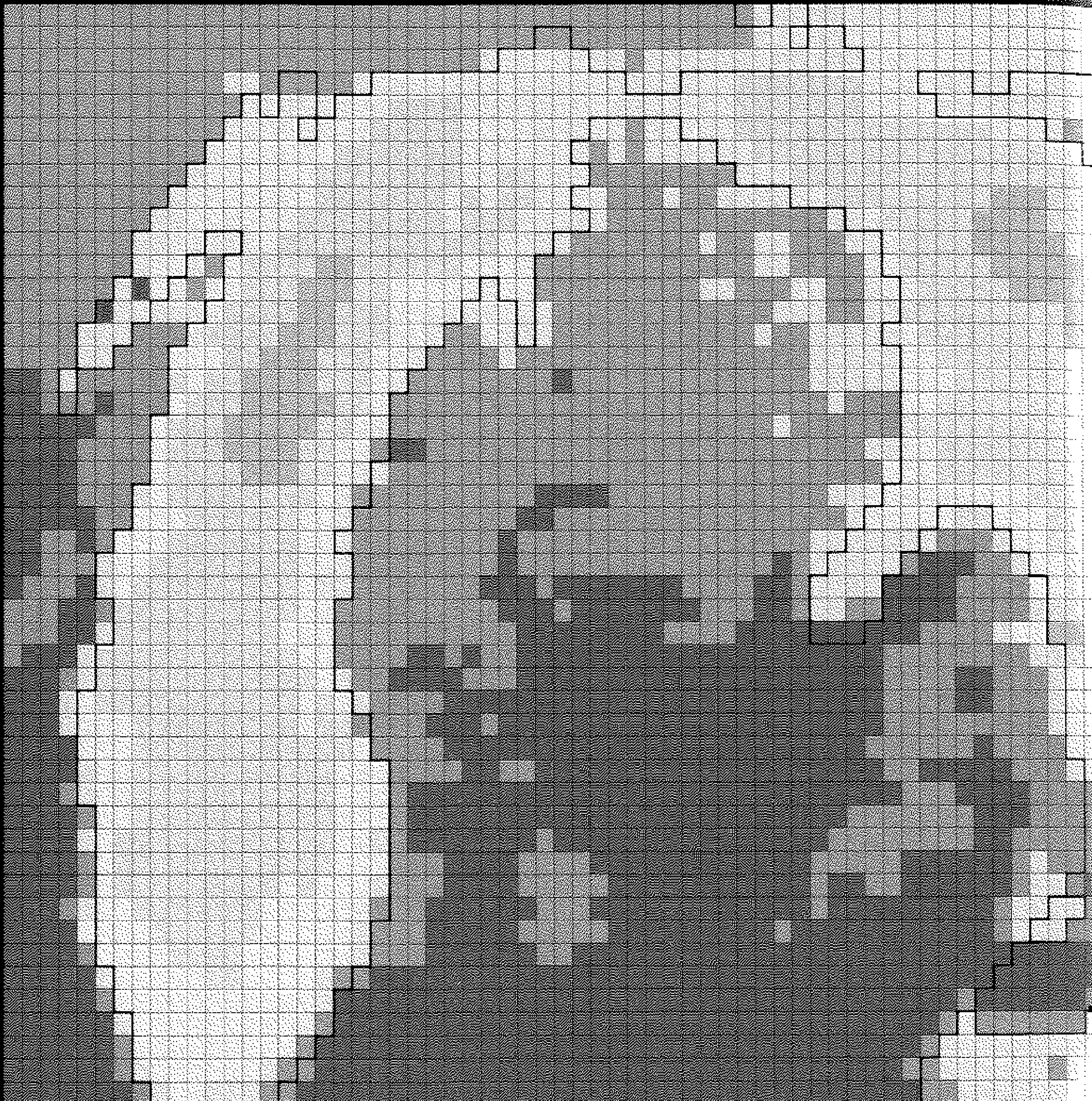
Fish in Lake Michigan

Distribution of Selected Species

Michigan Sea Grant Advisory Program



- Warmer than 71° F
- 64° to 71° F
- 56° to 63° F
- 48° to 55° F
- 40° to 47° F
- 33° to 39° F
- Cooler than 33° F

Lake Michigan's Surface Temperatures
3 p.m. EST, June 24, 1979

This map shows temperatures on the surface of Lake Michigan and surrounding land as recorded by the Geostationary Operational Environmental Satellite (GOES). From its altitude of 22,370 miles (36,000 km), the satellite can "see" heat as well as light across areas measuring about 13 by 18 miles (8 by 11 km). At mid-afternoon, the landmasses of Michigan, Wisconsin, Illinois, and Ontario were the warmest surfaces in the scene; Lakes Michigan and Huron were cooler, especially where they are deepest. (Continued on inside back cover)

FISH IN LAKE MICHIGAN

Distribution of Selected Species

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PREFACE

A water body as large as Lake Michigan has a geographic character exclusive of the land around it. The plant and animal life in the Lake, the physical characteristics of the water, the weather and climate over the water area, the geological structure forming the Lake basin, and the sediments on the bottom all exhibit patterns important to the human use of the water body.

This publication focuses on the seasonal distribution of eight fish species in Lake Michigan. These patterns are related to other physical characteristics of the Lake such as water depth and temperature, and human influences such as pollution and commercial and sport fishing.

Many people and organizations made this research possible. Funding was through generous grants from Michigan Sea Grant. The authors especially wish to acknowledge the encouragement and administrative support provided by Alfred M. Beeton, Howard E. Johnson and John H. Judd of Michigan Sea Grant.

The technique of depicting the seasonal distribution of fish species was developed with the aid of the biological expertise of LaRue Wells and Edward Brown, U.S. Fish and Wildlife Service, Great Lakes Fishery Laboratory, Ann Arbor, Michigan. These two Lake Michigan fish experts also reviewed the distributional patterns of perch, chubs, alewives and lake trout and provided valuable suggestions for the text accompanying the maps. Mercer Patriarche, Michigan Department of Natural Resources, reviewed the maps and text for whitefish and salmon. David Jude, Michigan Sea Grant, Ann Arbor, provided significant input to the text on the physical characteristics of the Lake in relation to fish. John Magnuson, Director, Institute of Limnology, University of Wisconsin-Madison, gave early encouragement to the study and reviewed the alewife maps. Clifford Mortimer, former director of the Center for Great Lakes Studies, University of Wisconsin-Milwaukee, was helpful in the research formulation stage. Fishery biologists who contributed significantly at various points were: Ronald Rybicki, Charlevoix Office, Michigan DNR Fisheries Division; Asa Wright, Lansing Office, Michigan DNR; Ronald Poff, Fisheries Division, Wisconsin DNR, Madison, Wisconsin; and James D. Moore, Green Bay Headquarters, Wisconsin DNR. Carlos Fetterolf, Executive Secretary, Great Lakes Fishery Commission, provided encouragement. The DNR offices in the states bordering Lake Michigan also provided essential planting information on salmon and lake trout.

This publication is truly the product of an interdisciplinary team. The cartography was done primarily by Cymbria Thompson and Thomas W. Colucci at the Center for Cartographic Research and Spatial Analysis, Department of Geography, Michigan State University. Under the direction of J. Michael Lipsey, various student cartographers also made important contributions. Theodore Alm researched, designed and drafted several maps in the early stages of the project. John Plough, Department of Geography, MSU, compiled an annotated bibliography of Lake Michigan for the project.

Lawrence M. Sommers

June 1981

INTRODUCTION

Billions of fish inhabit the shallows and depths of Lake Michigan, the sixth largest lake in the world. Anyone who has ever tried to hook a succulent lake perch knows that the movements of fish are anything but reliable. Yet their actions are far from random.

This publication tries to explain the distribution patterns of selected Lake Michigan fish species. It links the physical and geological characteristics of the Lake, the biological requirements of the fish, and the influence of human use of the Lake which together have shaped the distribution of fish in Lake Michigan.

Several unusual conditions make Lake Michigan an interesting case study for analyzing fish distribution. First, Lake Michigan stretches 307 miles (494 kilometers) north to south. Second, over the years the Lake Michigan fish community has undergone several changes in species composition, population level and location. Third, population levels and preferred locations change for fish from season to season. Fourth, recently, predators and pollution have affected the fish populations. Fifth, the amazing growth of the sport fishery since salmon planting began in 1966 is unprecedented in the world. Sixth, the large human population with easy access to the Lake puts huge pressures on the fish resources. Thus, Lake Michigan illustrates the effects of several factors important in fish distribution.

The Lake

Lake Michigan, the largest lake entirely within the United States, covers 22,400 square miles. It is roughly divided into two basins. The northern half has a complex, rugged bottom topography. It has several islands and two major bays—shallow Green Bay and the deeper Grand Traverse Bay. The deepest point is 923 feet (281 meters). The southern basin is shallower, more gently sloping and has a smooth bottom. Its maximum depth is 558 feet (170 meters). The northern shore is largely rocky, the eastern and southern shores are sandy and the western shore is mixed glacial materials—clays, silts, gravel and boulders.

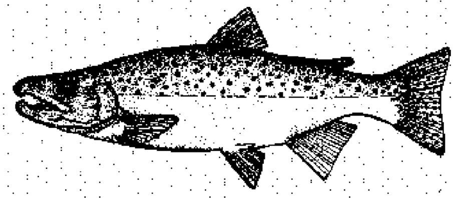
About 40 fish species are commonly found in Lake Michigan, about a fifth of all the species in the Great Lakes basin. Most species are native to the Lake. A few have been added by design and others have made use of human alterations of the connecting waters and channels to gain access to Lake Michigan.

The Land

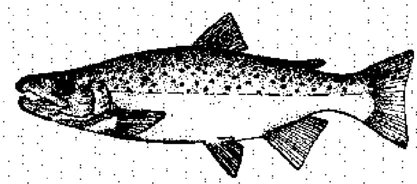
Glaciers shaped the Lake Michigan basin. The topography varies from rock-scoured hills in the north to sands, clays, silts, gravels, and boulders along the other shores.

The drainage basin is largest in Michigan with the St. Joseph, Kalamazoo, Grand, Muskegon, Manistee, and Menominee Rivers, all of considerable size and water volume. The Fox River, emptying into Green Bay, is the major drainage area in Wisconsin. Both Indiana and Illinois have very small shore areas that drain into Lake Michigan.

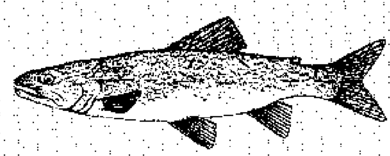
Land uses and population centers affect water quality and thus the fish populations of Lake Michigan. Plowing,



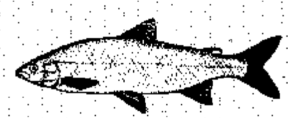
Chinook salmon
Oncorhynchus tshawytscha



Coho salmon
Oncorhynchus kisutch

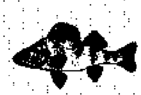


Lake trout
Salvelinus namaycush

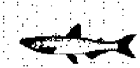


Lake whitefish
Coregonus clupeaformis

Bloater chub
Coregonus hoyi



Yellow perch
Perca flavescens



Rainbow smelt
Osmerus mordax

Alewife
Alosa pseudoharengus

Fish Species in Lake Michigan

Sea lamprey	*Petromyzon marinus*
Lake sturgeon	*Acipenser fulvescens*
Alewife	*Alosa pseudoharengus*
Lake whitefish	*Coregonus clupeaformis*
Bloater	*Coregonus hoyi*
†Blackfin cisco	*Coregonus nigripinnis*
†Longjaw cisco	*Coregonus alpenae*
†Shortjaw cisco	*Coregonus zenithicus*
†Deepwater cisco	*Coregonus johannae*
†Kiyi	*Coregonus kiyi*
†Shortnose cisco	*Coregonus reighardi*
†Lake herring	*Coregonus artedii*
Round whitefish	*Prosopium cylindraceum*
Lake trout	*Salvelinus namaycush*
Brook trout	*Salvelinus fontinalis*
Rainbow trout	*Salmo gairdneri*
Brown trout	*Salmo trutta*
Coho salmon	*Oncorhynchus kisutch*
Chinook salmon	*Oncorhynchus tshawytscha*
Rainbow smelt	*Osmerus mordax*
Northern pike	*Esox lucius*
Carp	*Cyprinus carpio*
Emerald shiner	*Notropis atherinoides*
Spottail shiner	*Notropis hudsonius*
Longnose sucker	*Catostomus catostomus*
White sucker	*Catostomus commersoni*
Channel catfish	*Ictalurus punctatus*
Bullheads	*Ictalurus spp.*
Trout-perch	*Percopsis omiscomaycus*
Burbot	*Lota lota*
Ninespine stickleback	*Pingitius pingitius*
Smallmouth bass	*Micropterus dolomieui*
Yellow perch	*Perca flavescens*
Walleye	*Stizostedion vitreum vitreum*
Freshwater drum	*Aplodinotus grunniens*
Slimy sculpin	*Cottus cognatus*
Spoonhead sculpin	*Cottus ricei*
Fourhorn sculpin	*Myoxocephalus quadricornis*

†rare or almost extinct

intense fertilization and applications of herbicides and insecticides are agricultural activities which affect water quality. Agriculture is well developed in the Fox River Valley and the coastal areas of Wisconsin with cash grain crops and dairy farming as major activities along with the specialized cherry production on the Door Peninsula. In Michigan, a fruit belt extends from Charlevoix to the Indiana border. Further inland, there is dairy farming, horticultural crops, and specialty agriculture such as chicken production in the Holland-Zeeland area. Surrounding northern Lake Michigan are forest and recreation lands. Lumbering and paper and pulp manufacturing are found in both Wisconsin and Michigan. The population of the northern Lake Michigan basin is small compared with the southern region.

Along the southern shores and adjacent areas, the industrial concentrations and dense urban populations have a major influence on Lake water quality and fish distribution. The Chicago-Gary, Indiana, consolidated metropolitan area, for instance, has a population of about 7.6 million and the Milwaukee-Racine area contains an additional 1.5 million people. The Michigan counties which drain into Lake Michigan contain about 2.5 million people. How these people earn their living in the Lake Michigan drainage basin shapes water quality of the Lake. Human uses of the Lake—for commercial ship transportation, recreation, fresh water supplies, commercial and sport fishing and others—all put pressure on Lake resources. The handling of the industrial, commercial, domestic and agricultural wastes is key to controlling Lake Michigan water pollution.

The Water

Lake Michigan contains 1,170 cubic miles (4,870 cubic kilometers) of water. Water flows in from tributaries draining the Lake basin and from the St. Marys River, and rain and snow falling on the Lake itself. Melting snows and basin precipitation in spring and summer add the most water. Thus, the highest annual water levels occur during the warm half of the year culminating in August. Water leaves the Lake mainly through the Straits of Mackinac and the rest of the Great Lakes system. Much water is also lost through evaporation.

Lake elevation above sea level also varies considerably due to water gain and loss over time. The highest recorded level was 581.3 feet in 1886 and the lowest 575.5 feet in 1964 (a difference of 5.6 feet). Varying water levels cause differences in the amount of beach area or erosion of shore dunes and bluffs; erosion influences harbor depths, water depths along shore, and the amount of suspended particles in the offshore water.

The temperature of the water varies greatly during the year. Nearshore areas freeze during the winter (normally January through March) but there are usually large areas of open water all winter in the center of the Lake. Colder winter air temperatures create more extensive ice cover in the northern shallow water areas. Normally, Green Bay completely freezes over in winter. Warm season temperatures vary with water depth, fluctuating air temperatures, and the direction and strength of winds.

Lake Michigan is classified as a cold, deep, and clear oligotrophic body of water; it has low levels of dissolved nutrients, is high in dissolved oxygen, and has few aquatic plants and algae. Water quality is generally high. Consequently, the most numerous phytoplankton—free-floating microscopic single-celled plants (algae)—are desirable diatoms; but green and blue-green algae are also abundant during certain warm water periods.

The Lake has been enriched in this century by nutrients in sewage, agricultural drainage and other runoff materials. Enrichment has caused the Lake to become slightly mesotrophic (containing moderate levels of dissolved nutrients). Enrichment and pollution levels are highest in the southern half of the Lake corresponding with population concentrations and lake use. Recently, the enrichment process has been slowed considerably by pollution control and phosphate detergent bans. Along the shore where major urban and industrial wastes are entering Lake Michigan there are some localized pollution problems. Together the land and water have influenced the kind of fish populations that have evolved in Lake Michigan. Major species are shown on page 1. Changing physical, biological, and human factors all played important roles in the character of the water and the fish community of Lake Michigan.

The Fish

In the last 30 years, the fish community in Lake Michigan has undergone major upheavals. The invader sea lamprey decimated native fish populations, clearing the way for a massive population explosion of alewives. Salmon were introduced to feed on the alewives and to provide a sport fishery. Salmon have revolutionized sport fishing patterns in Lake Michigan and have sparked new interest in Lake Michigan among many people.

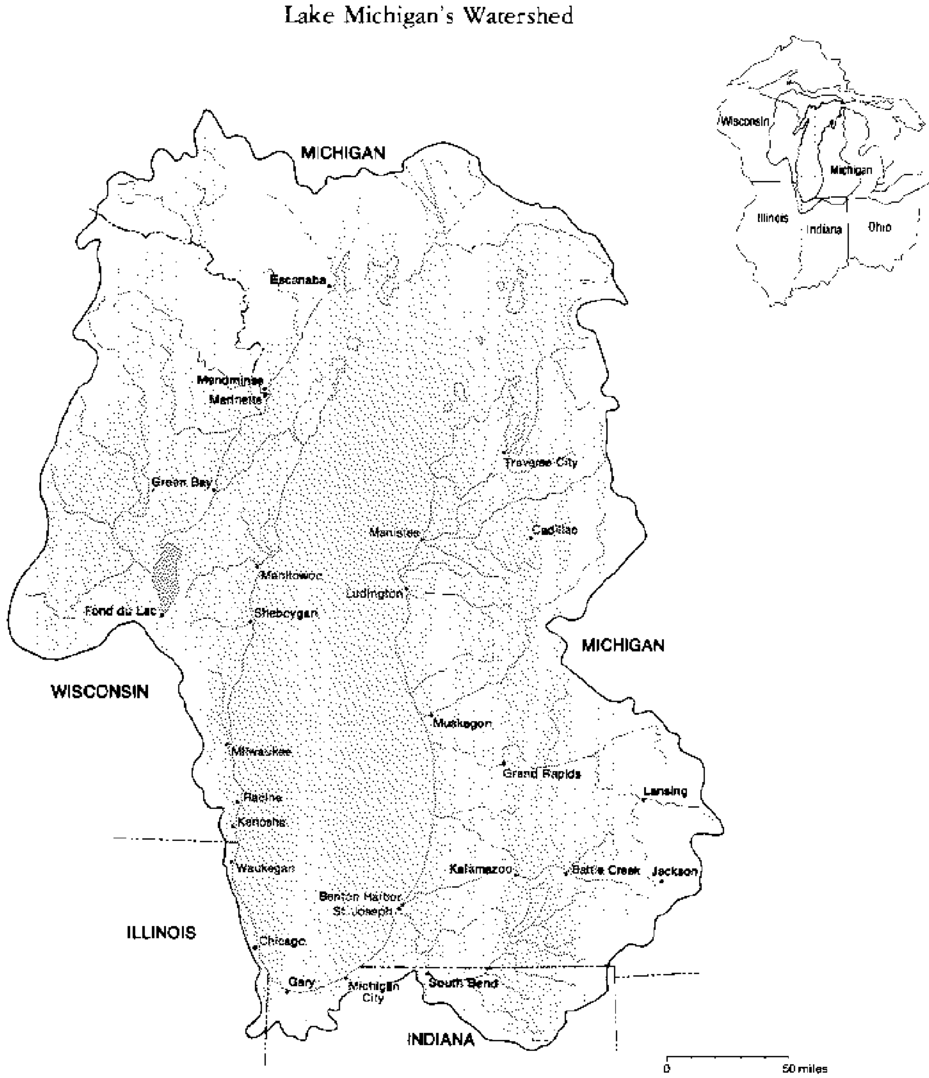
The Approach

Drawing on the wealth of scholarly work available on Lake Michigan fish, this publication presents, largely in map and graphic form, the distributional characteristics of some major fish species found in Lake Michigan. Also, the important factors responsible for the distributional patterns are analyzed. The approach is primarily the spatial distribution and analysis methodology of the discipline of geography. The publication is designed to be useful to fishers, scholars, planners, decision-makers, students, and the curious.

