part in all aspects of the business, including fish processing and sales. Knowledge of the lakes is also critical to success. Commercial fishers often have detailed understanding of lake bottom conditions such as depth, current and substrate, landmarks and navigation, fish movements and subpopulations, and weather patterns. Often, they have understanding and skill in boat maintenance and repair, knot tying and net repair.

Most commercial fishing in the region is done with trap nets, pound nets or gill nets, although trawls are used in places for smelt, bloater and lake whitefish fisheries (and in the past for alewife). While various technological advancements have aided the commercial fisher in recent years, it is still a time-consuming and difficult occupation. In spite of this, many speak of how fishing and the lakes are "in their blood."

Subsistence Fishery

The Great Lakes also support a small subsistence fishery. Subsistence fishing includes harvesting of fisheries resources for personal or family consumption or use. Subsistence fishing is often related to customary and traditional uses of fish resources, but primarily speaks to the dependence of users on fisheries resources for food and health. Subsistence fishers may include Native Americans; however, many other people who fish with state and provincial "sport" licenses may also rely on Great Lakes fishes as a primary food resource. Estimates of the economic importance of Great Lakes fisheries to subsistence fishers are difficult to obtain.



Walleye
(Stizostedion vitreum)

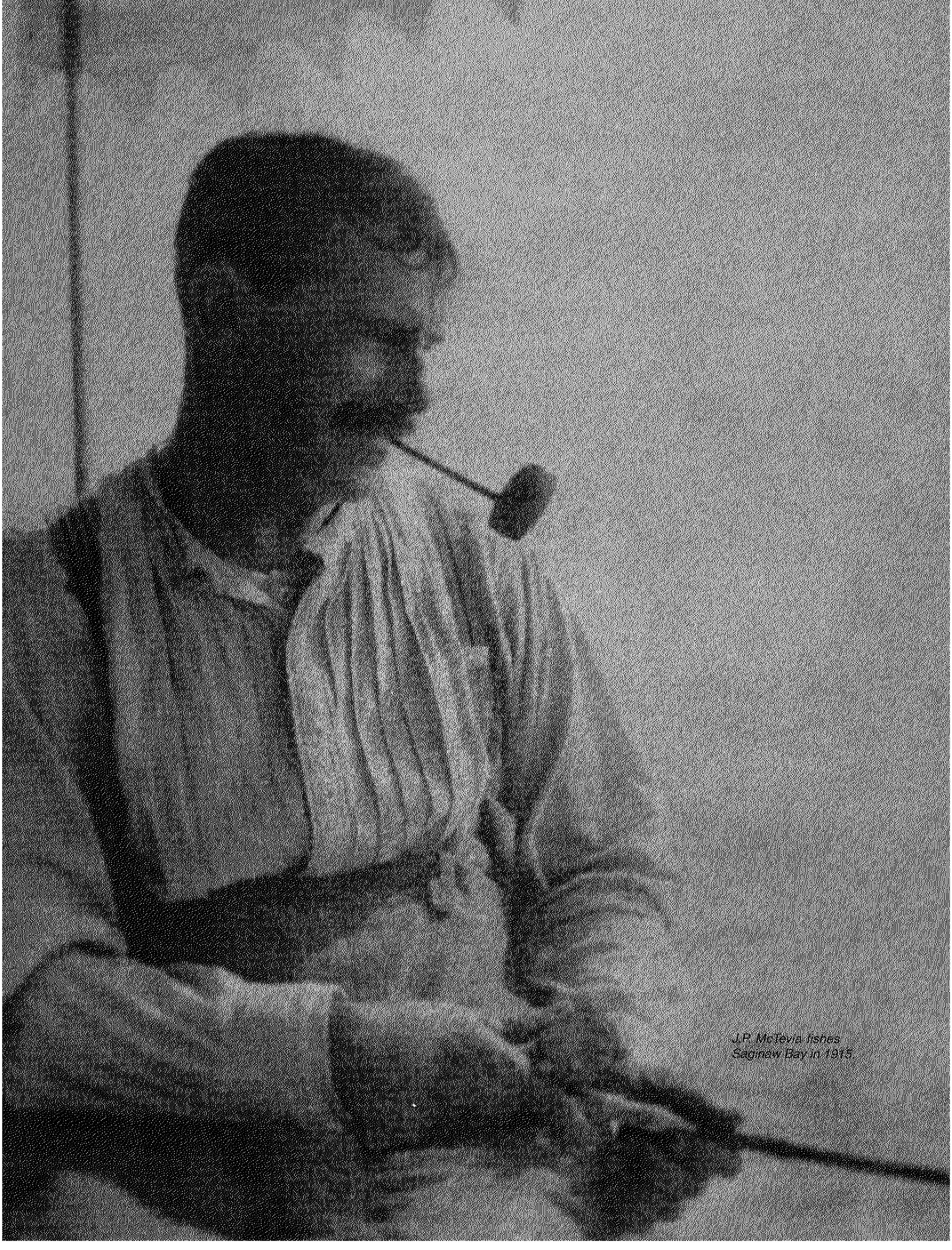
Aquaculture

Aquaculture—the cultivation of aquatic plants, invertebrates, fishes and amphibians—has grown significantly in the region.

Aquaculture production in the U.S. is diverse and varies by state, ranging from food-fish to baitfish, aquarium fish for the pet trade, to fish for stocking, and even plants for food, wetland mitigation, and water gardening. Aquaculture provides the Great Lakes region with economic benefits and another source of fish for the food market, as well as fish that are used for bait. Moreover, aquaculture (primarily agency fish culture) provides fish for stocking in public waters of the states and provinces, whereas private fish producers may culture fish to stock in private recreational waters or for sale to other fish growers and for fee-fishing operations. Fish growers in the region raise many types of fishes including bass, catfish, sunfish, and yellow perch. Aquaculture in this region will continue to grow to meet increasing demand for high quality fish products.

From private fish farms to agency fish hatcheries, more than 1,000 aquaculture producers exist in the eight Great Lakes states. In 2000, Ontario identified 190 private-sector fish production facilities in Ontario, providing 230 full-time jobs as direct employment and another 250 indirect employment positions. In the mid-1990s, aquaculture production in the U.S. Great Lakes states was valued at $54.4 million, and the total economic contribution of aquaculture in Ontario is estimated at $60 to 65 million. In many states, aquaculture is legally considered as a type of agriculture, and may not always be associated directly with waters of the Great Lakes. On the other hand, Ontario primarily produces rainbow trout, growing over 8.8 million pounds in 2000, and nearly 80 percent (by weight) of this production now comes from cage culture operations in Georgian Bay and the North Channel waters of Lake Huron.

Aquaculture plays important roles in Great Lakes management, such as rearing fish for stocking and providing a source of baitfish for a thriving sport fishery. However, some argue that it is risky because of its potential for unintentionally or even intentionally introducing non-native species into the Great Lakes. The aquaculture industry in the Great Lakes region has increased its attention toward reducing the risks associated with its operations. Such risks include unintentional introduction of exotic or non-native species, introduction of disease, or even marked changes in genetics of biological stocks within the Great Lakes basin. In 1999, Sea Grant began the development of Aquatic Nuisance Species-Hazard Analysis and Critical Control Point (ANS-HACCP) plans to identify and control potential hazards related to aquaculture. The ANS-HACCP program includes bait producers and focuses on reducing the risk of spreading exotic species or disease through that industry.



J.P. McTevia fishes
Saginaw Bay in 1915.

History *of the* Great Lakes *fisheries*

Waves of Change

To understand what the fisheries are today and what they may be in the future, it is important to review their complex and evolving history. Waves of change have always moved throughout the lakes. Social, technological and environmental changes have spread, sometimes simultaneously, through the entire basin. Taken together, those changes make today's Great Lakes fisheries quite different than they were thousands of years ago. In the last century, and particularly in recent decades, the pace of change has accelerated, and some of the changes have been dramatic.

Early Times: Era of Abundance

(12,000 years ago to about A.D. 1800)

About 12,000 to 11,000 years ago, people arrived in the region and hunted large mammals such as the mastodon. From 6000-3000 B.C. (Middle Archaic Period), fishing became more common for people living in the Great Lakes region. Archaeologists believe fish hooks were invented during this time.

By the Late Archaic Period (beginning in 3000 B.C.), Great Lakes peoples were trading with others in more distant regions. These groups developed spearing (for lake sturgeon, northern pike, suckers) and angling for a variety of fishes from a canoe or through the ice. Spears were made of copper, bone and antler. Fishing hooks and gorges, straight tools similar to hooks, were made of copper or bone. **Weirs**, small dam structures, were sometimes used to help concentrate the fishes. This early gear was used to catch mainly those fishes that were abundant during the spring **spawning** season in nearshore, shallow areas or streams.

By about 1000 B.C., the abundance of fishes was a major influence on the cultures of people in the region. Groups in the northern Great Lakes region subsisted mainly by fishing and hunting and supplemented their diet with plants. The seasonal movements of fishes into the shallow areas of the northern Great Lakes were a major influence on these peoples' subsistence and settlement patterns. In the southern Great Lakes region, agriculture emerged and corn arrived around 300 B.C., and people supplemented their diet with fish and game.

During the Woodland Period (1000 B.C. to 1600 A.D., prior to the arrival of the Europeans), two technological changes in fishing gear occurred among the peoples of the upper Great Lakes. Harpoons with detachable heads attached to a line allowed for more efficient capture and retrieval of large fish, such as lake sturgeon, than was possible with spears. Woodland period people made seine nets of wild hemp or nettles, with cords of basswood bark or of leather, edged at the bottom with small notched stones (net sinkers); these seines were used to corral fishes such as northern pike, drum, bass and suckers to the shore. These technological changes facilitated some social changes. These fishing techniques required cooperation, so family groups gathered at Great Lakes shorelines to work together during fishing seasons.

Native peoples began modifying their nets into gill nets around A.D. 800. This allowed the harvest of offshore, fall **spawners** such as lake trout and lake whitefish. Fall fishing meant that a large catch could be preserved by smoking or freezing for use throughout the winter.

Factors Influencing Today's Great Lakes Fisheries

Social Changes

Settlement
- Cultures mixing (Native, European)
- Immigration
- Population pressures
- Urbanization

Changes in Values Over Time
- Subsistence
- Developing markets in eastern U.S. and Canada
- Rise of recreation and tourism
- Global markets, economics
- Changing tastes
- Environmentalism, sustainability

Sociopolitical Changes
- Treaties
- Policy changes: state, federal, tribal
- Cross-jurisdictional (interstate) and international cooperation

Technological Changes

Land Use Patterns
- Logging, dams, canals
- Conversion of land from prairie and forest to agricultural, industrial and residential uses
- Sprawl

Harvest and Other Technologies
- Nets, floats
- Boats, engines
- Radios, navigational equipment
- Fish finders
- Transport and refrigeration

Management Science Technologies
- Hatcheries
- Genetics
- Population and ecosystem modeling
- Computers
- Restrictions
- Disease detection, monitoring and management

Environmental Changes

Modification of Drainage Basins
- Landscape, physical, chemical and biological changes

Exotics
- Varied sources of introduction
- Prevention and management strategies

Physical and Chemical Modifications
- Cultural eutrophication
- Contaminants

Atmospheric and Global Changes
- Atmospheric deposition of contaminants
- Movement of contaminants in ecosystems
- Global warming

Spring fishing also continued, using the earlier technologies and the gill net.

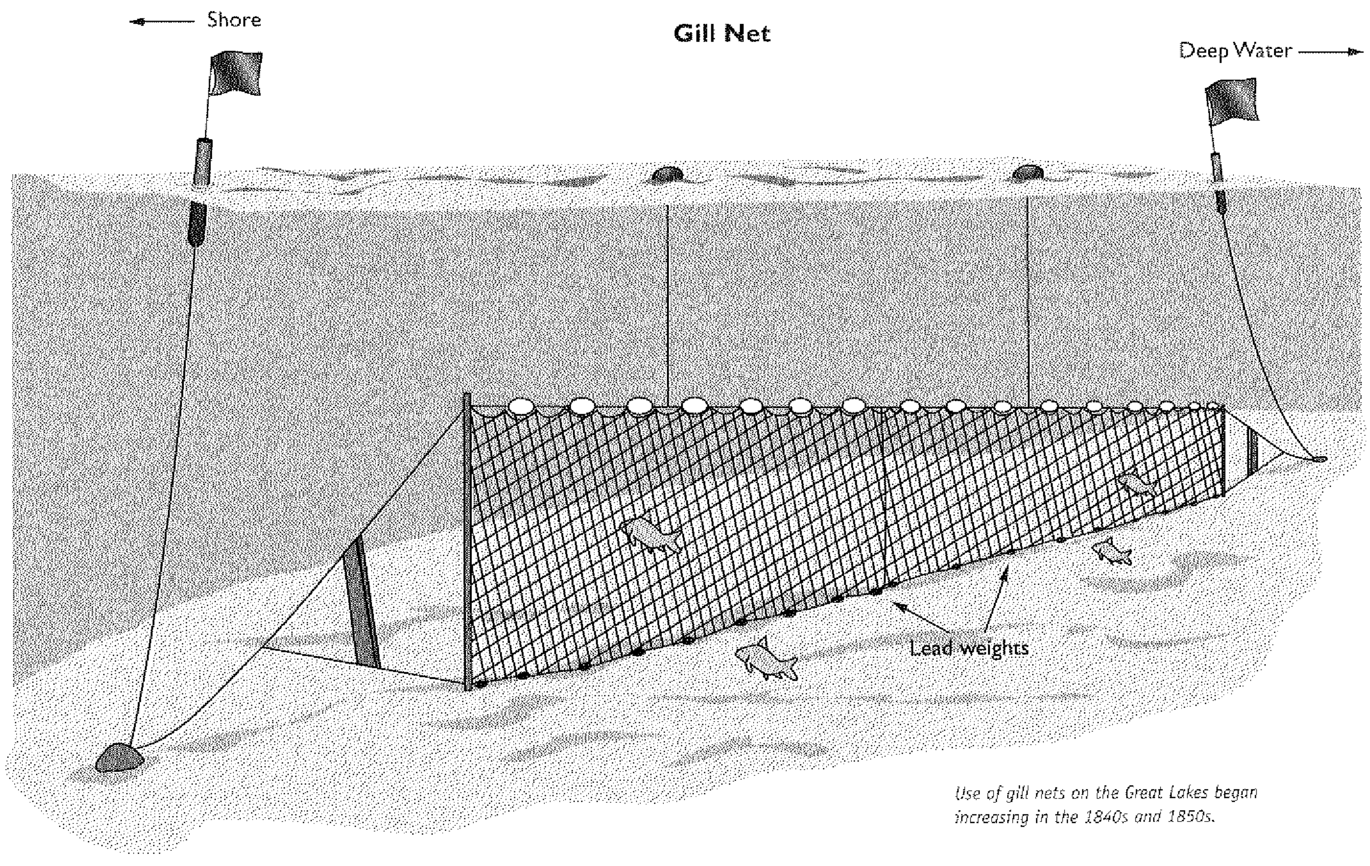
When Europeans first began exploring, about 60,000-117,000 native people lived in the region. (In contrast, about 33 million people now live in the Great Lakes Basin.) Fishes native to the Great Lakes were generally abundant relative to the number of people. The tribal groups in the region at that time included the First Nations, the Anishinabeg (Ottawa, Potawatomi, and Ojibwa, or Chippewa) the Iroquois and Huron and the Menominee, Winnebago, Illinois and Miami. By this time, fishing had grown to be vitally important in the lives of the peoples in the upper Great Lakes region. Villages were organized around the inland shores fishery. The peoples of the lower Great Lakes and the St. Lawrence River also relied on fisheries resources (including American eels) for part of their diets.

French explorers and early missionaries began arriving in the upper Great Lakes in the 1660s. Europeans learned about the long-established North American fishing techniques and also wrote about the unique dip-net fishing done from canoes in the St. Marys River between lakes Superior and Huron. Europeans also saw the extent of the Native American fishery, which occurred in open water and also through the ice in winter.

With the arrival of the Europeans, fur trading became a major historical influence on the Great Lakes region. This area was controlled mainly by the French, although the British were also trading with the native peoples. The lakes became the key routes for travel, trade, warfare, communication and diplomacy. Two worlds met, and Europeans and native peoples exchanged more than furs. Items of trade also included nets and other native gear that made hunting and fishing easier.

In 1763, the Treaty of Paris concluded the French and Indian War. The Great Lakes region was transferred from French to British control, though many French settlers remained in the region. In 1783, another treaty established what is now the U.S.-Canadian border. The tribes, the British and the Americans were still active in the fur trade, particularly in the western end of the upper Great Lakes. The frontier was in transition for several decades; both the U.S. and the British encouraged settlers to move to the Great Lakes region.

Prior to the arrival of Europeans, native tribes held all rights of ownership to the region's land and water. After the U.S. Revolutionary War, treaties with Native Americans led to land "cessions" in the United States and to land "surrender" in Canada. (Cession and surrender are terms for the process by which the governments acquired native peoples' lands for sale to settlers.) As settlement of this region by Americans and Europeans proceeded, both groups needed the land and resources. Sometimes the lands were obtained through warfare or other such means. Typically, the resources were procured through negotiation or purchased through treaties. A **treaty** is a tool and process used by one government to give its word to another government; the intention in a treaty is to protect a particular inter-governmental agreement over a long period of time. As land cessions occurred, communities began to grow, and populations of settlers increased greatly.



Use of gill nets on the Great Lakes began increasing in the 1840s and 1850s.

In the late 1700s, the demand for fur in Europe helped to strengthen the fur trade. This, in turn, necessitated early commercial fishing to feed the traders and settlers. The Northwest Fur Company dominated the west end of Lake Superior, particularly the Chequamegon (Wisconsin) area in the 1780s to 1790s. The company fished the north side of Isle Royale to feed people at its trading stations in western Lake Superior. Also in the 1790s, a hook and line commercial fishery developed on Lake Erie (near Presque Isle, Pennsylvania). Little is known about the earliest commercial fishing enterprises.

Before the 1800s, Great Lakes fish populations were thought to be unlimited and inexhaustible. But all of the changes brought by the new settlers set the stage for dramatic and rapid changes in fisheries in the next era.

Pound nets were used throughout the Great Lakes by the 1840s and 1850s. The stationary nets redirect fish swimming along shore, funneling them toward the crib or pound (enclosed end) offshore.

Changing Times: Era of Exploitation and Degradation

(About 1800 to 1870s)

Social Changes

Increasing numbers of settlers began arriving in the Great Lakes region and the northeast U.S. and Canada from1800 to the 1840s. The tremendous population growth in the region would have serious implications for environmental quality and fish populations.

The first large commercial fishery on Lake Huron was established around Fort Michilimackinac by 1800 and was an important element of the continuing fur trade. John Jacob Astor, along with the former Northwest Fur Company, incorporated the famous American Fur Company in 1808. After the War of 1812, the British agreed to withdraw to Canadian territory, and the upper Great Lakes were fully open to American fur traders. After the war, some of the first widespread commercial fisheries in the Great Lakes were established on Lake Erie, near the Maumee River and on the Detroit River. Commercial fishing was well established on the Canadian side of the lakes by the 1820s and 1830s. These commercial fisheries served eastern cities growing larger with immigrants. In 1826, the first shipments of salted whitefish and lake trout left Detroit for eastern markets.

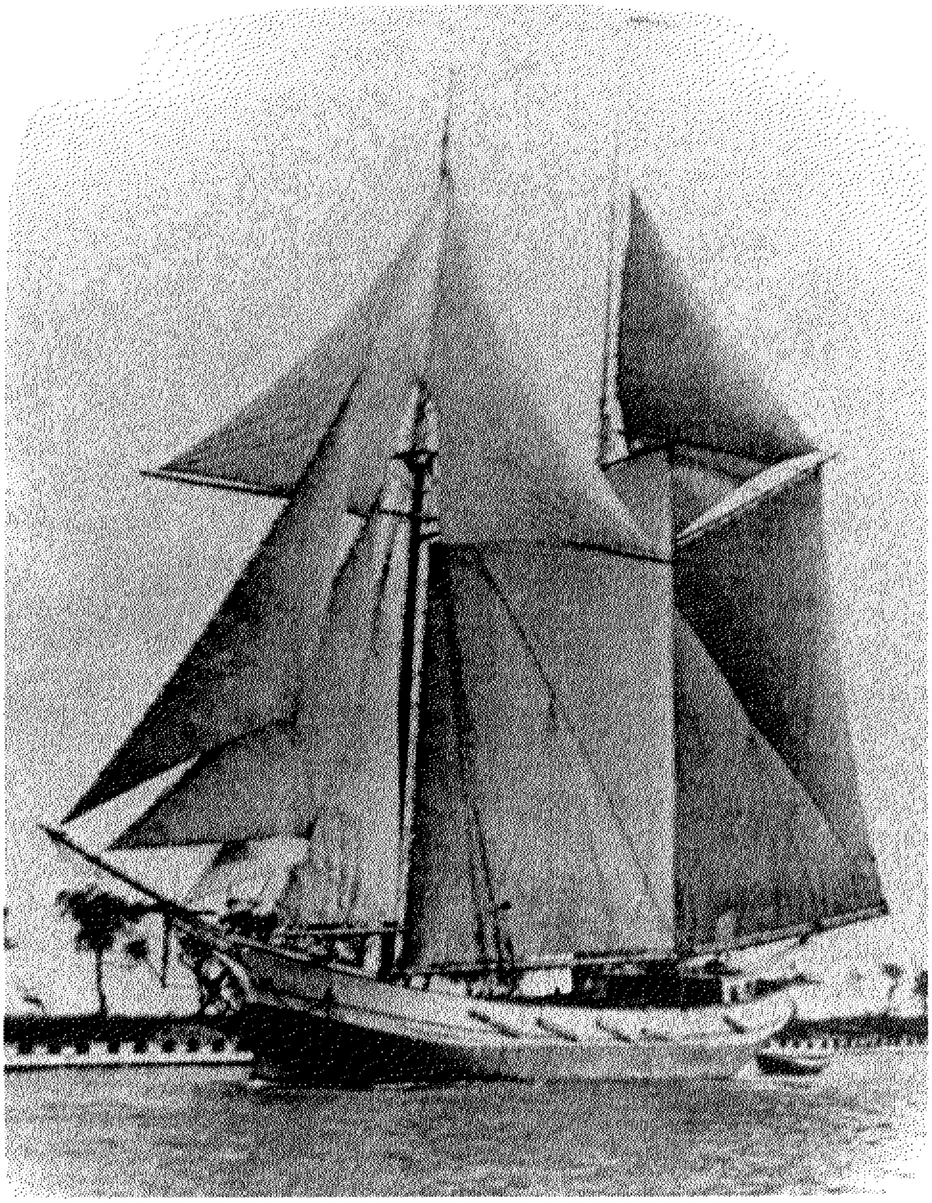
After 1834, Mackinac Island was reduced in status as a fur trading station, and the American Fur Company made its headquarters in western Lake Superior. The company built two schooners to carry furs to be sold in Sault Ste. Marie. The boatmen no longer needed for rowing the fur-carrying craft were employed as fishermen. Fishing stations were established throughout the western basin of Lake Superior. Men fished with handmade twine nets from wooden boats propelled by oars or sail. Others were employed at the fishing stations to clean, salt and pack the fish and to make the barrels in which fish were shipped to growing markets in the Ohio River Valley. The Hudson's Bay Company likewise employed men at fishing stations. Thus began large-scale, organized commercial fishing in the Great Lakes.

After the financial Panic of 1837, a depression put an end to the fishing business of the American Fur Company. By this time, the demand for furs in Europe had dropped dramatically. The company split up, and fishing continued on a smaller scale for a while.

Throughout this period, treaties were established between the native peoples and the new governments in the region. Another effort at land cession was made by the United States in the early 1800s to help the government through economic hard times. Although the Native Americans lost their land base through the negotiation of these treaties, fishing and hunting rights in the region were retained. Specifically, the results of this social change allowed Native Americans to retain their rights to fish in the waters of the Great Lakes ceded under the treaties. Thus, tribes were established as sovereign nations, managing their own governance systems and resources.

Several treaties still govern tribal fishing in the U.S. portion of the Great Lakes region and its waters. (In addition, Canada protects tribal fishing rights on the Great Lakes today under the Canadian Constitution Act of 1982.) The Treaty of 1836, or the Ottawa-Chippewa Treaty, ceded to the United States one of the largest tracts of land in the Great Lakes region in the area that was to become Michigan. Under the Treaty of 1842, the Red Cliff, Bad River, and Keweenaw Bands of Ojibwa exercised their treaty-fishing rights in Lake Superior. By the end of this era, most of the Native American land in the region had been ceded and reservations were being established.

Iron ore was discovered in upper Michigan in 1844, and waves of immigrants arrived to work in the iron and copper mines of the upper Great Lakes region. Rapid



The Jenny Weaver, a commercial fishing schooner of W.P. Kavanaugh Fishery, based in Bay City Michigan, 1880s.

technological changes allowed engineers to make modifications in waterways, which in turn provided easier transportation routes for the arriving immigrants. Communities throughout the Great Lakes region began to grow substantially.

Technological Changes

Boats and navigation in the Great Lakes began to change early in the 1800s. Steamboats first arrived in Lake Erie in 1818, and soon steam-powered boats were found throughout the region. Navigational improvements followed. In 1825, the Erie Canal opened, more directly connecting lakes Ontario and Erie with the Atlantic Ocean via the Hudson River and the port of New York. The Welland Ship Canal was constructed between lakes Ontario and Erie in 1829 to provide a route around Niagara Falls. This canal was improved and enlarged several times from 1833 to 1919. The Rideau Canal system was completed in 1832, connecting Kingston, Ontario with Ottawa. The St. Marys Falls Ship Canal (popularly known as the Soo Locks) connecting Lake Superior and Lake Huron was enlarged in 1855 to accommodate large lake-going vessels. These new watery connections would benefit immigrants and commercial vessels and would also play major roles in the story of Great Lakes fisheries in years to come!

Before 1850, simple fishing techniques on Lake Erie included seines (for sauger, walleye and smallmouth bass), brush weirs, spears, and trotlines (lines with multiple fish hooks). Seines and dipnets were also used. Almost all of the effort was concentrated in nearshore areas and focused on the major spawning runs of Atlantic salmon (in Lake Ontario), **coregonines** (lake whitefish and related fishes including lake herring, ciscoes and bloaters), and **percids** (members of the perch family including yellow perch and walleye).

Wooden boats were used to travel farther from shore. Pound nets were used throughout the Great Lakes, and gill net use was increasing by the 1840s and 1850s. Handmade cotton twine nets were replaced in the 1840s with cheaper machine-made nets. Linen nets were first used in the 1850s. These technological changes allowed fishing in deeper waters and led to larger catches. By the 1870s, seines were almost completely replaced by gill nets and pound nets. Steam-powered fishing tugs were introduced by the mid-1870s, allowing fishermen to travel even greater distances and to work in foul weather.

In 1851, the Erie Railroad became the first line connected to the Great Lakes, further changing the transport of fish. The Northern Railway connected Collingwood on the southwest portion of Georgian Bay (on Lake Huron) in 1855 with a large market in the developing Toronto area. Faster shipping of iced and frozen fish to eastern markets was now possible. Fishermen could store frozen fish until markets and prices were favorable for selling.

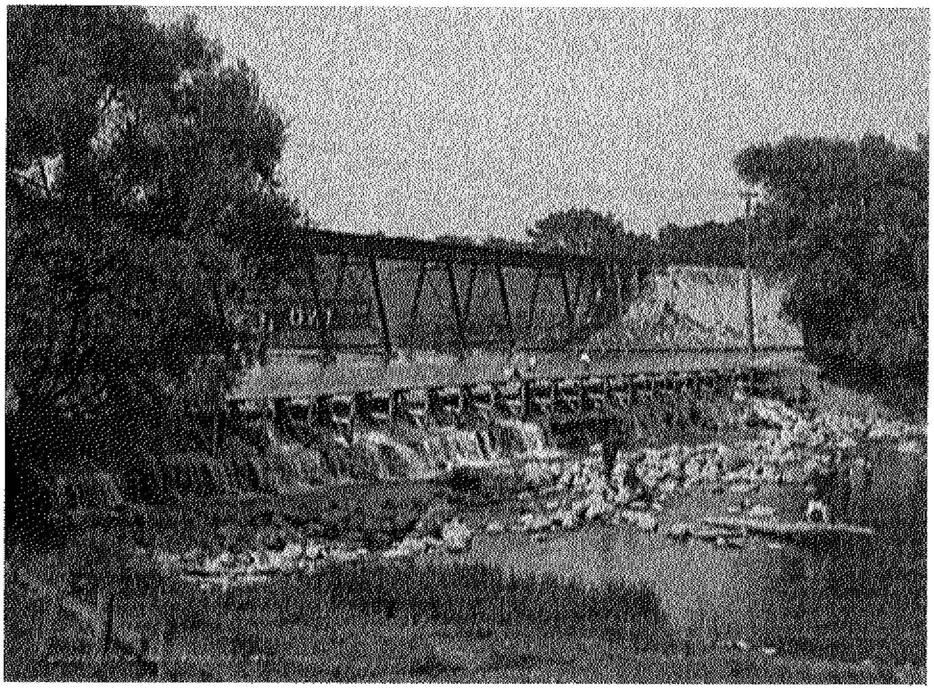
During the mid-1800s, the roots of **fisheries science** were established. In 1848, Professor Louis Agassiz and 15 others began one of the earliest scientific expeditions on the Great Lakes. They studied the north shore of Lake Superior. These scientists compiled some of the earliest technical descriptions of Great Lakes fishes. Other scientists were beginning to study lake level fluctuations and water chemistry.