The Method

Complete statistics do not exist to show where the various species of Lake Michigan fish can be found at various times of the year for all parts of the water body. However, fishery biologists using research trawls have collected information on how deep, at what temperatures, and in what amounts various species of fish occur at different times of the year. Also, scientists and fishers have information on commercial and sport catches, spawning grounds, and migrations. This information was used to supplement sampling statistics. Experimental maps were compiled showing three categories of concentration—*main, moderate,* and *light or none.* Zones delineating the seasonal distributions of most species were drawn in consultation with fish biologists LaRue Wells and Edward Brown of the Great Lakes Fishery Laboratory, Ann Arbor. A bathymetric map showing bottom depths in feet was used as the base map. Bottom depths rather than water depths were used because most species show concentrations near shore and few or no fish occur at the same water depth in the central part of the Lake. Experts checked the draft distributional maps for each species for accuracy. The maps on pages 21 to 35 show places where fish are likely to be found at different times of the year based on factors which affect distribution. The maps show Lake areas where conditions exist for certain concentrations of a given species but this does not guarantee that fish will actually be found evenly distributed through these areas.

Lake Michigan's Watershed



Factors of Distribution

Fish in Lake Michigan contend with a variety of physical, biological and human-induced factors which determine their survival as a species and their population size. These same factors often determine distribution and migration patterns as well.

Natural factors include water depth, temperature, surface currents, and upwellings. Water quality is a combination of natural and human causes. Human interventions include stocked species, species inadvertently admitted to the Lake, and fishing pressure.

This section emphasizes the variables which influence the distribution of fispecies in Lake Michigan and make it possible to map those distribution patterns.

Some factors are closely related such as high summer water temperature and shallow water depth. Sometimes the relationships are human-caused such as high water temperatures in the vicinity of heated water discharges from electric generating plants.

Together with food availability and spawning requirements, water temperature is the primary determinant of life distribution in the Lake. Water temperature is affected by water depths, air temperatures, surface currents, upwellings and heat from the sun. Fish distribution patterns shown in this publication are closely related to seasonal water temperature changes; these vary by depth as well as geographical location in Lake Michigan.

WATER DEPTH

Lake Michigan was formed during the Pleistocene (Ice Age) Period about 11,000 years ago. Continental glaciers gouged out river valleys to form the Lake Michigan Basin. The Lake floor consists of the sands, silts, gravels, clays and boulders which the glaciers deposited on the rest of the Upper Midwest. Thin layers of fine sediments have since been laid down on top of the glacial materials in most Lake bottom areas.

Lake Michigan divides roughly into northern and southern basins with a shallow area separating the two. The shallow area roughly between Muskegon and Milwaukee ranges from 240 to 360 feet (79 to 118 meters) deep through the central portion of the Lake.

The southern basin has relatively simple bottom and water depth patterns. The Lake deepens gradually to a maximum depth of 558 feet (170 meters). The shallow water zone less than 60 feet (20 meters) deep is nearly twice as wide in the west (Wisconsin) and south (Illinois) as on the east (Michigan) side. This shallow zone is the most productive area of the Lake because of the greater concentration of nutrients in the water.

The northern basin of Lake Michigan has a highly diverse bottom topography. This portion of the Lake can be divided into four regions. A relatively shallow area extends across the entire Lake west of the shore between Ludington and Muskegon; maximum depth is about 570 feet (188 meters). A very deep area between Ludington and the mouth of Green Bay reaches a maximum depth of 923 feet (280 meters). The shallow bays—Green Bay, and Little and Big Bay de Noc with a maximum depth of 120 feet (39 meters) contrast with the deep bays—Grand Traverse and Little Traverse Bays—which reach depths of over 600 feet (190 meters). In the northwest the bottom topography is complicated by islands, deep troughs, and shoals. The islands are surrounded by large shallow water areas.

The variety of water depths in the northern part of the Lake creates suitable habitat for a variety of fish species. The island shallows and Green Bay are warm in summer, a suitable habitat for species such as yellow perch. The deep bays, Grand Traverse and Little Traverse Bays, remain cool all summer. Their depths are favored by lake trout and whitefish during much of the year.

In general, Lake Michigan's shallow waters are warmer in summer and colder in winter than its deep waters. Thus, depth plays a major role in fish distribution by setting up temperature zones to which fish react.

TEMPERATURE

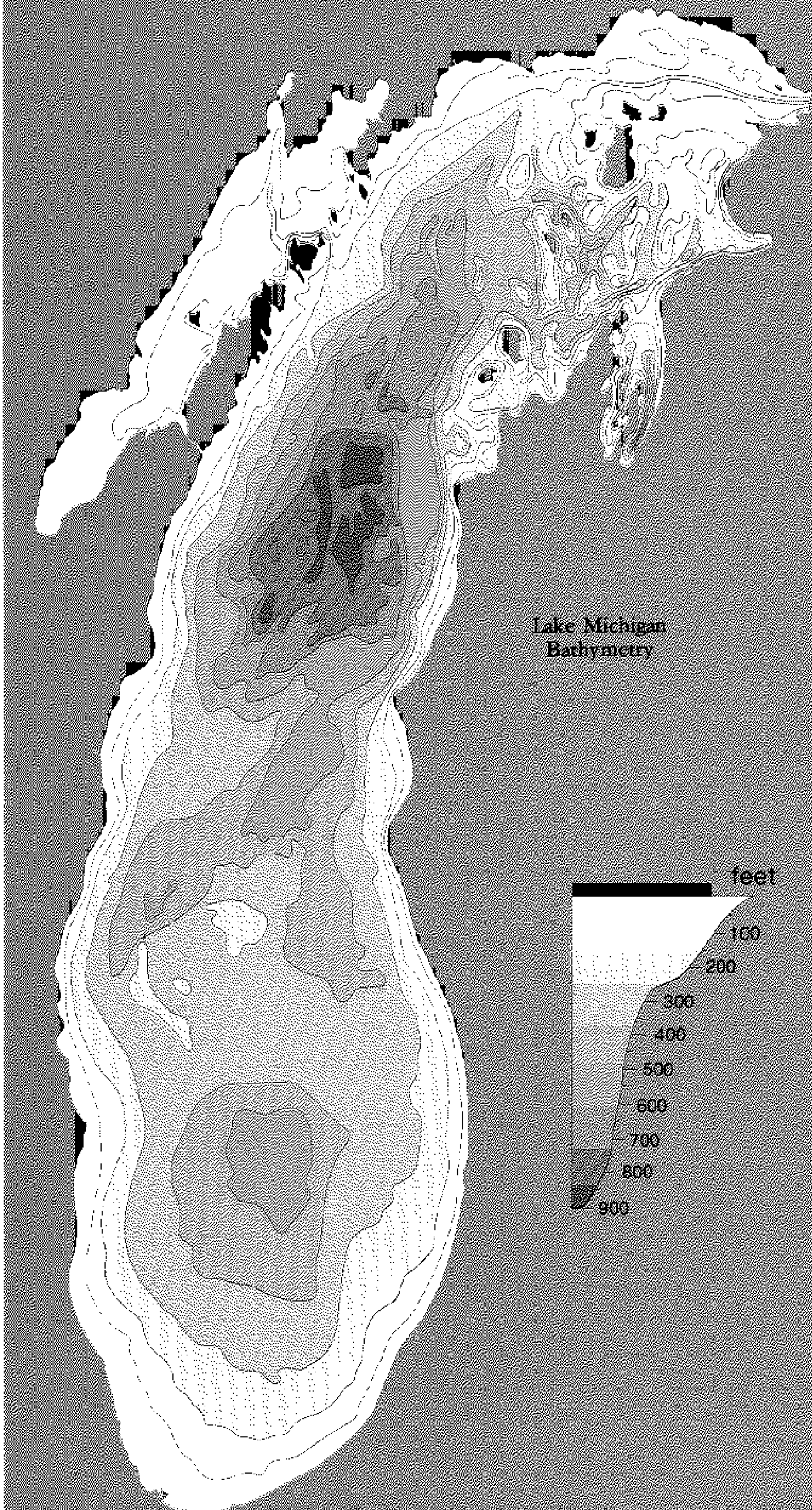
Because fish are cold blooded, they take on the temperature of the water around them. Temperature also controls many aspects of fish physiology and behavior. Thus, it is not surprising that water temperature is the principal factor influencing the distribution of fish in Lake Michigan throughout the year.

Fish respond to daily, periodic, and seasonal changes in water temperature by moving to another place in the Lake with water of a preferred temperature. Also, changes in water temperature may trigger some behavior such as spawning or migration. Some fish react more strongly to water temperature than others. Fish seek water temperatures best suited to their daily and seasonal activities. Their preferred temperatures vary by species and by activity. For example, lake trout prefer cooler temperatures for feeding than do yellow perch. Salmon tolerate warmer temperatures when spawning than they do when feeding. Combining Lake Michigan water temperature patterns with the fish's preferred temperatures suggests places where fish are likely to concentrate at a particular time of year. However, predictions are difficult because Lake Michigan is so large and deep that its temperature patterns are quite complex.

Just as the land surrounding Lake Michigan routinely moves through the seasons, the Lake itself undergoes its own continuous water temperature cycle.

The water temperature profiles on the accompanying diagrams help show the changes in water temperature that occur through the year. Imagine that Lake Michigan is sliced in two on a line from Manitowoc to Ludington. The temperature profile shows an end-on view of one slice of the Lake. The lines are isothermal lines (*iso* meaning the same and *thermal* for temperature) which link depths of the Lake having the same water temperature. What follows is a simplified description of the Lake Michigan temperature cycle. Keep in mind that the entire Lake does not reach the same temperature nor respond to seasonal changes at exactly the same time.

Winter and summer temperature profiles are stable, but the warming and cooling of spring and fall produce constantly changing thermal patterns. By the end of March, the close of the Lake winter, Lake Michigan water is at its coldest, usually slightly below 32°F (0°C). The coldest water is found near the shore. Warming begins in early April and is generally confined to the shallow areas nearest shore. April warming sets up sharp contrasts between the warm



shore water and the cold, deep-basin water. This contrast intensifies as warming proceeds through May and early June. The thermal bar, a narrow, nearly vertical curtain of water separating the warm and cold water, is displayed on the profile by the cluster of vertical isothermal lines which parallel the shore.

By the end of June, the Lake is thermally stratified. The relatively warm surface layer is separated from the cold, deep layer by a zone of rapid temperature decline called the thermocline. On the temperature profiles, the thermocline appears as a cluster of isothermal lines parallel to the Lake bottom.

Lake Michigan summer stratification is usually complete by the end of June. Throughout July and August, maximum heating occurs. This raises the temperature of only the warm upper layer, reinforcing the stratification. The thermocline is most pronounced by the end of August and lies somewhere between 45 and 65 feet (15 and 21 meters) deep.

Cooling begins in September when the thermocline is found at greater depths, and it continues through October to roughly the beginning of November when the thermocline is at its deepest level. It is also less definite and less stable than during summer. By the end of November, the thermocline is completely disrupted. Water formerly separated into layers now mixes freely from top to bottom.

Cooling continues through December until the average water temperature of the Lake is between 39°F and 41°F (4° to 5°C). Through January and February more cooling occurs, particularly along shores. The annual cycle is completed by the end of March when Lake Michigan is cold throughout and unstratified.

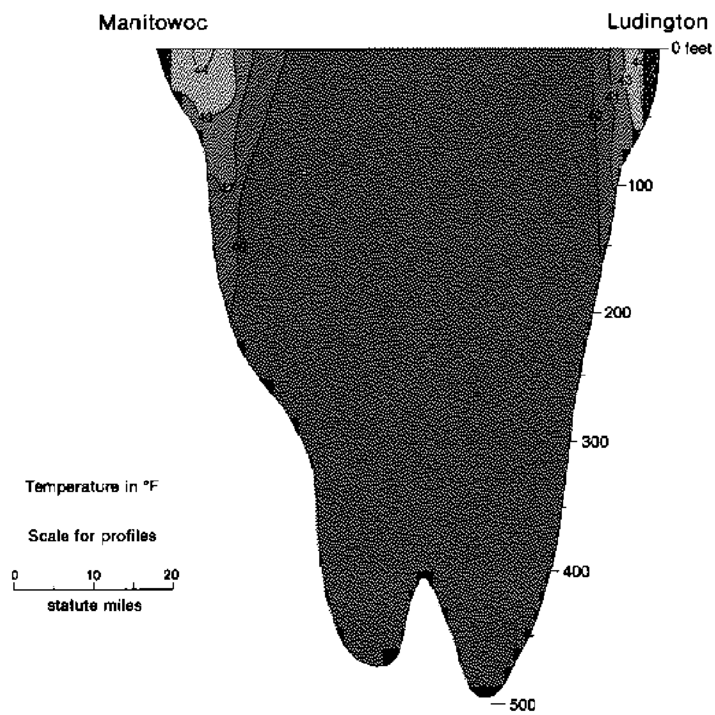
The temperature-density relationship of water is the key to understanding the seasonal influence of temperature on Lake Michigan. Water is most dense at 39°F (4°C). Warmer water is less dense and thus lighter and floats on colder water the way oil floats on water. With spring warming, Lake Michigan surface waters are less dense and begin to form a layer which is separate from the deeper zones. The Lake stratifies and the thermocline forms. Differences in density, caused by differences in water temperature across the thermocline, form an actual physical barrier to mixing of deeper layers with surface waters.

In late fall, when water cools and more and more of the Lake is again at the same density allowing wind and currents to mix it freely from top to bottom, *overturn* occurs.

This generalized temperature cycle is only one part of Lake Michigan's temperature patterns. Temperatures are also influenced by weather and latitude. Each latitude has a characteristic amount of heating from the sun. The northern portion of the Lake has a shorter warming period and longer cooling season than the southern part. Ice can be forming in the northern part of Lake Michigan at the same time that it is melting in the southern basin. While the warmest temperatures are generally found in southern Lake Michigan, shallow bay areas such as Green Bay are exceptions.

Local variations in Lake Michigan temperature patterns can occur after unusual weather and winds. In general, however, water temperatures are closely related to latitudinal location.

East to west temperature variations are usually less pronounced and more difficult to explain than the north to south differences attributed to latitude. These east to west differences are most noticeable during summer stratification.



May 13, 1955

Sometimes dramatic differences result from persistent winds which can cause upwellings (see pages 10 and 11). The wind moves aside the warm surface water from one side of the Lake, forcing colder water from the Lake depths to replace the displaced, warm inshore water. This alters the slope of the thermocline. Cold water is closer to the surface on the windward side of the Lake and warm water is deeper on the opposite side. The idealized horizontal thermocline described earlier is more the exception than the rule during the Lake Michigan summer.

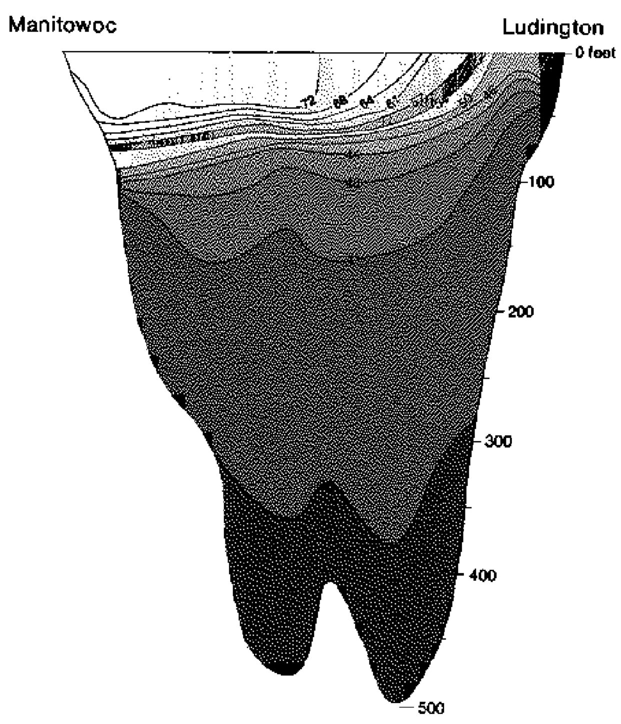
Many aspects of Lake Michigan's thermal patterns affect fish distribution. First, fish will actually congregate in areas of the Lake where the temperature best suits their needs. These preferences are determined by the fish's physiology. Second, changes in water temperature may trigger spawning migrations and behavior. Also, temperature often controls the presence or absence of a fish's food source.

Food

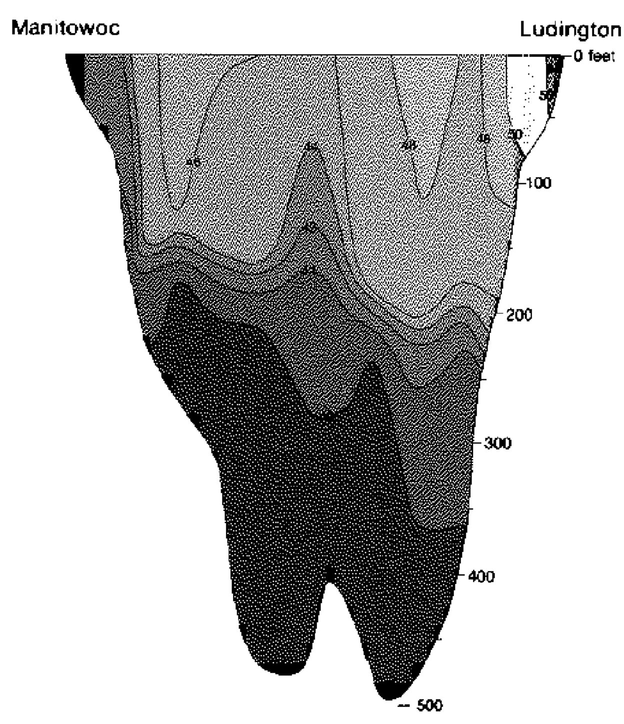
Many young fish feed on zooplankton which are tiny free-floating animals, or phytoplankton, tiny free-floating plants. As the fish grow older they may switch to benthos, creatures which dwell near the Lake bottom, or to other small fish like perch. Two crustaceans, *Mysis relicta* and *Pontoporeia*, are important food organisms. Larger fish species like lake trout and salmon are primarily carnivores.

A significant difference exists in the availability of benthos between inshore waters and the deeper waters. The shallow inshore waters are often in turmoil and thus not reliable areas for the development of food for fish. Turbidity cuts down light penetration in the water, slowing algae growth. These shallow waters are often subject to rapid temperature changes. Food-producing conditions alter rapidly because of upwellings, temperature changes, strong surface winds, and water currents. The food types available are also affected by nutrients from municipal, industrial and agricultural discharges. Near river mouths and urban areas, enriched waters may alter the types of foods and thus fish species found in the area. The availability of benthos for fish food is more reliable in water deeper than 60 feet (20 meters).

Temperature and food availability are closely related in Lake Michigan. Together with spawning, temperature



August 13, 1955



November 8, 1955

and food explain most of the seasonal distributions of fish species.

More detailed information about the temperature responses of eight fish species appears in the text and maps in the second half of this publication.

CURRENTS

Surface currents move and mix Lake Michigan waters. Wind provides the energy for these currents. Current direction and velocity depend on wind source and intensity, especially in the upper 5 feet (1.5 meters) of water. However, deeper currents may move against the wind, responding to strong internal waves.

Currents are named for their direction of flow. A current that flows toward the north is a northerly current. This is in contrast to winds, which are labeled by their direction of origin. A north wind blows out of the north, toward the south.

The major influence of currents on fish distribution is their effect on water temperatures. Surface currents tend to mix water layers, eventually making all the surface water the same temperature. In shallow areas, where the influence of currents is strongest, local fish distributions may be altered by the currents.

Surface current patterns for Lake Michigan vary with the seasons. The winter pattern is less complex than the summer arrangement. The patterns are shown on the accompanying illustrations.

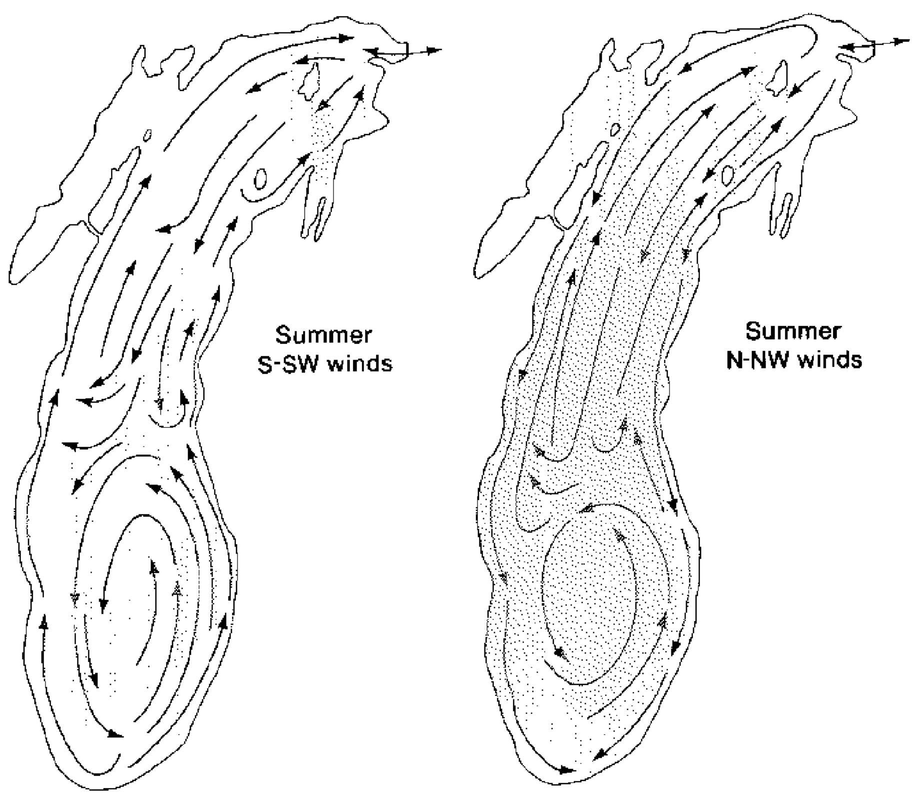
Wind strength and direction determine winter patterns. Each basin has its own circulation with the same pattern repeated in each. Southerly and southwesterly winds drive nearshore currents northerly. Over the deeper basins, the water moves counterclockwise. When winds are from the north or northwest, nearshore currents flow south. In the remaining inner portions of the basin, water circulates clockwise.

Ice alters the current pattern in winter by impeding water flow. Along the Michigan shore, wind-driven ice builds to a considerable thickness and width, particularly in a severe and consistently cold winter.

In summer, surface current patterns are more complex. The wind changes direction more frequently, southerly winds are stronger and more frequent, and no ice cover interferes with water movement.

Both the northern and southern basins show nearshore currents that are responsive to prevailing winds. Surface water in the inner parts of the southern basin generally flows counterclockwise, regardless of wind direction. Offshore water movements are very complicated as the accompanying maps indicate. During warm months, internal waves drive currents in offshore waters. These waves respond to changes in wind direction and velocity. In deep areas, currents are also affected by the earth's rotational force which deflects water movements to the right.

In shallow areas, several factors affect inshore currents. Constructions extending into the Lake, particularly



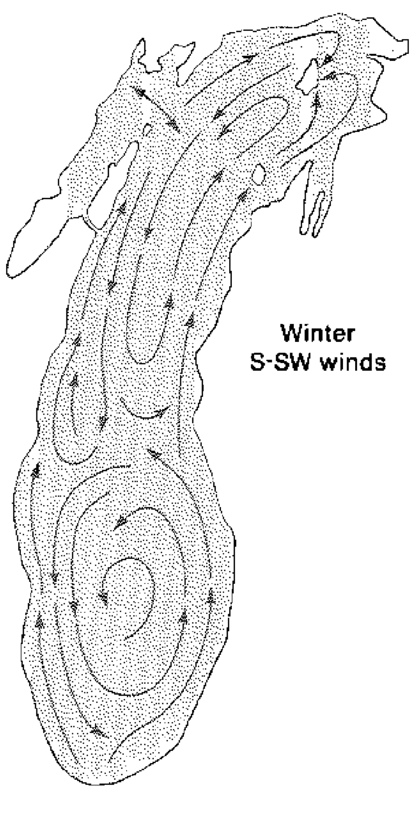
Prevailing Surface Currents

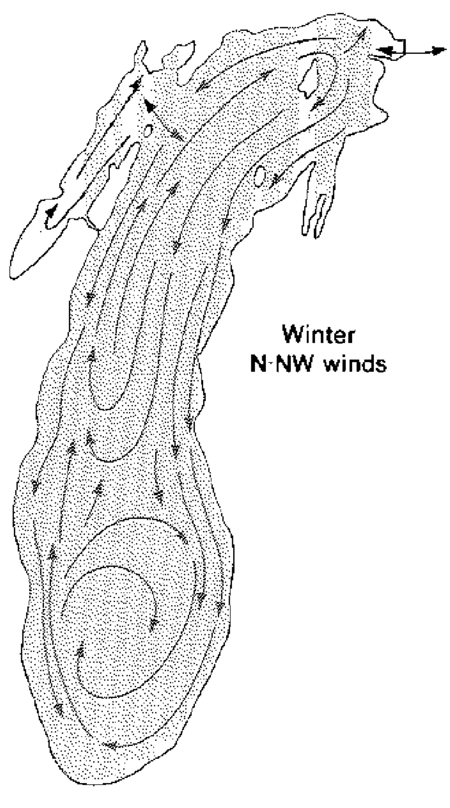
piers protecting harbor entrances, divert currents for several miles to either side of them. Natural coastline irregularities may alter shallow water current flows. Currents may be changed by rivers or other large volume discharges. Rivers are most influential during spring snowmelts or after heavy rains. Another influence on currents is upwelling.

UPWELLINGS

When a strong, steady summer wind blows across the Lake Michigan shore, the warm upper water layer moves off shore, and cold waters from the depths of the Lake rise to the surface to replace the warm layer. This phenomenon is called upwelling. An upwelling along one shore is usually mirrored by a downwelling on the opposite shore as Lake water rushes in to replace water which has welled up to the surface.

Upwellings affect fish distribution because they alter the relationship between temperature and water depth. Because fish prefer particular temperatures, they may move about to maintain that temperature. In an upwelling, colder water is nearer the surface than in nearby, stationary waters. Thus, fish preferring these cold temperatures may be found in shallower water in upwellings than in adjacent waters. Fish preferring warmer waters will usually move from upwelling areas into warmer areas.





Upwellings occur along the western and eastern shores of Lake Michigan in summer and early fall. The most significant upwellings occur along the eastern shore when a steady cold wind blows from the northeast, moving the surface water south. Along the western shore, an upwelling occurs in response to southwest winds. Winds responsible for upwellings generally cover large areas of the Lake.

The June 29, 1955, map of Lake Michigan surface temperatures shows a normal thermal pattern under calm wind conditions. In upper water layers, surface temperatures are highest in the south and gradually taper off toward the north. This surface temperature gradient is caused by latitudinal differences in solar heating, and can be rapidly changed by shifting winds. Just how dramatic a temperature change can take place is illustrated by the upwelling that was recorded little more than a month later.

The August 9, 1955, map shows the strong upwelling which was caused by a high velocity, steady north wind which began August 7, 1955, and continued for 2 days. The coldest water temperature along the Michigan shore was 45°F (7°C). The cold isothermal lines are very close together and roughly parallel the shore. Cold water formed a narrow band about 15 to 20 miles wide (24 to 32 kilometers). The remaining three quarters of the Lake west of the 53°F (11°C) line showed little temperature change in the surface water. The maximum water temperature for August 9, 1955, was 55°F (13°C) along the western shore south of Sheboygan, Wisconsin. Surface temperatures indicate that a lot of warm water had been pushed into the southern end of the Lake. Cold water had risen to the surface from a considerable depth because the coldest water in the Lake at that time of year would have been about 36°F (2°C).

Upwellings on the western side of Lake Michigan, brought about by southwesterly winds, generally cause less severe temperature changes in coastal waters than upwellings on the eastern side.

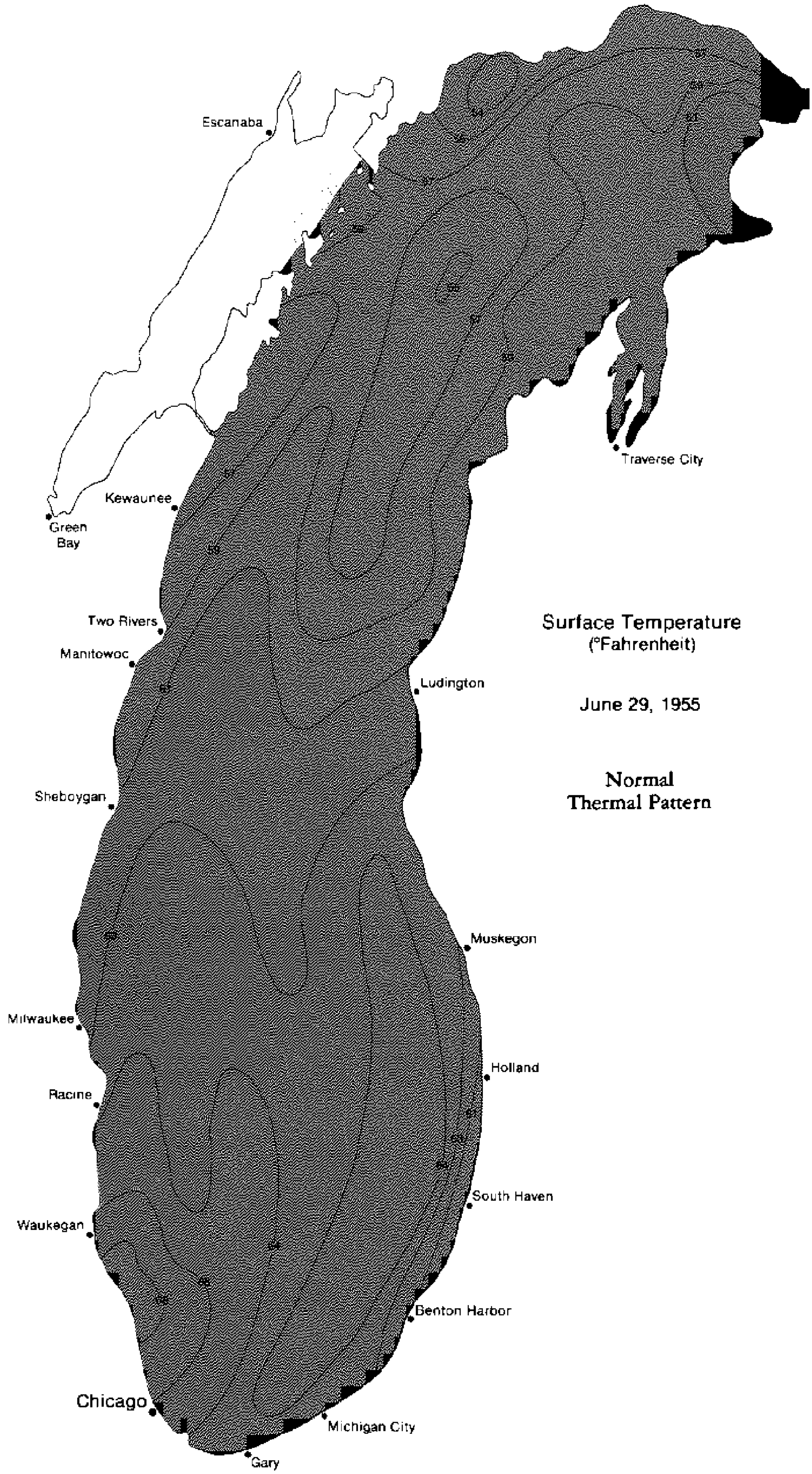
Upwellings and downwellings may alter other water movements in the Lake. They may speed up coastal currents, especially in shallow water no more than 20 miles (32 kilometers) from the shore.

In nearshore areas, water temperature changes caused by upwellings can markedly alter the distribution of fish, especially those such as alewives and perch which prefer warm water during summer. The distance from shore at which salmon, trout and whitefish may be found may also be affected. During an upwelling, these fish may be found closer to shore than is usual for that time of year.

WATER QUALITY

High quality water in Lake Michigan makes it possible for billions of desirable fish to live there. Water quality, however, changes from time to time and place to place in the Lake.

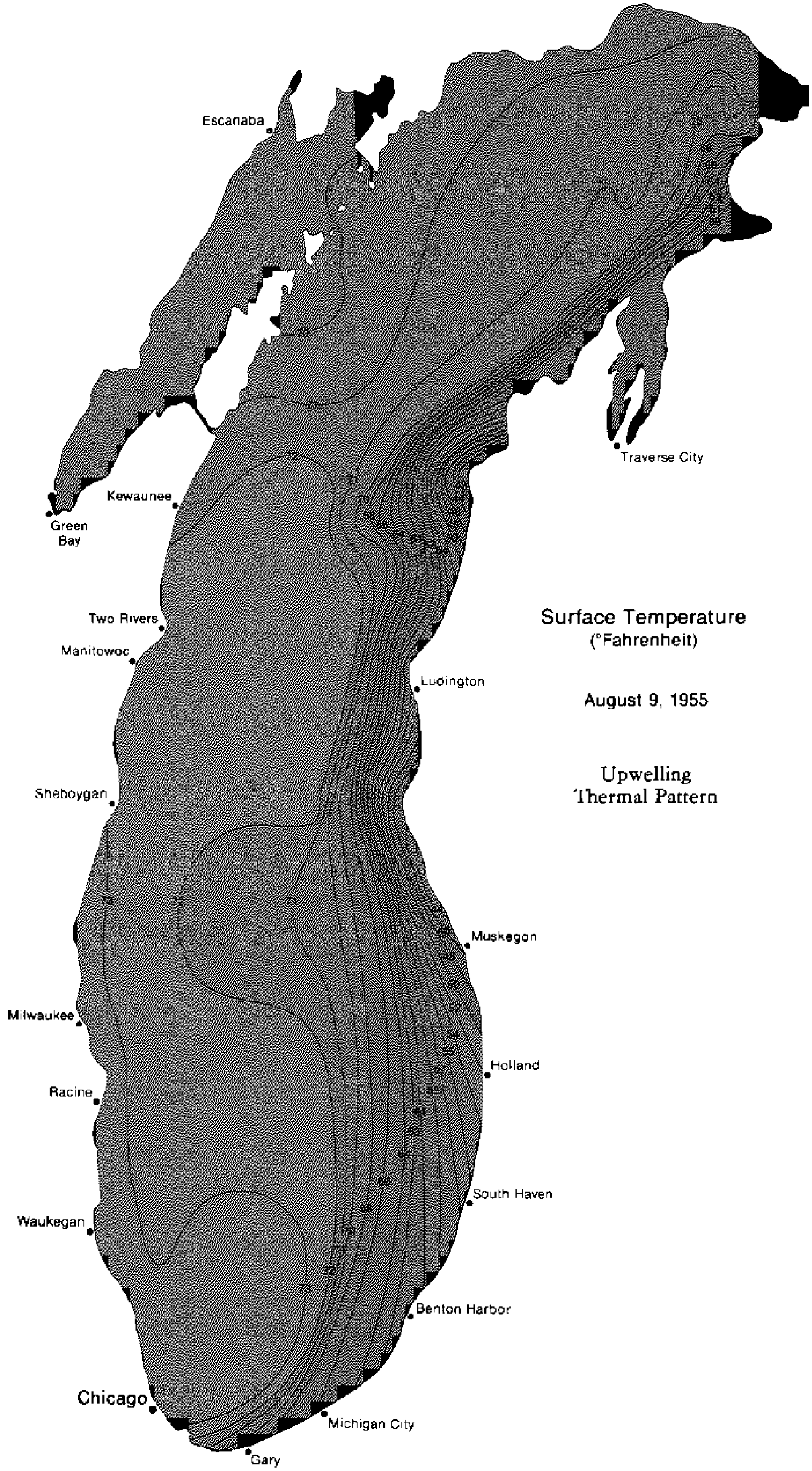
When Lake scientists discuss "water quality," they are usually talking about three categories of materials which can be found in water: suspended solids, nutrients and contaminants. In Lake Michigan suspended solids are a problem in river plumes and in waters adjacent to eroding shorelines but not in open waters. Nutrients cause problems in enclosed harbors, in several bays and



Surface Temperature
(°Fahrenheit)

June 29, 1955

Normal
Thermal Pattern



Surface Temperature
(°Fahrenheit)

August 9, 1955

Upwelling
Thermal Pattern

near some large cities. Contaminants find their way into water and fish anywhere in the Lake.

Suspended Solids

Soil and clay particles suspended in water cloud the water. Such cloudiness, called turbidity, may reduce light penetration below the surface, preventing algae growth. As particles settle, they may smother fish eggs. Suspended solids may carry chemicals attached to them.

Most Lake Michigan water is clear. Turbid areas usually occur where rivers enter the Lake. Many of these river "plumes" fan out for several miles into the Lake. Narrower bands of turbid water parallel eroding sand and clay shores.

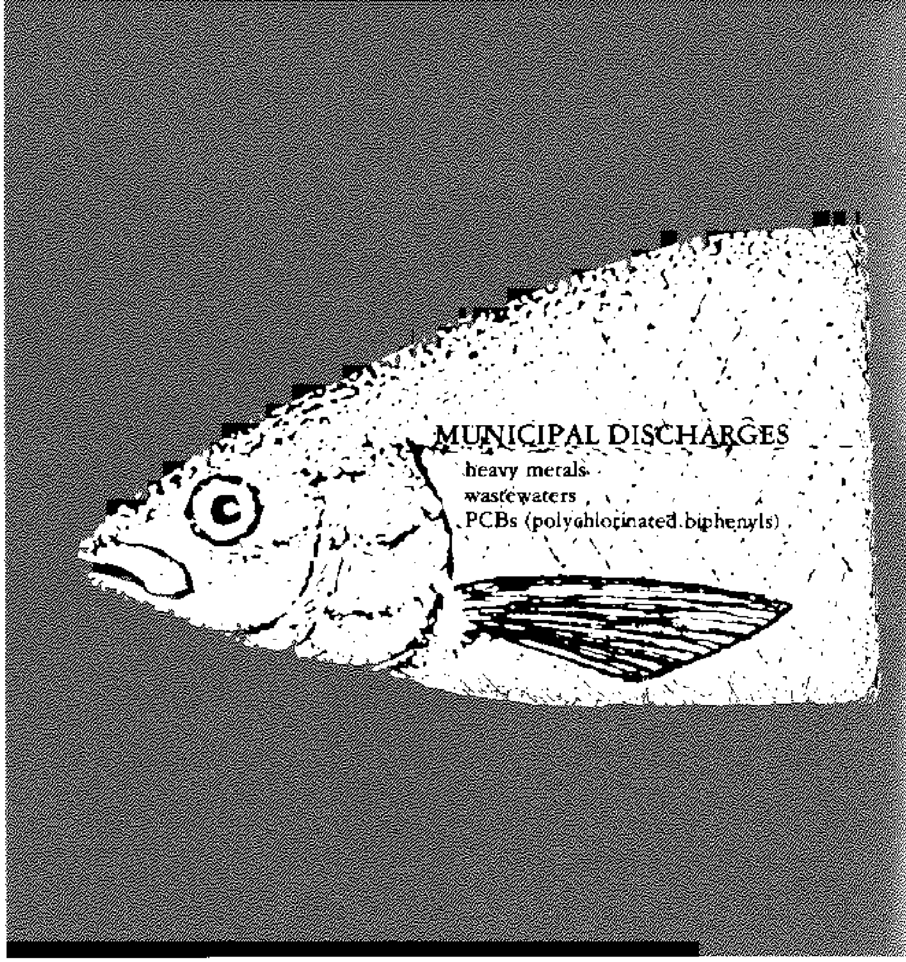
Nutrients

Without nutrients, there could be no plant growth in Lake Michigan, and without plants, no animals would survive.

The nutrients necessary to support life are chemical compounds containing phosphorus, nitrogen, calcium, silica, manganese, magnesium, iron and many other elements. When the Lake has just enough of these chemicals to support desirable plant growth, they are called nutrients. When levels of these same chemicals are so high they support too much plant growth, they are pollutants.

Nutrients enter the Lake in municipal and industrial discharges and in waters draining urban and agricultural areas.