Environmental Changes

Habitat degradation, due to increasing human populations and activities, and the arrival of **exotic** species were two major environmental changes that began to influence Great Lakes fisheries in the 1800s. The Lake Ontario basin was the first area in the region to be altered by canals and dams. Changes that occurred in the Lake Ontario Basin during the 1800s would be repeated in the other lakes from 1900 to the present.

The most profound early environmental changes in the lakes occurred during the logging era. Logging activity peaked first in New York in the mid-1800s, then farther west in Michigan in the 1860s to 1870s. These logging and settlement activities caused the first type of environmental change: loss of fish habitats due to extreme modifications of Great Lakes drainage systems. By the mid-1800s, water-powered mills of all sorts (including sawmills) were common on streams in the region. Many Great Lakes tributaries were dammed, preventing fish from passing upstream to spawn and concentrating them in downstream areas where they were more susceptible to over fishing. Heavy logging increased soil erosion into streams, causing **turbidity** (muddy, cloudy water), covering spawning areas and warming the waters, further degrading fishes' spawning habitats. Wetlands—spawning areas for other fish species—were drained and modified. Logging wastes such as sawdust were disposed of throughout coastal areas and in streams. Human and animal wastes from settlements and cities also entered the waterways. Thus, the effect of pollution on Great Lakes fisheries began rather early and is not merely a modern phenomenon.

The second type of environmental change that began in the 1800s was the arrival of exotic (nonnative) marine species in the Great Lakes. The sea lamprey was noted in Lake Ontario by the 1830s. By 1873, the alewife, a cool water fish from the Atlantic Ocean, had traveled through the Erie Canal and was established in Lake Ontario. The effects of the alewife would be felt throughout the Great Lakes food web within a few decades.



Construction of dams on Great Lakes tributaries in the mid 1800s prevented fish from swimming upstream to spawn.

Changes in the Great Lakes Fisheries

Major changes in Great Lakes fish populations began in the early 1800s in Lake Ontario. The earliest intensive fishery in the region was for Atlantic salmon, the most valued and heavily exploited fish from the late 1700s to the mid-1800s. Mill dams concentrated these fish and made them more vulnerable to harvest. These and other changes in the **tributary** streams decreased the amount of accessible spawning habitat. The main reasons for the loss of salmon were probably habitat degradation and intensive fishing. By the 1830s and 1840s, this loss caused the first major fisheries-related alarm on the Great Lakes. Restrictions on harvest and the first attempts at **stocking** in the 1860s led to a temporary, small recovery for Atlantic salmon, but the turn of the century brought the last record of native salmon in Lake Ontario.

During the early 1800s, intensive fishing for other Great Lakes fishes also occurred. Lake whitefish was the most fished species at this time in the four upper Great Lakes. Lake trout were second in all the lakes; harvest of lake trout became even more important when lake whitefish numbers were low and as Atlantic salmon decreased in Lake Ontario. Other important fishes included the lake herring in Lake Erie, Saginaw Bay (Lake Huron) and Green Bay (Lake Michigan), the lake sturgeon throughout the lakes, and deepwater ciscoes in lakes Huron, Michigan and Superior. By 1860, the catch of lake whitefish in Green Bay had declined by 50 percent. By the 1860s, laws in the region began to restrict fishing by establishing catch limits and closed seasons. As early as 1861, Ohio declared its first closed season for some fishes. Significant changes for Great Lakes fisheries had already begun.

Early Efforts: Era of Regulations and Stocking

(1870s to early 1900s)

Social Changes

After the U.S. Civil War, the Great Lakes region experienced more settlement. Railroad construction expanded, and large shoreline cities such as Chicago grew even larger. More Native American reservations were established as lands in the region were ceded to the U.S. government and surrendered to the British government in Canada. Some sportfishing began; in 1885, daily sportfishing excursions were offered on Lake Erie. When Great Britain entered World War I in 1914, fishing in Canada was declared an essential service.

Technological Changes

In 1870, the first Canadian steam-fishing tug above the Niagara River began to work in Lake Huron. In the 1870s, steam engines were improved, and work proceeded on internal combustion engines in 1886. Gasoline engines began catching on around the turn of the century, and Ole Evinrude of Minnesota developed the first commercially successful outboard motor in 1909. Diesel engines with fuel injection were available by 1910, and the first diesel boats on the Great Lakes were built in 1920. Throughout this era, however, the steam tug remained most numerous on the Great Lakes. Steel was first used in shipbuilding in 1875.

As engine technologies changed, so too did the technologies used to haul larger and larger nets from the water. In 1895, the Connable steam net lifter was patented, and its use around the turn of the century allowed more gill nets to be set and hauled. Gasoline net lifters were also developed.

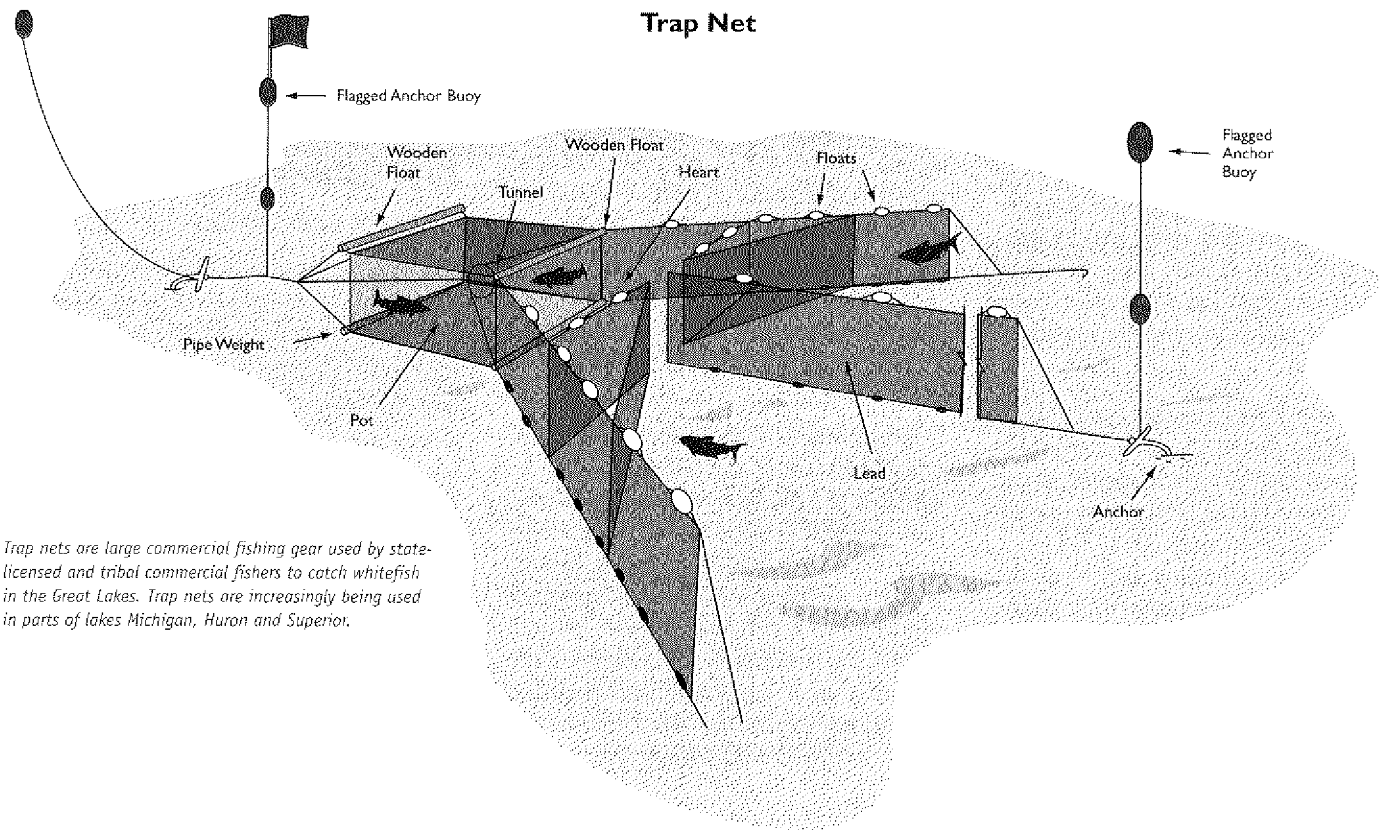
Navigational improvements of this era included construction of the Chicago Sanitary and Ship Canal around 1900, connecting the Great Lakes with the Mississippi River watershed.

Fishing techniques also changed around the turn of the century. During the 1890s, a new type of gear called the trap net was used in the Great Lakes (in Saginaw Bay and the St. Marys River). This net was a more efficient, easier-to-move variation on the pound net. This net was popular in U.S. waters, but it was not legal in Canadian waters until 1950 (although it was used earlier in Georgian Bay).

Pound net fishermen and gill net fishermen had disagreed over which nets should be used, and some fishermen worried that the efficient trap nets would result in overfishing. While this controversy was beginning to simmer, even more efficient variations on the gill net were appearing. About 1900, "canning" of gill nets began. Canning (floating) gill nets in mid-water rather than anchoring nets to the bottom allowed nets to be moved to various water depths with changes in seasons and temperature. Catches increased. In 1905, U.S. fishermen on Lake Erie invented a variation of the gill net called the bull net. Until then, gill nets used to catch herring were only about five feet tall; however, bull nets were up to 22 feet tall! Around 1900, less expensive cotton nets were introduced. In summary, during this era, nets became cheaper, larger, easier to move and to haul out of the water, and more efficient. The **mesh sizes** of fishing nets were shrinking, taking younger and younger fish; larger, older size classes were "fished out."

Fisheries management began in full force during this era. In 1870, the American Fish Culturists' Association, a professional organization, was formed; in 1884, this group became the American Fisheries Society. In 1871, J. S. Milner began a survey for the U.S. Commission of Fish and Fisheries. He toured the shores and islands of Lake Michigan, collecting information on the life histories of fishes important to the commercial fishing industry. Unfortunately, much of his fish

Trap Net

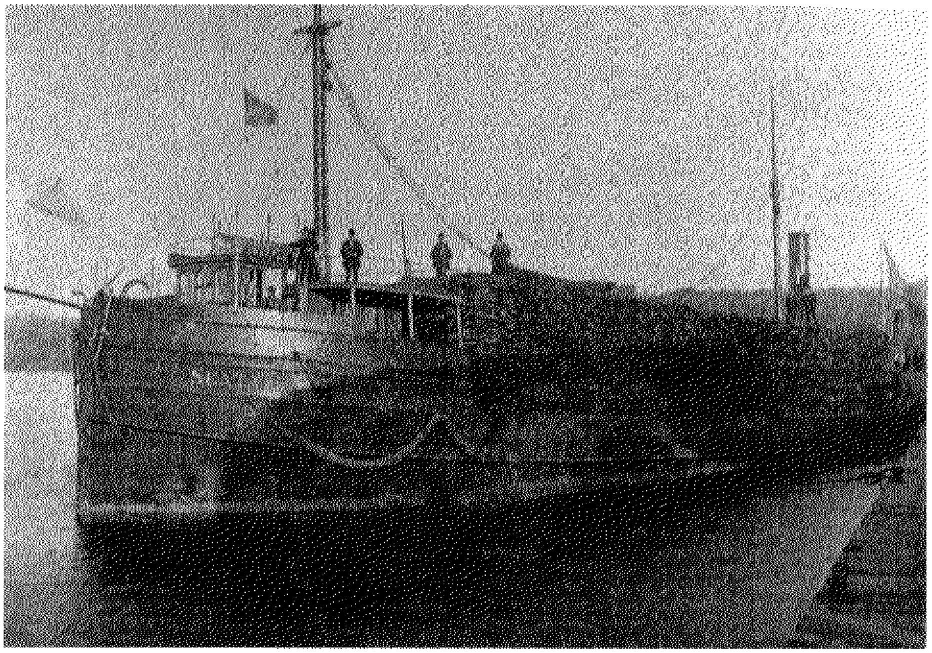


Trap nets are large commercial fishing gear used by state-licensed and tribal commercial fishers to catch whitefish in the Great Lakes. Trap nets are increasingly being used in parts of lakes Michigan, Huron and Superior.

collection, stored at the Chicago Academy of Science, was lost in the Great Chicago Fire of 1871. In 1872, he extended his survey to lakes Superior, Huron, St. Clair and Erie. His reports discussed what were probably the first scientific efforts to study lake whitefish migrations by tagging fish. Milner's studies gave evidence of serious declines in Great Lakes fisheries, and he recommended protective legislation and hatchery propagation of fish.

Hatchery rearing of fish was a major focus of fisheries management in the Great Lakes during this era. While some hatchery work had been tried in North America in the 1850s and 1860s, these efforts did not evolve into large-scale efforts until later. In the late 1860s, Ontario's Samuel Wilmot became involved in trying to restore the Atlantic salmon by artificial propagation. In 1876, he was made superintendent of fish culture, and the hatchery effort expanded in Canada. In 1874 in Michigan, the Board of Fish Commissioners (started just one year earlier) established a fish hatchery on the Detroit River. Several other states also established hatcheries during this period. During the 1880s and 1890s, the U.S. government began operating hatcheries in Michigan at Northville and Alpena, in Sandusky and Put-in-Bay, Ohio, in Duluth, Minnesota, and in Cape Vincent, New York. Little is known about the success of these early programs. By the turn of the century, people were already disgruntled that the **stocking** efforts were not noticeably increasing fish abundance.

In this era, fisheries research was just beginning. The major philosophy at the time was that fish were declining because they were having trouble reproducing; thus, if more hatchery-reared fish were added (i.e. if the reproductive process and the early survival of fishes were helped along), more fish would ultimately be available to harvest. Concern about fish population declines, however, prompted some researchers to investigate underlying factors such as water quality and food availability that affect **fish production**. Researchers in the United States and Canada were just getting started. At the same time, concern about the poor water quality in the Great Lakes prompted the first successful international agreements. In 1909, the Boundary Waters Treaty between the United States and Canada established the International Joint Commission (IJC) to study water quantity and quality issues in the Great Lakes. Extensive studies began and continued into the following eras.



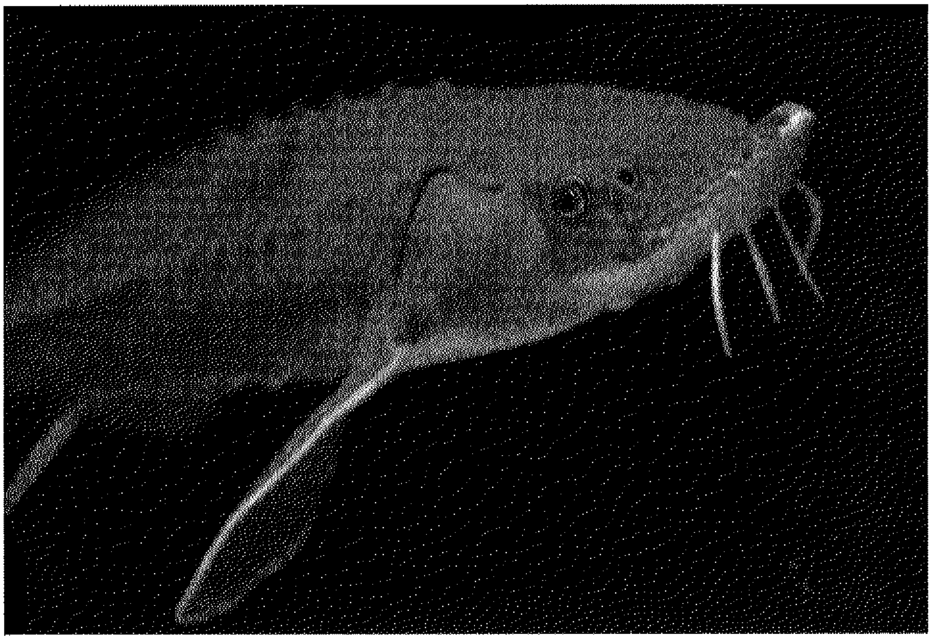
The most profound early environmental changes in the lakes occurred during the logging era. Heavy logging increased soil erosion into streams, causing turbidity (muddy, cloudy water) that contributed to a loss of fishery habitat.

Environmental Changes

The two themes of environmental change—modification of drainage systems and invasion by **exotic** species—continued between 1870 and the early 1900s. For example, human population growth, forest cutting, land clearing, development, wetland drainage, harbor dredging, pollution from lumbering activities, and sewer outflows continued throughout the Lake Michigan basin after 1850 and until the early 1900s.

Many serious fires raged throughout the region in the decades immediately following the peak of logging. In 1871, a fire burned the northwestern edge of Lake Michigan, from just north of the city of Green Bay, Wisconsin to just south of Escanaba, Michigan. Other fires of this era burned along the coasts of Lake Huron. With fires came soil erosion and increased turbidity and pollution in the water. Areas such as Green Bay in Lake Michigan began to experience the severe problems with environmental quality that lakes Erie and Ontario had experienced earlier.

In this era, an important environmental change was just starting to take its toll on water quality and fisheries. **Eutrophication** (a term not coined until the 20th century) is the process by which waters increase in nutrients. While eutrophication occurs naturally as lakes age over geological time, cultural eutrophication is a process of rapid changes due to human influences in the watershed. This process was already affecting the more southerly, shallow Great Lakes during the late 1800s and at the turn of the century. These early effects were caused by the logging activities in the Great Lakes watershed and by the rapid settlement of portions of the basin, particularly the lower lakes (St. Clair, Erie and Ontario). These activities caused soil erosion, warming of the water, and the run-off of nutrients from the land into the waterways, thus causing cultural eutrophication. Other locations experiencing these early effects were the shallow bays such as Green Bay and Saginaw Bay. Fish species adapted to the **oligotrophic** (cold, deep, low nutrient) conditions of the lakes also experienced declines, one of the effects of cultural eutrophication.



Overfishing and loss of nearshore spawning habitat contributed to the decline of lake sturgeon in the Great Lakes between 1890 and 1910.

The arrival and impacts of exotic species in the Great Lakes (particularly those upstream from Lake Ontario) were noted during the late 1800s. Sea lamprey were first noted in Lake Ontario in the 1830s, and by the 1880s they were causing problems for fish populations there. Sea lamprey had either arrived through the Erie Canal or they had been native to the Lake Ontario basin. By 1921, the sea lamprey had made its way into Lake Erie. The rainbow smelt was introduced intentionally into Crystal Lake at the edge of Lake Michigan in 1912. During the next two decades, it would make its way into all of the other lakes. Another marine invader, the alewife, had first appeared in Lake Ontario in 1873. Some species were intentionally introduced into the Great Lakes during the heydays of hatchery propagation; these included steelhead, Chinook salmon, brown trout, and carp.

Changes in the Great Lakes Fisheries

After the loss of the Atlantic salmon in Lake Ontario, the next major decline in the Great Lakes was the lake sturgeon. At first, this species was not commercially important and was destroyed because it damaged fishing nets. Later, though, many uses for this fish were found and many products were derived from it. Sturgeon caviar (eggs) became popular, and oil from the fish was used for a variety of purposes. Its air bladder was used to manufacture isinglass (a gelatin used as a clarifying agent and in jellies and glue), and carcasses were used as fertilizer.

Between 1890 and 1910, lake sturgeon declined in all the lakes. In 1879, the sturgeon catch for Lake Michigan was 3.8 million pounds (1.7 million kilograms), but some decline had probably already occurred. By 1911, the catch was only 14,000 pounds (6,350 kilograms), and after that the fish was nearly nonexistent in commercial catches. Lake Erie's sturgeon catch was about 5 million pounds (2.3 million kilograms) in 1885, but dropped to only 100,000 pounds (45,360 kilograms) in 1916 and never recovered. Lake Huron sturgeon experienced a similar decline but reached low levels later in the 1930s. Lake Ontario's sturgeon catch dropped from 581,000 pounds (263,500 kilograms) in the 1890s to only 10,000 pounds (4,500 kilograms) by the 1920s. Much of this loss was due first to overfishing and second to the loss of spawning habitats in inshore areas and rivers. The biological characteristics of the sturgeon made it extremely difficult for the fish to recover; it matures late, grows slowly, and is relatively easy to capture. (It is now found in certain local areas of the Great Lakes such as Lake Huron's North Channel, the Menominee River, parts of Lake Superior, and the St. Clair River.)

The next major loss of Great Lakes fisheries was the decline of river-run lake trout, lake whitefish and lake herring. These were subgroups that spawned in river habitats. The largest runs were in the rivers emptying into lakes Huron, Michigan, St. Clair and Erie. These fishes were lost by the early 1900s, mainly because of modification of the river drainages caused by logging and sawmilling activities and dams.

One group of fishes, the **coregonines**, experienced heavy fishing pressure during this era. The coregonines are members of the family Salmonidae, forming the subfamily that includes lake whitefish, lake herring, and ciscoes (commonly called "chubs"). By 1879, great fluctuations occurred in lake whitefish catches from Lake Ontario, (as well as fluctuations in ciscoes and lake herring). By the 1920s, however, lake whitefish had recovered in Lake Ontario. By 1880, Lake Erie pound netters complained of decreased lake whitefish harvests. In the western basin of Lake Erie, smaller lake whitefish were being harvested as smaller and smaller net mesh sizes were used to catch lake herring. From 1885 to 1911, Lake Superior saw declines in lake whitefish, so effort switched to another species, and this period began the "glory years" for lake trout there. In Lake Michigan, lake whitefish were fairly stable with a harvest of 1-2 million pounds (0.45-0.91 million kilograms) per year from 1894 to 1927. In the 1920s, lake whitefish catches increased.

Other coregonines—lake herring and ciscoes—were sensitive to fishing pressures and other factors during this time. Throughout the lakes, it was difficult to trace the actual fluctuations of individual species of coregonines, because catch statistics for lake herring and the various cisco species were often combined. The year 1910 saw a major decline in lake herring in Lake Michigan. (In Lake Michigan, most of the lake herring and ciscoes were taken from Green Bay.) Before then, catches of up to 20 million pounds (9.1 million kilograms) were reported, though numbers of these fishes varied widely. The first species of ciscoes to decline were the larger ones, such as the blackfin. As larger ciscoes were fished out, fishermen would switch to smaller and smaller net mesh sizes to take the other smaller species. Fishermen would also move to take advantage of **stocks** (groups of fish that spawn in a particular part of the lake or at a certain time), sometimes following them during their seasonal migrations. As the larger species of ciscoes declined, the catches of smaller species such as the bloater then increased and remained high. The Great Lakes fisheries were beginning to change dramatically. The number of unique forms of ciscoes declined; only a few species of Great Lakes coregonines remain today.

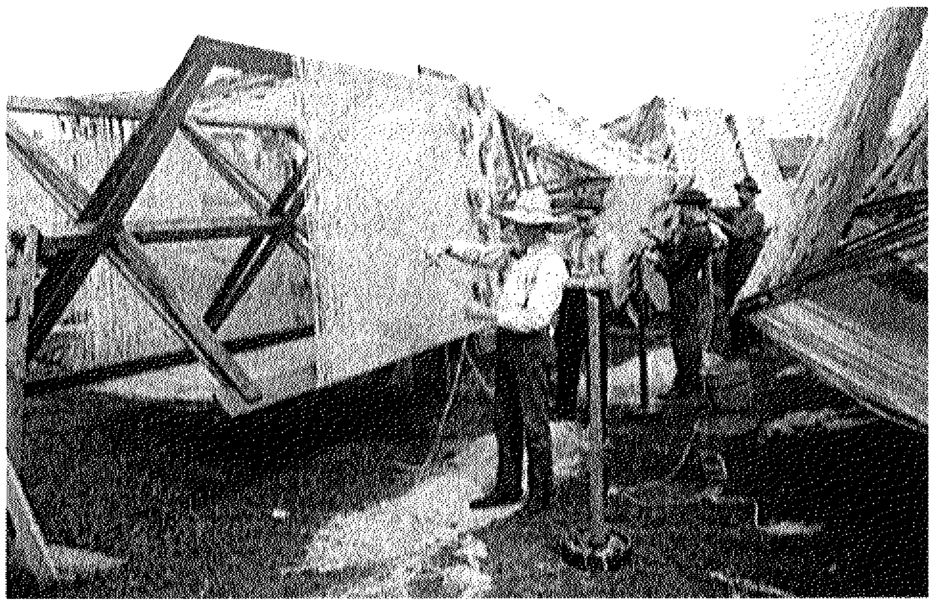
Unlike lake herring and its relatives, lake trout were amazingly resistant to intensive fishing for a long time. From the late 1800s to the early 1900s, this fish supported a stable and great fishing effort. The lake trout is a large predator that occupies a variety of areas in the Great Lakes, from shore to shore and from top to bottom. Because it fed on many different species of forage fishes—including lake herring, ciscoes and sculpins—and because the forage base as a whole remained stable throughout much of this era, the lake trout were able to maintain their numbers in the upper Great Lakes.

In the lower Great Lakes, however, lake trout populations began to experience the combined effects of intense fishing pressure and eutrophication. In Lake Erie, lake trout populations began to decline earlier than in the other lakes. Since Lake Erie is at the southern end of the range of the coldwater lake trout, this fish was never abundant and had been relatively rare in the shallower western and central basins. By the end of the 1800s, it had declined, and it was seldom caught after the 1930s.

The lake trout story in Lake Ontario was more complex. Trout there experienced the combined effects of over fishing, cultural eutrophication and the impacts of the exotic invaders. In the 1870s, after the loss of the Atlantic salmon, the alewife increased in Lake Ontario. Alewife may have competed with and forced the decline of other plankton-eating fishes such as the coregonines and yellow perch. In the 1880s, sea lamprey increased in the lake, in part due to the fact that the streams warmed slightly by environmental changes were better suited now for sea lamprey reproduction. The sea lampreys were **parasites** on lake trout and other fishes, and so the populations of these fishes began to decline in Lake Ontario.

This era had brought tremendous changes to the life of the Great Lakes. Early in this period were the heydays of commercial fishing on many of the lakes. In 1871, over 32.2 million pounds (14.6 million kilograms) of Great Lakes fish were handled at major fish markets, and more were probably consumed locally. Lake Michigan alone had a commercial industry employing over 2,000 people and 600 vessels. By 1889, more than 10,000 people fished the lakes. In 1899, Lake Ontario experienced a peak in its catch. Around 1900, the catch from Lake Erie surpassed or equaled the production of all other lakes combined. But the combined effects of social, technological, and environmental changes were beginning to take their toll on fishes.

Overfishing (with improved technologies) had seriously affected populations of Atlantic salmon and lake whitefish. New invaders had already made their presence known in the lower lakes and would quickly change the entire Great Lakes fisheries. By the end of this era, agencies responded to the decline of some fishes by establishing fishing regulations. Fisheries laws developed at this time included gear restrictions, closed seasons and catch limits. For example, by the late 1800s, laws regulated the **mesh size** of gill nets used in the Great Lakes. In 1906-07, Ohio and Michigan began to license their commercial fishermen. Fisheries law enforcement started in the region, but (like today) officers were few compared to the vastness of the lakes they were responsible for covering. Differences in state and provincial fishing laws also made enforcement difficult. Changes in the fisheries in this era set the stage for the next era.



Commercial fishermen mend their gill nets, Charlevoix, Michigan, 1906.

Era of New Invaders, New Challenges

(1920s to 1950s)

Social Changes

During the 1920s and even into the 1930s, a new way of looking at the Great Lakes took greater form. The tourism business boomed. Visitors flocked to shoreline resorts, even to remote areas of the lakes such as Isle Royale, and the wealthy developed their own lakefront retreats. Visitors of all types dined on Great Lakes fishes. Charter fishing became more common during the 1920s when commercial fishermen took recreational anglers fishing for lake trout.

Meanwhile, the commercial and subsistence tribal fishery continued. In 1924, U.S. citizenship was granted to Native Americans. In 1930, a court case in Michigan declared that Native Americans had no special fishing or hunting rights under state regulations. At this point, Native Americans did not challenge this court decision, and they had to buy state commercial fishing licenses.

In 1929, the U.S. stock market crashed, and many fish wholesalers went out of business. In 1939, Canada entered WWII and, by 1942, the U.S. was at war. Fishing was again declared an essential service, and commercial fishermen were exempt from the draft. By 1945, the war was over, but the world had changed. Global markets were opening, and sportfishing began to rise again.

Technological Changes

During the 1920s and 1930s, the fishing fleet in the Great Lakes began converting to diesel engines. These were less bulky and used less fuel and labor to operate. The older steam fishing tugs had required a crew of seven—a captain, an engineer and five fishermen. Diesel boats, however, did not need an engineer and needed only half as many laborers. Also at this time, the first steel-hulled Great Lakes fishing boats began to replace wooden hulled boats.

In the 1920s, the bull net was still in use; peak bull net use and increasing gill net use in Canadian waters of Lake Erie occurred in the mid-1920s. In the 1920s, a new version of the trap net appeared on Lake Huron. Called a "deep trap net," it was set in greater depths and on a variety of bottom types. It could be handled more easily than previous pound nets and was used to catch lake whitefish in their deep summer **habitats**. It was introduced on Lake Huron in 1928; over the next two years, fishermen scrambled to convert to the new gear. Catches of lake whitefish doubled, then lake whitefish began disappearing from the northern grounds of Lake Huron. Gill and pound netters protested the new gear. Governments began investigating this issue in 1931. In 1934, the conflict among the various fishermen had escalated, and southern fishermen drove out the encroaching northern deep trap netters trying to fish their southern waters. This net was banned in U.S. waters by the mid-1930s (it had never been used in Canada); eventually, its use was governed by size and depth restrictions. This story is one that had already occurred on the lakes and would repeat itself: the story of conflict among fisheries user groups and of the crusade by some users to protect the resource upon which they all depended.