The open, deep water of Lake Michigan contains very low levels of nutrients. This part of the Lake is called



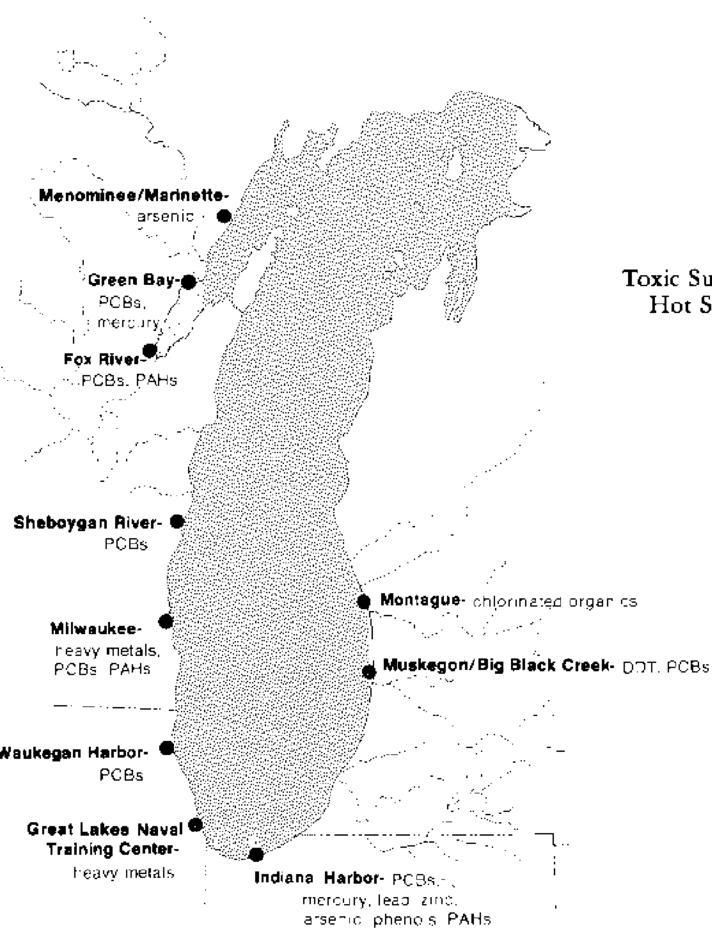
Major Lake Michigan Toxic Substance Sources

oligotrophic; it has a low nutrient supply in relation to the volume of water. Oligotrophic water is preferred by lake trout, whitefish, and salmon.

The *eutrophic* waters of Lake Michigan contain high levels of nutrients compared to the volume of water. The abundance of nutrients supports rich plant growth, both large rooted weeds and floating algae. These waters are thought of as polluted or overenriched. Eutrophic waters frequently have oxygen shortages in summer. The fish commonly found in these waters are minnows, carp, bass, catfish and other warmwater species.

Only a few Lake Michigan areas are eutrophic. Southern-most Green Bay is fed by the Fox River which carries heavy loads of nutrients in municipal and industrial wastes. Milwaukee Harbor and Little Bay de Noc are also eutrophic.

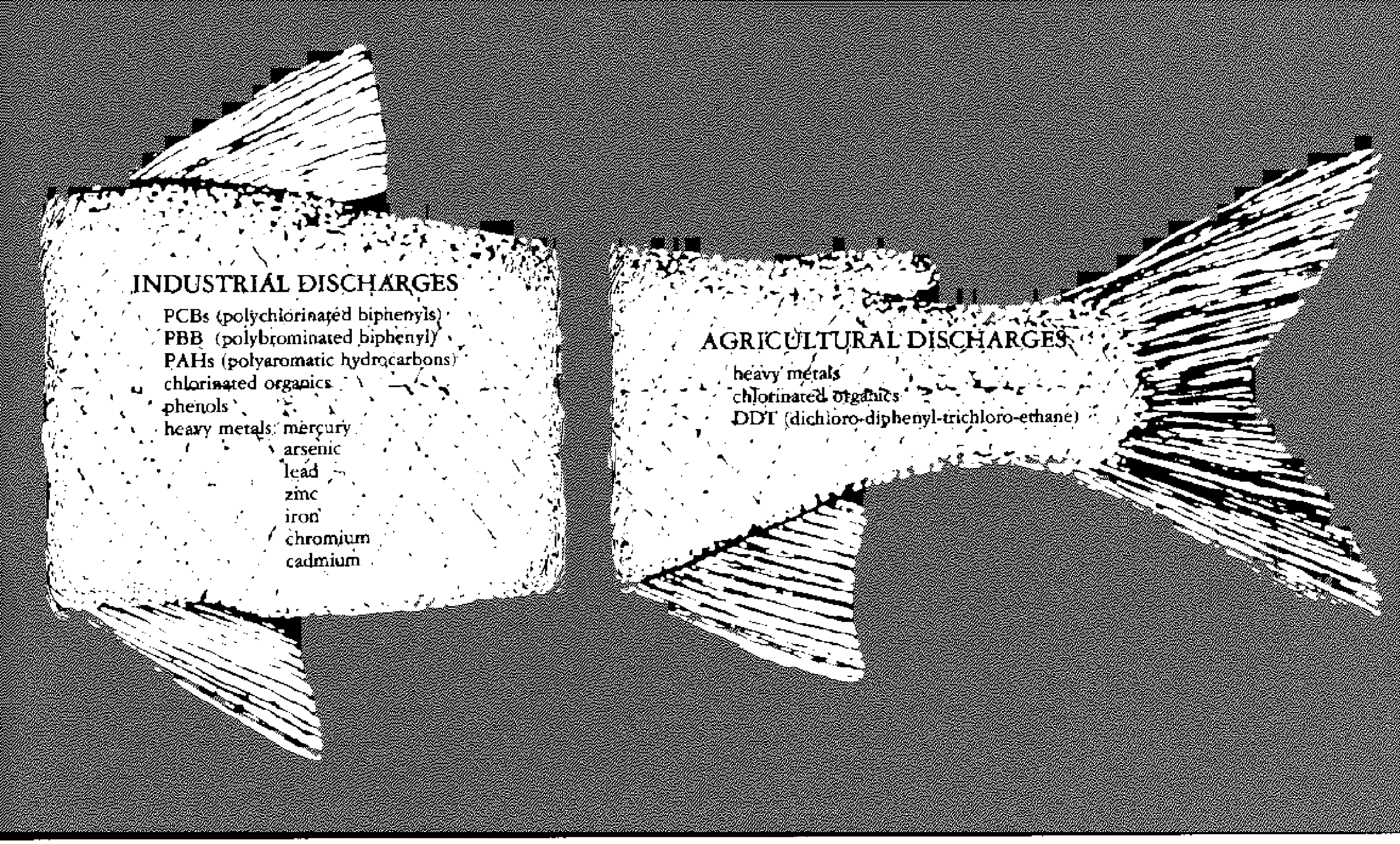
The rest of Lake Michigan is ringed by a three-mile (five-kilometer) wide band of *mesotrophic* water. Mesotrophic water is between oligotrophic and eutrophic waters in terms of nutrient supply for water volume. These waters support the widest variety and greatest numbers of fish. Mesotrophic waters are often productive fishing areas.



Toxic Substance Hot Spots

Contaminants

These substances are either not found naturally in the environment or are present in unnaturally high concentrations. Frequently such materials are toxic. Toxic substances which plague Lake Michigan are:
1) heavy metals, for example mercury, lead and arsenic; 2) petroleum products;
3) radioactive substances; and
4) halogenated organic compounds, for example DDT and PCBs. The most troubling substances in the Lake today are these halogenated chemicals.



Note: No suggestion intended that toxic materials are concentrated in specific parts of fish

Many toxic substances enter Lake Michigan from the atmosphere. Some scientists estimate that up to 80% of PCBs reach the Lake from the air. Municipal incinerators and landfills where PCB-containing papers and plastics are disposed of release PCBs to the atmosphere. PCBs are still used in electrical transformers as insulation. This equipment may "sweat" PCBs into the atmosphere.

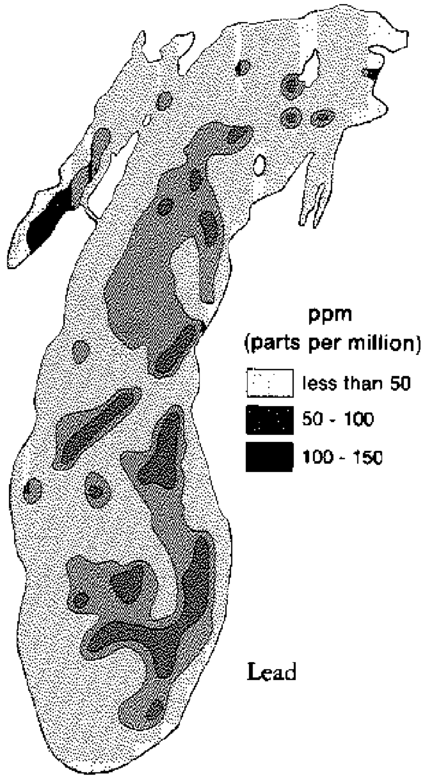
Cadmium (a metal) is another airborne pollutant. It is released into the air from coal combustion, automobile tire wear and metal smelting.

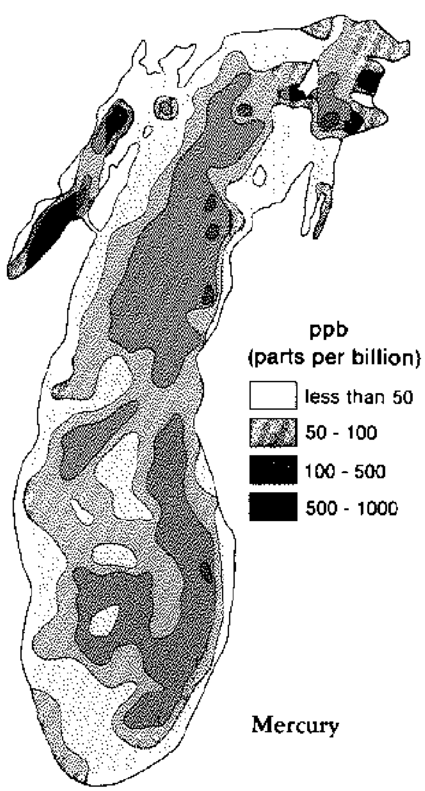
Contaminants are also dumped directly into the Lake in sewage and industrial discharges and runoff from land.

TOXIC SUBSTANCES

The map on page 12 shows toxic substance hot spots in Lake Michigan. PCBs are the most widespread toxic problem. The most serious toxic substance problem in Lake Michigan is caused by halogenated organic compounds like PCBs and DDT. Heavy metals like mercury are serious problems in some other Great Lakes but only cause problems in a few spots in Lake Michigan. The fate of a toxic substance once it enters Lake Michigan depends on the chemical. A few break down quickly into harmless substances. Some like DDT take decades to degrade. Others, the basic elements like mercury, are around forever.

It is the persistent chemicals which pose the greatest threat to water quality in Lake Michigan. Persistent chemicals may attach to particles, remain dissolved in the water, or be buried in the bottom muds. Some contaminants end up in the tissues of plants and animals. Some contaminants can be directly absorbed by or attached to surfaces of living things like algal cells or fish gills. Most of these contaminants dissolve more easily in fats and oils than in water. PCBs are an example. PCBs are typical of the chemicals which cause problems in Lake Michigan and in other Great Lakes. They are widely used, degrade only slowly, and work their way through the food web into Lake fish. Even very small amounts of PCBs in the water may become concentrated in the fatty tissues of fish through a process called ***biomagnification.*** Once in the Lake, PCBs attach to algal cells. The algae are likely to be eaten by Lake creatures, perhaps by the tiny opposum shrimp, the *Mysis.* Through its life span the *Mysis* may eat thousands of algae, each containing a little PCB which will concentrate in the *Mysis'* body. Mysids are eaten by many fish including chubs. A chub may eat





thousands of *Mysis*, accumulating all the PCBs in its body.

Several important factors control the build up of contaminants in fish. First, predators like trout and salmon usually have higher contaminant levels than plant-eating species like perch. Second, fat fish are usually more contaminated than lean fish; only alewives have high contaminant levels even though they eat low on the food chain. Also, fish size is important. Older, larger fish usually carry more contaminants. Lake Michigan fish with the lowest contaminant levels are generally plant-eating, lean, small fish. Perch, suckers, young whitefish and smelt are examples. Chubs, alewives, trout and salmon have higher contaminant levels.

U.S. Food and Drug Administration (FDA) regulations prohibit the sale of fish which contain more than 5 parts per million PCBs. There are similar regulations for pesticides and other contaminants.

There is little information on how toxic chemicals affect fish. Some research suggests that low levels of PCBs accumulated in fish reproductive tissues may damage eggs, sperm and young fry. Most contaminants, though, occur in such low concentrations that any effects are almost impossible to detect.

METALS

Two very poisonous metals present in Lake Michigan are mercury and lead. They are harmful to humans and fish even at low concentrations. The accompanying maps show their concentrations in Lake Michigan sediments.

Lead enters Lake Michigan from the air. The main source is lead in exhausts of cars which burn leaded gasoline. Atmospheric lead is directly related to traffic levels, and thus, most of it comes from the Chicago-northern Indiana area.

Mercury enters Lake Michigan in water which drains off farm fields, where it is used in seed treatments and pesticides. The pulp and paper industries have also contributed mercury to the Lake, especially in Green Bay.

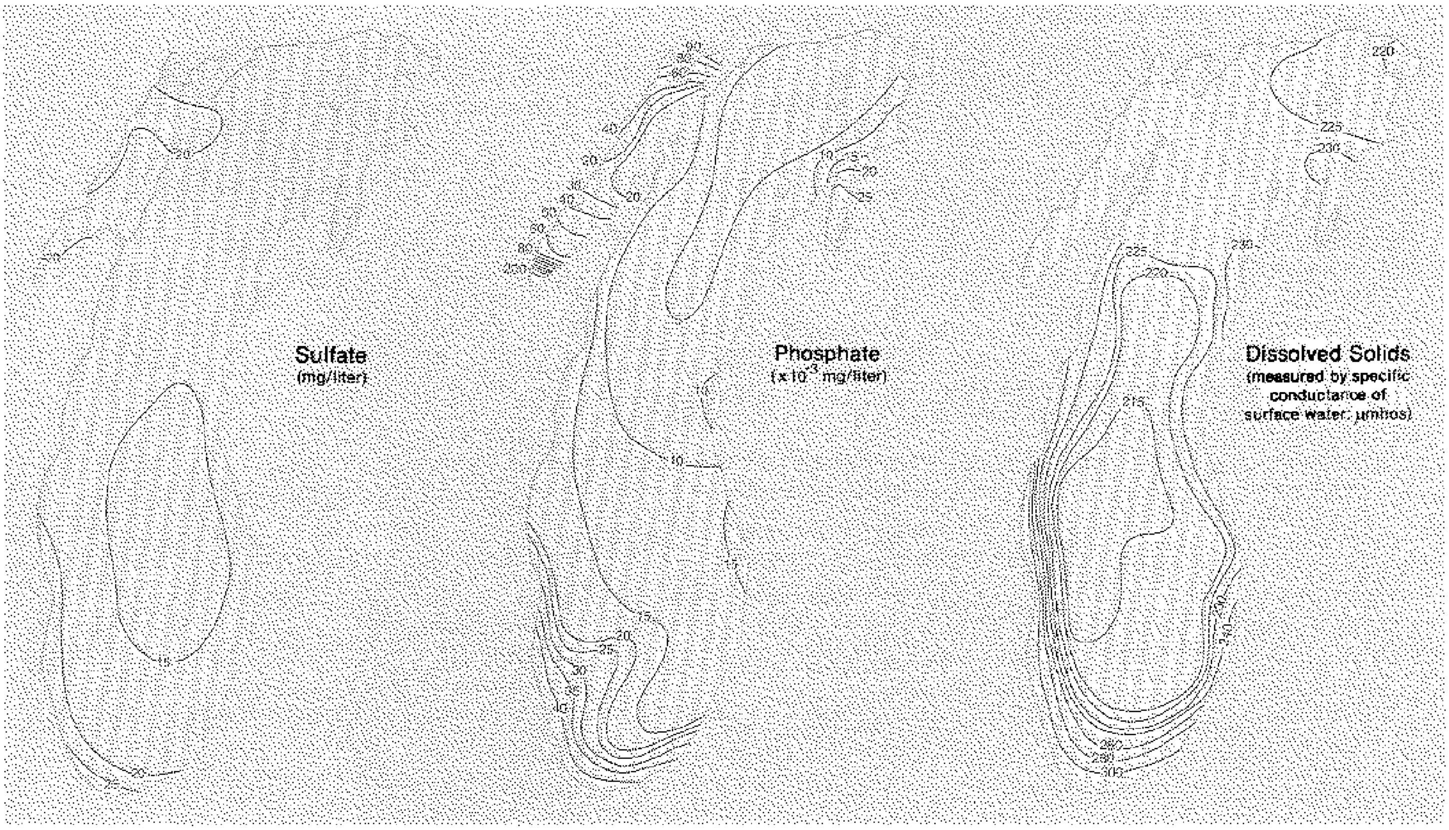
Many other metals enter Lake Michigan water and sediments in trace amounts. Generally, they are found dissolved in water north of Frankfort, Michigan and toward the mouth of Green Bay.

Metals are taken out of Lake circulation by being buried in "ultimate sinks." These are places where the Lake is deep enough and the waters are still enough that particles can settle to the bottom and be buried by layer after layer of mud. Eventually enough mud covers the metal so that it is permanently buried in the sediments.

The ultimate sinks can be seen in maps showing the levels of lead and mercury in bottom sediments. One lies west of Grand Haven.

Metals do not appear to affect Lake Michigan fish distribution to any great extent. Many common metals are quite poisonous to fish and there may be some local problems in highly polluted areas. Also when spring snowmelts flush acid waters into the Lake, the acids may temporarily dissolve metals like aluminum present in nearby rocks. Aluminum is quite poisonous to newly-hatched and young fish.

Cadmium is one metal causing concern in the Milwaukee Harbor. Cadmium is concentrating in the tissues of common fish food organisms in that area. The creatures seem to be able to tolerate the levels currently found in their tissues but scientists do not know if cadmium contamination is decreasing the amount of food available to area fish. Fishery biologists are trying to determine what effect cadmium is having on area fish populations.



SULFATES

Of all the pollutants entering Lake Michigan, sulfates have increased the most during the last 100 years. Sulfates cause a major part of the "acid rain" problem. They billow from chimneys of coal-burning power plants and wash into the Lake in laundry detergents. Altogether over half the sulfates entering the Lake probably come from human activities. The map (page 15) shows the relationship between sulfates and human activities. The highest accumulations of sulfate in water are found in the southwestern portion of the Lake and other nearshore areas.

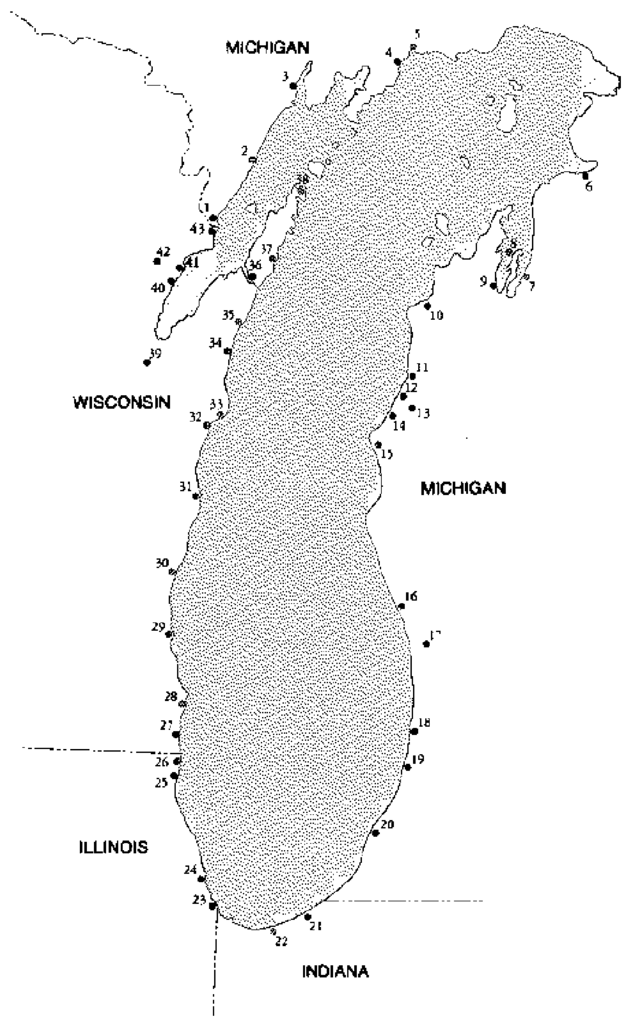
Sulfates are probably not seriously harming fish populations in Lake Michigan. The water is "hard" enough to neutralize the acid formed by sulfates. The limestone in the Lake watershed is calcium carbonate which provides the buffering action. In "soft" water lakes like those in the western Upper Peninsula and Ontario, sulfates appear to deform and injure young fish and fish food organisms.

PHOSPHATES

A high phosphate level in a lake usually signals overenrichment. Over-enriched waters are called eutrophic. They have abundant plant life and fish species which can tolerate the conditions. The water is usually murky and warm and often low in oxygen. While phosphate levels are a good indicator of eutrophication, these waters usually have parallel concentrations of other plant nutrients. In Lake Michigan such waters are limited to areas near cities and river mouths with major sewage discharges. Along some shorelines, phosphate levels are elevated as a result of runoff of fertilizer from agricultural lands. Limited circulation also tends to concentrate phosphates in Green Bay, Little Bay de Noc and Milwaukee Harbor. In recent years Lake Michigan phosphate levels have fallen. This is probably the result of sewage treatment improvements and bans on high phosphate detergents.

TOTAL DISSOLVED SOLIDS

"Total dissolved solids" is the way a Lake scientist says "etcetera." It is a method of adding together all the materials dissolved in the water including carbonates, bicarbonates, chlorides, sulfates, phosphates and others. TDS levels are general indicators of water quality. They show the amounts of nutrients available to Lake organisms. In Lake Michigan, TDS levels are highest near the shore and lowest in open waters. They are highest in southern Lake Michigan, Green Bay and certain harbor areas. The fish found in waters with high TDS levels are those associated with eutrophic conditions. Chloride (ordinary salt) is one substance measured in TDS readings. Chloride levels have risen steadily in Lake Michigan, especially in nearshore areas. There is some evidence that juvenile fish may be harmed by high chloride levels. Chlorides may cause localized problems in spring when melting snows suddenly flush winter road salt into the Lake.



Fish Plantings in Lake Michigan Tributaries, Bays, and Harbors

STOCKING

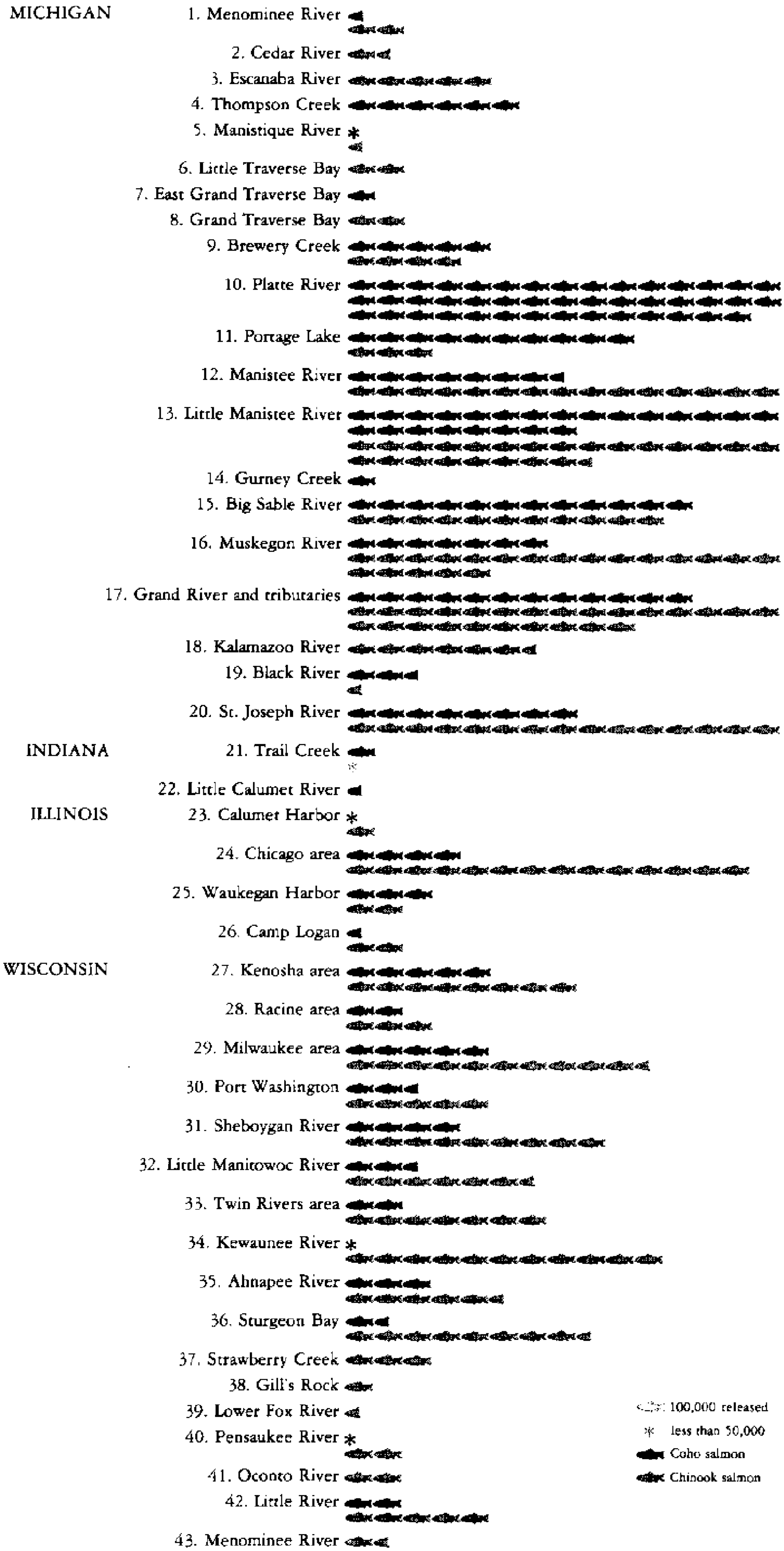
The popular salmon fishery in Lake Michigan is a phoenix story. Out of the ashes of a devastated fish community rose a glittering new fishery. The sea lamprey and intensive fishing all but eliminated lake trout by 1956. Then the lamprey reduced populations of other deepwater predators, namely lake whitefish, burbot and the larger chubs. The virtual absence of predators allowed an unchecked explosion of alewives. The population soon reached epidemic levels. By 1966 alewives made up 80% of the poundage of fish in the Lake. The alewife had little commercial value and no sport value, but it provided abundant forage for valuable sport and commercial species.

The ultimate aim of the salmon stocking program was to convert the superabundance of alewife into good food. This would also improve availability of game fish. A second objective was to revive the depressed commercial fishery. The second goal has not met with as much success as the first.

An efficient management program proved the key to restoring a natural predator-prey balance. The Michigan Department of Natural Resources Fisheries Division began researching species which could be introduced to the Great Lakes. They looked for 1) a species with a short life cycle and rapid growth, desirable due to the lamprey presence; 2) a voracious feeder to feast on the alewives; 3) a brood stock able to reproduce naturally and survive in Lake Michigan; 4) an anadromous species that begins life in tributary streams, migrates to open water to feed and mature, and then returns to streams to spawn; 5) a species capable of hatchery culture. This was important since the gravel beds required for spawning were already being used to capacity by stream species such as brook trout. Also the DNR wished to eliminate any competition with other sport fish.

All their research pointed to Pacific salmon. They decided to introduce both coho and chinook species. The coho was introduced primarily because of its short three-year life span; the chinook has a five-year life cycle.

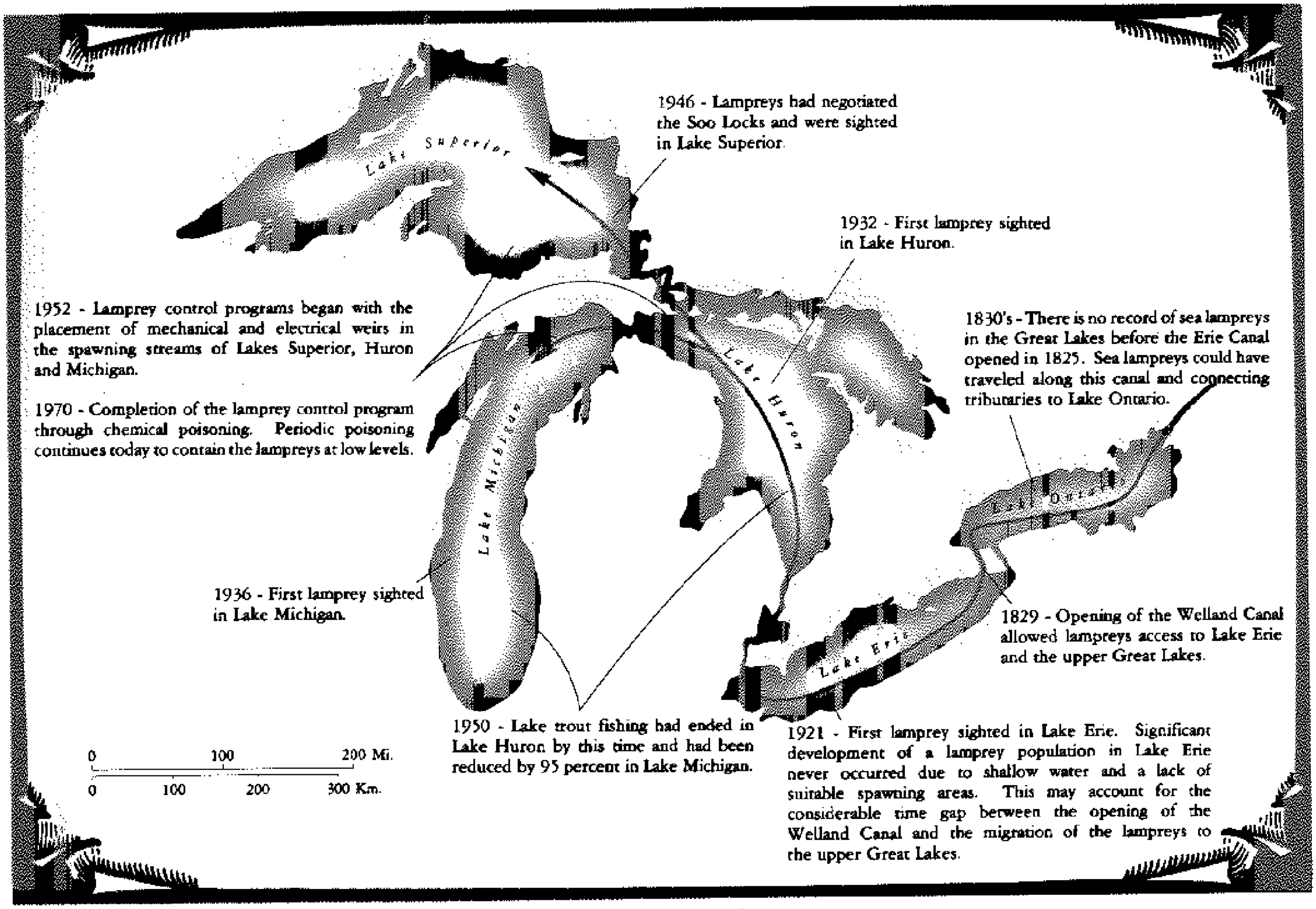
There was some apprehension about using these fish because they required a migration to saltwater as part of their life cycle. Would the fish be able to adapt to an all-freshwater existence? In December 1964, the Oregon Fish Commission supplied Michigan's fish hatcheries with one million eyed coho eggs which were raised to yearling size. By early spring 1966, 850,000 had successfully reached smolt stage. Half the smolts were released in two Lake Michigan tributaries. The Platte River and Bear Creek received about a quarter of a million smolts each. In fall 1966, 8,000 precocious males (males which mature a year early) and a few ripe females returned to their home streams. Eggs



taken from these females hatched successfully. This was an early sign that coho could complete their life cycle in fresh water.

The accompanying chart shows Lake Michigan tributaries and fish plantings. Michigan leads the Great Lakes region in numbers of the salmon stocked. Stocking programs got started later in Wisconsin. Thus, the numbers planted in any one river do not equal those of the Platte and Little Manistee in Michigan. Chinook have dominated the planting because they grow larger and attract anglers. Streams emptying into Green Bay have only limited plantings because the water is too warm and polluted.

Because very few rivers empty into Lake Michigan from Illinois and Indiana, these states have only small stocking programs. They got started after Michigan and Wisconsin and they are further restricted by the industrial character of the shore. Nonetheless anglers can be seen pursuing salmon offshore from the industrial developments from Chicago to Michigan City, Indiana. The smolts planted in Illinois and Indiana waters have been kept in cages in harbor areas to increase their homing instinct.



Sea Lamprey Migrations

SEA LAMPREY

Sea lampreys have disrupted Lake Michigan fish communities for at least five decades. These animals migrated from the Atlantic Ocean through the Erie Canal to Lake Ontario in the early 1800s. They bypassed Niagara Falls through the Welland Canal and eventually reached Lake Huron where the cold water, gravel-bottomed spawning streams and large populations of food fish such as lake trout provided them an ideal home. They multiplied quickly and spread to Lake Michigan and Lake Superior where conditions were similar. The first Lake Michigan sea lamprey was recorded in 1936. By 1947, lake trout had already suffered serious damage from the lamprey.

At first glance, a lamprey resembles an eel. Both have long, snake-like bodies and grow 2 feet (two-thirds of a meter) long. However, a sea lamprey skeleton is cartilage; eels have true bones. The lamprey mouth is a jawless, round suction cup with concentric circles of sharp, hooked teeth. The eel has powerful jaws and rows of tiny straight teeth.

Sea lampreys begin life in cool, fast-flowing streams. Adults deposit fertilized eggs in gravel nests in stream bottoms. The young hatch and then float downstream to muddy areas where they burrow in. They may live there for eighteen years. At this stage, they are called ammocoetes.

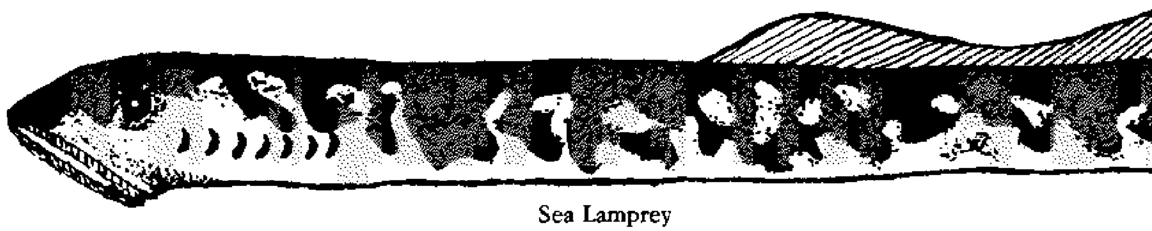
When the ammocoetes transform into adults, they swim out to the open Lake. There they attack fish. Adult sea lampreys prey on fish for two years and then return to streams to spawn. Each lamprey may kill 40 pounds of fish during its life in the Lake.

When lamprey originally invaded Lake Michigan, their first target was lake trout, a species preferred by both sport and commercial fishers. Lake trout populations declined and virtually disappeared between 1945 and 1950. The decline spread progressively from north to south. Fishery biologists attribute the decline primarily to lamprey predation, not overfishing.

Other large fish species were also hit hard by sea lamprey. Whitefish and burbot stocks fell as the lamprey populations increased in northern Lake Michigan.

Lake trout and burbot feed mainly on chubs. After sea lamprey reduced these predators, chubs increased significantly and became important to the commercial fishing industry.

The decline of native fish species created favorable conditions for the alewife *(Alosa pseudoharengus)*, which



Sea Lamprey

invaded the Great Lakes in the late 1940s. Without predators, the alewives flourished and out-competed species like the bloater chub, lake herring, yellow perch and emerald shiner.

The North American public became alarmed as these fish populations fell, like so many dominoes, in the wake of the sea lamprey invasion. An international treaty created the Great Lakes Fishery Commission which sought effective control methods and coordinated fishery research and management in the U.S. and Canada.

A team of researchers set about finding ways to eliminate sea lampreys. First, they figured out the sea lamprey's life cycle and located sea lamprey spawning streams. Surveys in 1947 and 1948 found spawning sea lampreys in 79 streams and rivers entering Lake Michigan.

Mechanical traps and electrical shocking devices were installed to prevent lamprey from swimming out of streams into the Lake. Often the barriers broke down allowing adults to migrate upstream.

Meanwhile other scientists sought a chemical pesticide which would kill lampreys while leaving other creatures unharmed. About 6000 chemicals were tested before researchers discovered 3 trifluoro, ethyl-4-nitro phenol (TFM) which killed ammocoetes but not other fish when properly administered. In 1960, fishery managers began treating Lake Michigan streams with TFM. Chemical treatment proved superior to electromechanical barriers.

TFM is dripped into the stream at the correct rate so that fast currents can mix it into the water. As the chemical moves down stream, ammocoetes lying in the mud hemorrhage internally and die.

Between 1960 and 1978, 115 Lake Michigan tributaries received 364 treatments. Now fishery scientists have another chemical, Bayer 73, which can be used to kill ammocoetes in still or slow-moving water.

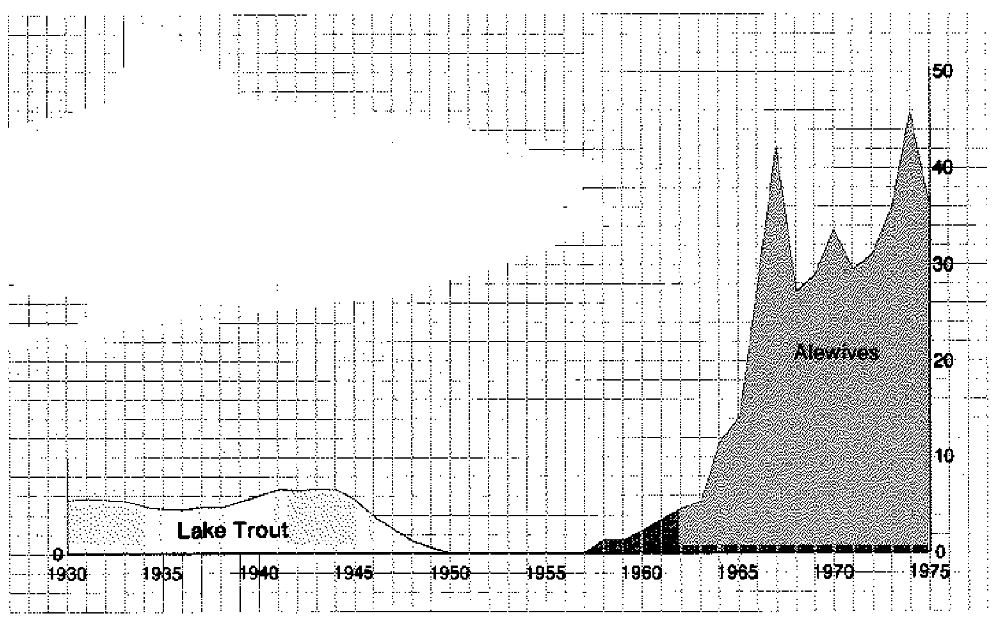
Biologists evaluate the success of this treatment program periodically by counting lamprey scars on lake trout. Recently, wounding rates have been low on fish from Michigan and Indiana waters. Wisconsin fish showed higher wounding rates, however, until recent treatments of Green Bay tributaries caused decreases in lamprey populations.

Control of the lamprey population is important to long-term restoration of desirable fish stocks in Lake Michigan. Only with the lamprey under control have fishery managers and scientists been able to undertake stocking of lake trout and salmon. Healthy numbers of these large fish are important to a balanced community of fish which effectively uses Lake Michigan waters and food stocks. These large fish are also popular with people who fish the Lake.

FISHING PRESSURE

People first fished Lake Michigan for food, later for a living and most recently for recreation. Today all three types of fishing occur in Lake Michigan. The purposes of the fishery have changed over time and so have the fish communities. Fishing intensity has played a role in the species composition and population levels of Lake Michigan fish.