An important change in net technology began when nylon was invented in 1935. Nylon was lighter, did not absorb water, and decayed more slowly than cotton and linen net materials. Nylon nets could be left in the water longer, were easier to handle, and were nearly invisible to the fish. By the 1950s, nearly all of the gill nets in the Great Lakes were replaced with nylon, and within 10 years so were the pound and trap nets. In addition, around WWII, the old-style wooden floats, or "corks," which fishermen had carved from cedar, were replaced with plastic or aluminum floats that allowed fishing in deeper water.

Other semi-modern advances were made in these few decades. In the 1930s, refrigerated trucks transported fish to markets. In 1935, radar was invented, but would make its way into the lakes gradually. In the 1940s, fishermen began to use sonar (depth finders) and radios.

Fisheries science made important advances, too. The collapse of the lake herring fishery in Lake Erie by 1925 prompted large-scale studies on Great Lakes ecology. One study sponsored by Ohio examined the effects of pollution in Lake Erie. A 1927 study by the U.S. Bureau of Commercial Fisheries was the beginning of federal fisheries research on the Great Lakes. This study examined the limnology (the chemistry, plankton and benthos) of Lake Erie. A third study on Lake Michigan was conducted by the U.S. government, the states of Michigan and Wisconsin and four net manufacturers. This study examined gill net size and effects on harvest of chubs while avoiding unintentional catches of small lake trout.

In the 1940s, a better understanding of the factors influencing fish production led fisheries managers to use a philosophy of **Maximum Sustainable Yield (MSY)**. The philosophy requires understanding fish reproductive and growth requirements in relation to the productive capacity or biomass that the fish habitat will support. In theory, managers can use this knowledge to create quotas or regulations that result in the maximum harvest yield that can be maintained without causing declines in fish populations or health.

Environmental Changes

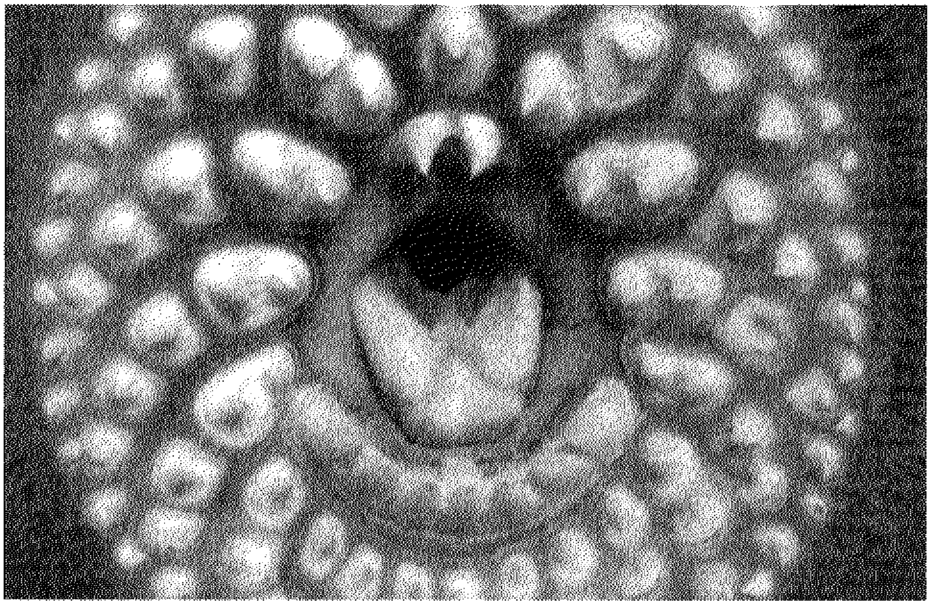
Cultural eutrophication became a major force of environmental change during this era. Trends of decline in water quality continued and spread to the upper Great Lakes. The effects of these changes were compounded by the second major type of environmental change that would happen during this time—the increasing invasion of exotic marine species such as alewife, sea lamprey and smelt. These were the newest characters in the drama of the life of the lakes.

The alewife and sea lamprey had made their way from Lake Ontario into the other lakes through the Welland Canal and/or Erie Canal. Neither the alewife nor the sea lamprey became very well established in Lake Erie, probably due to poor water quality in its tributaries and because this lake has many areas that are warmer than these species prefer for part of their life cycles. The sea lamprey moved into the upper lakes slightly ahead of the alewife; both species first moved into lakes Huron and Michigan, then into Lake Superior.

Year of First Record for Exotic Species in the Great Lakes

Lake	Sea Lamprey	Alewife	Smelt
Ontario	1830s	1873	1929
Erie	1921	1931	1932
Huron	1932	1933	1925
Michigan	1936	1949	1923
Superior	1946	1954	1930

Source: Hartman 1988; Mills et al. 1993



Sea lampreys attach to fish by using a sucking disk with sharp, rasping teeth. Parasitism by sea lamprey has contributed to declines in large predator species such as lake trout.

Changes in the Great Lakes Fisheries

The declines of the previous era continued into the 1920s and beyond. Among the most dramatic declines ever experienced in the Great Lakes was the collapse of the lake herring and cisco fisheries beginning in the 1920s. The fluctuations in these populations finally led to a crash of the Lake Erie lake herring fishery in the 1920s. The fishery there dropped from an earlier high harvest rate of around 32 million pounds (14.5 million kilograms) per year to a low of only 5.7 million pounds (2.6 million kilograms) per year. Similar declines in lake herring catches from lakes Huron and Michigan occurred in the 1930s and again in the 1950s. Lake Superior's lake herring catch remained high until 1941, then declined. These declines were probably caused by overfishing and environmental degradation, particularly degradation of spawning areas in places such as Green Bay. After smelt had become established by the 1930s and 1940s, it may have competed with or preyed upon lake herring larvae, further influencing that fish's decline, especially in Lake Michigan.

The cisco catch rates of the Great Lakes also experienced serious declines by the 1950s. As lake trout populations reached their final peak in the 1920s, their prey (ciscoes) decreased. Once the lake trout began its decline, numbers of ciscoes increased somewhat in the 1930s and 1940s. With the decline of lake trout, fishermen switched to catching ciscoes, exploiting them in sequential order from the largest species to the smaller. Cisco catches were high for a short time. In the 1940s, cisco populations in Lakes Ontario and Huron collapsed due to a combination of overfishing, environmental degradation, and possible competition from rainbow smelt and alewife. The cisco catch in lakes Superior and Michigan remained constant through the 1950s but collapsed in the following decades.

As usual, fishermen responded to declines in lake herring and ciscoes by switching their effort to other species. Perch catches in lakes Huron and Erie increased in the late 1920s and early 1930s. Eventually, smelt became so well established in the lakes that fishermen began to utilize them. A smelt fishery using trawl nets developed on the Great Lakes.

The story of the sea lamprey's effects on various fishes is intricate. Once the sea lamprey became established in a lake, the first declines occurred in the large, deepwater species such as lake trout, burbot and the largest of the deepwater ciscoes. These were the species upon which the sea lamprey was a predator. The sea lamprey occasionally preyed upon the other coregonines such as lake whitefish and lake herring, and on walleye, bass, channel catfish and bullheads. As sea lamprey attacks increased, their prey declined. Because the numbers of large predator fish (mainly the lake trout) were declining, alewife were able to increase in abundance, especially in lakes Huron and Michigan. (Lake Superior and its tributaries were probably too cold for alewife to become as well-established.)

The alewife's story overlaps that of the sea lamprey. The alewife eats mainly large plankton just as the native lake herring does. As the alewife increased, the native lake herring and some other fishes decreased. The alewife, which traveled in dense schools, may have out-competed the young of native species or simply preyed on their eggs and **fry**. Eventually, the alewife became the dominant forage fish in the lakes.

Sea lamprey and alewife caused some of the most significant changes for the life of the lakes. Lake trout declined to a catch of less than 1,000 pounds (454 kilograms) in Lake Erie in 1937. Trout catches had already dropped in Saginaw Bay and Green Bay. Trout declined in Lake Huron in the late 1930s, and in Lake Superior in the 1940s. Finally, the lake trout fishery suffered a dramatic collapse in Lake Superior in the 1950s; fishermen switched back to lake herring, and their catch of this fish increased. Lake whitefish declined in the western basin of Lake Erie in the 1920s, and fishermen there switched to yellow perch. In Lake Michigan, lake whitefish had a resurgence in the 1920s, but the catch dropped again in the 1930s. By the 1930s, Lake Huron fishermen were noticing rapid drops in lake whitefish, and conflicts arose. Lake Superior continued its reputation as being somewhat isolated from and resistant to negative impacts — a recovery of lake whitefish occurred there in the 1930s and 1940s.

Other species showed dramatic effects during this era. In the 1930s, Lake Ontario's total fish production dropped behind even that of the historically less productive Lake Superior. In 1924, sauger in Lake Erie declined. Northern pike in Lake Erie had already declined by 1915, largely due to loss of wetland spawning areas.

In summary, because of over fishing, invasion by sea lamprey and alewife, and environmental degradation, this era saw the end of the Great Lakes commercial fishery for some native species that had influenced coastal history.

Era of New Problems, New Management Objectives and Recovery

(1950s to 1980s)

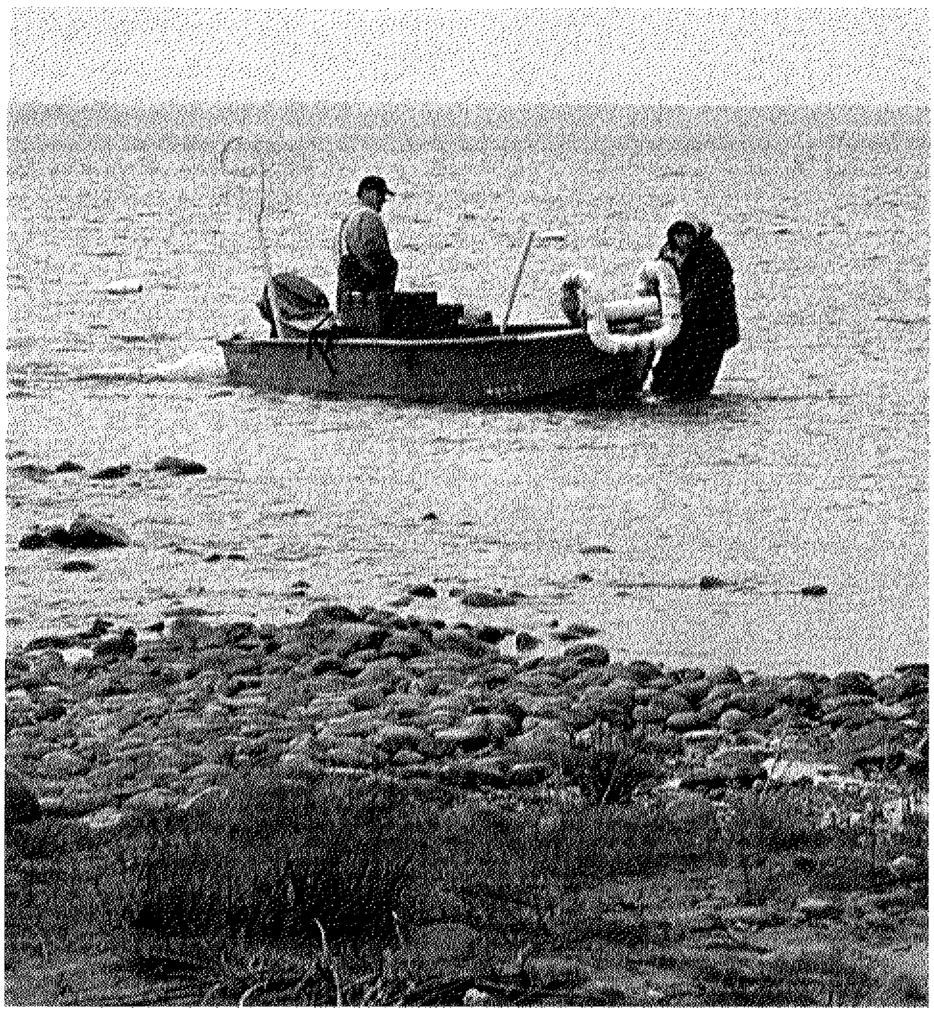
Social Changes

After the St. Lawrence Seaway system opened in 1959, the Great Lakes were accessible to medium sized, ocean-going vessels. The region became a bigger player in the global marketplace, spurring further industrial growth and development. However, with this direct opening came problems. The industrial boom led to new, more insidious environmental degradation.

Eventually, the U.S. and Canada experienced a social reawakening. Environmental quality had become so poor that the environmental movement came hand-in-hand with other social movements of the 1960s and 1970s. Environmental awareness of the Great Lakes increased when the mass media warned, "Lake Erie is dead." Rachel Carson's book *Silent Spring* told of the newest threats to the environment—pesticides and other chemical **contaminants**. Environmental groups formed, and sweeping reforms were made in national environmental legislation. The first Earth Day was held in 1970, largely in response to the eutrophication of the Great Lakes. People spoke up for laws to make water "fishable, swimmable and drinkable."

A multitude of changes in the Great Lakes environment and resulting declines in fisheries populations led to tremendous change in the social policies concerning tribal fishing in the region. States increased restrictions on tribal fishermen who had purchased state commercial fishing licenses. In 1972, the Gurnoe Decision of the Wisconsin State Supreme Court reaffirmed fishing rights originally specified in the Treaty of 1842 (for the Red Cliff, Bad River and Keweenaw Bay bands). This led to the establishment of 10-year fishing agreements negotiated between the tribes and the state of Wisconsin to establish fishing zones, harvest quotas, fishing effort and types of gear that may be used. In addition, the agreements also require exchange of biological information between the state and tribes.

Beginning in the 1970s, as sportfishing began to grow, widespread conflict occurred over tribal fishing rights in the Treaty of 1836 waters of lakes Huron and Michigan and eastern Lake Superior. In some communities, violence and vandalism against the Indian community and tribal fishers occurred. From 1971 to 1979, a Native American fisherman named Abe LeBlanc set gill nets in an effort to challenge the restriction of treaty fishing rights. By 1979, this effort had reached the courts; the judge decided in favor of tribal fishing rights in ceded waters of lakes Huron, Michigan and Superior. But while the issue was under consideration by the courts, a "racehorse" fishery existed; fishing activities by all parties went unchecked for years. Further controversy arose over the use of gill nets. Participating in court discussions were tribes, federal and state governments, as well as sportfishing organizations. In 1980, the U.S. Court of Appeals agreed with the judge's decision that the state could not interfere with tribal fishing unless it could



After a morning of fishing, a Bay Mills Indian Community small boat fisher is being pulled out of Lake Huron by his grandson.

be shown that the fishery was in jeopardy. The U.S. Supreme Court agreed with this decision by declining to review it. This process assured the tribes' right to self-regulation of fishery resource use.

In 1981, the tribes in the upper Great Lakes region established the Chippewa-Ottawa Treaty Fishery Management Authority (COTFMA), now known as the Chippewa Ottawa Resource Authority (CORA). This organization is responsible for establishing and enforcing fishing regulations for tribes' members. In cooperation with other fisheries management agencies and on the advice of the Inter-Tribal Fisheries and Assessment Program, CORA establishes harvest quotas, conducts fisheries research and enhancement projects, and conducts long-term studies on contaminants in fishes. Another important organization is the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), which supports fisheries conservation efforts conducted by tribal groups in the Lake Superior region.

Technological Changes

Along with the changes in shipping and global economies came other technological changes. The computer age began, allowing more accurate navigation and data processing. Fish finders and Loran-C navigation soon became commonplace.

With industrial growth in the region came a vast array of industrial, agricultural and household chemical products. Point sources of pollution included municipal sewage treatment plants and a variety of new industrial processes, supported by new technologies. Nonpoint sources of pollution included agricultural runoff, household use of such products as detergents with **phosphates,** and lawn and garden chemicals. These products were used by a growing population in cities, suburbs and even rural areas of the Great Lakes region. It would take some time before people realized the impacts such chemicals could have in the Great Lakes.

Several chemicals, arising from the agricultural and industrial sectors, are important in the story of technological change in the Great Lakes due to their serious effects. The main "advances" in this era were **DDT**, used as an insecticide to battle the organisms causing Dutch elm disease and to eradicate mosquitoes, and **PCBs**, one of many chemicals used in electrical insulation and in manufacturing and other processes. PCBs were widely used in plastics, paints, electrical parts and transformers, carbonless copy paper, adhesives, fire retardants and lubricants in industrial machinery, commercial refrigeration units, inks, and carpets. DDT and PCBs, as well as some other chemicals used in and chemical by-products of industrial processes, were identified in this era as **persistent chemicals**—substances that break down very slowly and that accumulate in the environment over long periods of time. Their legacy was to impact the life of the lakes markedly during this era of great technological and environmental change.

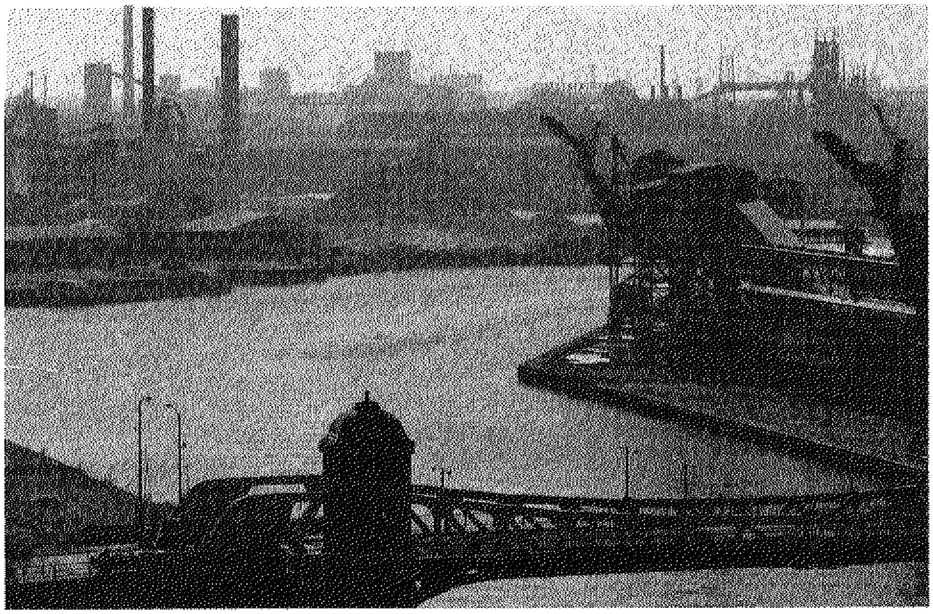
Anglers fish from the banks of the Detroit River.

Environmental Changes

Exotic species continued to exert their influences in the Great Lakes. The effects of the sea lamprey worsened in the 1950s until the first control efforts with lampricides began in 1958. The alewife had increased greatly. Massive die-offs of alewife began in the late 1950s and increased substantially in the 1960s, causing aesthetic problems on beaches. Other new invaders appeared years later in the Great Lakes, although this time these hitchhikers—notably the spiny water flea, zebra and quagga mussels, and ruffe—rode in aboard trans-oceanic vessels.

Very serious and obvious problems due to cultural eutrophication attracted public attention to Great Lakes fisheries. Although news media reported the "death" of Lake Erie, actually it was too alive. The eutrophication process had brought nutrients into the lake and over-enriched its productivity. Algae bloomed and died; combinations of small aquatic life changed (for example, tubificid worms replaced the burrowing mayfly). Increased plant life meant more decay, particularly at the lake bottom. This decay led to lower oxygen levels in the hypolimnion, the bottom, coldest layer of water. All of these factors led to fish kills and obvious changes in the life of the lake.

The public was alarmed! While Lake Erie was the most affected of the lakes because of the shape of its basin, its shallowness, the basin's larger human population, its greater pollution, and its southernmost location, the other lakes were beginning to experience some of the same serious changes, particularly in the bays. The shallows of the Great Lakes were important to Great Lakes fishes for **spawning** and early growth and important to humans for water supply, waste dilution, and recreation. These shallow, in-shore areas were the first to be affected by pollution. By the end of this era, the public supported broad-ranging legislative



Industrial complexes like this one on southern Lake Michigan contributed to an influx of pollutants into the Great Lakes in the 1960s.

initiatives in controlling some of these obvious sources of pollution. The lakes, including Lake Erie, began to recover from nutrient over-enrichment. They are now, in most ways, in better condition for humans and fishes than they were only a few decades ago.

While the eutrophication problems of the 1960s and 1970s were literally blooming, another insidious challenge to **ecosystems** was developing. This was the challenge posed by other chemical **pollutants**. Many modern-day pollutants are not very visible or obvious; in fact, the eutrophication problems of the past partially masked the effects of these other contaminants. Eventually, the presence of contaminants became known in the late 1960s and 1970s when people began to observe their effects on fish and wildlife. Some species, such as the bald eagle, had nearly disappeared from the Great Lakes region.

Meanwhile, scientists developed the technology to measure smaller and smaller concentrations of chemical contaminants in water and in animal tissue. Some contaminants, such as DDT and PCBs, are fat-soluble and are stored in an animal's fatty tissue. While only trace amounts of these chemicals were present in the water, through the processes of bioaccumulation and biomagnification the living organisms of the lakes collected quantities that affected them.

Bioaccumulation is the process of buildup of a material in an organism's body throughout its lifetime. Different fish and wildlife species are more or less susceptible to bioaccumulate certain materials; for example, long-lived species such as bald eagles and lake trout have a longer time to bioaccumulate potentially harmful substances. In addition, species with relatively high body-fat content (such as lake trout) accumulate more fat-soluble contaminants such as PCBs than do other, less fatty organisms.

Biomagnification is the process by which concentrations of persistent contaminants are increased along trophic levels of a food chain. For example, when animals such as zooplankton eat phytoplankton, they also consume the contaminants that have accumulated in their food. Contaminants (such as PCBs and DDT) that are persistent and fat-soluble remain in the body of the animal. At the next trophic level, when fish eat zooplankton, they absorb all the contaminants that the tiny animal received from its food and the water environment. Contaminants become increasingly concentrated or biomagnify in each animal along the food chain. Consumers such as eagles and humans can have concentrations of contaminants that are over one million times greater than the water concentration. Therefore, even very low environmental concentrations of certain contaminants may reach levels in top predators that may affect their health.

The use of DDT was banned in Great Lakes states between 1969 and 1971, then banned by the United States and Canada in 1972. The use and manufacture of the insecticides aldrin and dieldrin were banned in 1974. Voluntary control of PCBs began in 1971, and their manufacture was banned in 1977. PCBs, however, still enter the environment through improper disposal of products containing PCBs, and airborne PCBs from distant sources still enter the Great Lakes basin. DDT and its derivatives continue to be deposited into the Great Lakes from air masses picking up material from other countries where DDT is still used. Toxic quantities of such contaminants as DDT and PCBs still remain in bottom sediments where these non-water-soluble chemicals settled. Disturbance of sediments by dredging, shipping activity, storms, and burrowing organisms can bring these contaminants back into the food chain. Ironically, since deposition of these contaminants has been on a gradual decline, the lakes, themselves, now act as a source for these contaminants!

Unfortuntely, many of the areas of greatest contamination are of vital importance to the Great Lakes fisheries. Nearshore areas that provide critical habitat for fish spawning and for juvenile fishes are particularly vulnerable to point source pollution and to the input of contaminants from tributaries, runoff, and shoreline development. These littoral areas also are the most productive regions of the lakes, influencing their overall health and productivity. Contaminants in organisms in these nearshore areas influence the entire food webs of the lakes. In addition, most fishing occurs in the nearshore areas of the lakes such as bays, connecting channels, and lower reaches of tributaries, thus bringing humans into more direct contact with potentially contaminated fishes.

The problem of what to do about contaminants still exists. While levels of some contaminants have declined by up to 90 percent in most areas since the 1970s, some (such as PCBs) are still entering the basin, and some remain in sediments and probably will for a long time. Further gains in pollution control and reduction of nonpoint source pollution will be more difficult and will come at a greater cost.

Changes in the Great Lakes Fisheries

The changes in water quality and in the supply of invertebrate benthic fish foods due to eutrophication were felt in the fish populations of lakes Erie and Ontario. Warming, the lack of oxygen at the lake bottom in summer months, and the lack of burrowing mayflies and other benthic foods were particularly serious in the central basin of Lake Erie. By the late 1950s, these conditions led to the collapse of lake whitefish in Lake Erie. Walleye had also lost their important summer habitat, and commercial catches of this fish in Lake Erie declined by 1969 because of habitat loss and overfishing.

Another problem—**stunting** or slow growth—of yellow perch occurred in Green Bay and Saginaw Bay, partly due to the lack of large predators to remove enough perch so that the remaining perch could grow. Also, burrowing mayflies (a food source for yellow perch) were absent, probably due to contaminants and/or low oxygen in the lake sediments.

Throughout the lakes, the decline of lake trout finally reached catastrophic levels. In Lake Ontario, the lake trout catch in 1964 dropped to less than 1,000 pounds (454 kilograms). Even in Lake Superior, the lake trout declined dramatically in the 1960s. The effects of predation by the sea lamprey and intensive fishing pressure with nylon gill nets were too much for populations to withstand. The only fishes left to support the Great Lakes commercial fishery by the 1960s were smelt, yellow perch and bloaters. White perch, an exotic that arrived in the 1950s, supported a small fishery in the Bay of Quinte on Lake Ontario.

In summary, by the 1960s, the total effect of human population growth and technological changes had forever changed the Great Lakes fisheries. Many of these changes had occurred over a long time. In fact, some had their roots in the earliest technological changes at the beginning of settlement and commercial fishing in the area. Social, technological (including overfishing), and environmental changes (such as modification of drainage basins due to forest cutting and settlement, invasions by marine and other exotic species, and cultural eutrophication) had profound impacts. Great Lakes fisheries changed in two major ways:

- native species were replaced with exotic species such as smelt and alewives, thus altering the forage base for the larger fish in the lakes; and
- a general, widespread decline of lake whitefish and of large predators such as lake trout, walleye, and burbot occurred, and formerly relatively stable fish populations changed; lakes Ontario and Erie and deepwater regions of lakes Superior, Huron and Michigan showed the greatest changes.

These changes in the fisheries demanded three types of drastic action. Pollution control, sea lamprey control, and new directions for fisheries management were initiated throughout the region.

1) Pollution control:

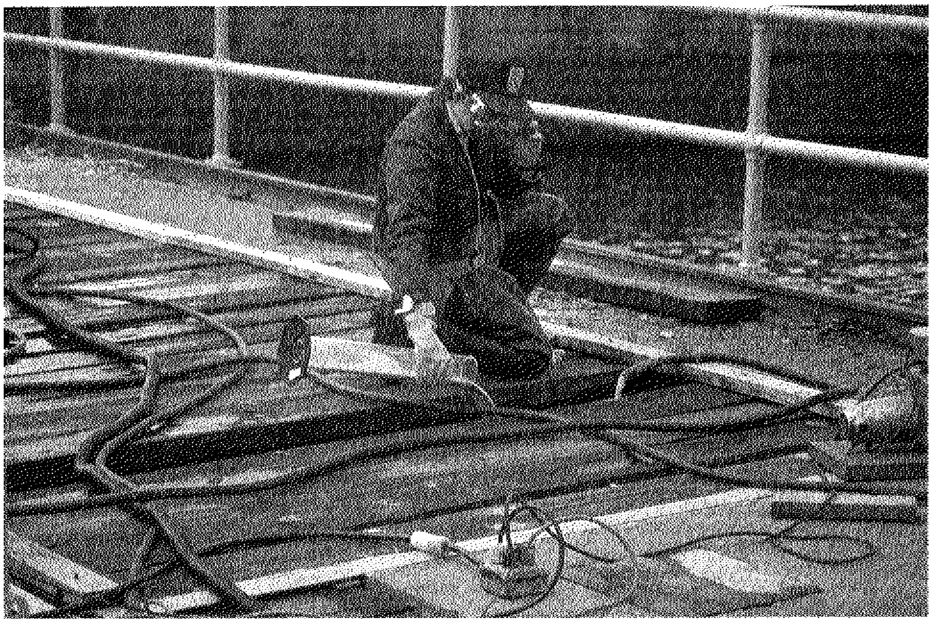
New water quality standards established in the 1970s went a long way toward controlling the factors that had so altered fish habitats in the Great Lakes. The governments of Canada and the United States signed the first Great Lakes Water Quality Agreement in 1972. Under this agreement, each government agreed to reduce the inputs of phosphorus, which had caused cultural eutrophication in the lakes. The International Joint Commission (IJC) was charged with overseeing progress in this area. In the United States, pollution control and cleanup were carried out by several states in conjunction with the Environmental Protection Agency (EPA) according to the Federal Clean Water Act. New wastewater treatment plants were constructed, and phosphates in detergents were reduced or banned. In Canada, the Province of Ontario's Ministry of the Environment joined forces with Environment Canada and many other governmental agencies to implement the agreement. Starting in 1987, under the leadership of the IJC, the United States and Canada identified areas of the Great Lakes basin severely affected by pollution. Each of these 43 Areas of Concern (AoCs) has a Remedial Action Plan (RAP) process, which takes a comprehensive approach to restoring the area's "beneficial uses," such as fishing and swimming. These RAPs allow many different agencies, communities and individuals to work together to solve serious water quality problems within the AoCs. Combined, these measures resulted in greatly improved water quality in the Great Lakes and in additional agreements to limit other pollutants in the basin.

2) Sea lamprey control and resulting changes in fisheries management in the basin:

The second set of drastic actions in the basin was spurred by the losses of fisheries due to the sea lamprey. In 1955, in one of the most important developments in Great Lakes fisheries management, the Great Lakes Fishery Commission (GLFC) was formed as a result of an international convention between the United States and Canada. The GLFC was established for two reasons:

- to coordinate and facilitate fisheries research programs, which would help in the sustained productivity of fishes, particularly the native lake trout; and
- to develop a program to eradicate or minimize sea lamprey in the lakes.

Over time, the GLFC has become an "umbrella organization" for collaborative fisheries management in the region through its system of technical and lake committees involving a wide array of scientists, managers and stakeholders. The GLFC provides a forum through which state and tribal agencies having jurisdictional authority over the fisheries can achieve consensus on management issues. The GLFC Strategic Plan is a document guiding these agencies, as well as the national level agencies and organizations concerned with fisheries issues in the region.



Lampricide treatment in the St. Louis River near Duluth, Minnesota.

Efforts by the U.S. Fish and Wildlife Service and the GLFC on sea lamprey research soon began to pay off. State, provincial and federal governments began cooperating on research; the establishment of the GLFC allowed fisheries managers to enter into a new era of international, broad-scale management. Several years of extremely intensive research led to the discovery in 1957 of the chemical lampricide called TFM. This lampricide works effectively to eliminate the larval sea lamprey that live in sediments in Great Lakes tributaries, while minimizing impacts on other life in the streams and rivers. By the 1960s and 1970s, many Great Lakes tributaries had been treated successfully with TFM. The sea lamprey problem had come under control to some degree.

3) New directions in fisheries management

A third set of drastic actions further influenced the direction that Great Lakes fisheries were to take in the modern era. New fisheries management goals were needed to address the current situation of low native fish populations, new forage fishes (some of which—namely alewives—were dying on beaches) and changing market demands. In 1966, the Michigan Department of Natural Resources (MDNR) began to take bold steps in changing the course of fisheries management toward a primary goal of establishing recreational fisheries. Over the next few years, the MDNR:

- prohibited the commercial harvest of lake trout and walleye in certain Michigan waters;
- regulated the commercial fishing effort by designating fishing zones and depths, banned gill nets for many state-licensed fishermen, limited the number of licensed commercial fishermen, and established catch and effort quotas;
- shifted the commercial fishery to the species less valued by sport anglers;
- decided to use the low value, smaller-sized fishes as a forage (food) base for desired sport fish;
- introduced Pacific salmon (coho salmon in 1966 and Chinook salmon in 1967) and built hatcheries to continue these stocking efforts.

Similar changes were soon made throughout the region. For example, the New York State Department of Environmental Conservation also reduced commercial fishing through such programs as its "buy-out" of Lake Erie fishermen.

This shift in basic philosophy benefited millions of Great Lakes residents by giving them a chance to experience the Great Lakes through recreational fishing. This change also reflected a change in fisheries management philosophy from Maximum Sustainable Yield (MSY) to **Optimum Sustainable Yield (OSY)**. Optimum Sustainable Yield blends biological, ecological, social, economic and political information and values in developing unique management goals for various fisheries to produce the optimum (most favorable or acceptable) benefits to society from fish stocks.

There was much discussion and controversy throughout the region as these sweeping changes were made. The Province of Ontario did not agree with this basic philosophy of introducing exotics (the Pacific salmon) to manage other exotics (alewife and smelt) in the Great Lakes. Instead, Canadian Great Lakes fisheries management goals targeted native fishes such as lake trout and their habitats. Some states shared those goals, but eventually, to one extent or another, other Great Lakes states and the Province of Ontario began stocking Pacific salmon.

Michigan Department of Natural Resources orders restricting commercial fisheries quickly put some commercial fishermen out of business. But this was an enterprise diminishing in the Great Lakes region due to declines in lake trout and other coldwater species. The loss of small-scale family fishing in the region can be compared to the loss of small family farms. Family members converted to other enterprises and left the Great Lakes fishery and their traditions behind. Fewer young people took up the traditional skills and lifeways of their parents. A few families were permitted to carry on their fishing activities in certain areas of the Great Lakes, including urban areas, under fisheries assessment programs established by resource management agencies. These fishermen continued their tradition of stewardship for fisheries by collecting age, growth and reproductive data to help agencies with management decision-making. Over time, however, aging fishermen have left the fishery, and agencies have issued fewer commercial fishing licenses. In spite of these declines, the remaining fishing operations are economically viable, and commercial fishing remains important in the Great Lakes region.

The Recent Past: Era of Adaptive, Collaborative Management of Ecosystems

(1980s to present)

Social Changes

By the 1980s and 1990s, it became clear that the cumulative effects of social, technological, and environmental change over centuries would require new approaches to collaborate across political boundaries and to work together for fisheries management.

These new approaches would need to reach across varied stakeholder groups and through such bi-national organizations as the International Joint Commission and the Great Lakes Fishery Commission. New, more flexible management strategies were needed, allowing state and federal agencies and tribal organizations to improve and sustain fisheries and the entire ecosystems on which they depend.

One driving force for change in this era was continued controversy over treaty fishing rights. An important question remained undecided: how should the overall Great Lakes fishery resources be allocated among tribal, commercial and recreational users? In 1985, the state of Michigan, the tribes and the federal government arrived at a 15-year negotiated settlement called the "Entry of Consent Order," ordered by the federal courts. In this agreement, tribes agreed not to fish in certain treaty waters that were important for sportfishing and regained exclusive commercial fishing rights in certain other waters. Great Lakes waters were divided into three distinct zones: tribal fishing zones, zones for state-licensed commercial fishing, and lake trout refuges (rehabilitation zones). In refuges, neither gill netting nor sportfishing for lake trout was allowed. The Technical Fishery Review Committee composed of the tribes (as represented by CORA), the U.S. Fish and Wildlife Service and Michigan Department of Natural Resources was established. This committee studies and establishes the total allowable catch (TAC) levels, population levels of fishes, catch and effort statistics for sport and commercial fisheries, and other important management data. In addition to this system of management for the upper Great Lakes, a mechanism for resolving disputes was established.

The agreement, which expired in 2000, turned out to be generally effective for both sport and tribal fisheries. Primarily, it allowed a 50-50 tribal-sport allocation of the fishery resources; more importantly, it eased some social conflicts and tensions by segregating the lakes into zones. Despite its flaws, the agreement ended a racehorse exploitation of the fishery and created an atmosphere by which all parties work in good faith toward resource management. In addition to CORA, the Great Lakes Indian Fish and Wildlife Commission and other tribal groups interact with states and the U.S. government in a similar manner. Although current management structures have settled some of the major, emotional disputes, treaty fisheries issues are a continuing challenge.

Technological Changes

After an economic decline in the 1980s, business and industry were "booming" again by the 1990s. International trade agreements and other economic forces brought more and larger ocean-going vessels into the region. Particularly noteworthy were the vessels travelling to and from the Ponto-Caspian region of Europe. Changing technologies have led to increased global communications, trade and shipping, which have been related to increased risks of introducing exotic species.

Within the Great Lakes, both sport and commercial fisheries benefit from boat designs, motors or engines, and fishing equipment, which continued to improve through the 1990's. Advanced "fish finding" technologies, GPS (Global Positioning System) technologies, and real time monitoring of water temperatures using satellites are among many of newest technologies that sport and commercial fishers use to find fish quickly and efficiently. These same advances in technology, along with more advanced computers, software, and other electronic technologies contributed significantly to fisheries research and management work. Using these new technologies, fisheries researchers and managers have greater abilities to monitor and collect data on fish populations and to better understand and manage more complex ecosystem interactions.

Environmental Changes

Environmental changes of the 1960s and 1970s continued into this era. To address the contamination of fishes and possible human health risks, Great Lake states and the Province of Ontario began to issue fish consumption advisories. To establish these advisories, which guide anglers in their choices about eating fish, managers use the science of **risk assessment**, a procedure used to estimate the probability

International trade agreements and other economic forces brought a growing number of ocean-going vessels into the Great Lakes region in the 1990s.

Recent Invaders of the Great Lakes

Lake	White Perch	Ruffe	Water Flea	Zebra Mussel	Round Goby
Ontario	1950	—	1985	1989	1998
Lake St. Clair	—	—	—	1988	1990
Erie	1953	—	1985	1988	1993
Huron	1980	1995	1984	1990	1992
Michigan	1990	2002	1986	1989	1994
Superior	—	1986	1987	1989	1995

Source: Data courtesy of U.S. Geological Survey

of negative health effects from a specific source and at a particular exposure level. Risk assessments are conducted in many different ways. For example, methods developed by the U.S. Environmental Protection Agency use estimates of increased cancer risks associated with specific amounts of contaminated fish consumed. Other agencies, such as the U.S. Food and Drug Administration, use a different approach. In this "safe level" approach, fish over a given "action level," such as fish with over 2 ppm (parts per million) of PCBs, are not to be sold in interstate commerce.

Each state then uses different assumptions about this risk assessment information to devise its **risk management** plan; this step incorporates the social, economic and political information to decide how to reduce or eliminate the potential risks to humans.

Thus, a mosaic of fish consumption advisories exists for the Great Lakes region. To learn about the current fish consumption advisories for a given jurisdiction of the Great Lakes, consult your state or provincial fishing regulation information. These advisories provide information on species and sizes of fish from certain bodies of water to avoid or minimize consuming. Advisories also provide information on which groups of people (such as pregnant women, children) should minimize or avoid fish consumption.

Fish consumption advisories are risk management tools. They tell anglers how to minimize their risk of negative effects of contaminants by following certain fish preparation and consumption guidelines. Since many contaminants, including PCBs, are fat-soluble, ways to reduce exposure include trimming fatty tissue in the belly flap, around the lateral line and dorsal areas, and cooking the fish by broiling or grilling so that fat drains away. During the 1980s to the present, concentrations of contaminants in fish flesh declined in most areas of the lakes.

Several studies have been conducted to learn about how eating contaminated fish affects humans. Some researchers believe that some contaminants may negatively influence infant birth weight and early childhood development; more recent studies, however, consider such factors as how much the mother smokes or drinks alcohol and did not find relationships between fish consumption levels and such effects on babies. Work continues on assessing the possible links between contaminants in many foods (not just fish) and cancer or reproductive effects on humans and wildlife. Long-term, more complex studies will provide scientists and managers with even better information in the future.

Changes in the Great Lakes Fisheries

During this era, the parade of exotic species entering the Great Lakes continued as did the management problems presented by each new species. Even the sea lamprey, which had been in the basin for decades, continued to present management challenges for fisheries biologists. In some areas of the lakes, for example northern Lake Huron, sea lamprey numbers and wounding rates on lake trout and salmon increased in the late 1980s and early 1990s. Reasons for this resurgence of sea lamprey probably included improved water quality in spawning areas, recovery of a key prey species (the bloater), lack of sea lamprey control treatments in large systems such as the St. Marys River (because of prohibitively high costs), and reductions in funding for sea lamprey control. The Great Lakes Fishery Commission refocused its efforts in sea lamprey research, assessment and control during this era. The pesticide TFM, long used in sea lamprey control, faced reregistration with the U.S. EPA, requiring additional research on its use and effects. Research and use of alternative controls, such as different types of barriers—electrical, velocity (high current), and physical (low-head dams)—and the release of sterile males began in the 1990s. Sterile males mate with females, causing them to spawn unsuccessfully. Research on using pheromones or scents to induce lamprey spawning in the wrong habitats or during the wrong time of the year also began as this era came to a close.

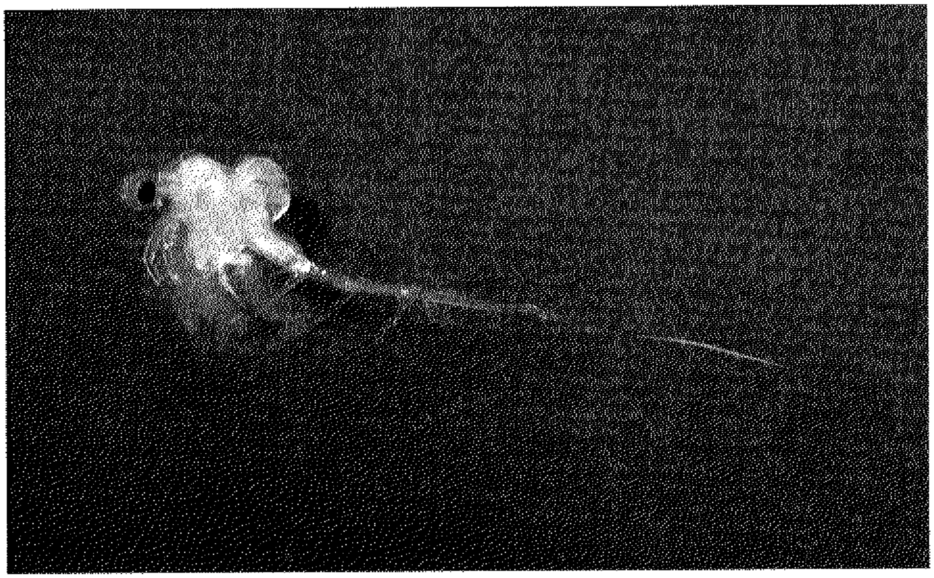
Another sea lamprey management victory would come near the end of this era. In 1999, a coalition of scientists and managers from the United States, Canada, and tribal governments applied a lampricide (granular Bayluscide) specially suited to the deep water and strong currents of the St. Marys River, one of the largest untreated lamprey breeding grounds. Using helicopters and global positioning technology, this chemical could be applied to specific "hot spots" or prime lamprey spawning habitat identified through previous biological assessment work, allowing a very large river system to be treated with a large but still manageable budget. This effort was done in conjunction with trapping and removing spawning lamprey, as well as releasing sterilized males. These combined resources and efforts of bi-national management agencies, fishery managers, and user groups were estimated to result in an 85 percent reduction of sea lamprey in Lake Huron and northern Lake Michigan.

Meanwhile, new, unwanted exotic species in the basin threaten to have as much or more impact than the sea lamprey. The invasion by the zebra mussel has been related to significant ecosystem alterations and has caused some concern about impacts on Great lakes fisheries. Research in lakes Erie and St. Clair has found that, as zebra mussels filter out phytolankton and nutrients, water clarity increases, but less food is available for the zooplanktonic portion of the food web. In shallower water areas, increased water clarity has increased the extent of bottom area that sunlight reaches, increasing the available habitat for macrophytes and littoral food webs. These changes undoubtedly affect the composition of the fish community.

Zebra mussels also affect populations of native mussels in the Great Lakes basin by occupying their bottom substrates and habitats and outcompeting the natives for food. In addition, zebra mussels kill native mussels by attaching to their shells, smothering them and preventing feeding. Researchers in the 1990s began investigating whether any control measures could effectively and appropriately manage the zebra mussel in inshore areas. Another invader is the quagga mussel, a close relative of the zebra mussel. The quagga mussel is of concern because it tolerates cold, deep water and it colonizes on softer sediment than the zebra mussel and may have impacts similar to its shallow-water relative.

Some fishes have the type of tooth structures necessary to prey on both zebra and quagga mussels. These fishes include the freshwater drum, the redear sunfish, the pumpkinseed, the lake sturgeon, and the river and copper redhorse suckers. However, the zebra and quagga mussels' best predator might be yet another exotic species—the round goby. Gobies co-evolved with zebra and quagga mussels in the Ponto-Caspian Sea region. Biologists acknowledge that gobies—a prolific forage fish—provide an abundant prey source to some shallow water fishes, and therefore can convert nutrients and biomass trapped in zebra mussels into predator fish biomass through the food chain. Despite this, researchers, biologists, and managers fear what is yet to come if native food webs and ecosystems continue to slowly be affected by exotic species from other parts of the world. Another big concern is establishing a new pathway for bioaccumulation of toxic contaminants from the sediments. Zebra mussels concentrate these sediment contaminants, passing them to gobies, which then pass the cumulative burden to their predators, including possibly to popular sport fish.

The ruffe—a perch-like nonnative fish—was discovered in 1986 in Lake Superior near Duluth, Minnesota, and soon after in Thunder Bay, Ontario. It has increased



The spiny water flea (Bythotrephes longimanus) is an exotic species that preys upon other zooplankon in the Great Lakes, reducing the availability of food for young native fishes.

dramatically in numbers and has moved as far as the Ontonagon and Firesteel rivers and the Keweenaw region in Michigan, to Little Bay de Noc in northern Lake Michigan and the Thunder Bay River, a tributary of Lake Huron. Scientists have studied this fish's effects on other species. It may prey on lake whitefish and herring eggs and have an impact on populations of these important fishes. To try to prevent its spread, Great Lakes managers and shippers agreed to avoid dumping **ballast** water from the Duluth area into other parts of Lake Superior, but even these practices have not been able to stop the ruffe's population expansions.

Not all potentially important invaders are larger animals. A **zooplankton** by the name of *Bythotrephes longimanus* (spiny water flea) arrived in the 1980s and quickly spread throughout the Great Lakes. It was closely followed by another similar zooplankton, the fishhook flea (*Cercopagis pengoi*), which is working its way throughout the Great Lakes after arriving in the late 1990s. Like the zebra mussel, these **exotic** organisms are believed to have made their way into the Great Lakes in the **ballast water** of foreign, ocean-going vessels. The spiny water flea and the fishhook flea are relatively large and have long barbed spines (total length about 0.3 in./8 mm) making them difficult for small alewife, bloaters, yellow perch, lake trout and rainbow trout to ingest, although they are eaten by larger fishes. Both exotic waterfleas are **predators** on other **zooplankton**. Researchers began to investigate the ultimate effects on the entire Great Lakes **food web.** We now know that these exotic zooplankton reduce the availability of smaller **zooplankton** (such as *Daphnia*) that are important to young native fishes.

Once certain **exotic** species arrive in the Great Lakes and begin to thrive, complete eradication probably is not possible. However, some measures can be taken to slow these invasions. For example, ships are now required to exchange their **ballast water** before entering the St. Lawrence Seaway. Voluntary guidelines for Canadian and U.S. waters established in 1989 became mandatory in U.S. waters in 1992.

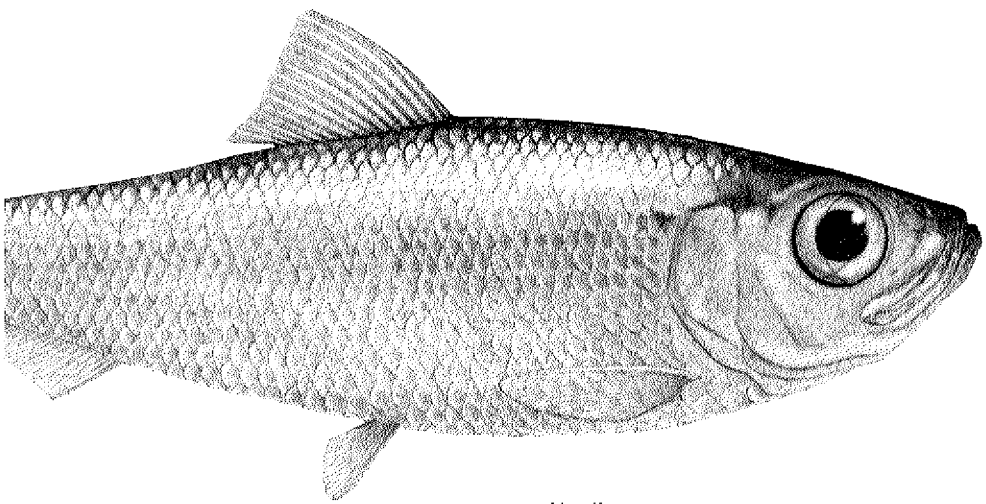
Fish health became a more important concern during this era. In the late 1980s, bacterial kidney disease (BKD) was found in large numbers of Chinook salmon and has been proposed as a cause of declining stocks, particularly in Lake Michigan. BKD has always been present in low levels in Great Lakes salmon. Fish with BKD show signs of bloating, internal bleeding, and susceptibility to other **parasites** and diseases. Certain environmental conditions trigger the disease to become more common in fish and to have greater impacts on fish populations. Researchers have investigated ways of controlling or limiting the occurrence of BKD in hatchery-reared fish. BKD and its impacts have even caused fish managers to rethink the role of hatcheries in sustaining fish populations in the basin. Some managers believe that reduced reliance on hatchery fish for **stocking** will lead to more viable and resilient populations of wild-produced fish. This is now a viable management strategy, because in some areas of the lakes, salmon populations are **naturalized** – able to reproduce in the wild at least enough to contribute substantially to some local populations.

By the mid-1980s, the status of **forage fishes** became of great concern for fisheries managers throughout the Great Lakes Basin. In lakes Michigan and Huron, alewife populations declined sharply through the 1980s. In Lake Superior, rainbow smelt declined and lake herring increased, but both of these fishes tend to fluctuate widely in numbers, possibly due to climate variations from year to year. In Lake Ontario, older and larger alewife and rainbow smelt declined, contributing to a decline in overall forage biomass between 1991-92 and 1992-93. Alewives in poor condition may be especially susceptible to die-offs during extreme weather (cold winters). Although weather may play a role in influencing forage species' population levels, researchers and managers have discovered that high levels of **stocked** salmonids also played a role in reducing the forage base. Ironically, decreased **phytoplankton** abundance due to lake clean-up efforts and water quality improvements has also been linked to declines in the forage base.

The decline in forage **stocks** and the effects of BKD together may have contributed to declines in salmon in many areas of the lakes, especially in Lake Michigan. In turn, recreational salmon fishing efforts and catches decreased dramatically in the late 1980s. Managers concluded that **stocking** programs for salmonids had reached their limits; most states and the Province of Ontario then reduced **stocking** levels to a more sustainable level in relation to the lakes' **forage** base.

However, forage fish **ecology** is complex. In Lake Michigan, for example, as alewife declined, other **forage fishes**, including bloaters, increased. Pacific salmon in Lake Michigan will make some use of these alternative forage fishes, but still seem to prefer alewives. The declines of forage fishes impact other parts of the **food web**, namely the quantity and types of zooplankton. The amount of zooplankton available in turn affects the feeding habits and growth rates of juvenile fishes of a variety of species.

Management of Great Lakes fisheries continues to be a complex task. Managing fisheries under a philosophy of **Optimum Sustainable Yield (OSY)** means trying to balance the interests of a variety of stakeholders. The fisheries are an international and multi-state resource. Their management also involves treaty arrangements with various tribal groups in the region.



Alewife
(Alosa pseudoharengus)

Recently, federal agencies in the United States and Canada have made larger investments in **fisheries management** and research in the Great Lakes. For example, the U.S. Fish and Wildlife Service has taken a major role in coordinating federal and state activities under the Great Lakes Initiative, a program designed to address the goals of the Great Lakes Fish and Wildlife Restoration Act of 1990. For all of these agencies, re-establishing productive fish populations has been a primary emphasis in recent years. Yet, at present, the extent to which native fish communities can be restored and **habitats** rehabilitated is unknown. State agencies, however, have placed greater emphasis than federal agencies on managing the Great Lakes fisheries for recreational fishing by **stocking** hatchery-reared fishes.

State agencies have responded, in part, to stakeholder demand for recreational fishing opportunities. Angler organizations have had strong voices in setting priorities for large salmonids in the region. Individual anglers also have a variety of expectations, some of which include **rehabilitation** of Great Lakes **ecosystems**. Throughout the 1990s and since, agencies have conducted research to better understand angler expectations. In addition, agencies have helped anglers develop expectations based on quality fishing experiences (however one might define "quality") as a realistic expectation of what the fish populations, habitats, and the Great Lakes ecosystem can actually produce.

Meanwhile, there is evidence that some fishes such as lake trout, steelhead, and even salmon are reproducing naturally in parts of the Great Lakes. Little is known about the potential impacts of this natural reproduction on forage **stocks**. This natural reproduction raises the question of how much relative investment should be made in hatchery rearing and **stocking** of these fish versus protecting and improving **habitats** for "naturalized" fish populations. This question will receive increased discussion.

Environmental quality issues continue in the Great Lakes basin. **Wetlands** and coasts continue to be affected by development. Extending the winter navigation season, as proposed in the Great Lakes, may cause ice movements which would damage fish **habitats** along coasts. Providing structures that allow fish passage around hydroelectric dams on Great Lakes tributaries is also an issue.

In the year 2000, the 1985 Consent Order for treaty fishing in Michigan waters (under the 1836 Treaty) expired. Fishing rights held in treaties might be compared with modern-day property rights, where an owner might sell the land but retain certain rights such as an easement. Each treaty has its own language in respect to the relationships between the tribes, state and federal governments, the public and the fisheries resources. No two are alike, and, in the United States, many court cases have been heard on state and federal levels to interpret these treaties. Where treaty rights are affirmed, tribes regulate licensing, biological management, and law enforcement over the tribal fishery. However, state and federal agencies remain responsible for biological management of the fisheries resources, such that they are not destroyed beyond repair. Therefore it must often be determined how to jointly manage and allocate the fishery between tribal and state fishers.

Tribal biologists on tribal (individual bands) and intertribal levels (CORA, GLIFWC) take responsibility for managing tribal fishers and the fishery resource itself. Tribal management authorities set regulations that establish license/permit requirements, fishing seasons, and harvest limits. Tribal biologists conduct Great Lakes fisheries research, such as annual fish stock assessments and surveys, monitoring tribal harvests, and mapping fish spawning habitat. Tribal fish hatcheries rear fish such as walleye, lake trout, and coaster brook trout for stocking in the Great Lakes.

Today, tribes manage and share information regarding the fishery inter-tribally through authorities such as GLIFWC and CORA, much the same way as the United States organizes fisheries management work through USFWS and state agencies. As equal fishery management partners, the tribal management authorities also cooperate with state, federal, and international fisheries management efforts, including participation on GLFC. Yet, sharing the Great Lakes fisheries resource has not been without its conflicts.

The 2000 Consent Degree is a 20-year pact; two of its keys are to eliminate tribal/state zones and to build a mutually beneficial agreement based on joint, science-based management of the fishery. The agreement focuses on allocation, management and regulation of state and tribal fisheries in the waters covered by the 1836 Treaty. More importantly, those participating in the agreement have committed to the rehabilitation of lake trout in lakes Michigan and Huron and to work cooperatively to resolve issues or conflicts utilizing the best available science, emphasizing communication between the tribes, state, and federal agencies.

The agreement features an allocation of fish species in treaty-ceded waters, with the tribes focusing their fishing effort on whitefish, while state-regulated anglers continue to focus on traditional sport species. Harvest of species such as lake trout that are of both sport and commercial interest are to be split 50-50. Just as importantly, the agreement addresses the issues of gear and social conflict by designating specific areas, seasons, equipment, and allocations of fish in ways that maximize benefits for tribal commercial and sport anglers sharing the Great Lakes Fishery resource. Many tribal commercial fishing operations converted from using over 14 million feet of gill net to using trap nets or impoundment gear. Trap nets allow the tribes to maintain or expand their commercial fishing for whitefish while reducing incidental harvest pressure on lake trout and other sport fish. Under this agreement, the state also manages the sport harvest of fish such as lake trout primarily through size limits.

Tribal, state, and federal biologists have jointly created lake trout and whitefish population models. Based on these biological models, the Technical Fisheries Committee (TFC) established by the 2000 Consent Degree can predict population changes due to things such as fishing, and will determine biologically safe harvest levels and set gear and harvest limits accordingly. Many believe this joint management and harvest is critical for conserving fisheries resources, particularly toward achieving lake trout rehabilitation in the Great Lakes. The goal of this agreement is that, through joint management and resource conservation, fishing opportunities for all user groups will be enhanced.

In recent years, state and federal agencies and the tribes have worked together to conduct strategic planning for fisheries which broadens agency and citizen roles in management. Specifically, the Great Lakes Fishery Commission (GLFC) sponsors dialogue among researchers, managers and stakeholders. Lake committees for each of the Great Lakes are composed of diverse members. In addition, each committee establishes specific task groups to consider particular species, habitat or ecosystem issues. The lake committees use the input of their task groups to set fish community goals and objectives and environmental objectives for each lake. In addition, in 1980, the Great Lakes Fishery Commission and all **fisheries management** agencies within the basin completed the *Joint Strategic Plan for Management of Great Lakes Fisheries*. This plan articulates a common vision for Great Lakes fisheries and provides strategies being implemented to work toward that vision. This plan has been revisited and revised throughout the 1990s, and continues to guide interjurisdictional and bi-national fisheries management in the region. State and federal agencies and tribal fisheries organizations then use this guidance to develop their own strategic plans and their tactical and operational plans with input from stakeholders.

In the future, state, provincial and federal agencies and tribal organizations will have an even greater need to work together and with citizens in formulating and carrying out a common vision for the Great Lakes fisheries and the "Life of the Lakes."


The values and attitudes of Great Lakes anglers will be an increasingly important factor in fisheries management decisions.

Future of the Great Lakes fisheries

Overview

In the coming years, Great Lakes fisheries will continue to experience the implications of many challenges from the past—notably contaminants, exotics, changes in the status of certain fisheries, and management of a vast international resource. Many significant challenges have already been met. Important victories include reducing point source pollution through the Clean Water Act and the Great Lakes Water Quality Agreement and management initiatives toward re-establishing functional, productive Great Lakes fish communities.

Managers and public users will struggle with more complex issues in an effort to accomplish smaller, but equally important, research and management victories. Advances in research and technology will be important, but collaborative efforts among managers and users will be essential to achieving broader ecosystem management goals and initiatives for an increasingly diverse set of users and values.