Native peoples of the Lake Michigan region relied on Lake fish for food. When Europeans ventured into the region, the



Lake Trout and Alewives Commercial Harvest Trends

Indians bartered their fish for other goods. Early European settlers also relied on Lake fish for food.

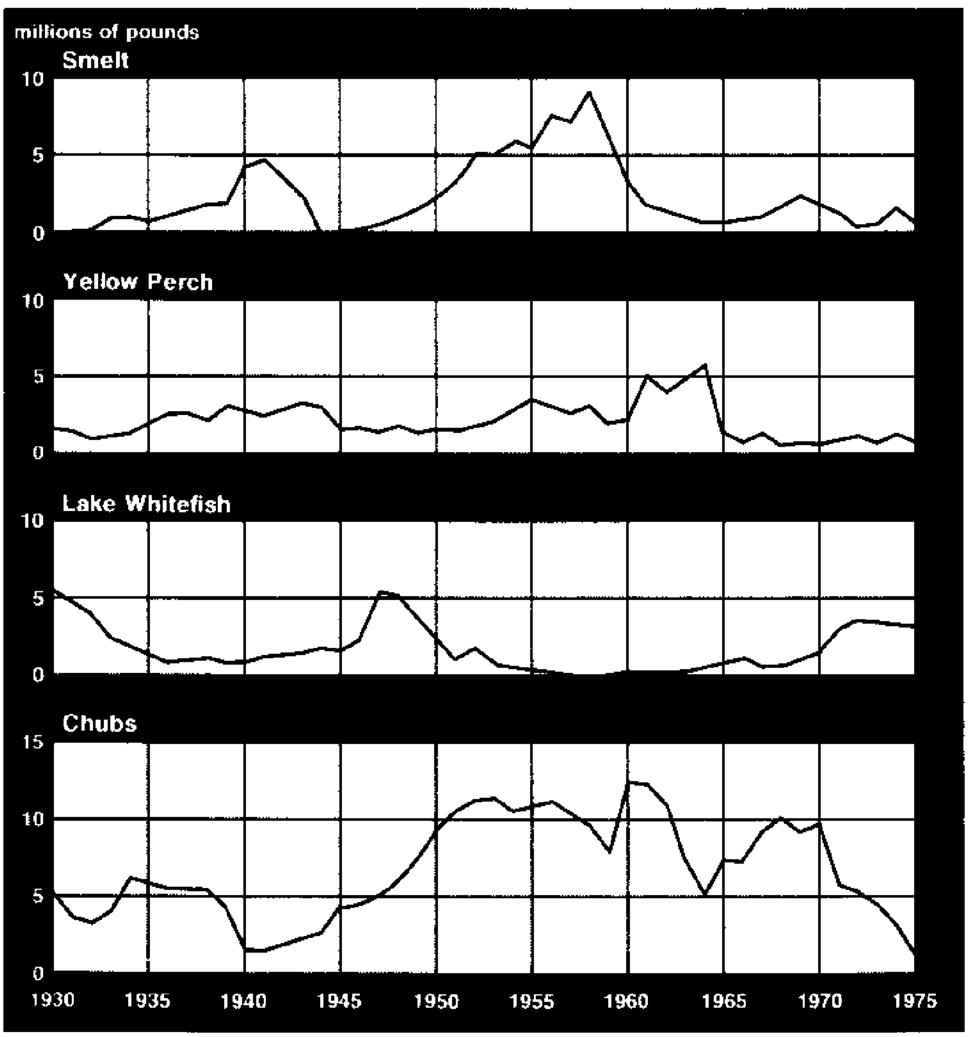
The early commercial fishery, begun at least by 1843, harvested fish from bays, rivers and nearshore areas with haul seines. Later, commercial gear became more sophisticated and nearshore populations dwindled. The fishery ranged into deep water after lake whitefish and trout. Gill nets, pound nets and trap nets became standard gear.

Sport fishing in Lake Michigan was occurring as early as the 1880s off the piers of Chicago. Today's sport fishery was spawned in the mid-1960s when states began planting Pacific salmon in the Lake. Yellow perch remains a popular species with both commercial and sport fishers.

Lake Michigan commercial fish production peaked about the turn of the century at 41 million pounds; from then through the 1960s, 25 million pounds were hauled in yearly; since the mid-60s fishery production has averaged 50 million pounds a year.

While pounds harvested has doubled since the 1950s, today's catch is mostly low value alewives. In 1978, commercial fishers harvested 42 million pounds of alewives and only 8 million pounds of other species. In 1909 the catch was high value whitefish and trout; there were no alewives in the Lake.

Lake Michigan Commercial Fish Harvest (Selected Species)



Dependence on a very few valuable species has always plagued the Great Lakes fishery. Typically, as one important species declined, the fishery intensified on another species, and so on.

Lake whitefish were the mainstay of the early fishery. By 1885 abundance had been severely reduced, especially in Green Bay. Whitefish are again the most valuable species. Lake trout was the most valuable commercial species from 1890 until the mid-1940s. The lake trout was remarkably resistant to fishing pressure. It wasn't until the sea lamprey invasion of the 1940s that the population was decimated.

While fishing pressure played a role in population declines, scientists cite other potent human influences which altered the fish community. Many changes in the Lake basin—dammed streams, dredged marshes, cleared forests, plowed fields, discarded wastes—led to changes in fish habitat. Other human actions admitted species that preyed on or out-competed native species.

Current threats to the fish populations are controversy over Native American treaty rights to regulate their harvests; shoreline development pressures from marinas and other businesses which support the sport fishery; and contaminant problems.

Despite these assaults on Lake Michigan fish, today some species are remarkably healthy. The commercial fishery is struggling to revitalize in the face of gear restrictions and contaminant problems. The sport fishery is flourishing on stocked fish. All who fish the Lake are concerned about allocating fish stocks among commercial, sport and Native American fishers in ways that maintain healthy fish populations.

Coho & Chinook Salmon

COHO
(Oncorhynchus kisutch)
CHINOOK
(Oncorhynchus tshawytscha)

The introduction of coho salmon in 1966 made Lake Michigan the site of one of the most outstanding freshwater sport fisheries in the world. A mail census of anglers in 1979 showed that almost 350,000 coho and 505,000 chinook salmon were caught in the Michigan waters of Lake Michigan. Fishery scientists estimate another 370,000 chinook and 170,000 coho were caught in Michigan tributary streams. In the fifteen years since the first salmon plantings, the financial benefits from the sport fishery revolving around the salmon have grown rapidly in Wisconsin and Michigan. The sale of boats, tackle, food, motel rooms, gasoline, charter services and other items required by anglers has mushroomed.

The presence of coho and chinook is a major factor affecting the distribution and abundance of other Lake Michigan fish species. Especially important is the control of alewives which the salmon and other predators provide. Alewives are ideal forage for salmon and are responsible for the rapid growth rates characteristic of Lake Michigan salmon. Salmon have helped reduce the huge populations of alewives and resulting dieoffs. At the same time, salmon have created a major sport fishery.

The distributional patterns of coho and chinook are different from other species because salmon return to their original streams to spawn in fall. They migrate from south to north during the main fishing seasons from late spring to late fall.

Fishing begins in the southern basin in late March and moves northward during the succeeding months, following the movements of the salmon. In fall, they congregate in Lake Michigan waters off the mouths of their home streams. Salmon begin to move into the streams by late September and the spawning process is completed by late October or early November. The fish die after spawning.

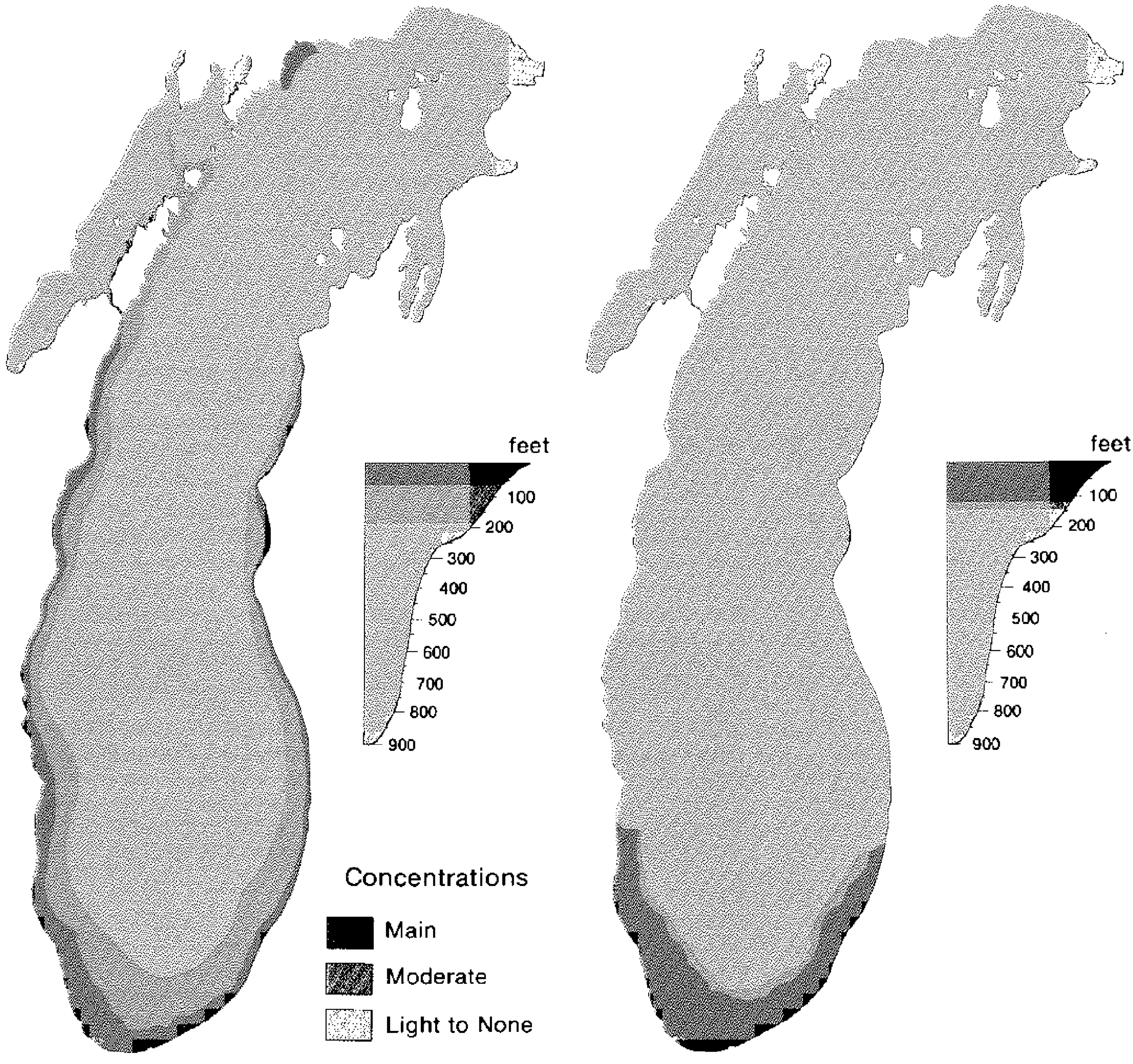
Both coho and chinook are anadromous species. They spawn in streams but range into the ocean or large lakes for feeding and maturing. Salmon are ocean species, and fishery biologists were doubtful whether the salmon could survive an entirely freshwater existence. However, growth rates have been very good in Lake Michigan. Natural reproduction is not sufficient to support the large sport fishery so annual plantings are necessary to maintain the fishery and keep the alewife population in check. Recent findings indicate chinook are making substantial natural additions to the fish population; this is called "recruitment" by fishery scientists.

Both coho and chinook salmon become active after the ice leaves Lake Michigan in the spring and surface waters begin to warm. They remain active and roam around the Lake during the summer. Most return to their home streams in fall.

During the summer, they seek their most desired temperature range. Coho prefer water temperatures in 53° to 55°F (12° to 12.5°C) range. Chinook salmon prefer slightly cooler temperatures in the 50° to 54°F(11° to 12°C) range. Local changes in temperature such as those caused by upwellings will greatly affect the depth at which salmon are found in summer.

During winter and early spring, both coho and chinook are found in the southern basin of Lake Michigan. Most will be south of a line generally from South Haven, Michigan to Milwaukee, Wisconsin. The main concentrations of fish will be in coastal waters and out to a depth of about 120 feet (39 meters). Moderate concentrations may extend beyond to depths of 120 to 140 feet (39 to 46 meters). The rest of the Lake probably has only a few salmon during winter.

After the ice melts in early spring, salmon begin moving out of the southern basin first westward and then north as the season progresses. The migration brings large concentrations of fish gradually northward until they reach the waters off the mouths of the streams in which they were planted or hatched. Thus, the main concentrations of chinook and coho in summer and early fall are in waters up to 60 feet (20 meters) deep. The coho often are found slightly closer to shore where the water is their preferred 55°F (12.5°C); the chinook will be somewhat farther out and deeper where the water is cooler (51°F, 11.5°C). This time of year, neither species is normally found close to shore



Summer - Early Fall

Winter - Early Spring

Distribution of Chinook and Coho Salmon

except in an upwelling of cold water. The rate at which migrations take place and the exact locations of the largest numbers of fish seem to be related to daily, weekly and other periodic changes in water temperatures. The main concentrations occur south of a line from Empire, Michigan to Sturgeon Bay, Wisconsin. An exception is the area off the mouth of Thompson Creek near Manistique, Michigan.

Moderate concentrations of salmon occur during the summer in waters 60 to 180 feet (20 to 59 meters) deep in the southern two-thirds of the Lake, portions of Green Bay, and near the Wisconsin coast and the islands off Door County, Wisconsin. The rest of Lake Michigan contains few if any salmon during summer.

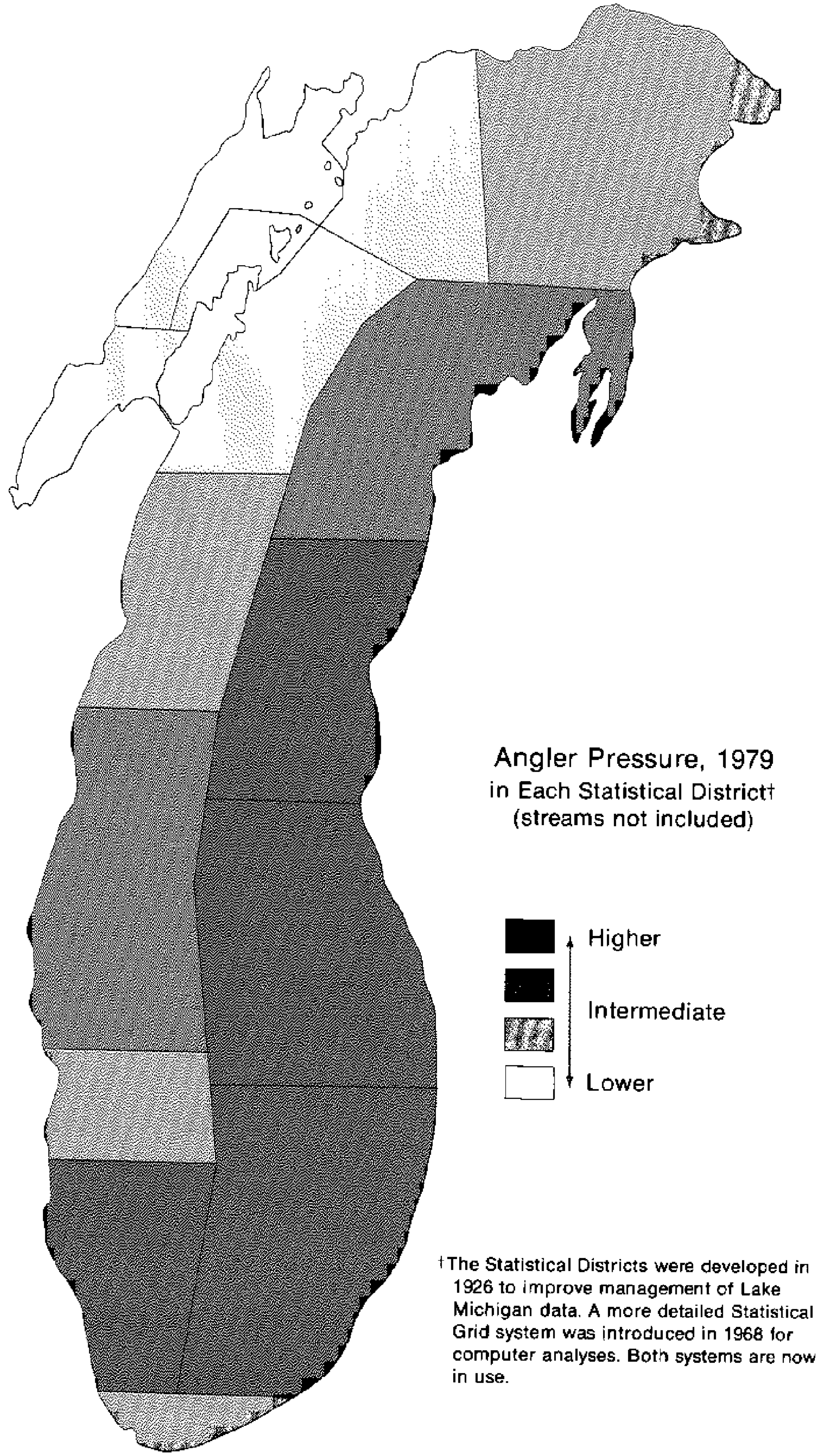
Another indicator of salmon concentrations is the numbers of salmon caught in various sections of Lake Michigan. The largest numbers are caught in the most southerly portion of the Lake and numbers decrease northward. This can be explained by the

This map tries to show the intensity of sport fishing for salmonids* on Lake Michigan. It gives a rough picture of where most fishing ("angler pressure") occurs, but its accuracy is impaired by a problem that often plagues spatial research: division of an area among jurisdictions.

Wisconsin, Illinois, and Indiana interview anglers as they fish to obtain the number of hours spent fishing, number and species caught, etc. Michigan uses a postcard sampling of fishing-license holders to learn the number of fishing trips made, fish caught, etc. Wisconsin, Illinois, and Indiana include yellow perch in their surveys while Michigan does not (Michigan perch estimates were added for this map).

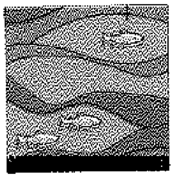
These and other differences in survey methods and questions produce results that are difficult to compare. Michigan's method may at times overestimate "angler effort" while Wisconsin, Illinois, and Indiana's may tend toward underestimation. Thus the map can only suggest variations in Lake Michigan's sport fishery.

*Coho and Chinook salmon; lake, rainbow/steelhead, and brown trout; and yellow perch.

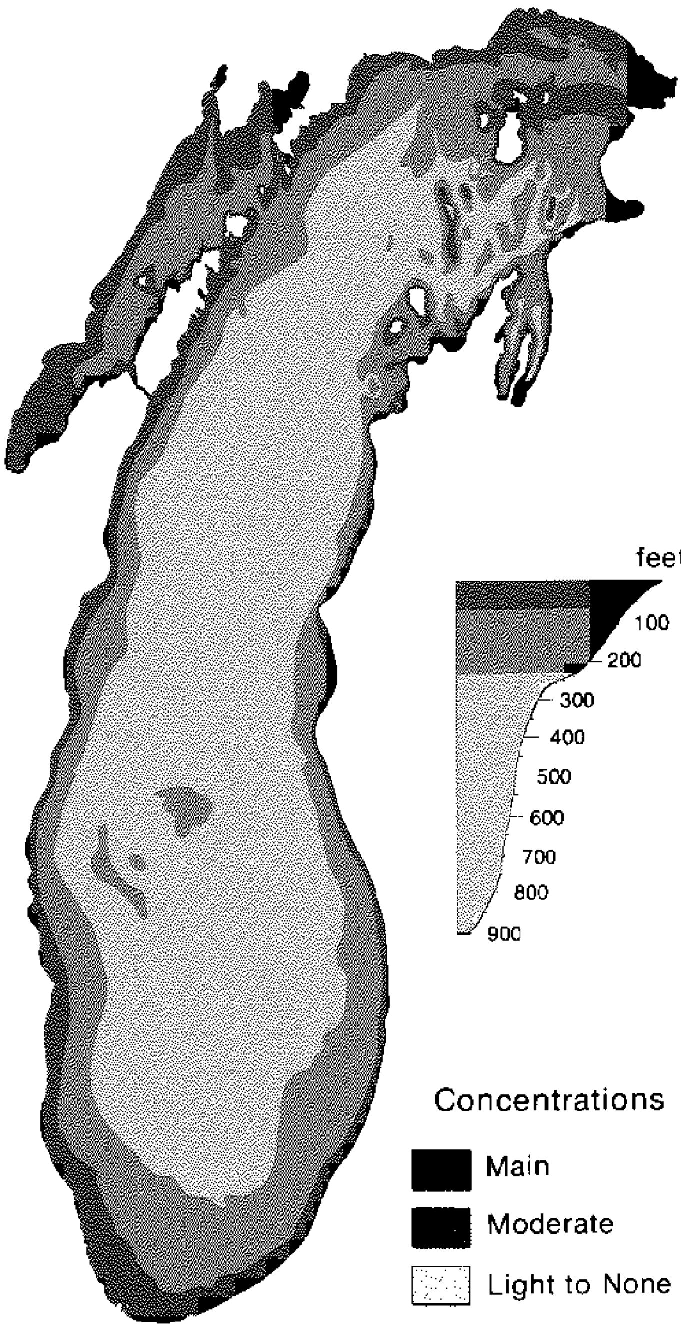


†The Statistical Districts were developed in 1926 to improve management of Lake Michigan data. A more detailed Statistical Grid system was introduced in 1968 for computer analyses. Both systems are now in use.

year-round salmon fishing season in southern Lake Michigan. The catch of salmon in Michigan tributaries is roughly proportional to the number planted in them.