Future Great Lakes fisheries will face challenges in three main areas:

- Ecosystem management
- Research, fisheries management, and involvement of decision makers
- Involvement of user groups in fisheries management

The Challenges of Ecosystem Management

Fisheries researchers and managers have shifted from managing individual species and localized areas of the Great Lakes and have begun thinking about managing fish communities on an ecosystem scale. **Ecosystem management** is the holistic management of Great Lakes fisheries based on their interactions and interrelationships within the entire Great Lakes ecosystem. The challenge will be to continue making progress toward this global view. Many different issues—including the impacts of exotic species, restoration of native fishes, and management and allocation of harvestable predators and their prey—must all be considered in relationship with each other. To do this will require increased cooperation among researchers, managers, and decision-makers. In addition, user groups and the public will need to take more responsibility for their actions toward fisheries.

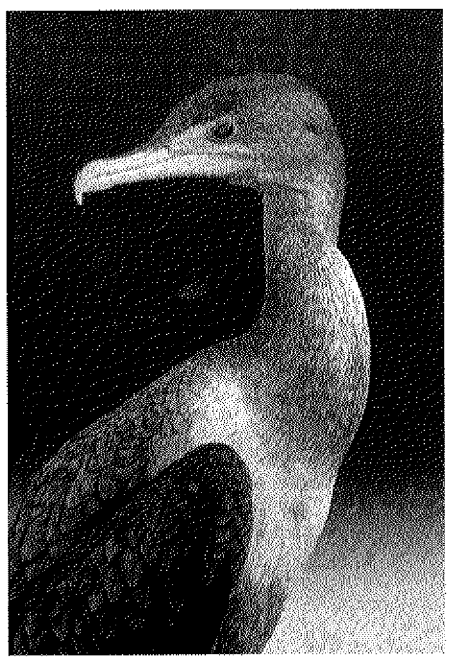
The newest challenge for managers and stakeholders is to consider the many influences of a functioning ecosystem on the populations of specific species. Some ecosystem challenges, which collectively influence the overall management and health of the Great Lakes fishery, may include:

- Sustainability of fisheries
- Stocking, genetics and harvest of predator species
- Predicting and managing the forage base
- Other fish consumers
- Exotic species
- Restoration of native species
- Diseases
- Contaminants
- Habitat quantity and quality

Sustainability of Fisheries

As a result of human alterations and interactions, Great Lakes fish communities today are much different than those of the past. Some native species have disappeared, new species have been introduced either intentionally or unintentionally, and still other species suffer from habitat alterations, pollutants, and overfishing. The concept of sustainable fisheries is complex. Managing Great Lakes fish communities for sustainability may require much work to reduce exotic nuisance species, manage popular non-native species, or restore and rehabilitate native species.

Sustainability can mean managing for the long-term health and stability of fish populations, particularly commonly targeted or harvested fishes. Long-term trends show that fishery fluctuations are part of a natural cycle. Populations experience highs and lows—even extinction—based on habitat and environmental changes, predator-prey interactions and many other unknown factors. The ecology of fisheries leaves no reason to believe this will change. The challenge will be to monitor and predict, manage and live with these continually fluctuating populations. Managers must consider whether or not each new change in a fish population is the result of a natural cycle or an indicator of fishery health issues, habitat alterations, overfishing, or other manageable factors.



The population growth of double crested cormorants has been a frequent topic of fisheries management discussions.

Understanding sustainability of fish communities—including the diversity of species, the structure of communities, and functional characteristics of fish within these communities as well as the food web supporting them—will also be critical. In addition to individual species, researchers and managers are working to better understand the relationships between predator and prey species, such as carrying capacity for predator fishes in relation to available forage fish. Managers face many issues when planning stocking and overall fish management. These issues include the types of fish species best suited to habitat and food availability, genetic variation, natural reproduction rates, characteristics and ecological function of various species, competition and interactions between species, and values and goals of diverse user groups and management jurisdictions. Understanding fishery sustainability in the context of entire Great Lakes fish communities will be a challenge.

Stocking, Genetics and Harvest of Predator Species

Managing for a diversity of predator fishes will be important. Predators such as lake trout, salmon, walleye, pike, and large- and smallmouth bass are among the most popular fish sought. Some of today's challenges involve calculating stocking rates, enhancing natural reproduction and understanding genetic diversity of species. Managers must also consider appropriate predator habitats and ecological niches, striving to maintain healthy predator-prey relationships within the Great Lakes ecosystem and balancing these considerations with diversity, numbers and stability of fish available for catching.

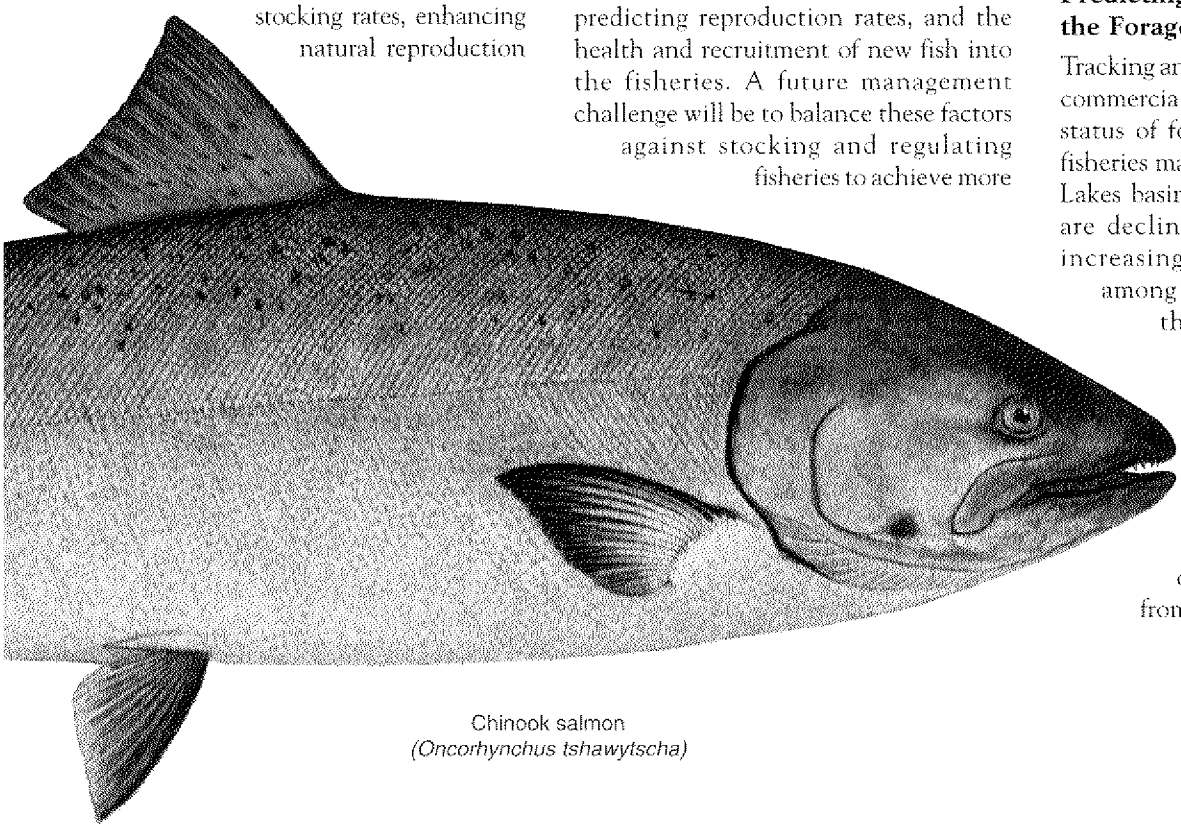
Historically, stocking predator fish in the Great Lakes was thought to be a main goal for fisheries management. Some believed that more fish stocked equaled more fish caught. Today, managers know this is not true; they recognize that stocking too many fish increases the risks to the forage base and fish health. Habitat improvements to enhance natural reproduction will be important in the future, but it is likely that natural reproduction alone may never meet the current and increasing demands on the Great Lakes fishery resource. Future stocking of predators must focus on supplementing, not replacing, natural reproduction. Stocking decisions must also take into account the appropriate mix of predators and their genetics in relation to Great Lakes habitats, fisheries communities, and management and user values and goals.

Natural reproduction of fishes, which most consider preferable to stocking, also presents challenges in monitoring and predicting reproduction rates, and the health and recruitment of new fish into the fisheries. A future management challenge will be to balance these factors against stocking and regulating fisheries to achieve more stable population cycles and sustainable harvests. Little is known about the combined impacts of stocked and naturally reproduced predators on forage fish populations. Managers must weigh the relative investment in hatchery rearing and fish stocking versus protecting and improving habitats for naturally reproducing fish populations.

Future challenges for managing predator fish populations will include meeting the needs of many different user groups. Recently, Great Lakes fishery managers involved user groups in decision-making on managing salmon stocking based on the best scientific information about natural reproduction rates and available forage fish abundance. In light of increased natural reproduction and declining populations of alewife—the salmon's primary forage—managers reduced salmon stocking in lakes Michigan and Huron. It was predicted that, without stocking reductions, both lakes faced potential collapse in predator species as a result of too many predators and not enough food. Scientists believe that these reductions will help create healthier fish populations. The goal is to provide more sustainable harvests over time and to avoid fish population extremes or "boom and bust" periods.

Predicting and Managing the Forage Base

Tracking and managing popular sport and commercial fish populations based on the status of forage fishes is important to fisheries managers throughout the Great Lakes basin. While some forage species are declining, other populations are increasing. These fluctuations vary among the lakes. Factors that affect this fluctuation include the amount of food available, competition for food resources, exotic species interactions, predator feeding pressure on the forage base, reproductive cycles, or even climate variations from year to year. In turn, forage

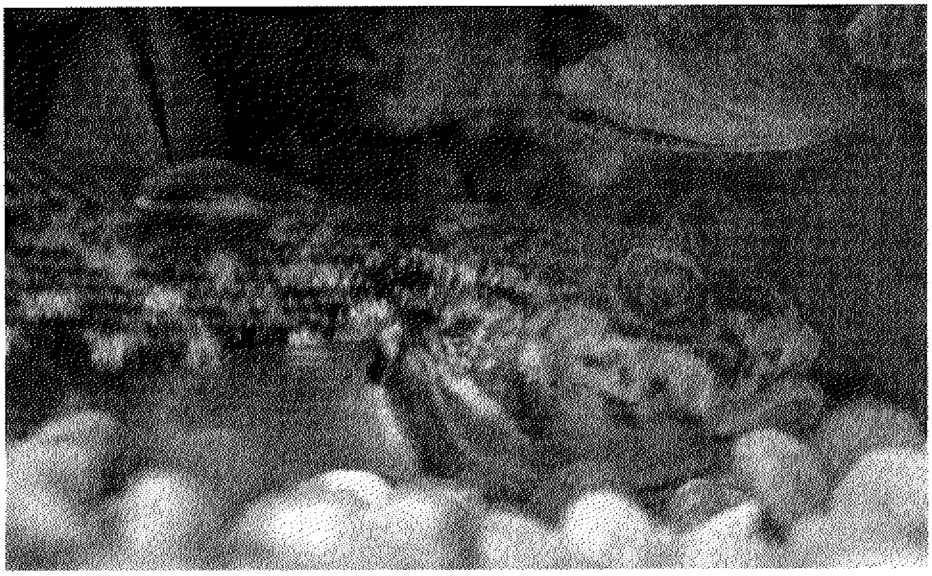


Chinook salmon
(Oncorhynchus tshawytscha)

fishes impact other parts of the food web, such as quantities and types of zooplankton, which affect the feeding habits and growth rates of juvenile fishes of various species. As prey, forage stocks contribute to the overall health and status of Great Lakes predators. Scientists and managers are now sorting out the implications of changes in the forage base for management of all Great Lakes fisheries. New sampling techniques and technologies will allow better estimates of the abundance of forage fishes. However, many difficulties in measuring, estimating and making decisions around forage base populations will continue.

The non-native alewife has become important for the management of introduced salmon in the Great Lakes. When alewife populations declined, biologists responded by reducing salmon stocking to match the reduction in forage or food fish. Understanding and managing for alewife populations affects the productivity of salmon in the Great Lakes, which in turn, impacts regional economic, social, and cultural contributions. Yet managing for alewives may present a different set of challenges for the management and population health of native fishes such as the lake trout, due to the effects of the high levels of the enzyme thiaminase found in alewife. One challenge will be managing forage fish populations for multiple uses, for example, by supporting both a salmon fishery and the recovery of native fish populations.

Many forage fishes such as bloater (chubs) and herring are harvested commercially, and managers will be challenged to manage and allocate a commercially harvestable forage fish in relation to the predatory needs of popular sport fish. Allocation of fishery resources will be an important issue when forage species can be monitored, managed or at least predicted. One question managers might ask: which predator species should be favored based on forage populations? A more likely question relates to allocation of fisheries at the top of the food chain. Among these considerations are human and other fishery consumers within the food web of the Great Lakes ecosystem.



Coping with invasive species such as round gobies and zebra mussels is an ongoing fisheries management challenge.

Other Fish Consumers

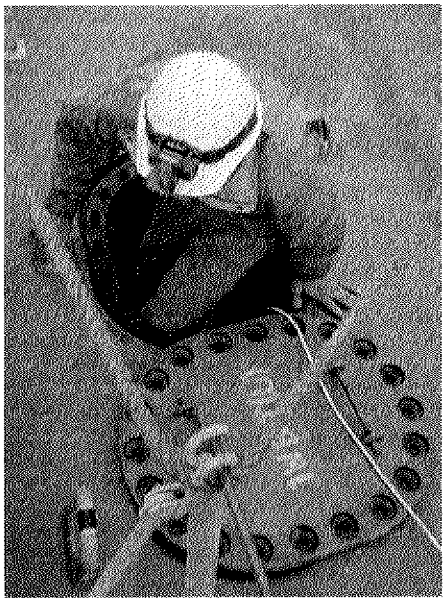
Many birds, including eagles, loons, mergansers, and cormorants, also consume Great Lakes fish. In the past, habitat degradation and health problems caused by pesticides reduced populations of these birds. Since then, people have worked hard to eliminate use of harmful chemicals, reduce pollutants in the environment and find ecologically friendly products and production methods. One measure of success has been the recovery of the Great Lakes fishery; another is the resurgence of Great Lakes fish-eating birds.

The recovery of birds creates an additional competition factor for available harvests of fishery resources. Many humans value eagles, loons, mergansers, cormorants, and other fish-eating birds as part of a healthy Great Lakes ecosystem, but they are also challenged by how to allocate available fishery resources between the birds and people. One frequent topic of fisheries management discussions has been the population growth of double-crested cormorants. Many fear that too many of these fish-eating birds could increase competition for valued species. Increasing harvest pressure by multiple consumers could lead to negative impacts on fish populations. A future challenge will be to expand ecosystem management efforts to accommodate the needs of diverse human and wildlife fish consumers.

Exotic Species Management

The combination of many control methods has greatly increased effectiveness in dealing with the negative impacts of sea lamprey, which has been in the system for decades, at a cost of significant time and money. Since the 1980s, many more exotics have arrived—among them zebra and quagga mussels, round and tubenose gobies, ruffe, spiny water flea and the fish hook water flea. Each new species has the potential to alter the Great Lakes community of organisms by changing or competing for habitat, competing for forage or prey resources, preying on native species, or even introducing new pathogens, such as diseases, parasites, or bacteria. The unknown impacts of these alterations have led to significant research on food web dynamics of the Great Lakes ecosystem.

Some believe that the Great Lakes have become a large living experiment on the long-term implications of exotic species. Some researchers propose a theory of "invasional meltdown," suggesting that the ecosystem is already weakened and that each new introduction or change might bring it closer to collapse. So the question remains: how many new exotics can the Great Lakes ecosystem sustain before it collapses? What can be done to prevent or manage such changes?



A researcher enters a ship's ballast tank to collect sediment samples for analysis of living organisms.

It will be very difficult, perhaps impossible, to stop exotic species from arriving in the Great Lakes. Faster shipping technologies to support an increasingly global economic community increase opportunities for exotics to arrive alive from around the world. The Ponto-Caspian Sea region, the origin of many recent exotic species introductions, has been identified as a high-risk "donor region." Researchers have identified other species from this region that are suited for survival in the Great Lakes, given amenable vectors and timing.

Another possible source of exotics is the Chicago Sanitary and Shipping Canal, a small waterway connecting the Great Lakes basin and the Mississippi River watershed—two very large and very different ecosystems. Asian carp—including the black, silver and bighead carp—have entered the Mississippi drainage. As these species move northward, they present a new threat to the Great Lakes. These large fish feed primarily on the lower end of the food chain, which could affect habitat and reduce food for existing Great Lakes species. The carp themselves would be too large as a prey species.

Recent attention has also focused on aquaculture and pet trades as vectors for importing and transporting various exotic species into the Great Lakes region. Some Great Lakes states have banned fish such as the snakehead because it can survive in Great Lakes waters as an aggressive predator and compete with native species. Managers don't want to risk the fishes' release or escape from pet aquariums. A future challenge will be to identify and prevent the movements or accidental releases of high-risk species.

Once certain exotic species arrive in the Great Lakes and begin to thrive, complete eradication is probably not possible. However, some measures can be taken to slow these invasions. While most ships now exchange their ballast water before entering the St. Lawrence Seaway, small amounts of sediment and water remain in the bottoms of ballast tanks—enough to allow the continued movement of exotic species throughout the world. Researchers scramble to find chemicals, ultraviolet radiation and screen structures that might filter and eliminate exotics from ballast tanks. To date, the most hopeful and feasible solutions may lie in chemical biocides, such as glutaraldehyde or minute doses of chlorine. Yet many people are reluctant to resort to chemicals. Other methods, including localized education, legal, and legislative efforts have been employed to restrict transportation and spread of exotics. However, the interconnected nature of the Great Lakes demands bi-national and multi-jurisdictional solutions. How and at what cost will it be possible to manage exotic species already established in the Great Lakes as well as limit new introductions?

Restoration of Native Species

Work toward lake trout rehabilitation continues, but it will be challenging and costly. Since the early 1960s, attempts to achieve self-sustaining and harvestable stocks of lake trout in the Great Lakes have been largely unsuccessful, except in Lake Superior. In lakes Michigan and Huron, lake trout stocking and management continues but with no success in creating naturally reproducing populations, much less rehabilitation. One key will be managing for a sufficient number of adults of reproducing age to produce enough young to maintain a stable population.

Computer lake trout population models have been created collaboratively by biologists working for state and federal agencies, universities, and the tribes. These models allow biologists to predict how lake trout populations will respond to changes in fishing pressure from tribal, state, and provincial fishers, to reduced lamprey predation, and to various stocking strategies. For example, lamprey-induced mortality will be sharply reduced with lampricide treatment of the St. Marys River. Based on these biological models, size limit changes were made in certain areas of the Great Lakes to protect lake trout spawners from sportfishing mortality. Mortality from tribal commercial fishing will be cut significantly through a combination of harvest quotas, reduction in use of gillnets, and the conversion to trapnet gear by some tribal fishers.

The opportunity exists to provide a steadier supply of larger lake trout in the lakes and simultaneously improve opportunities to achieve naturally reproducing or even self-sustaining lake trout populations. Several issues must be considered with lake trout rehabilitation. Some experts voice concerns that larger and older lake trout also accumulate more contaminants over time, increasing risks associated with fish consumption. The Great Lakes historically hosted different lake trout strains, which may have been more successful in specific habitats. Consequently, other issues will include genetic strains, hybridizing, and decisions on what is being stocked and where.

The lake sturgeon, once abundant throughout the Great Lakes, is another depleted native species drawing increased interest and attention toward rehabilitation efforts. Among the issues involved in lake sturgeon rehabilitation are habitat degradation, over-harvesting and poaching of the reproducing adults. Researchers and managers have invested a great deal to understand lake sturgeon populations, genetic diversity of stocks, range restrictions (such as dams blocking sturgeon passage to river spawning grounds), and fishery conflicts, such as whether or not to allow minimal harvest of protected populations. Because these fish are long-lived, they can also bioaccumulate contaminants. Protecting juvenile lake sturgeon, susceptible to chemicals used to kill sea lamprey, may create conflicts and challenges toward other management efforts, such as lake trout rehabilitation.

Coaster brook trout, a lake run strain of the brook trout species, is another native that has been a focus of rehabilitation efforts. Primarily found in Lake Superior waters, native strains of coaster brook trout are being protected and genetic stocks identified. Researchers have identified several remnant stocks and are implementing a rehabilitation plan that involves hatchery rearing for stocking, tightened regulations, and habitat improvements. The U.S. Fish and Wildlife Service, state agencies, tribes, as well as national and state-level user groups, are investing in a rehabilitation effort that focuses on historically important stream and river systems that are best suited for improving coaster brook trout populations. Enhancing coaster brook trout may mean tightening regulations and adjusting stocking or management strategies in ways that may conflict with management or use of other Great Lakes species.

Fish Diseases and Health

Research and technology are allowing scientists to better understand diseases and fish health issues of the Great Lakes fishery. Future challenges will include new diseases and health issues that arise through exotic introductions and other pathways. Yet the largest challenge may be correcting fishery health issues within the contexts of the larger ecosystem. For example, biologists now better understand BKD (Bacterial Kidney Disease) and its effects on salmon. They understand that overpopulation of predators and poor health due to an inadequate forage base may be related to increased epidemics of BKD. The challenge is then to better understand forage stocks and manage predator stocking in relation to natural reproduction to create a healthy mix of predators and prey.

An additional challenge is that the answer to one fishery health issue might be the cause of another problem. For example, managing for healthy salmon might depend on healthy stocks of alewives. However, current research indicates that alewives are very high in thiaminase (an enzyme that destroys thiamine); the result may be increased early mortalities for young lake trout, which lack important thiamine in their system due to their mothers' alewife consumption. Scientists predict that more alewives in the Great Lakes means that lake trout depend more on alewives for food, possibly increasing mortality of young lake trout. Managers worry that managing for salmon might inhibit lake trout rehabilitation efforts, yet both species are important within the Great Lakes ecosystem and to the fishery.

Contaminants

Pollution and contaminant loadings into the Great Lakes have been curbed, but some contaminants remain trapped in sediments or accumulated throughout the food web. Managing fish habitat will involve dealing with these existing contaminants.

Beyond impacts on the fishery, contaminants in the Great Lakes pose human health concerns. In addition, some may continue to voice concern for the quality of the fishery and struggle to understand how contaminants might affect human health through fish consumption. Alternatively, Great Lakes fish provide many health benefits, and much can be done to understand and greatly reduce the contaminant risks associated with eating fish. Weighing the relative risks and benefits is an important future challenge.

Habitat

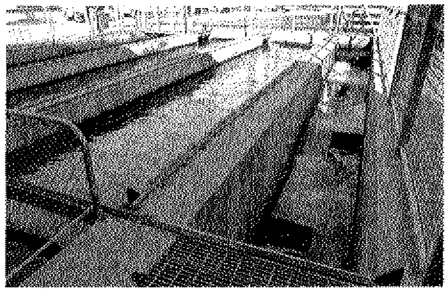
Managers recognize the important relationships of nearshore, riverine, and wetland habitats with healthy Great Lakes fishery communities. These areas provide critical spawning habitat and nursery areas for juvenile fish. Managers now recognize that these habitats can yield an abundant and sustainable production of fish—without the costs and management of hatcheries! Great Lakes tributaries are estimated to yield nearly 30 percent of the salmon production in the Great Lakes. Native fish such as walleye, perch, pike, suckers and sturgeon also depend on river systems, wetlands, and nearshore habitats for successful reproduction. From an ecosystem management perspective, understanding, protecting, enhancing and increasing access to spawning and nursery areas will be important for fish production and

Managers recognize the important relationship of nearshore, riverine and wetland habitats with healthy Great Lakes fish communities.

future fisheries. However, protecting and managing nearshore and inland waters, particularly those associated with lake shoreline, riverfronts, and wetlands will become increasingly difficult with expanding human populations and the encroachment of development.

Dams on Great Lakes tributaries create another fishery habitat issue. These structures limit access to migrating Great Lakes fish for anglers who fish inland rivers. Dams also limit access to rivers for Great Lakes fish that utilize tributaries for spawning habitat and juvenile fish that utilize inland wetlands as nursery areas before migrating into the lakes. Managers contend that dam removal could greatly increase the natural reproduction of many Great Lakes fish. **Fish passages** or fish ladders are often used to allow fish to navigate around dams to move up and down rivers, but even these may be designed only for specific species such as salmon or trout. Species such as suckers, walleye, or sturgeon may be less able to navigate fish passages.

Dams also alter the natural flow of biological nutrients and production in rivers and alter fish habitat simply by changing the flow of water or increasing temperature of pooled water behind dams. In a free-flowing tributary, these nutrients are ultimately transported downstream, and enhance production of the Great



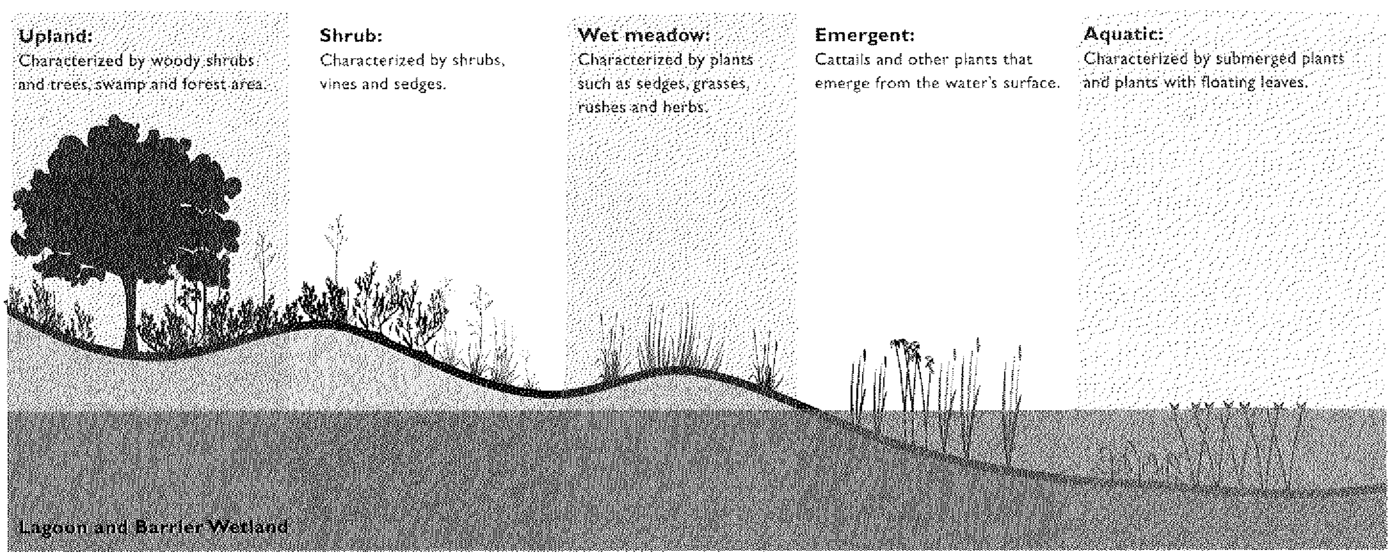
Fish ladders are often used to allow fish to migrate upstream around dams.

Lakes. Management decisions and agreements with operators of dams, particularly hydroelectric structures, have resulted in compensation for fish damages (such as habitat loss and fish mortalities). Maintaining a constant or "run-of-river" flow of water past dams, as well as water quality standards, have vastly improved fish production. But is there still room for improvement?

Simply removing dams to increase Great Lakes fish production or fish health is a costly venture with some potentially negative implications. Dams also impede many exotic species such as lamprey from moving upstream where they would spawn in tributaries. Dams prevent soil erosion sediment from moving downstream, and contaminants are trapped and buried within these sediments. In some cases, removing dams could allow increased sea lamprey production or contaminants to be re-released into the water column and downstream into the Great Lakes. Managers, as well as the public will need improved scientific knowledge to make dam management decisions that are ecologically sound and economically feasible.

Understanding the long-term cyclical nature of water levels will also be a challenge. In the past century, Great Lakes water levels have been at record highs and near-record lows. Trend analysis of Great Lakes water levels suggests that levels rise or recede yearly and that, over long periods of time, changes can be as great as a meter in either direction compared with the long-term average. Some question whether the long-term dynamics of water levels will change if global warming occurs as some scientists predict. Changing water levels and subsequent changes to habitat present challenges in understanding the Great Lakes as an ecosystem. Strategies for identifying, protecting and managing nearshore habitats may have to be altered as water levels change. User groups will need to adapt to changing water levels and may consider dredging and development to maintain boat access during low water levels. Equally important is the need to minimize fish habitat impacts as people alter ecosystems to adapt to changing water levels.

Wetland Zones



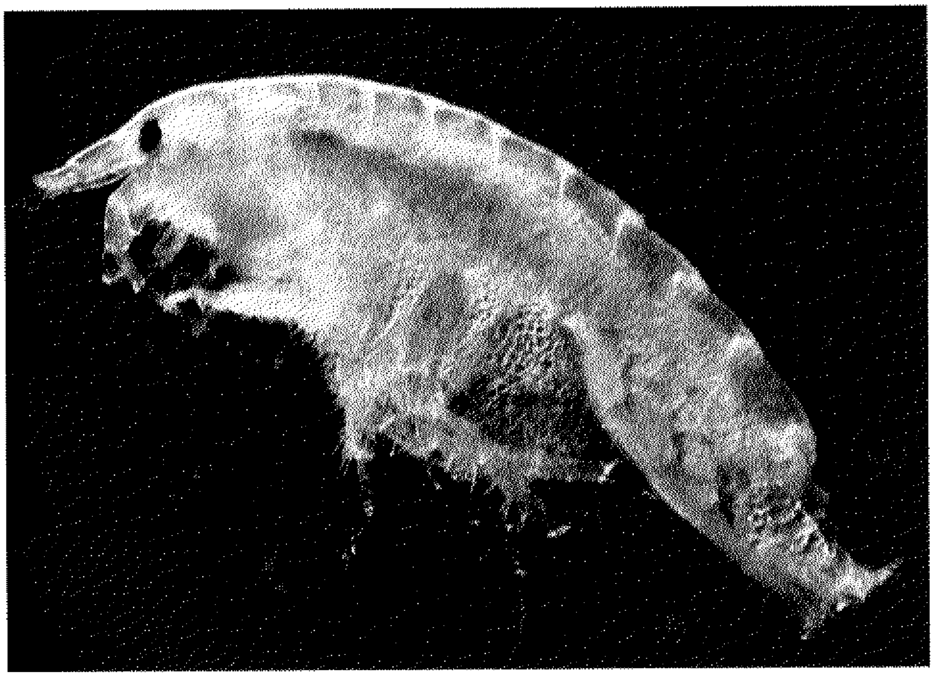
Source: Great Lakes Wetlands: A Field Guide by Walter Hoagman

These are some of the many issues that must be considered when managing the Great Lakes fishery as an ecosystem. The large size of the system and the complexities of the biotic community—from plankton up the food chain to predator fishes—present significant challenges. These challenges will require working among multiple jurisdictions to meet the needs and demands of the great diversity of user groups. If these challenges are to be met in the future, researchers, fishery managers and decision makers will need to engage in Great Lakes basin-wide management at its fullest potential.

Research, Fisheries Management and Involvement of Decision Makers

Fisheries research and management issues are rarely localized to one area or around one species. The sheer size, ecological complexity and diverse uses of the Great Lakes ecosystem make it difficult for researchers, managers and decision-makers thinking holistically about the Great Lakes basin. With two different countries and multiple agencies and organizations responsible for the Great Lakes, political jurisdictions and social cultures can sometimes create difficult barriers to joint or shared management.

Many impediments to ecosystem management of fisheries arise in working across multiple jurisdictions and interests. Very different visions or goals for Great Lakes fishery management may exist. Even where goals are agreed upon, the necessary research or information to generate action or informed management decisions may be lacking. Finally, management decisions may require tradeoffs between short-term and long-term benefits. Many efforts, agreements and organizations have been designed to overcome these multi-jurisdictional barriers, and many successes have been documented and achieved. Strategic planning efforts of the Great Lakes Fishery Commission have aided in coordinating fishery management activities and will continue to play an important role in building consensus and resolving conflict.

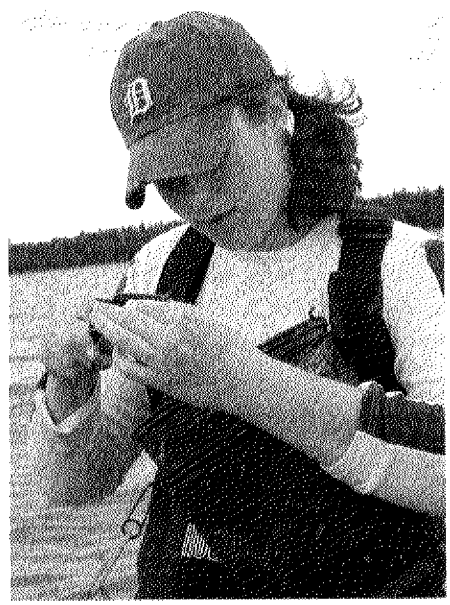


The long-term effects of the decline of Diporeia, an important Great Lakes organism, are still unknown.

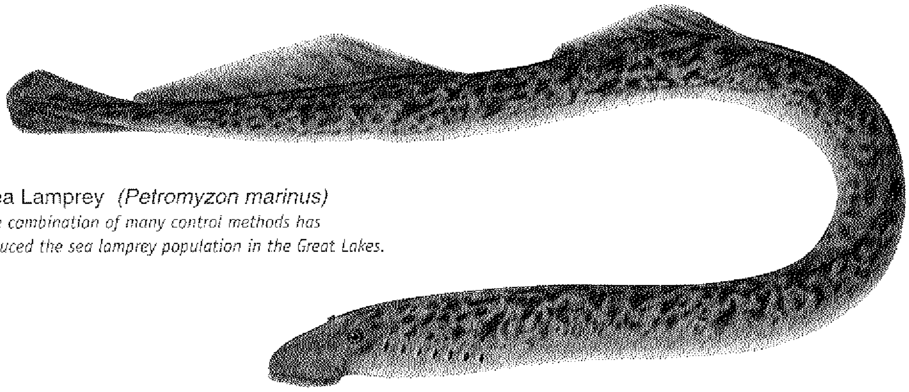
In ecosystem management, researchers and managers must work beyond the Great Lakes, understanding inland tributaries, wetlands and a multitude of smaller watersheds that feed into the larger Great Lakes basin. Moreover, they must think beyond the water, considering land-based issues, such as land use practices, erosion (resulting in sedimentation of waterways), point and nonpoint pollution. Implications of such land-based issues are just as complex and vary across regional, agricultural and urban settings. Some of the more obvious impacts have been addressed through the use of green belts, riparian corridors and controlling point source pollution, but problems such as nonpoint pollution remain.

Interactions of the fisheries community—from predators to forage fish—must be considered. It will be important to understand life cycles, population trends, and general health of individual species; this knowledge is critical to understanding the larger fishery community picture. Understanding the Great Lakes biotic community in its entirety will also be key to understanding these fisheries communities. Many concerns and questions remain about the long-term impacts of exotic species introductions, declines of certain key native, benthic zooplankton populations such as *Diporeia*, and the resurgence of fish-eating birds. Much is unknown about how these factors affect Great Lakes fisheries and fisheries management.

Decisions made by fisheries managers affect a wide diversity of stakeholders. Understanding stakeholder values, including these user groups in the decision making process, and meeting user needs without compromising ecosystem health will continue to prove very difficult. Researchers and managers must understand the diverse people who utilize Great Lakes resources—



A student researcher surveys native crayfish in the Les Cheneaux region of northern Lake Huron to determine the extent of invasion by the exotic rusty crayfish.



Sea Lamprey *(Petromyzon marinus)*
The combination of many control methods has reduced the sea lamprey population in the Great Lakes.

their differing levels of participation and methods by which they participate, as well as their values and actions toward the fisheries. Managing for increasingly diverse user group values may be difficult and provide conflicting burdens for managers and researchers.

The users range from those who catch fish in quantity, such as commercial fishers, to those who go to great lengths to catch a single trophy fish. Some value harvesting fish for consumption while others believe strongly in releasing the fish that they catch. Biologically, managers can choose to manage for either large catch rates at the expense of size or to grow trophy-size fish at the expense of losing harvestable fish to natural mortality. How to allocate fisheries (and related management decisions) among various sport and commercial user groups can become a difficult decision for managers. Should a manager choose one type of management over the other? Who decides how to manage a public resource when conflicting values exist? Who decides when to manage only for trophy fishes? What is a trophy fish? How should decisions about sport and commercial gear use and regulations on the fishery be made? What types of commercial nets are appropriate for harvesting fish? Should sport anglers be allowed to utilize live bait or artificial baits only? If gear should be restricted, which waters are affected? Who decides?

Finally, what is known and understood regarding the ecosystem and its users can change at any time. Population cycles or fluctuations, new diseases or introductions of new species, habitat loss or habitat improvements, angler attitudes or restructuring state/provincial agencies are examples of very real changes that can happen quickly. These changes sometimes have unpredictable effects on Great Lakes fisheries and fisheries management, but they must be considered!

On a local level, the number, activities, and involvement of non-profit or public watershed organizations in the Great Lakes region has increased dramatically. The mission of these watershed organizations typically involves developing linkages and partnerships between government agencies, fishing organizations, water quality entities, or any other public organizations or individuals to tackle challenges involved with issues on a watershed scale.

Some state agencies, such as the Michigan Department of Natural Resources, have restructured their fisheries management units to coincide with watershed boundaries. They have reorganized to carry out assessments, research, and management within the context of entire river systems or watersheds and their relation to the Great Lakes. The logistics of carrying out management on a watershed level can be difficult due to costs, travel, and communication, but decision-makers recognize the importance of moving management in this direction.

Bi-national organizations such as the Great Lakes Fishery Commission or the International Joint Commission continue to build on successes in bridging the gaps between a multitude of different agencies and organizations responsible for Great Lakes management. The Great Lakes Fishery Commission has traditionally organized the multiple stakeholders and agencies to work as lakewide management committees. These committees share information, create joint management objectives, and work cooperatively to achieve results and evaluate them. Bi-national organizations continue to be a factor in the ultimate success of ecosystem, basinwide, or watershed management initiatives.

New management technologies and tools for making decisions will be necessary in managing on an ecosystem or basinwide scale. The accuracy and timeliness of information will be critical in making informed and scientifically sound decisions. Advances in research and new technologies may allow managers to collect increasingly accurate and real time data and information regarding Great Lakes predator species, forage base or food webs. The opportunity is for more efficient management decisions in response to an ever changing Great Lakes fishery.

Many managers are advocating and adopting **adaptive management** strategies. The concept behind adaptive management is to allow management decisions to be flexible to the unknowns of a constantly changing Great Lakes environment. For example, adaptive management principles might apply to the harvest regulations for a particular fish. In this scenario, management decisions are made on the best possible research and scientific information available. Managers closely monitor and evaluate the impacts of their management decisions in relation to their goals, then adjust regulations as needed to continue to meet management goals or objectives for the fishery.

Risk-based decision making is another tool that managers and decision makers can use in managing a very complex Great Lakes ecosystem. In fisheries management, this approach depends on the technologies of fish population and fish community modeling. Using computers and systems modeling, researchers and managers run management scenarios or options and statistically assess the risks related to the uncertainty of the biological aspects of the fishery. Although it may not be possible to understand Great Lakes ecosystems perfectly, risk-based decision making allows decisions to be made within the acceptable range of risk that managers and users are willing to take, based on what information is known and the estimated risks of unknowns.

Management on a larger, ecosystem scale will be a great challenge facing the Great Lakes fishery. Advances in research, improved technology, and new fisheries management tools may help managers understand and manage the complexities of a Great Lakes ecosystem. However, coordinated, collaborative and shared or joint management will continue to be one of the most important barriers facing the future of fisheries management in the Great Lakes. Basin-wide management will require the collective efforts of universities and agencies, researchers, managers and decision makers of states, provinces, federal governments and tribes in two different countries—a challenge that speaks to enhancing and better realizing vision and goals of existing organizations such as the Great Lakes Fishery Commission.

Yet management of the Great Lakes fishery is not just the role or responsibility of agencies or managers: it also includes the vested interest and participation of Great Lakes user groups.

User Groups in Great Lakes Fisheries Management

Today, managers recognize that managing fisheries toward Optimum Sustained Yield (OSY) may be unrealistic in the sense of attempting to measure, quantify and balance management strategies to maximize fishery benefits (ecological, economic and sociological) for each of the many diverse stakeholders. However, this OSY philosophy remains in practice, as managers work to gather sociological and economic data from diverse stakeholders and integrate this information with biological and ecological factors. Management goals and outcomes still reflect attitudes toward managing diverse aquatic resources for diverse stakeholder values and uses and diverse fishery benefits. A management philosophy that speaks to diverse and multiple values and uses demands that state-, provincial-, and tribal sport, charter and commercial interests all be included and involved in management processes and decisions. Cooperation and coordination among researchers, managers, and decision-makers will be essential. In addition, user groups and the general public will need to take more responsibility for their actions toward the fisheries resource, involving themselves in the management process.

Diverse groups and organizations exist today, focusing on interests related to salmon and steelhead, trout and trout habitat, bass, pike, muskellunge, walleye and more. Many of these groups invest resources and energy in advocating for increased or decreased regulation or management attention toward specific species. Also involved are professional associations that speak for charter and commercial fishing interests. The tribes also invest considerable resources speaking for and protecting the interests of tribal fishers whether they are sport, subsistence or commercial.

Public involvement in the processes of Great Lakes fishery management will be critical in the future. Many agencies recognize the value of having an educated citizenry involved in fisheries decision-making processes. For example, the Michigan Department of Natural Resources has organized citizen advisory teams for each of the Great Lakes bordering the state. The agency shares biological information and management options with these advisory groups, and the advisory groups learn, discuss, and create recommendations for the agency on what management options are best for the fisheries and the publics who use them. Wisconsin hosts a similar process, allowing public and organizational representatives to vote on issues and proposals sent forth by user groups. The results of this voting process help guide the management decisions of Wisconsin agencies.

Citizen involvement opportunities also exist on lakewide, regional, and bi-national levels. The states surrounding Lake Michigan have jointly hosted several lakewide and interstate meetings on management issues such as yellow perch declines and salmonid stocking. The Great Lakes Fishery Commission, on a bi-national level, is primarily suited to cross-border communication and cooperation; advisory committees for each lake involve the public and user groups representing sport, charter, and commercial communities.

Angler Licenses Sold

State	Licenses	$ Value
Illinois	749,091	9,167,808
Indiana	619,383	6,241,866
Michigan	1,251,146	23,370,478
Minnesota	1,565,708	17,997,913
New York	1,056,841	13,910,714
Ohio	938,602	13,135,288
Pennsylvania	1,082,850	19,454,282
Wisconsin	1,430,714	24,491,155
Total	8,694,335	127,769,504

Source: U.S. Fish and Wildlife Service, 2001

Federal Aid in Sport Fish Restoration Funds

State	$ Value
Illinois	4,861,689
Indiana	3,653,281
Michigan	8,322,341
Minnesota	9,037,578
New York	6,006,050
Ohio	6,260,195
Pennsylvania	5,970,833
Wisconsin	7,222,083
Total	51,334,050
U.S. Total	240.8 Million

Sport Fish Restoration Funds fiscal year 2001

In recent years, most Great Lakes states have reported declines in fishing license sales, and national sport fishing surveys suggest similar declining trends. The U.S. Fish and Wildlife Service reports a 28 percent decline in the number of anglers fishing U.S. waters of the Great Lakes since 1991. Canadian officials note similar angler declines in Canadian Great Lakes waters. Yet demands on fisheries management efforts continue to increase to meet the challenges of ecosystem or basin wide management, as well as the demands of a more diverse set of fishery user groups. Because fishing license dollars and taxes on fishing equipment in large part fund fisheries management personnel, programs and activities, the decline in angler numbers and license sales presents a future challenge. Fisheries managers and interest groups raise an increasingly important question: Who will pay for fisheries management activities if angler participation, and revenue generated from this participation, continues to decline?

For example, in the United States a significant portion of fisheries management funds come directly from fishery user groups. In 2001, Great Lakes anglers in the United States spent nearly $128 million purchasing fishing licenses, tags, and permits. This money is dedicated by state agencies for fisheries management activities. That same year, the federal Sportfish Restoration Fund (money collected through excise sales taxes on fishing gear and equipment) allocated over $51 million to Great Lakes state agencies. These two funding sources, generated by those who use the fishery resource, combine to form the primary funding foundation for Great Lakes management activities in the U.S. Public support may also help generate funding support for other programs, such as sea lamprey control, from other budget resources within the state, provincial, or federal government.

Developing exact figures about use of the fishery resource, relating sport and commercial harvest to management decisions, is difficult. Managers must measure or estimate how many sport anglers or commercial fishing licenses exist and how many people are using the fishery. These measurements are not always done on a regular basis, or they may not always be accurate or complete. Complicating matters is the fact that not all sport anglers or commercial fishers may fish for the same amount of time, target the same species or areas of the lakes, or make the same decisions about how they utilize the resource (for example, harvest or catch-and-release). The challenge then is developing management decisions that are based on scientific estimates of effort and harvest by sport and commercial fishers.

More precise, timely information, measurements and predictions regarding recruitment, retention, and involvement of those who utilize the fishery resource could help to improve opportunities and management of fishery resources. Increasing efforts toward recruiting and retaining anglers will become a more important issue in the years to come. Many education efforts are underway throughout the region to introduce, educate, and involve new anglers in the Great Lakes fishery. While some fear that too many anglers will increase pressure on the fishery, possibly leading to conflict, angler participation is a necessary element of the fishery. Without angler investment in the resource, financing fisheries management activities will become a challenge. Even more important, the public interest and involvement in conservation of a healthy, usable fishery resource could be lost.

Amid the complexity of the Great Lakes ecosystem, stakeholder expectations and involvement, and agency structures and objectives, change will always occur. Yet, some of the life of the lakes is amazingly resilient. Great Lakes fisheries will continue to serve as indicators of the system's health and quality. Because people value the fisheries, they have become much more involved in fisheries and environmental issues. In the future, state, provincial and federal agencies will have an even greater need to work together and with citizens in formulating and carrying out a common vision for the Great Lakes fisheries and the life of the lakes.

How You Can Help Great Lakes Fisheries in the Future

Become informed! Read fisheries-related information. Contact science-based organizations, such as your state Sea Grant program or the Great Lakes Fishery Commission. Support university research about water quality and fisheries management.

Contact an agency responsible for managing and regulating the fishery, such as the U.S. Fisheries and Wildlife Service. Keep track of legislative issues and stay in touch with your state and national legislators.

Become a member of an organization and encourage that group to take a balanced approach to fisheries issues. Join organization and agency mailing lists.

Visit fisheries-related locations, where commercial fishing is still active and where sport fishing is popular. Visit historical museums with fisheries displays and events. Attend events that celebrate Great Lakes fisheries and water quality!

Take part in activities to improve fisheries habitat. Participate in clean-up projects, stream improvement projects or other activities. Protect coastal wetlands (important fisheries habitats) or participate in land-based habitat projects (e.g., streambank stabilization efforts or reducing fertilizer/herbicide use) to help prevent unhealthy runoff into our Great Lakes waters. Join efforts in the Great Lakes to help clean up an Area of Concern or become involved in the Lakewide Management Plans.

Be an informed consumer. Learn about how to minimize your intake of contaminants by properly preparing fish. Ask questions about various contaminants, and think critically about news stories you read.

Take everyday actions to protect water quality and healthy fisheries: we are connected to the Great Lakes through watersheds. Choose, use and dispose of home and garden chemical products wisely. Dispose of used motor oil and other hazardous wastes properly. Learn about the impacts of exotic aquatic nuisance species and how you can help prevent their introduction or spread.

Promote fishing ethics. Learn more about fish species, fish biology and ecology, and fisheries management. Teach someone how to fish.

Share your understanding of fisheries with others—in classrooms, youth clubs, local civic organizations.

Learn about the history and culture of treaty, commercial and sport fishing. Read stories, learn traditional skills and crafts (e.g., net making, knots, fish decoy carving); interview older community members about fishing or preparing fish; learn arts related to fisheries (e.g., Great Lakes songs).

Appendices

Glossary

abiotic: (AY-BYE-ah-tick) nonliving.

adaptive management: a style of decision making allowing fisheries management decisions to be flexible to the unknowns of a constantly changing Great Lakes environment.

algae: (AL-gee) simple, photosynthetic plants that lack true roots, stems, or leaves.

algal blooms: large growths of algae in a body of water.

anadromous: (a-NAD-ra-muss) fish that migrate up river to spawn, but live in lakes (or oceans) as adults.

aphotic zone: deepest portion of a lake where light energy cannot penetrate. Also called the profundal zone.

aquaculture: the cultivation of aquatic plants or animals.

Areas of Concern (AOC): severely polluted areas of the Great Lakes that have been designated by the International Joint Commission for clean-up effort upon recommendation by state/provincial officials.

ballast water: water held in a boat or large vessel to help balance it.

benthic: refers to animals and plants that live in or on the bottom of a lake or sea.

bioaccumulation: the build-up of a substance in a plant or in an animal's body.

biomagnification: the process by which concentrations of contaminants in plants and in animals are increased along a food chain; organisms (e.g., consumers) at higher trophic levels have higher concentrations.

biomass: the total mass of all living things in a given area.

biotic: living.

carrying capacity: the maximum number of individuals of a species that can be supported in a given area or habitat over an extended period of time.

common property resource: a resource owned not by individuals but by the general public and managed by the government on the public's behalf.

community: an interacting group of different plants and animals.

competition: an interaction between two or more individuals or species that require the same limited resource to survive; this interaction can be harmful to one or more of the organisms.

consumer: organisms that eat other organisms or plants for nourishment.

contaminant: a chemical substance that is not naturally found in the environment, usually made by humans.

coregonines: (kor-eh-GO-neens) lake whitefish and their relatives including herring and deepwater ciscoes (chubs).

DDT: chemical contaminant, used as an insecticide, that can build up in living organisms and cause health problems. Banned by the U.S. and Canada in 1972.

detrital rain: dead algae and zooplankton that sink down to lower levels from upper layers of water.

detritivores: (deh-TRY-ti-vore) small animals that feed on decomposing matter and organic debris.

detritus: (di-TRY-tus) organic material that is either waste material from an organism or decomposing plants and animals.

diatoms: (DY-ah-toms) single-celled plants with hard "shells" of silica.

downrigger: a weighted device that allows a lure to be trolled at a given depth.

ecology: the study of the interrelationships between organisms and their environment.

ecosystem: all the animals, plants and environmental factors that interact within a system; the living and nonliving parts of the environment that interact.

ecosystem management: the holistic understanding and manipulation of the Great Lakes fisheries in relation to their interactions and interrelationships within the entire Great Lakes ecosystem.

epilimnion: (EP-ah-LIM-nee-on) the warmer, buoyant top layer of water in a lake during summer stratification.

exotic: not native; not originally found in that area, and usually brought in by humans, either by accident or on purpose.

eutrophic: (yoo-TROF-ick) a water body that is rich in nutrients and has high productivity–often turbid, with algal blooms and periodic decreases in dissolved oxygen.

eutrophication: (yoo-TROF-i-KAY-shun) the process through which waters become eutrophic.

fishery: the complex interactions between fish population(s) being used, the humans using it, and the environment of each.

fisheries management: the manipulation of people, aquatic populations, and/or habitats in an effort to obtain the goals desired for that aquatic population or ecosystem by its human members.

fisheries science: the scientific study of aquatic (water-related) living resources of the world; the study of the structure, the dynamics (or changes), the interactions of habitat, the aquatic organisms, and humans in order to achieve the goals set for that resource by humans.

fish passage: fish ladders or other mechanisms intended to allow fish to navigate around dams in order to move up and down rivers or waterways.

fish production: the amount of new biomass of a given fish species in a given area over a given period of time.

food chain: the chain of organisms which feed, in turn, on each other and through which energy is passed on from one organism to another.

food web: a set of food chains intersecting and overlapping each other.

forage fishes: small fishes that are preyed upon by larger fishes; i.e. bloaters, lake herring, sculpins, alewife, smelt, and the juveniles of larger fish.

fry: newly-hatched young fish.

habitat: an area that provides life requirements such as appropriate food, water, shelter and space for a particular organism.

hypolimnion: (hi-po-LIM-nee-an) colder, denser water located at the bottom of a lake during summer stratification.

landed value: price paid to fishers for fish prior to processing, wholesaling or retailing.

limnetic zone: area of a lake where light can penetrate. Also called the photic zone.

limnology/limnologist: (lim-NOL-ah-gee) the study of/person who studies freshwater bodies/ecosystems (ponds, lakes and streams) and the relationships between their inhabitants and their environment.

littoral: (LIT-ah-rahl) the area near the shore that is shallow enough for light to be able to penetrate the water, reach the lake bottom and allow rooted plants to grow.

macroinvertebrates: a small animal, able to be seen with the naked eye, that does not have a backbone.

macrophytes: large, rooted aquatic plants that grow in areas where light reaches the lake bottom.

Maximum Sustainable Yield (MSY): to produce the greatest number of pounds of fish over a given time with a given level of fishing effort; this is done by determining the requirements of fish and the productivity of the environment.

mesh size: the size of the open spaces between the cords of a net.

mesotrophic: a water body that has a moderate amount of nutrients and moderate production of organic matter; midway between oligotrophic and eutrophic.

metalimnion: (met-ah-LIM-nee-an) water layer between epilimnion (warm, top layer) and hypolimnion (cold, bottom layer), where temperature drop-off is greatest.

nonindigenous: species that are living outside of the area where they evolved.

nonpoint source pollution: pollutants that do not enter the lakes at a single confined source, but rather from diffuse multiple sources such as agricultural runoff, road salt and acid rain.

oligotrophic: (o-li-go-TRO-fik) waters that are low in nutrients and in productivity and are often cold and deep.

Optimum Sustainable Yield (OSY): harvest level for a species that achieves the greatest benefit, economically, socially, and biologically.

parasite: an organism that lives in or on another living organism (host) and receives nourishment from it, but gives nothing to the host organism in return.

PCB: polychlorinated biphenyl; a type of persistent hydrocarbon that is toxic to some organisms and bioaccumulates.

pelagic: (pah-LAJ-ik) the open-water area of a lake.

percids: members of the perch family including yellow perch, walleye and sauger.

persistent chemicals: chemicals that are not decomposed in the environment. Many persistent chemicals accumulate in the tissues of animals as they eat contaminated prey.

phosphate: chemical nutrient containing phosphorus that can be found in agricultural or industrial runoff, household wastewater and storm water that accelerates the eutrophication of a body of water.

photic zone: area of a lake where light can penetrate. Also called the limnetic zone.

phytoplankton: (FYE-toe-PLANGK-ton) small free floating plants, including algae, diatoms and cyanobacteria.

piscivorous: (pi-SIEVE-er-us) fish-eating.

plankton: (PLANGK-ton) plants or animals that inhabit lake or sea and drift with the currents; they may have some abilities to move; they range in size from single-celled plants or animals to large jelly-fish.

planktivorous: plankton-eating.

point source pollution: pollution that has a distinct and identifiable source; it usually comes from a single pipe or series of pipes.

pollutant: a contaminant or natural substance present in large enough quantities to cause a problem.

predator: a species that lives by killing and eating other prey species.

processed value: value of a commercial fish harvest after processing.

producer: converts and stores the sun's energy and nonliving materials into living biomass (tissue), which is then available to other organisms in the food chain.

profundal zone: deepest portion of a lake where light energy cannot penetrate. Also called the aphotic zone.

reef: a ridge of rock or sand at or near the surface of the water that provides habitat for many aquatic plants and animals.

rehabilitation: the repair of degraded aquatic ecosystems to increase their ability to sustain aquatic communities and provide benefits to society.

Remedial Action Plan: a plan to restore water quality in a severely polluted Area of Concern (AOC).

restoration: to return to nearly a former condition or status.

risk assessment: procedure used to estimate the probability of negative effects from a specific source of a contaminant and at a particular exposure level.

risk-based decision making: a strategy of accounting for and eliminating risk factors involved with fisheries management decisions, allowing for decisions to be made within the acceptable risk range that managers and users are willing to take, based on what information is known and the estimated risks of unknowns.

risk management: the process of incorporating social, economic and political information with risk assessment information to decide how to reduce or eliminate potential risks for humans or fish populations.

scientific method: a systematic way of gathering and evaluating information by posing specific research questions, designing experiments, making observations and measurements and compiling and interpreting results to answer the questions.

sediment: the deposited material, both organic and inorganic, at the bottom of water bodies.

spawn: to breed and deposit eggs.

stock: (noun) a group or population of a fish species that is different from other groups of the same species (i.e. spawns in a different habitat, at a different time)

stocking: (verb) the act of artificially introducing a group or population of a fish species into waters, particularly to introduce new or supplement existing fish populations or stocks.

stunting: reduced growth due to lack of adequate food.

thermal stratification: vertical layering of water of different densities that results from water temperature.

toxic: a substance that is poisonous and present in sufficient quantity to cause death or serious injury to an organism.

treaty: a tool and process used by one government to give its word to another government. The intention of a treaty is to protect a particular inter-governmental agreement over a long period of time.

tributary: (TRIH-bu-tair-ee) stream or river flowing into a larger body of water.

trophic level: any of the feeding levels that energy passes through as it continues through the ecosystem.

turbidity: (tur-BID-i-tee) the condition where sediment and/or other particles are stirred-up or suspended in the water, giving it a muddy or cloudy appearance.

upwelling: a mass of water that has moved to the surface of a lake or the ocean.

watershed: a region or area that is drained by a river system.

weir: (WEER) small dam which may be used for taking spawning fish.

wetlands: areas that contain a lot of soil moisture, can support vegetation that needs wet soil, and has standing water for some part of the year; these areas include swamps, marshes, bogs, coastal areas, and estuaries.

zooplankton: (ZO-PLANGK-ton) tiny or even microscopic and floating or free-swimming animals.

References on Great Lakes Fisheries Resources

Ecology of the Great Lakes

Beeton, A. M. and D. C. Chandler. 1966. "The St. Lawrence Great Lakes" in *Limnology in North America* (D. G. Frey, ed.), University of Wisconsin Press, Madison, Wisconsin.

Botts, L. and B. Krushelnicki. 1988. *The Great Lakes: An Environmental Atlas and Resource Book.* Available from: Great Lakes National Program Office, U.S. EPA, 230 S. Dearborn St., Chicago, IL 60604.

Michigan Sea Grant College Program. Great Lakes Map Brochures. Great Lakes Basin (E-1865). Lake Superior (E-1866). Lake Michigan (E-1867). Lake Huron (E-1868). Lake Erie (E-1869). Lake Ontario (E-1870). Michigan State University Extension, East Lansing, Michigan

Bails, J.D. 1986. "Waters of Change" in *Michigan Natural Resources* 55(3): 45-55.

Baldwin, N. A., R. W. Saalfeld, M. R. Dochoda, H. J. Buettner, and R.L. Eshenroder. August 2002. *Commercial Fish Production in the Great Lakes 1867-2000.* http://www.glfc.org/databases/commercial/commerc.asp

Becker, G. C. 1983. *Fishes of Wisconsin.* The University of Wisconsin Press, Madison, Wisconsin.