Alewives



Late Spring - Early Summer

Distribution of Alewives

ALEWIVES
(Alosa pseudoharengus)

In spring 1967, billions of alewives died in Lake Michigan. Beaches were so thickly covered, the small silvery fish were bulldozed away. This was visible, odorous evidence of the tremendous buildup of alewives in Lake Michigan since this species was first recorded there in 1949. The population explosion was aided by the sea lamprey, which destroyed lake trout and other alewife predators.

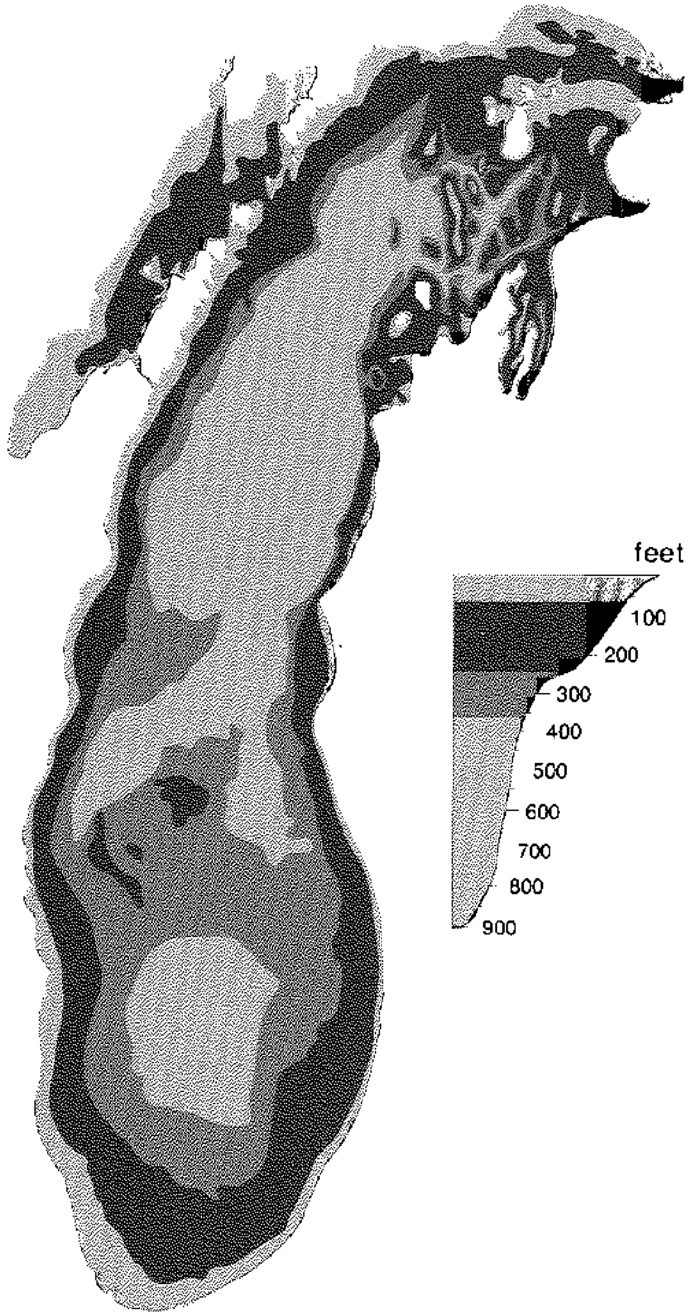
In 1960, alewives were 8% of the fish biomass (living fish by weight) in Lake Michigan, but a mere six years later alewives accounted for 80% of the fish biomass. By 1978, they had dropped to well under 70% of the total. Since the 1967 dieoff, the alewife population has stabilized considerably, but population levels vary from year to year.

The seasonal distribution and the migrations of adult alewives, illustrated on the accompanying maps, are determined somewhat by annual water temperature changes in Lake Michigan. Alewife migrations may influence the distribution of their predators.

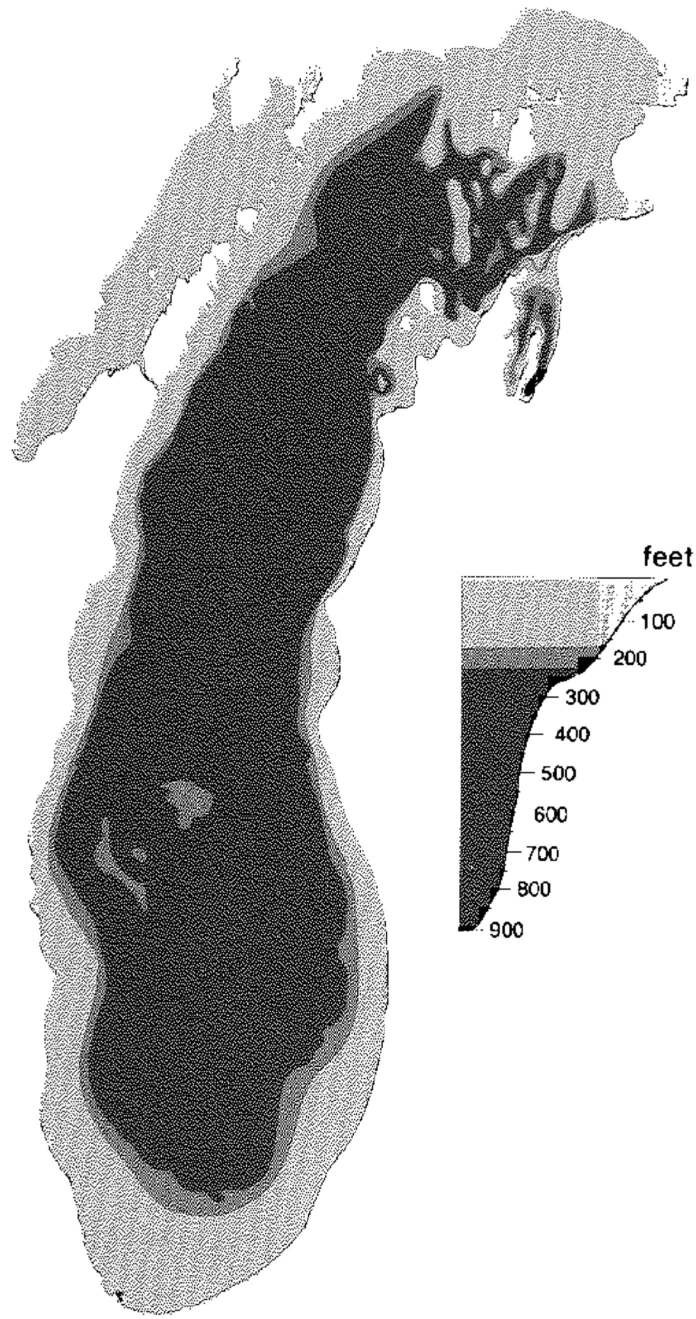
In late spring and early summer alewives spawn in rivers, bays and shallow water near shore. The fish concentrate in warm waters less than 60 feet (20 meters) deep. This is also the principal dieoff period. Moderate numbers of fish congregate in waters 60 to 240 feet (20 to 79 meters) deep. Their preferred depths are in Green Bay and the southern third and extreme northern part of the Lake.

In fall, alewives migrate offshore into deeper areas. They concentrate in waters 60 to 240 feet (20 to 79 meters) deep; moderate numbers concentrate in waters 240 to 360 feet (79 to118meters) deep. Near shore, temperatures decrease rapidly during fall while remaining more stable in deeper waters.

In winter, adult alewives move into the deepest portions of the Lake or water 240 feet (79 meters) deep and deeper. Moderate concentrations are found in a very small band where the water is a bit shallower, 210 to 240 feet (69 to 79 meters) deep. During winter, there are rarely alewives in water shallower than 210 feet (69 meters). Winter concentrations are in the deepest parts of the northern and southern basins of Lake Michigan where the water temperature is 35°F (1.5°C); in shallow water it may



Fall



Winter

be less than 50°F (10°C).

Since the 1950s alewives have had a major impact on the composition of the total Lake Michigan biomass and the distribution and abundance of other Lake species. Alewives have been particularly detrimental to native species associated with shallow waters. Since alewife competition, Lake Michigan emerald shiners and lake herring have been largely eliminated and there are fewer yellow perch and smelt. The large mass of alewives in deep water during the winter has crowded out chubs.

Alewives dominate the Lake Michigan commercial catch but they are not marketed for human consumption. Alewives are made into pet food, fertilizer, fishmeal and oils. The catch averaged 36.1 million pounds annually during the 1967-77 period.

Chubs

CHUBS
(Coregonus)

Fish markets around Lake Michigan are famous for tasty smoked chubs. A soft, oily fish, chubs obtain an excellent flavor and rich, golden hue when smoked.

Seven species of deepwater ciscoes, called "chubs" in the Great Lakes, once inhabited Lake Michigan. The fate of the chub species in Lake Michigan is the classic story of increasing exploitation and dwindling fish stocks in the history of Lake Michigan fisheries. Beginning in 1869, Lake Michigan supported a substantial chub fishery. Chubs were caught exclusively in gill nets set in deep water. The fatter, larger chubs were preferred. The largest was the blackfin cisco which was fished so intensively it virtually disappeared by the turn of the century. Then the fishery turned to the other large species, the longjaw, the shortjaw, and the deepwater cisco. When their numbers declined, the fishery intensified on the shortnose and the kiyi.

When the sea lamprey reduced trout catches in the 1940s, commercial fishers began relying more heavily on chubs. In the 1950s, chub catches averaged 10.2 million pounds. Trends in commercial harvest are shown on page 20. Commercial production peaked in 1960 at 12.5 million pounds; the catch fell to 371,000 pounds in the 1970s. Recently chub harvests have been curtailed by contaminant problems in southern Lake Michigan.

Overfishing and sea lamprey predation led to the decline or extinction of all but the smallest species, the bloater. In the absence of its natural predator, the lake trout, and with the other chub species reduced in number, the bloater was able to greatly increase its abundance. The bloater was abundant until the mid-1960s when it was out-competed by alewives and overharvested by commercial fishers.

Alewives feed on bloater eggs and probably compete for the same food desired by chubs. Alewives and bloaters are found in similar water depths during both summer and winter. Restrictions on the commercial harvest and some decline in alewife abundance have allowed the bloaters to stage a comeback.

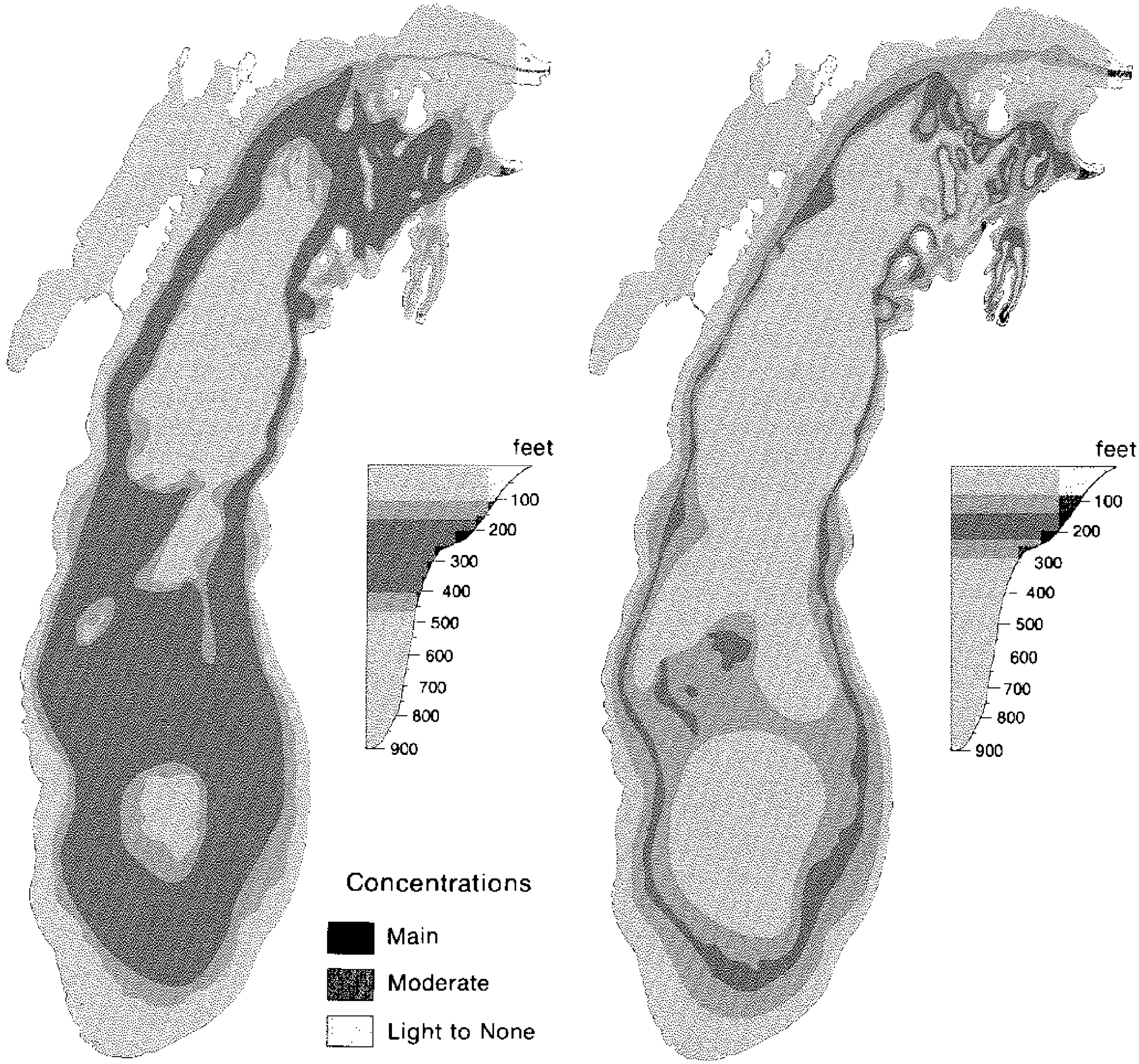
Bloater chubs are silvery fish averaging 8 to 10 inches (203 to 254 millimeters) long. They spawn in March over all Lake bottom types. Most larval fish are found in water no warmer than 40°F (5°C).

Chubs feed at or near the bottom. Small fish eat mainly zooplankton, tiny free-floating animals, while larger fish feed on *Mysis* and *Pontoporeia* and other small creatures like molluscs.

Bloaters were important forage for the once-abundant Lake Michigan lake trout. Scientists estimate at least 30 million pounds of bloaters were eaten annually by lake trout to support the commercial yield of 6 million pounds of trout. Lake trout were the main predators of bloaters but burbot also eat them.

The chub distribution patterns on the accompanying maps show present conditions. Main concentrations of chubs during winter (October to April) are at depths of 180 to 420 feet (59 to 138 meters). Moderate numbers of chubs can be found in shallower and deeper waters, 120 to 180 feet (37 to 59 meters) and 420 to 480 feet (138 to 157 meters). Thus, most of the deeper waters of the southern basin probably have a fair number of chubs in winter, but the deeper waters of the northern basin are probably too deep for many chubs. The shallow waters of Green Bay, northern Lake Michigan and the coastal waters around the entire Lake have few if any chubs during winter.

As water temperatures rise in late spring, chubs begin to move in toward shore. The main concentrations of chubs in summer are in waters from 150 to 240 feet (49 to 79 meters) deep. Moderate numbers congregate in waters 90 to 150 feet (30 to 49 meters) and 240 to 300 feet (79 to 98 meters) deep. Few chubs are found in very shallow and very deep waters this time of year. Except in its deepest portions, Green Bay has very few chubs any time during the summer. The periodic changes in summer water temperatures in shallow water caused by shifts in wind direction and speed affect the precise depths at which chubs congregate. For example, during coastal upwellings of cold water, chubs can be found in very shallow water as few as 18 feet (6 meters) deep. Usually they are not found in such shallow water.



Winter

Summer

Distribution of Adult Chubs (Ciscoes)

Lake Trout

LAKE TROUT
(Salelinus namaycush)

Lake trout have long been prized by both commercial and sport fishers. Today, anglers catch over a quarter million lake trout in Lake Michigan each year.

None of these trout, however, are native to Lake Michigan. The native strains were eliminated by the sea lamprey, probably completely by 1956. Some intensive commercial fishing is also implicated in the decline which proceeded rapidly after 1945.

Lake trout currently present in Lake Michigan were planted as part of state and federal efforts to restore the fish stocks. Plantings began in 1956 with about 1 million yearling trout. By 1980, 36 million fish had been planted and the numbers of fish have built up to a healthy level.

This build-up was possible despite the failure of the lake trout to establish self-sustaining populations in the Lake. Given the long life span of the fish (some live longer than 25 years) and with the sea lamprey effectively controlled and commercial and sport fishing closely regulated, it was possible for yearly plantings of trout to lead to a population increase.

One of the enduring mysteries of the Great Lakes is the failure of the lake trout to reproduce naturally in Lake Michigan. Scientists suggest several theories on why this is so. Some researchers believe there are inadequate numbers of spawning fish; some suggest predation, especially on trout eggs and larval fish. Contaminants or diseases that would reduce the chances of successful hatching are other ideas. Another theory is that inappropriate stocking methods such as planting fish of the wrong age or in unsuitable habitat have led to the failure. Some scientists think the fish fail to return to the proper spawning areas because they are not adapted to Lake Michigan. Some think the fish are maladapted to Lake Michigan because the stocked fish are not genetically native to Lake Michigan. Most scientists feel it is probably a combination of factors.

One theory that holds some promise is that the fish fail to reproduce because the reefs that they use to spawn on are covered with silt and algae that interfere with successful hatching of the fish eggs. This silting is a result of eutrophication, overenrichment of Lake Michigan from nutrient pollution.

There is some encouraging evidence of natural reproduction in Lake Michigan. The latest report dates from spring 1980. Divers on a research project in southern Lake Michigan discovered some larval lake trout. The fish were in an area of rocks placed in the Lake around the water intake of a power plant. Curiously all reports of natural reproduction of lake trout have come from areas with rock newly placed in the Lake.