Bolsenga, S. J. and C. E. Herdendorf (eds.). 1993. *Lake Erie and Lake St. Clair Handbook.* Wayne State University Press, Detroit, Michigan.

Christie, W. J., J. M. Fraser, and S. J. Nepszy. 1972. Effects of Species Introductions on Salmonid Communities in Oligotrophic Lakes, *Journal of Fisheries Research Board of Canada* 29(6):969-973.

Claudi, R. and J. H. Leach. 2000. *Nonindigenous Freshwater Organisms: Vectors, Biology, and Impacts.* Lewis Publishers: Boca Raton, Florida. 98 pp.

Colby, P. J., G. R. Spangler, D. A. Hurley, and A. M. McCombie. 1972. Effects of Eutrophication on Salmonid Communities in Oligotrophic Lakes, *Journal of Fisheries Research Board of Canada* 29(6):975-983.

Decker, D.J., R.A. Howard, Jr., W. H. Everhart and J. W. Kelley. 1980. *Guide to Freshwater Fishes of New York.* Cornell Cooperative Extension, Distribution Center, 7 Research Park, Cornell University, Ithaca, New York.

Edwards, C. J. and R. A. Ryder (eds.). 1990. "Biological Surrogates of Mesotrophic Ecosystem Health in the Laurentian Great Lakes." *Report to Great Lakes Science Advisory Board of the International Joint Commission.* Detroit, Michigan.

Everhart, W. H. and W. D. Youngs. 1981. Second edition. *Principles of Fishery Science.* Cornell Univ. Press, Ithaca, New York.

4-H Youth Programs. Great Lakes Fishes 4-H Fact Sheets. MSU Extension. Michigan State University, East Lansing, Michigan.

Hartman, W. L. 1988. "Historical Changes in the Major Fish Resources of the Great Lakes" in *Toxic Contaminants and Ecosystem Health,* (M. S. Evans, ed.), John Wiley & Sons, Inc., New York. pp. 103-131

Hesselberg, R. J., J. P. Hickey, D. A. Nortrup, and W. A. Willford. Contaminant Residues in the Bloater (*Coregonus hoyi*) of Lake Michigan, 1969-1986, *Journal of Great Lakes Research.* 16(1):121-129.

Hubbs, C. L. and K. F. Lagler. 1964. *Fishes of the Great Lakes Region.* The University of Michigan Press, Ann Arbor, Michigan.

Keller, M., K.D. Smith and R. W. Rybicki (eds.). 1990. Review of Salmon and Trout Management in Lake Michigan. *Fisheries Special Rep. No. 14.* Charlevoix Fisheries Station, Michigan Department of Natural Resources.

Kohler, C. C. and W. A. Hubert. 1999. Second edition. *Inland Fisheries Management in North America.* American Fisheries Society, Bethesda, Maryland

Kuchenberg, T. 1978. *Reflections in a Tarnished Mirror: The Use and Abuse of the Great Lakes.* Golden Glow Publishing, Sturgeon Bay, Wisconsin.

Mills, E. L., J. H. Leach, J. T. Carlton and C. L. Secor. 1993. Exotic Species in the Great Lakes: A History of Biotic Crises and Anthropogenic Introductions, *Journal of Great Lakes Research.* 19(1):1-54.

Page, L. M. & B. M. Burr. 1991. *A Field Guide to Freshwater Fishes.* Peterson Field Guild Series. Houghton Mifflin Co., Boston, Massachusetts.

Regier, H. A. and K. H. Loftus. 1972. Effects of Fisheries Exploitation on Salmonid Communities in Oligotrophic Lakes, *Journal of Fisheries Research Board of Canada* 29(6):959-968.

Reid, G. K. 1987. *Pond Life,* Golden Press, New York.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E.A. Lachner, R. N. Lea and W.B. Scott. 1991. Fifth edition. A List of Common and Scientific Names of Fishes from the United States and Canada, *Special Publication 20,* American Fisheries Society, Bethesda, Maryland.

Ryder, R. A. 1972. The Limnology and Fishes of Oligotrophic Glacial Lakes in North America (about A.D. 1800), *Journal of Fisheries Research Board of Canada* 29(6):617-628.

Ryder, R. A. and L. Johnson. 1972. The Future of Salmonid Communities in North American Oligotrophic Lakes, *Journal of Fisheries Research Board of Canada* 29(6):941-949.

Scott, W. B. and E. J. Crossman. 1973. Freshwater Fishes of Canada, *Bulletin 184*, Fisheries Research Board of Canada, Ottawa, Ontario. 966 pp.

Smith, C. L. 1987. *The Inland Fishes of New York State*. New York State Department of Environmental Conservation, Albany, New York.

Smith, P. W. 1979. *The Fishes of Illinois*. University of Illinois Press, Urbana, Ilinois.

Smith, S. H. 1972. Factors of Ecologic Succession in Oligotrophic Fish Communities of the Laurentian Great Lakes, *Journal of Fisheries Research Board of Canada* 29:717-730.

Spiny Tailed Bythotrephes in the Great Lakes. 1991. MICHU-SG-90-700-FS. Michigan Sea Grant College Program. Ann Arbor, Michigan.

Taylor, W. W. and C. P. Ferreri. 1999. "Ichthyofauna of the Great Lakes Basin" by T.G. Coon in *Great Lakes Fisheries Policy and Management: A Binational Perspective*. Michigan State University Press, East Lansing, Michigan.

Tomelleri, J. R. and M. E. Eberle. 1990. *Fishes of the Central United States*. University Press of Kansas, Lawrence, Kansas.

Trautman, M. B. 1981. Second edition. *The Fishes of Ohio*. Ohio State University Press, Columbus, Ohio.

The Fisheries of the Great Lakes. 1988. University of Wisconsin Sea Grant Institute, WIS-SG- 86-148.

Underhill, J. C. 1986. "The Fish Fauna of the Laurentian Great Lakes, the St. Lawrence Lowlands, Newfoundland and Labrador" in *The Zoogeography of North American Freshwater Fishes* (Hocutt, C. H. and E. O. Wiley, eds.), John Wiley & Sons, New York. pp. 105-136

Zebra Mussels in the Great Lakes. 1991. MICHU-SG-90-701. Michigan Sea Grant College Program. Ann Arbor, Michigan.

Today's Great Lakes Fisheries

American Sportfishing Association. 2002. *Sportfishing in America: Values of our Traditional Pastime*. (Statistics prepared by R. Southwick of Southwick and Associates) American Sportfishing Association publication, Alexandria, Virginia. http://www.asafishing.org/content/statistics/economic/lakes_fishing.html

Baldwin, N. A., R. W. Saalfeld, M. R. Dochoda, H. J. Buettner, and R.L. Eshenroder. (August 2002). *Commercial Fish Production in the Great Lakes 1867-2000*. http://www.glfc.org/databases/commercial/commerc.asp

Chippewa-Ottawa Resource Authority (CORA). Public Information and Education Office, CORA, Albert (Big Abe) LeBlanc Building, 179 W. Three Mile Road, Sault Ste. Marie, Michigan.

Dawson, C. P., F. R. Lichtkoppler, and C. Pistis. 1989. The Charter Fishing Industry in the Great Lakes, *North American Journal of Fisheries Management* 9:493-499.

Department of Fisheries and Oceans. (Canada). 2003. *2000 Survey of Sport Fishing in Canada*, Economic Analysis and Statistics Division, Economic and Commercial Analysis Directorate, Department of Fisheries & Oceans, Ottawa, Ontario.

Great Lakes Indian Fish and Wildlife Commission. *Masinaigan*. Newsletter supplement.

International Joint Commission, Great Lakes Regional Office, 100 Ouellette Avenue, Eighth Floor, Windsor, Ontario N9A6T3 or PO Box 32869, Detroit, MI 48232. Brochures: *Remedial Action Plans for Areas of Concern; The Great Lakes: A Vital Resource Worth Protecting* and *The IJC: What it is; How it Works*. Great Lakes Regional Office, Windsor, Ontario or Detroit, Michigan.

Lupi, F. 2002. Personal communications. Department of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan.

Cartier, D. 2002 Personal communications. Ontario Commercial Fisheries Association, Blenheim, Ontario.

Talhelm, D. R. 1988. *Economics of Great Lakes Fisheries: A 1985 Assessment*. Great Lakes Fishery Commission, Tech. Rep. No. 54, Ann Arbor, Michigan.

U.S. Department of Interior, Fish and Wildlife Service and U.S. Department of Commerce. 2002. *2001 National Survey of Fishing, Hunting and Wildlife-Associated Recreation*. U.S. Government Printing Office, Washington, DC.

U.S. Department of Interior, U.S. Geological Survey. 2002. *Commercial Fish Production – Pounds and Value, 2000*. USGS Great Lakes Science Center, Ann Arbor, Michigan. http://www.glsc.usgs.gov/data/noaa/noaa00.txt

Environment Canada. 2002. Great Lakes webpage. Environment Canada. http://www.on.ec.gc.ca/water/greatlakes/fisheries-oceans-e.html

Great Lakes Commission. 2000. Resolution on Recreational Boating. Adopted October 16, 2000 at 2000 Semiannual Meeting, Duluth, Minnesota, May 12, 2000. http://www.glc.org/about/resolutions/recboating.html

BOAT U.S. 2001. 2001 Great Lakes State Boating Facts. Boat Owners Association of the United States, Alexandria, Virginia. http://www.boatus.com/gov/lake_facts.htm

Great Lakes Information Network. 2002. www.great-lakes.net

Moccia and Bevan. 2000. *Aquastats 2000*. University of Guelph. Ontario, Canada. Agdex485/42. Order No. 01-002

Garling and Batterson. 1999. *Addressing concerns for water quality impacts from large-scale Great Lakes aquaculture*. Department of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan.

U.S. Department of Agriculture. 1998. *1998 Census of Aquaculture*. U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS), Washington, D.C. http://www.nass.usda.gov/census/census97/aquaculture/aquaculture.htm

Taylor, W. W. and C. P. Ferreri. 1999. *Great Lakes Fisheries Policy and Management: A Binational Perspective*. Michigan State University Press, East Lansing, Michigan. Chapters: Brown, R.W., M. Ebner, and T. Gorenflo. "Great Lakes Commercial Fisheries: Historical Overview and Prognosis for the Future" J. R. Bence and K. D. Smith. "An Overview of Recreational Fisheries of the Great Lakes"

History of the Great Lakes Fisheries

Bogue, M. B. and V. A. Palmer. 1979. *Around the Shores of Lake Superior: A Guide to Historic Sites*. University of Wisconsin Sea Grant Institute, Madison, Wisconsin.

Bogue, M. B. 1985. *Around the Shores of Lake Michigan: A Guide to Historic Sites*. University of Wisconsin Press, Madison, Wisconsin.

Bogue, M. B. 2000. *Fishing the Great Lakes: An Environmental History 1783-1933*. University of Wisconsin Press, 444 pp.

Chippewa-Ottawa Resource Authority (CORA). 1999. Michigan's 1836 Treaty Fishery Guide. Public Information and Education Office, CORA, Sault Ste. Marie, Michigan.

Cleland, C. E. 1982.*The Inland Shore Fishery of the Northern Great Lakes: Its Development and Importance in Prehistory*. American Antiquity (Society for American Archaeology) 47(4): 761-783.

Cleland, C. E. 1992. *Rites of Conquest: The History and Culture of Michigan's Native Americans*. The University of Michigan Press, Ann Arbor, Michigan.

Clifton, J. A., G. L. Cornell and J. M. McClurken.†1986. *People of the Three Fires: The Ottawa, Potawatomi and Ojibway of Michigan*. Grand Rapids Inter-Tribal Council, Grand Rapids, Michigan.

1836 Consent Agreement. 2000. Consent Decree (court document). United States District Court, Western District of Michigan, Southern Division: Kalamazoo, MI. Documents can be located at: Michigan Department of Natural Resources website - http://www.michigan.gov/dnr/0,1607,7-153-10364_10888-35091—,00.html or Chippewa-Ottawa Resource Authority website - http://www.1836cora.org/pdf/2000consentdecree.pdf

Cox, E. T. no date. *A Chronology of Events in the Development and Administration of Commercial Fishing on Lake Erie*. Lake Erie Assessment Unit, Ontario Ministry of Natural Resources, Wheatley, Ontario.

Danziger, E. J., Jr. 1979. *The Chippewas of Lake Superior*. University of Oklahoma Press, Norman, Oklahoma.

Gearhart, C. R. 1987. *Pity the Poor Fish, Then Man*: C. R. (Cliff) Gearhart Reflects on Fifty Years in Michigan's Commercial Fish Industry. Avery Color Studios, Au Train, Michigan.

Great Lakes Indian Fish and Wildlife Commission (GLIFWC). 2002. *Treaty Rights* (2002 Edition). Great Lakes Indian Fish and Wildlife Commission (GLIFWC): Odanah, Wisconsin.

Great Lakes Indian Fish and Wildlife Commission (GLIFWC). No date. *Lake Superior Indian Fishery* (brochure). Great Lakes Indian Fish and Wildlife Commission (GLIFWC): Odanah, Wisconsin.

Larson, G and R. Schaetzl. 2001. Origin and Evolution of the Great Lakes, *Journal of Great Lakes Research*. 27(4): 518-546.

Lloyd, T. C. and P. B. Mullen. 1990. *Lake Erie Fishermen: Work, Identity, and Tradition*. University of Illinois Press, Urbana, Illinois.

McCullough, A. B. 1989. *The Commercial Fishery of the Canadian Great Lakes*. Canadian Government Publishing Centre, Supply and Services Canada, Hull, Quebec.

Oikarinen, P. 1979. *Island Folk: The People of Isle Royale*, Isle Royale Natural History Association, Houghton, Michigan.

Oikarinen, P. 1991. *Armour: A Lake Superior Fisherman*. Manitou Books, 505 Oak St., Calumet, Michigan.

Rakestraw, L. 1968. *Commercial Fishing on Isle Royale*. Isle Royale Natural History Assoc., Houghton, Michigan.

Sivertson, H. 1992. *Once Upon an Isle: The Story of Sighing Families on Isle Royale*. Wisconsin Folk Museum, Mount Horeb, Wisconsin.

Tanner, H. H. (ed.) 1987. *Atlas of Great Lakes Indian History*. University of Oklahoma Press, Norman, Oklahoma.

Great Lakes Fishery Commission. 1980. *A Joint Strategic Plan for Management of Great Lakes Fisheries*, Ann Arbor, Michigan.

Michigan Department of Natural Resources. 1994. *State of the Great Lakes: 1993 Annual Report*. Office of the Great Lakes, MDNR, Lansing, Michigan.

Ontario Ministry of National Resources. 1992. *Strategic Plan for Ontario's Fisheries: SPOF II—An Aquatic Ecosystem Approach to Managing Fisheries*, OMNR, Toronto, Ontario.

Reinert, R. E., B. A. Knuth, M. A. Kamrin, and Q. J. Stober. 1991.Risk Assessment, Risk Management, and Fish Consumption Advisories in the U.S., *Fisheries* 16(6):5-12.

Strategic Vision of the Great Lakes Fishery Commission for the Decade of the 1990s. 1992. GLFC, Ann Arbor, Michigan.

Future of the Great Lakes Fisheries

DesJardine, R. L., T. K. Gorenflo, R. N. Payne, and J. D. Schrouder. 1995.

Fish-community Objectives for Lake Huron. Great Lakes Fishery Commission (GLFC), Spec. Pub . 95-1: Ann Arbor, Michigan. 38 pages.

Eshenroder, R. L., M. E. Holey, T. K. Gorenflo, and R. D. Clark, Jr. 1995. *Fish-community objectives for Lake Michigan*. 56 pages. Great Lakes Fishery Commission, Spec. Pub. 95-3: Ann Arbor, Michigan.

Fishery Division, Michigan Department of Natural Resources. Spring 1994. *Current Issues in Fishery Management in Michigan*, Lansing, Michigan.

Great Lakes Fishery Commission (GLFC). 1997. *A Joint Strategic Plan for Management of Great Lakes Fisheries* (1997 Revision). Great Lakes Fishery Commission (GLFC): Ann Arbor, Michigan.

Great Lakes Fishery Commission (GLFC). 2001. *Strategic Vision of the Great Lakes Fishery Commission for the First Decade of the New Millennium*. Great Lakes Fishery Commission (GLFC): Ann Arbor, Michigan.

Horns, W.H., C.R. Bronte, T.R. Busiahn, M.P. Ebener, R.L. Eshenroder, T. Gorenflo, N. Kmiecik, W. Mattes, J.W. Peck, M. Petzold, D.R. Schreiner. 2003. *Fish-community Objectives for Lake Superior*. 78 pages. Great Lakes Fishery Commission (GLFC), Spec. Pub. 03-01: Ann Arbor, Michigan.

Madenjian, C. P. et. al. 2002. Dynamics of the Lake Michigan Food Web, 1970-2000, *Canadian Journal of Fisheries and Aquatic Sciences*. 59: 736-753.

McGinn, N. A. 2002. *Fisheries in a Changing Climate*. 319 pages. American Fisheries Society: Bethesda, Maryland.

Ryan, P.A., R. Knight, R. MacGregor, G. Towns, R. Hoopes, and W. Culligan. 2003. *Fish-community Goals and Objectives for Lake Erie*. 56 pages. Great Lakes Fishery Commission (GLFC), Spec. Pub. 03-02: Ann Arbor, Michigan.

Stewart, T.J., R.E. Lange, S.D. Orsatti, C.P. Schneider, A. Mathers, M.E. Daniels. 1999. *Fish-community Objectives for Lake Ontario*. 56 pages. Great Lakes Fishery Commission (GLFC), Spec. Pub. 99-1: Ann Arbor, Michigan.

Taylor, W. W. and C. P. Ferreri. 1999. *Great Lakes Fisheries Policy and Management: A Binational Perspective*. Michigan State University Press, East Lansing, Michigan.

Chapters: Hansen, M. J. "Lake Trout in the Great Lakes: Basinwide Stock Collapse and Binational Restoration"

Auer, N. A. "Lake Sturgeon: A Unique and Imperiled Species in the Great Lakes"

Eshenroder R. L. and M. K. Burnham-Curtis. "Species Succession and Sustainability of the Great Lakes Fish Community"

Leach, J. H., E.L. Mills, and M. R. Dochoda. "Non-indigenous Species in the Great Lakes: Ecosystem Impacts, Binational Policies, and Management"

Hayes, D. B. "Issues Affecting Fish Habitat in the Great Lakes Basin"

Ferreri, C. P., W. W. Taylor, and J. M. Robertson. "Great Lakes Fisheries Futures:Balancing the Demands of a Multijurisdictional Resource"

Acknowledgements

Illustrations

Dave Brenner, pp. 4-7, 9, 12-15, 19, 20, 24, 29, 36, 46, 49, Insert: Great Lakes ecosystem diagram, phytoplankton and zooplankton
Emily Damstra, pp. 1, 11, 17, 38, 42, 48
Ned E. Fogle, Insert: Great Lakes fish species drawings

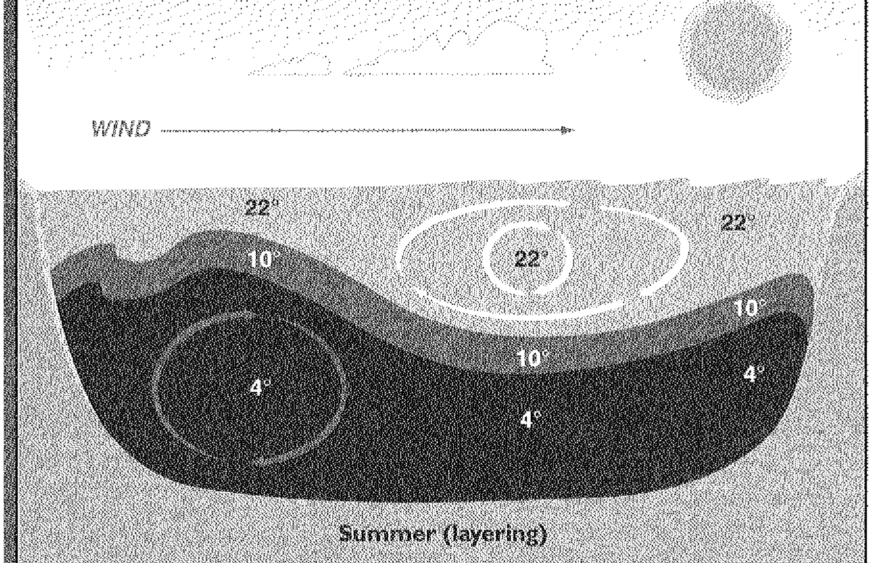
Photography

Courtesy of Ballor family, pp. 22
Courtesy Chippewa Ottawa Resource Authority (CORA), pp. 30
Cooperative Institute for Limnology and Ecosystems Research, pp. 44
Great Lakes Environmental Research Laboratory, pp. 47
University of Michigan, Dave Jude, pp. 16
Courtesy of Kavanaugh family, pp. 18
University of Michigan, Jennifer MacKay, pp. 47
Michigan Sea Grant, Elizabeth LaPorte, 49
Library of Congress, Prints and Photographs Division, Detroit Publishing Company Collection, pp. 23, 27
Michgan Sea Grant archives, pp. 12, 15, 17, 21, 23, 25, 27, 30, 34, 35
Michigan Sea Grant, Dave Brenner, pp. 2, 3, 8, 10, 12, 14, 26, 29, 31, 32, 35, 37, 40, 41, 43, 45, 46, 49
Minnesota Sea Grant, Jeff Gunderson, pp. 34
Mark Stephens, pp. 13
Peter Wallack, pp. 41

Reviewers and Other Contributors

Ray Argyle, Great Lakes Science Center, U.S. Geological Survey
Ted Batterson, Department of Fisheries and Wildlife, Michigan State University
Kieth W. Brickley, Statistical Services, Fisheries and Oceans Canada
Dennis Cartier, Ontario Commercial Fisheries Association
Tom Coon, Department of Fisheries and Wildlife, Michigan State University
Alan Crook, Ontario Ministry of Natural Resources
Jennifer Dale, Chippewa Ottawa Resource Authority
Sally DeRoo, educational consultant
John Dettmers, Illinois Natural History Survey
James Diana, School of Natural Resources and Environment, University of Michigan
Doug Dodge, Ontario Ministry of Natural Resources, retired
Chad Dolan, Illinois Natural History Survey
Randy L. Eshenroder, Great Lakes Fishery Commission
Jim Fenner, Ludington Charter Boat Association
Carlos Fetterolf, National Sea Grant Review Panel
Rosanne Fortner, Ohio Sea Grant
Marc Gaden, Great Lakes Fishery Commission
Don Garling, Department of Fisheries and Wildlife, Michigan State University
Robert Graham, Ontario Commercial Fisheries Association
David Greene, New York Sea Grant
Denny Grinold, Michigan Charter Boat Association
Todd Grischke, Fisheries Division, Michigan Department of Natural Resources
John Halsey, Michigan Department of History, Arts and Libraries
James Haynes, Department of Environmental Science, State University of New York - Brockport
Michael Hermann, Fisheries Division, Michigan Department of Natural Resources
David Jude, School of Natural Resources and Environment, University of Michigan
Robert Kavetsky, U.S. Fish and Wildlife Service
Kevin Kayle, Wildlife Division, Ohio Department of Natural Resources
Ronald Kinnunen, Michigan Sea Grant
Frank Lupi, Department of Fisheries and Wildlife, Michigan State University
David MacNeill, New York Sea Grant
Christine Manninen, Great Lakes Commission
Alastair Mathers, Ontario Ministry of Natural Resources
Nathaniel Matthews, outdoor/environmental writer
Philip Moy, Wisconsin Sea Grant
Bruce Patterson, teacher
Charles Pistis, Michigan Sea Grant
Mike Quigley, Great Lakes Environmental Research Laboratory
Bev Ritchie, Ontario Ministry of Natural Resources
Edmund Sander, Advisor, Great Lakes Fisheries Commission, Monroe County, NY Fisheries Advisory Board
Gerald R. Smith, University of Michigan
Rochelle Sturtevant, Great Lakes Sea Grant Network; Great Lakes Environmental Research Laboratory
Trent Sutton, Purdue University
James Thannum, Great Lakes Indian Fish & Wildlife Commission
Gary Towns, Fisheries Division, Michigan Department of Natural Resources
Thomas Trudeau, Illinois Natural History Survey

Water Temperature



Epilimnion

The surface layer of water that is constantly mixed by wind and waves and is warmed by the sun, from late spring to late fall.

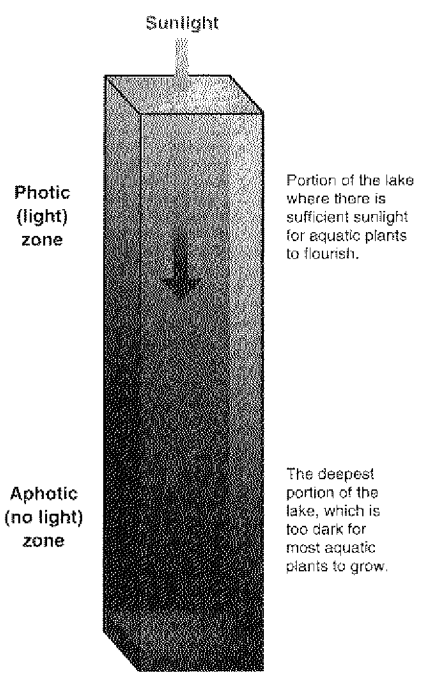
Metalimnion

The middle layer characterized by a steep gradient in temperature and demarcated by the regions above (epilimnion) and below (hypolimnion). The metalimnion is the barrier that prevents mixing and heat exchange between the epilimnion and hypolimnion.

Hypolimnion

The deepest layer of uniformly cold water that does not mix with the upper layers and has low circulation. The colder water within the hypolimnion is at its maximum density at a temperature of four degrees Centigrade.

Light Penetration



Offshore (pelagic zone)

Open-water area of a lake with certain fishes, such as salmon.

Great Lakes Ecosystem

Sun and Water (Thermal stratification)

Thermal stratification is a seasonal phenomenon that occurs from late spring to late fall in temperate regions. In the summer, the upper layer of water in the Great Lakes (epilimnion) is warmed significantly by the sun. Cooler water separates, forming two additional layers (metalimnion and hypolimnion) that are heavier or denser. During the winter, there is no stratification as the lake cools and the overall temperature of the lake is more uniform.

Food Web

A food web is the pattern of relationships in the feeding behavior of organisms in an ecosystem. Because organisms each eat more than one type of food, a food web consists of many linear (and not so linear) chains which interlock to form a network through which energy and nutrients are transferred. Distinct trophic (feeding) levels are differentiated by the type and quantity of food. Three major types of organisms are involved in the food web: producers, consumers and decomposers, which all feed on more than one type of food.

Lake Zones

Generally, the lake can be divided into nearshore and offshore habitats. The nearshore (littoral zone) habitats closest to the edge of the lake have the greatest light penetration and, due to their proximity to land, receive the most run off of nutrients and other materials from streams and rivers. Offshore (pelagic zone) habitats include the uppermost portions of the open water of the lake, as well as the depths. The pelagic zone is the open water area of a lake, away from the littoral zone. In the pelagic zone, the uppermost portion of the water is where light can penetrate and foster growth of algae and other forms of open water plants and life. Some adult fishes, such as salmon and lake herring, spend much of their time in the colder regions of the pelagic zone. Other species, such as smallmouth bass, prefer to spend their lives in the slightly warmer littoral zones. The benthic zone includes the entire bottom of the lake. In offshore areas, the benthic zone receives no light. However, near shore, the benthic life may benefit from light that reaches the bottom of the lake.

Producers

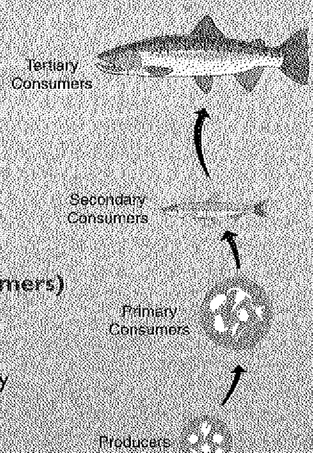
Phytoplankton and Macrophytes

As the first organism in the system, producers store and convert solar energy into living organisms such as phytoplankton (microorganisms) and large, rooted plants (macrophytes). Phytoplankton and plants are a food source for primary and secondary consumers.

Consumers

Zooplankton and Macroinvertebrates (primary consumers)

Zooplankton include microscopic floating animals, such as protozoans, copepods and amphipods. Macroinvertebrates include midges, leeches, snails and insect larvae. These primary consumers are a food source for small fishes.

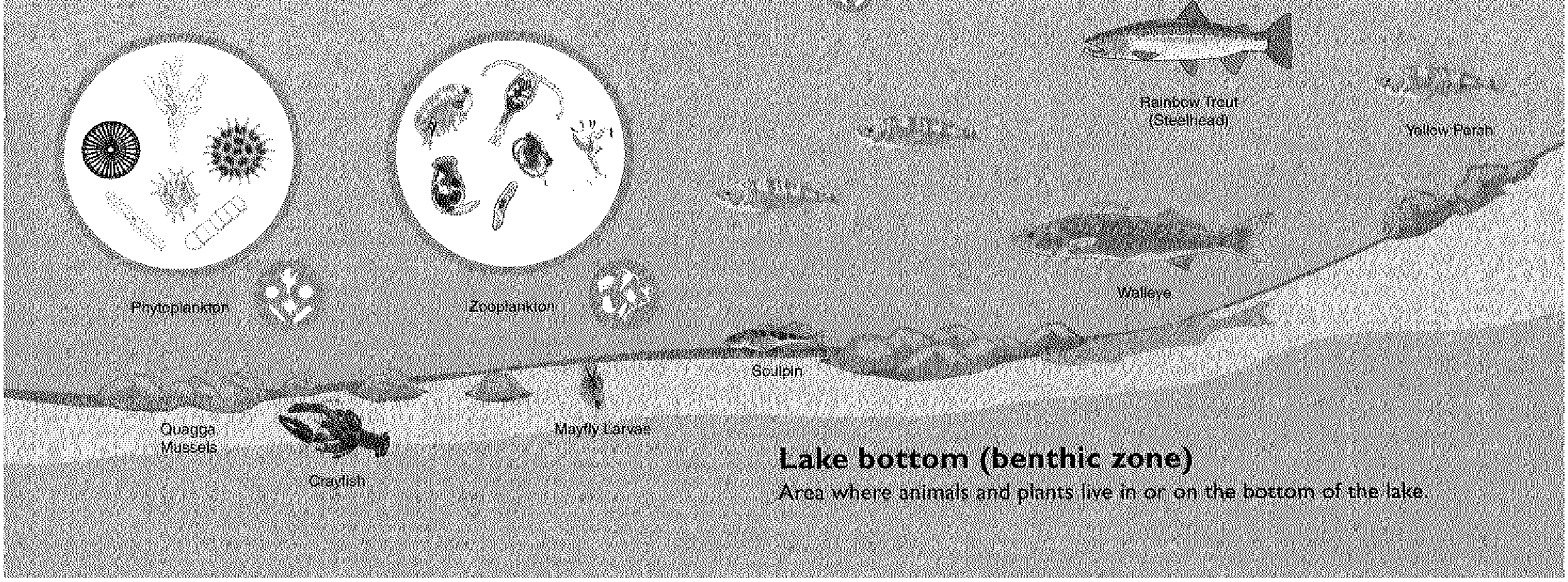


Forage fishes (secondary consumers)

Small (forage) fishes, the next trophic link in the system, feed on plankton and small macroinvertebrates. These forage fishes, such as alewife, smelt and sculpins, provide much of the food for larger fishes.

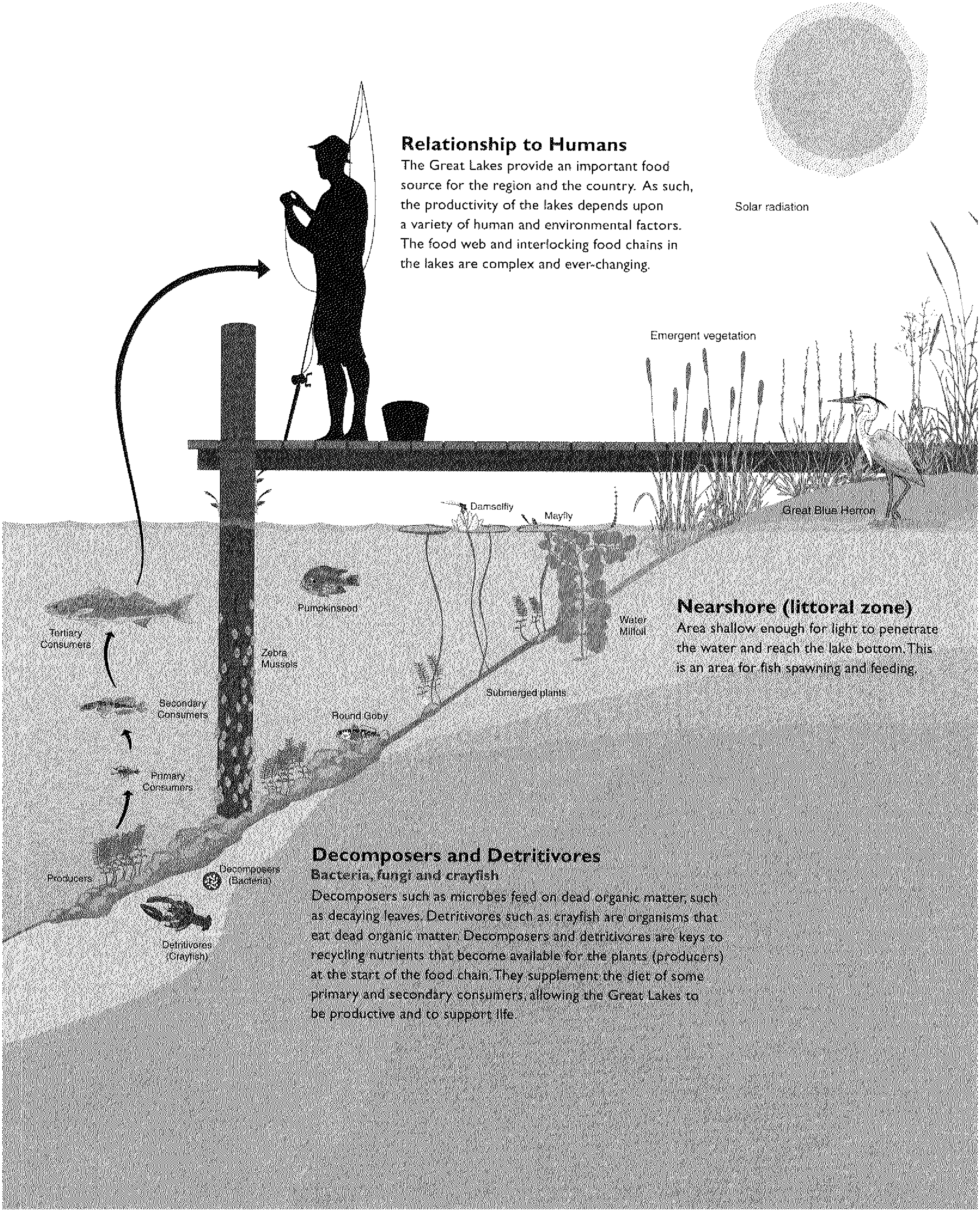
Large fish, birds and humans (tertiary consumers)

Larger fishes (piscivores) that feed on smaller fishes, form the next trophic level in the food chain. These larger fishes may include adult salmon, lake trout, walleye and bass. Other consumers of fishes include birds and mammals such as humans.



Lake bottom (benthic zone)

Area where animals and plants live in or on the bottom of the lake.



Relationship to Humans

The Great Lakes provide an important food source for the region and the country. As such, the productivity of the lakes depends upon a variety of human and environmental factors. The food web and interlocking food chains in the lakes are complex and ever-changing.

Nearshore (littoral zone)

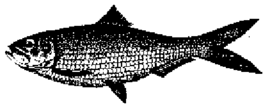
Area shallow enough for light to penetrate the water and reach the lake bottom. This is an area for fish spawning and feeding.

Decomposers and Detritivores

Bacteria, fungi and crayfish

Decomposers such as microbes feed on dead organic matter, such as decaying leaves. Detritivores such as crayfish are organisms that eat dead organic matter. Decomposers and detritivores are keys to recycling nutrients that become available for the plants (producers) at the start of the food chain. They supplement the diet of some primary and secondary consumers, allowing the Great Lakes to be productive and to support life.

Exotic (Invasive) Species in the Great Lakes

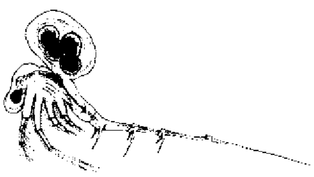


Alewife
(Alosa pseudoharengus)

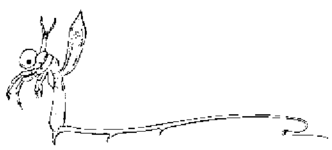
Description: 6-8 in.; silvery, iridescent (shifting, rainbow-like color), single black spot behind head at eye level.

Adult Diet: Planktivore (plankton-eating); may also eat small fishes and fish eggs.

Habitat/Behavior: Mainly pelagic, but also inshore; spawn in shallows in late spring, early summer; strain plankton from water through structures called gill rakers (in gills); schools move inshore to feed at night. Die-offs may occur in spring and summer. Not native to Great Lakes – invaded from Atlantic Ocean through the Erie Canal.



Spiny Water Flea
(Bythotrephes longimanus)

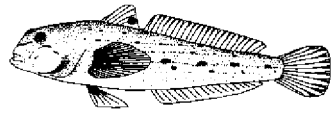


Fishhook Flea
(Cercopagis pengoi)

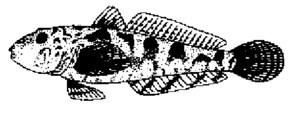
Description: Both waterfleas are crustaceans and very similar in description; measuring spine or tail, both about 1 cm. long; are considered zooplankton; long, spiny tail; large, single eye. Primary physical difference is that the fishook flea is distinguished by a smaller body size (about the size of the spiny water flea) and a unique loop at the end of its tail – a characteristic difficult to determine without a microscope.

Adult Diet: Both are predatory planktivores or raptorial predators (meaning they grasp, pierce and shred their prey) an important distinction because unlike most aquatic predators, they can eat things larger than their mouth. They grasp, pierce and shred zooplankton including *Daphnia*; and compete with fish (particularly juvenile fishes) and invertebrates for zooplankton food sources.

Habitat/Behavior: Pelagic zooplankton found in offshore areas; migrate to surface at night; reproduce rapidly during warm summer conditions; spines appear to serve as defense against predators; often found fouling fishing line and nets which have collected large numbers of them. Not native to Great Lakes, probably arrived in ballast water of international cargo vessels.



Round Goby
(Neogobius melanostomus)



Tubenose Goby
(Proterorhinus marmoratus)

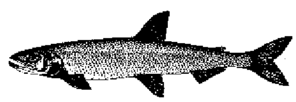
Description: Both goby species can be identified by a single fused pelvic (bottom) fin, forming a conical disk shaped like a "suction cup" – no native fish in the Great Lakes have this. Not native – both goby species arrived in Great Lakes in ballast water of international cargo vessels.

Round Goby – Usually 3-6 (up to 8) in.; characterized by large heads, they have soft bodies and no spiny fins; look similar to native sculpins; distinguished by a large black dorsal fin spot. Adults are yellowish-grey with black and brown blotches over their bodies with some tinge of green on the dorsal fin; young are a solid gray.

Tubenose Goby – Much fewer in numbers; generally are smaller than round gobies (less than 4 in.); they have smaller mouths than round gobies; have slightly visible nostrils extending beyond their nose or face.

Adult Diet: Feed voraciously, eating insect larvae, large invertebrates, zebra mussels, fish eggs, and small fish; tubenose gobies, due to smaller mouths, are restricted mainly to smaller prey, such as aquatic insects.

Habitat/Behavior: Benthic or bottom-dwelling fish preferring rocky or gravel habitat; often found on or near rocks, hiding in crevices and around any other substrate; although consumed as a forage fish, they also aggressively compete with native fishes for spawning territory and food; with a well-developed sensory system, can also feed at night. Spawning can occur frequently from April through September; deposit eggs in nests on tops or undersides of rocks, logs, etc.; tubenose gobies spawn in vegetated areas.



Rainbow smelt
(Osmerus mordax)

Description: 7-8 in. and under 4-16 oz.; long silvery body, with rainbow-like iridescent color on sides; adipose fin.

Adult Diet: Planktivore (plankton-eating); may eat very small fish.

Habitat/Behavior: Mainly pelagic; potamodromous (spawn in streams, rivers, and gravel beaches); spawn in spring. Not native to Great Lakes – intentionally introduced to Michigan inland lakes as a forage fish for salmon. Unintentionally introduced to Great Lakes, likely by escaping or by movement in bait buckets.

Sea Lamprey
(Petromyzon marinus)

Description: Grows up to 34 in.; lacks jaws; has circular, sucking mouth with rasping teeth; no paired fins.

Adult Diet: Fluids and tissues of large fish, particularly salmon and trout, which have small scales.

Habitat/Behavior: Pelagic and benthic; spawn in rivers and streams in spring; larval lamprey (called ammocoetes) spend 3-6 years buried in sediments feeding on detritus and small organisms filtered from the water. Migrate to open waters of Great Lakes for adult, parasitic phase (approx. 18 months), growing from 6-8" to 24" as an adult. Each adult estimated to kill 40 pounds of fish during parasitic phase. Not native to upper Great Lakes – arrrived in upper Great Lakes after the Welland Canal (bypassing Niagara Falls) was opened.

Zebra Mussel
(Dreissena polymorpha)
and
Quagga Mussel
(Dreissena bugensis)

Description: Both mussels are thumbnail sized, usually about 1/4 to 1 in.; light and dark banded shell coloration; quagga mussels may often have lighter colored shells or finer stripes, but patterns of both species can vary. Shell shape is primary difference, and quagga mussels typically have more rounded shells then zebra mussels.

Adult Diet: Filter-feeds primarily on phytoplankton, as well as other small particles and organisms suspended in the water; compete with zooplankton for phytoplankton food sources.

Habitat/Behavior: Both mussels live in similar habitats; adults of both mussels are benthic and attach to hard surfaces; quagga mussels can also colonize softer substrates and a wider range of water depths; usually found in clusters; larvae are planktonic (free-floating, microscopic). Prolific spring and summer reproduction results in rapid growth and expansion of mussel colonies. Not native to Great Lakes – arrived in Great Lakes in ballast water of international cargo vessels.

Phytoplankton and Zooplankton

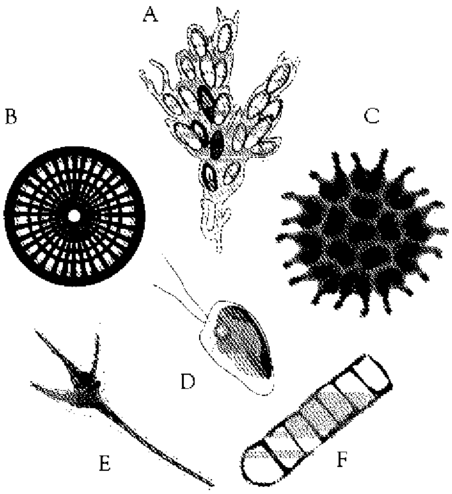


Fig. 1
(Note: Not drawn to scale. Scales range from 10,000 - 20,000 times life size.)

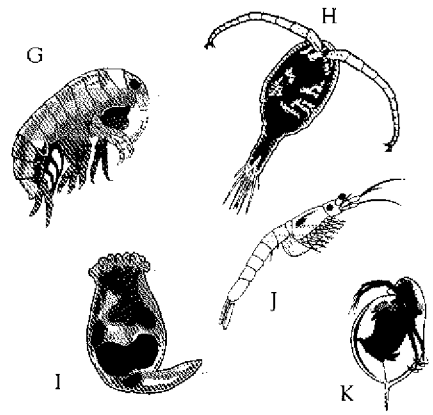


Fig. 2
(Note: Not drawn to scale. Scales range from 5 - 1,000 times life size.)

Phytoplankton Key

A – *Dinobryon spp.* (a chrysophyte)

B – *Stephanodiscus spp.* (a diatom)

C – *Pediastrum spp.* (a green alga)

D – *Rhodomonas spp.* (a cryptophyte)

E – *Ceratium spp.* (a dinoflagellate)

F – *Melosira spp.* (a diatom)

Zooplankton Key

G – *Diporeia spp.* (a crustacean)

H – *Diaptomus spp.* (a copepod)

I – *Philodina spp.* (a rotifer)

J – *Mysis relicta* (a malacostran)

K – *Daphnia spp.* (a water flea)

Phytoplankton

Description: Microscopic to visible floating plants; found to depths where light penetrates water.

Examples: Diatoms, green algae, blue-green bacteria, protists.

Zooplankton

Description: Microscopic to visible, free-swimming animals; includes a variety of types.

Cladocerans: Water fleas such as *Daphnia, Bythotrephes longimanus* and *Cercopagus pegnoi*; bodies have hard shells, branched swimming antennae; large eye.

Copepods – Oarsmen(cyclopoids and calanoids) cylinder-shaped bodies; long, segmented swimming antennae.

Malocastrans – Mysids such as opposum shrimp; 10 pairs of jointed legs; look like miniature crayfish; stalked eyes.

Rotifers – Rotating hair-like cilia at front of body.

Protozoans – Single-celled animals, such as the amoeba and paramecium.

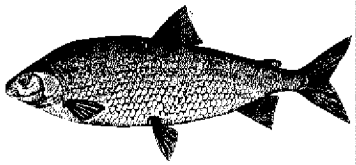
Zooplankton continued

Adult Diet: Many omnivorous, eating algae, detritus, rotifers, protozoa, other crustaceans and bacteria; some, including *Cyclops* and *Leptodora* (water flea), are predators which grasp their prey. Opossum shrimp, *daphnia* (water flea) and rotifers are filter feeders, straining food from the water.

Habitat/Behavior: Found throughout Great Lakes. Make vertical migrations daily which vary with light levels, season, and age and sex of the individual animal. Most migrate up as darkness sets in and return to deep at dawn, though some species reverse or twilight migration (at dusk and dawn).

Opossum shrimp (*Mysis relicta)* also make these migrations, but may be considered more benthic than other zooplankton, since they are more often found near the bottom (benthic) during the day and are found in the hypolimnion (deepest layer of cold water) during the summer. Opossum shrimp reproduce in fall, winter and early spring, then carry their eggs and young in a brood pouch for up to 3 months; young leave the pouch when about 3-4 mm long. Opossum shrimp and most other zooplankton are important food for a variety of fish (especially smaller juvenile and forage fish) such as lake trout, lake whitefish and chubs (ciscoes).

Fishes of the Great Lakes

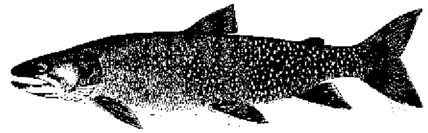


Lake Whitefish
(Coregonus clupeaformis)

Description: Usually 17-22 in., 1.5-4 lbs.; silvery with pale green-brown back; adipose fin.

Adult Diet: Benthivore, planktivore; feeding on *Diporeia*, some small fish, and fish eggs.

Habitat/Behavior: Benthic; spawn in November and December usually in shallows; found in schools; found in hypolimnion in summer where they range broadly, and move to shoals in spring. Important native commercial fish, sometimes caught by sport anglers.

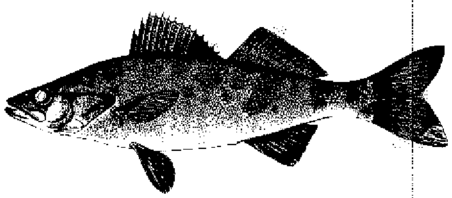


Lake Trout
(Salvelinus namaycush)

Description: Often about 31 in. and 10 lbs., but can grow much larger; scattered light spots on dark body; forked tail.

Adult Diet: Forage fishes such as chubs (ciscoes), lake herring, sticklebacks, alewife, smelt, sculpins, and macroinvertebrates.

Habitat/Behavior: Mainly benthic, but may be found at various depths (pelagic and littoral); spawn on rocky reefs during November and December. A variety or strain called siscowet (or "fat trout") is found in deepwater areas of Lake Superior, and another variety or strain called "humpers" have a different, humped body shape.

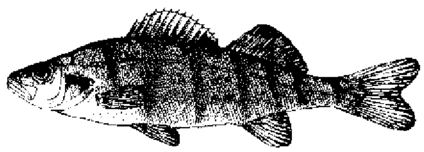


Walleye
(Stizostedion vitreum)

Description: Usually 13-20 in.,1-3 lbs. but can grow much larger; dorsal fin with spiny-rayed and soft-rayed sections; large eyes and white tip on tail.

Adult Diet: Piscivore (fish-eating).

Habitat/Behavior: Moderately shallow waters tending toward benthic habitats of inshore (littoral) habitats; spawn in spring or early summer in rivers and lakes over coarse gravel or rocks. Found in turbid areas and use plants, boulders, sunken trees for cover; commonly caught in shallow bays, river mouths, and Lake Erie; popular native fish.

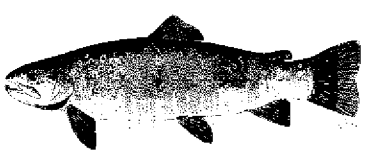


Yellow Perch
(Perca flavescens)

Description: Adults usually 6-10 in.; yellow belly and dark vertical bars on sides; one spiny-rayed and one soft-rayed dorsal fin.

Adult Diet: Forage fishes, aquatic insects.

Habitat/Behavior: Moderately shallow waters tending toward benthic habitats of inshore (littoral) habitats; spawn from late April through early May or mid-June (depending on lake) near aquatic plants in shallow reeds or in coastal lakes. Feed from mid-depths to near the bottom in summer; the basis of much local consumption; native fish to the Great Lakes region.

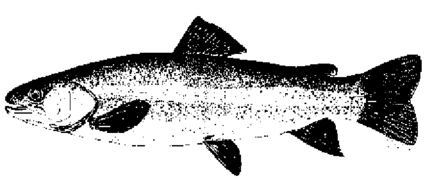


Rainbow Trout or Steelhead
(Oncorhynchus mykiss)

Description: Usually 20-30 in. and 6-10 lbs.; light body with dark spots, side has pinkish band.

Adult Diet: Invertebrates, plankton, forage fishes.

Habitat/Behavior: Pelagic (open-water); spawn in rivers, streams (potamodromous); enter rivers in late October through early May; spawn from late December through the spring (mostly in the spring); do not die after spawning. Not native to the region – introduced into the Great Lakes from the Pacific Northwest.



Brown Trout
(Salmo trutta)

Description: Usually 20-22 in. long but can grow much larger; 4-5 lbs; dark crosses or checks on silvery body, tail with occasional dark spots, 10-12 anal rays.

Adult Diet: Smelt, alewife, other forage fishes.

Habitat/Behavior: Pelagic (open-water) but also found in benthic and shallow inshore areas; potamodromous; spawn in late fall or early winter when 2-3 years old; do not die after spawning; not native—introduced into Great Lakes region.

Pacific Salmon

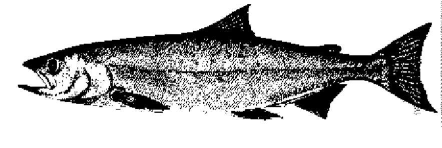
Description:

Chinook Salmon – Adults about 36 in., 18 lbs.; black mouth and inner gums, anal fin with 15-17 rays, black spots all over tail.

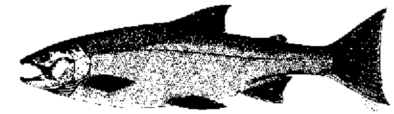
Coho Salmon – Can reach about 27 in., 6.5 lbs.; white or gray gums, anal fin with 13-15 rays, black spots on only upper half of tail.

Adult Diet: Alewife, smelt, other forage fishes.

Habitat/Behavior: Pelagic (open water), moving throughout the Great Lakes; potamodromous (spawn in rivers, streams); spawn in fall when 3-5 years old; adults die after spawning. Significant natural reproduction occurs, but population numbers are sustained through hatchery reared and stocked fish; 6-month-old chinook and 18-month-old coho migrate from rivers to Great Lakes. Not native to the region—introduced into the Great Lakes from the Pacific Northwest.



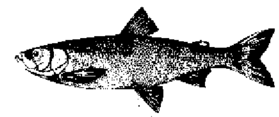
Chinook Salmon
(Oncorhynchus tshawytscha)



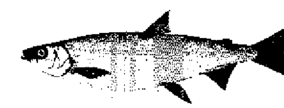
Coho Salmon
(Oncorhynchus kisutch)

Native Forage Fishes in the Great Lakes

Sculpin
(Cottus spp.)



Bloater (Chub)
(Coregonus hoyi)



Lake Herring
(Coregonus artedi)

Brook (5-spined) Stickleback
(Culaea inconstans)

Emerald Shiner
(Notropis atherinoides)

Description: Small fishes which serve as food for larger fishes, including sculpins, bloater, lake herring, brook and ninespine, and emerald shiner.

Adult Diet: Mostly plankton, insect larvae, some benthos; larger species may take small fishes.

Habitat/Behavior: Usefulness of forage fishes to predators depends on their size and on their location; any fish small enough to fit into a predator fish's mouth is potential forage. Many species of native forage fishes, some unique to the Great Lakes; were found virtually throughout the lakes until commercial fishing removed some of the larger species of chubs (ciscoes).

Species characteristics:

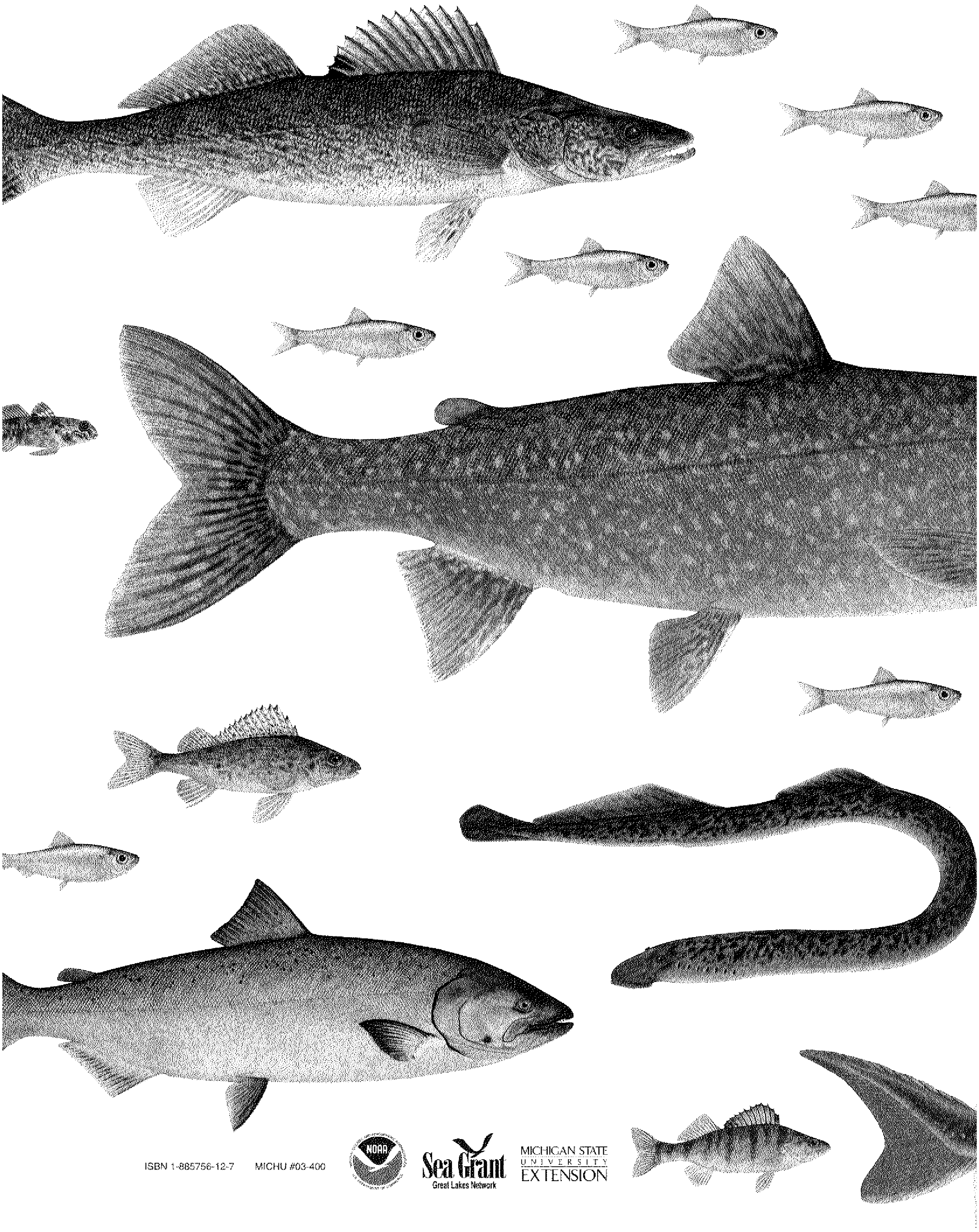
Sculpin – 7 in. or less; large head, stout body; large and fanlike pectoral fins; pelvic fins (usually with one spine) under pectoral fins. Benthic; some spawn in spring, others in late summer or early fall; deepwater sculpins spawn during winter months; mottled and slimy sculpins tend to inhabit more nearshore waters, nesting under rocks or other debris and deposit eggs on the ceiling of the nest. Deepwater sculpins inhabit deeper water areas, eating mainly midge larvae (chironomids), mysids (opossum shrimp), and *Diporeia spp*. Spoonhead sculpins eat planktonic crustaceans in deepwater areas, and aquatic insect larvae inshore. Other sculpins eat mainly aquatic insect larvae and crayfish.

Bloater – 8-10 in.; long, deep-bodied fish with adipose fin. Pelagic and benthic; spawns February through March. Eat mainly zooplankton, particular *Mysis relicta*, *Diporeia spp*.

Lake Herring – 8-12 in., sometimes larger; simila to bloater but with more gill rakers. Pelagic; gath in large schools to spawn in late November or early December. Mainly a zooplankton feeder eating *Mys relicta*, *Diporeia spp*.

Sticklebacks (Brook and Ninespine) – 2-4 in.; small, thin fish; dorsal spines unconnected by fi tissues. Littoral, pelagic and benthic; spawn in spri or summer. Some build nests of sticks or weeds. E aquatic insects, planktonic crustaceans.

Emerald Shiner – 2-3 in.; silvery, iridescent bod Mainly pelagic; spawns in summer. Form schools offshore in summer, move inshore in fall and in spring; spend days in deep water and move to the surface at night. Feed mainly on plankton and alga and eat some midge larvae.



ISBN 1-885756-12-7 MICHU #03-400

Sea Grant
Great Lakes Network

MICHIGAN STATE UNIVERSITY EXTENSION