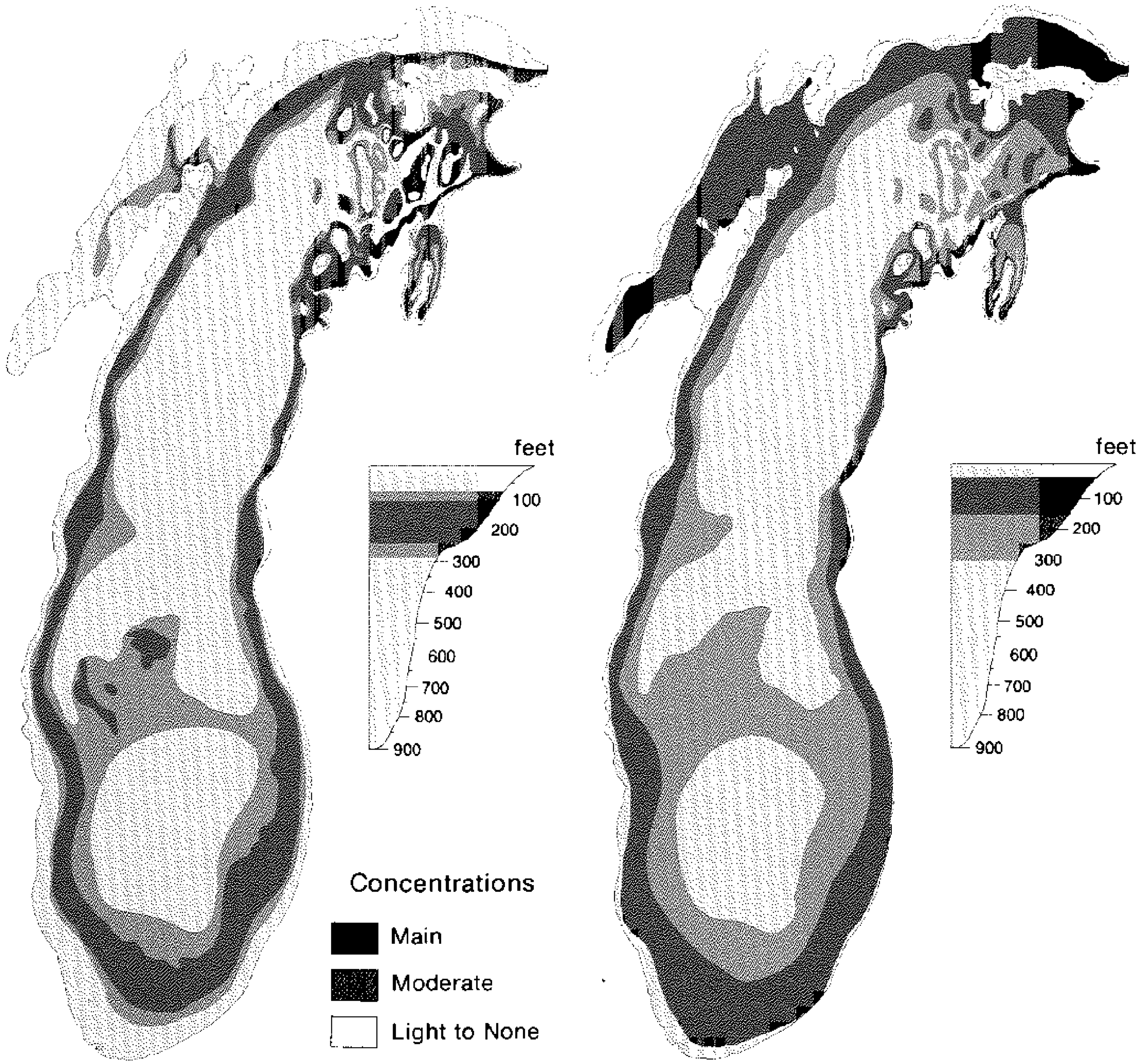
Another source of hope for establishing a naturally-sustaining population is the Green Lake strain which inhabits a shoal in south central Lake Michigan, the Sheboygan Reef. This strain may be genetically more similar to the original Lake Michigan strain than are other hatchery-reared strains. It is called the Green Lake strain because the fish were raised from eggs taken from trout in Green Lake in Wisconsin. The lake trout population in Green Lake is believed to have descended from Lake Michigan fish planted in Green Lake.

Before the decline of the species in the late 1940s and early 1950s, lake trout was an important commercial species. It replaced lake whitefish as the most valuable species in the commercial catch about 1880. The lake trout harvest peaked at 9 million pounds in 1896, but it continued to average 5 million pounds a year until 1945. Since 1950 the catch has been less than 100,000 pounds a year.

Today contaminants hold down the value of lake trout as a commercial species. Large fish often exceed FDA contaminant regulations for PCBs.

Lake trout prefer cold water year round. In winter, the main fish concentrations are found in water depth from 100 to 240 feet (33 to 79 meters). Moderate concentrations are found in shallower water, 75 to 100 feet (25 to 33 meters) and deeper waters 240 to 285 feet (79 to 93 meters). A few fish may be found in the rest of the Lake with none at all in some areas.

In late spring and early summer, lake trout distribution patterns are somewhat more complicated. Main concentrations are between 30 and 150 feet (10 to 49 meters). Moderate concentrations are found in water 150 and 300 feet (49 to 98 meters). As the waters warm during the summer, lake trout move into deeper water. Lake trout seek cold temperatures. The fish is active in temperatures between 44° and 53°F (7° and 11.5° C). Peak feeding occurs at 51°F



Winter

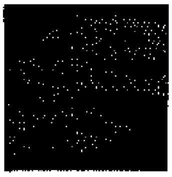
Late Spring - Early Summer

Distribution of Lake Trout

(10.5°C). When upwelling occurs near shore, lake trout can be found in the cold water nearer the surface and closer in to shore than under usual Lake conditions. Because lake trout feed chiefly on alewives, they follow closely the depth and movements of the alewives.

Lake trout generally spawn from mid-October to mid-November in shallow rocky bottom areas where the water is less than 15 feet (5 meters) deep. The eggs fall down into holes and crevices in the rocks. This protects the eggs from predators. The lake trout do not remain in the spawning grounds very long; instead, they move into deeper, colder waters.

Fish are more prevalent in the northern portion of the Lake because stocking was begun in the north and more fish were planted there.



Yellow Perch

YELLOW PERCH
(Perca flavescens)

Yellow perch, better known around Michigan as lake perch, has long been an important species to people who fish Lake Michigan for sport and for a living. Its sweet, nutty flavor made it the staple of the Friday Night Fish Fry which was once an institution in many Lake-side communities.

Perch is one of the smaller fish species popular in the Lake. The average length is only 4 to 10 inches (102 to 254 millimeters). Maximum age is about 10 years. Perch feed on immature insects, large invertebrates and the eggs and young of a variety of fishes. They will feed practically anywhere, in the open Lake or off the bottom. They feed actively year round and are relatively easy to catch. While they do not put up the fight of the big game fish, their excellent flavor and the possibility of catching good numbers of fish make a rewarding catch to the thousands of anglers who—spring, summer and fall—line Lake Michigan piers bent on bringing home dinner. In winter people fish for perch through the ice.

Yellow perch has been important commercially at least since the 1880s and a popular sport species since at least as early as the 1920s. The numbers caught decreased in the early to mid 1960s probably due to a combination of overfishing and interference from alewives, which became abundant in the 1960s. In spring when perch spawn, alewives are heavily concentrated in the shallow spawning and nursery areas favored by perch. Alewives may inhibit reproduction of perch by competing with the fry for planktonic food or actually eating the fry. The highest recorded commercial catch for perch from Lake Michigan was 5.8 million pounds in 1964. Since 1964, the annual commercial catch has been considerably lower. It reached 1.2 million pounds in 1974 but averaged 906,000 pounds from 1965 through 1977.

Perch spawn in early spring in water in the 44° to 54°F (8° to 12°C) range. Adults move shoreward into the Lake shallows to spawn. Perch are very adaptable and able to use a wide variety of warm and cool water habitats. They are most abundant in open, clear waters.

In late spring and summer the main concentrations of yellow perch, as indicated on the accompanying map, are found in shallow waters less than 82 feet (27 meters) deep. Within these shallow areas, the greatest concentrations are in Green Bay and southern Lake Michigan just north of Chicago to approximately Grand Haven, Michigan. These are two of the three Lake areas with the most water less than 60 feet (20 meters) deep.

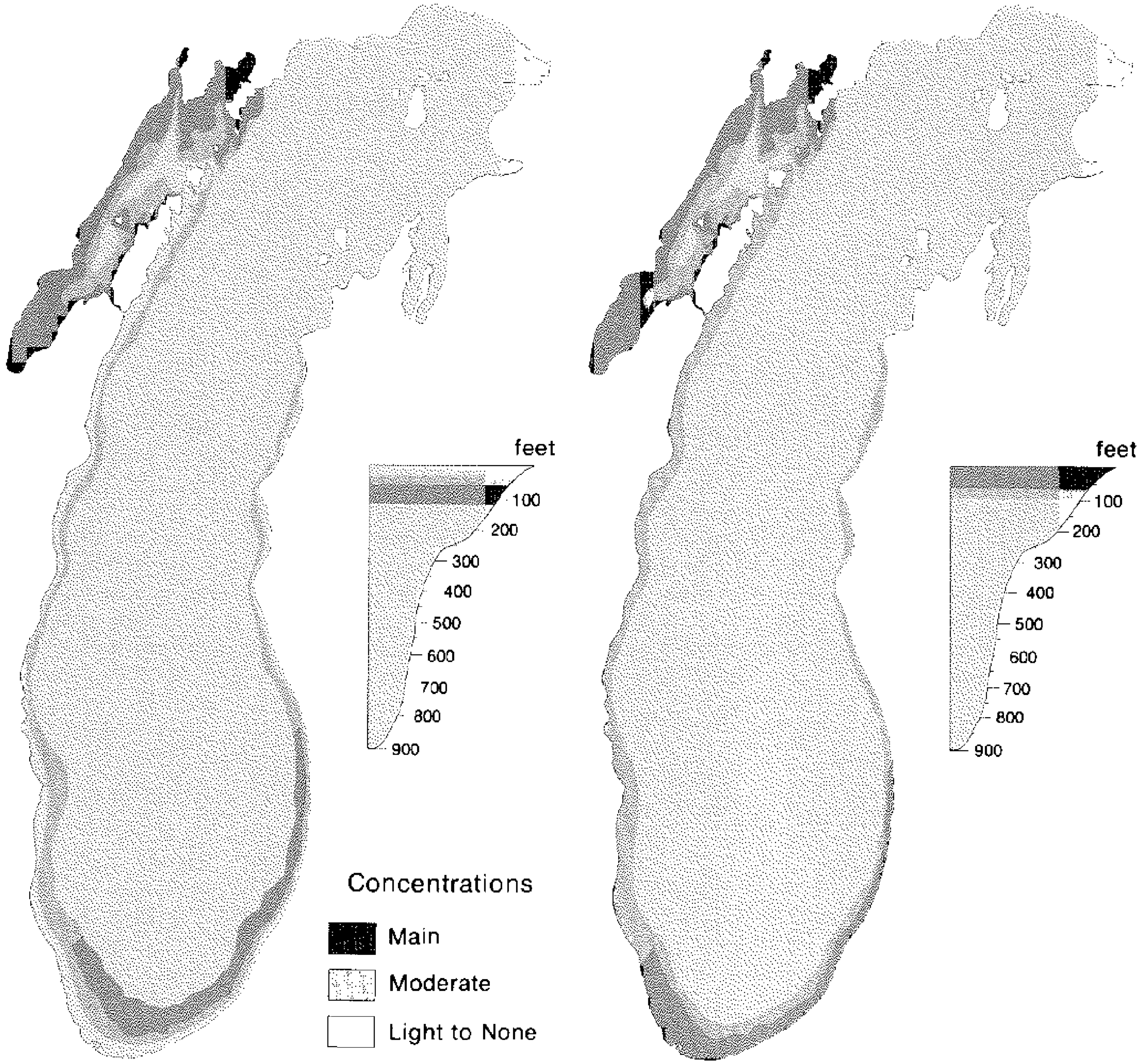
In summer, moderate numbers of yellow perch concentrate in shallow water from Grand Haven to Frankfort on the east side of the Lake. Within this area there are some pockets of heavier concentrations. On the west side of the Lake, perch congregate in shallow water from Chicago to Green Bay. This is the same geographical area as the main concentrations of perch, but the moderate concentrations are found in slightly deeper waters.

Few if any perch can be found in summer in the rest of the Lake including a rather large shallow area at the northern end of the Lake. This northern area is where the alewife first became abundant and it probably outcompeted the yellow perch. Overfishing may also have been a factor in the depletion as perch has not regained anywhere near its former numbers in this area.

The exact depth distribution of perch in summer depends on bottom water temperatures in shallow water. These temperatures can change suddenly with shifts in wind direction or speed. The temperature changes and consequent changes in perch depth distribution can be slight, but they may also be considerable when wind changes cause strong upwellings or when these upwellings subside.

During winter, yellow perch is mainly concentrated in waters between 60 to 120 feet (20 to 39 meters) deep in the southern end of the Lake and in shallow waters of Green Bay, 60 feet (20 meters) or less. Moderate numbers of perch congregate in waters 30 to 60 feet (10 to 20 meters) deep in southern Lake Michigan and at 60 to 120 feet (20 to 39 meters) in the rest of the Lake except in the extreme northern end. Over the rest of the Lake where bottom depths are greater than 120 feet (39 meters) or less than 30 feet (10 meters) and all depths in the extreme northern end, few if any lake perch are to be found.

According to LaRue Wells, a fishery biologist who is an expert on Lake Michigan fisheries, the future of yellow perch in Lake Michigan depends to a large extent on the density of alewives. There is some evidence that the alewife population has stabilized since 1970. But



Winter   Summer

Distribution of Adult Yellow Perch

it could change quickly depending on the amount eaten by predators and the extent of the spring alewife dieoff.

Smelt

SMELT
(Osmeridae)

Spring in the Lake Michigan region brings a nighttime ritual of lanterns, dip nets, and hauls of tiny silvery fish. When the water begins to warm, the tiny smelt seek stream mouths and nearshore areas to spawn. When they come in, avid smelt dippers are there waiting to haul in their silvery catch.

Smelt is not native to Lake Michigan. Also known as the rainbow smelt, it was originally found along the Atlantic coast from Labrador to Virginia. It is an anadromous species; that is, it spends most of its time in salt water, entering freshwater tributaries or estuaries only long enough to spawn. Some time ago, smelt began migrating up the St. Lawrence River, adapting to a totally freshwater existence in the process. Niagara Falls stopped further migration and smelt were found no farther west than Lake Ontario until 1912.

Around the turn of the century, efforts were begun to introduce smelt to the Great Lakes as forage for lake trout. After several unsuccessful plantings in various years and places, 16.5 million eggs were planted in Crystal Lake, Benzie County, Michigan in 1912. Evidence suggests that the entire American smelt population of the upper Great Lakes traces its ancestry to the Crystal Lake planting.

The first smelt reported in Lake Michigan were caught in a commercial net in 1923 off Frankfort, Michigan, at the mouth of the Betsie River which drains Crystal Lake into Lake Michigan. Smelt reached Green Bay by 1924; they had occupied the entire Lake by 1936 and had been observed as far down stream as Lake Erie.

The rapidly spreading Lake Michigan smelt population was not greeted kindly by human users of the Lake who viewed it as a nuisance fish and a potential menance to native fish. Dire predictions of the destruction of all Lake Michigan fisheries were accompanied by demands to control, if not eradicate, the smelt.

Events have proven the smelt not to be so villainous as first suspected although some evidence suggests they compete with herring, whitefish and walleye in Green Bay.

Despite their inauspicious introduction, smelt have become an important fish in Lake Michigan. In 1931, the first year of commercial harvest records, the smelt catch totalled 86,000 pounds; by 1941 the catch was nearly 5 million pounds. A catastrophic smelt die-off, attributed to an infectious disease, occurred in Lake Michigan in 1943. Thus the 1944 catch only reached 5,000 pounds. The smelt population recovered, however, increasing steadily to the record catch of over 9 million pounds in 1958. Since then harvests have dropped off sharply and have remained low and highly variable, averaging perhaps 1 million pounds each year.

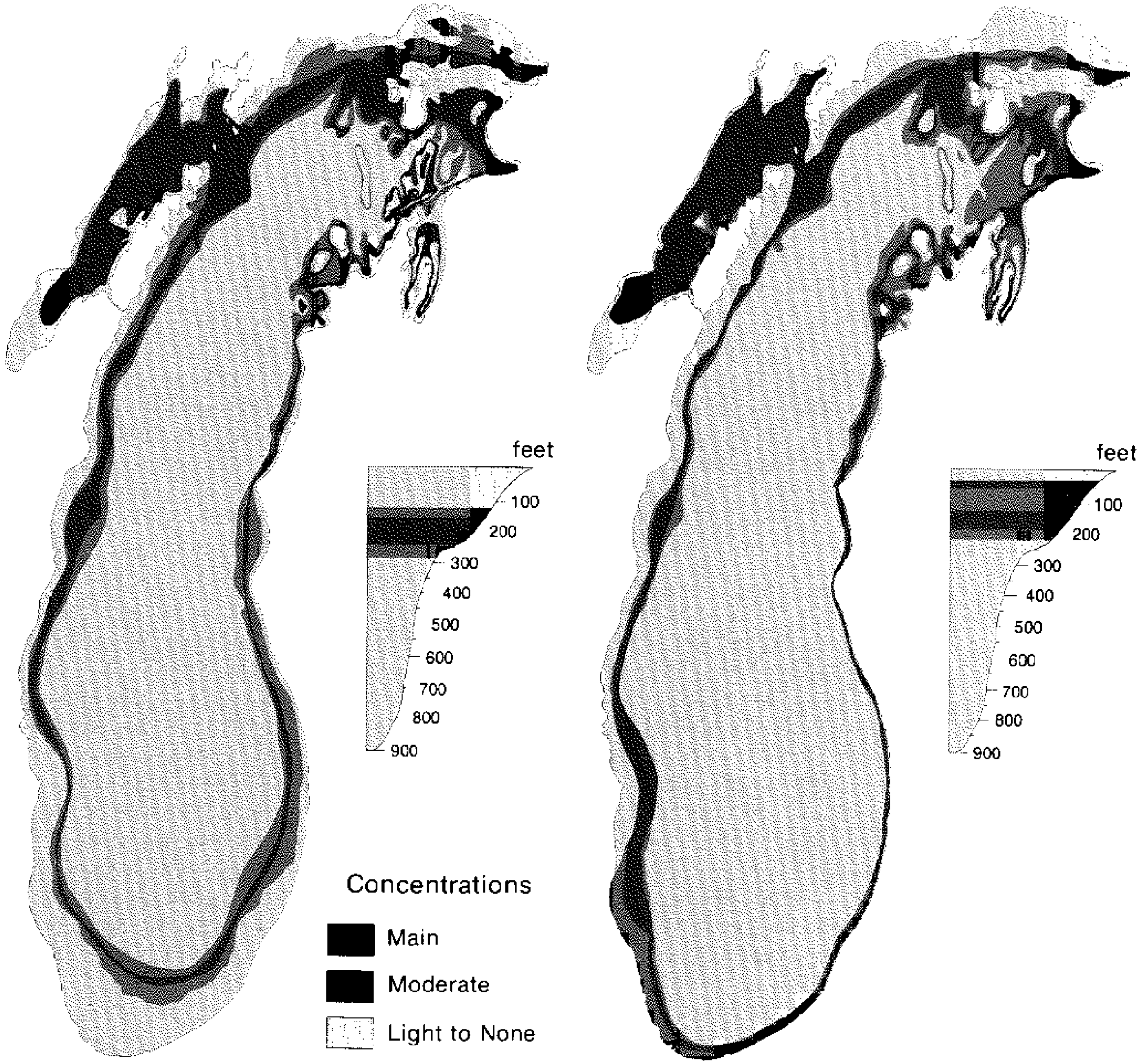
Smelt are abundant throughout Lake Michigan, with predominant concentrations in the northern portion of the Lake and Green Bay. In recent years, over 90% of the commercial harvest has been from the bay. The overall quantity of catches has been low but this reflects the market for smelt rather than the size of the fish population.

Smelt prefer cool water; 50°F (10°C) is their optimum temperature. They are sensitive to light as well as to temperature. Perhaps this accounts for their nighttime spawning habits.

During fall and winter, the main concentration of smelt is in the northwestern part of the Lake around Manistique, Michigan. Smelt are found concentrated in waters 150 to 240 feet (49 to 79 meters) deep; in southern Lake Michigan heaviest concentrations of smelt are in waters 150 to 180 feet (49 to 59 meters) deep. Moderate densities of smelt occur in waters 30 feet (10 meters) deeper and shallower than areas of main concentration.

During early spring, smelt migrate to shallow waters and tributary streams to spawn. After spawning they move into deeper water, apparently more rapidly in the northwestern than the southern portion of the Lake. In later spring and early summer, they occupy a very narrow band at a depth of 30 to 50 feet (10 to 16 meters) from Ludington southward on the east side of the Lake to Waukegan on the west. In other parts of the Lake at this time of year, the main smelt population is at depths of 120 to 180 feet (39 to 59 meters) deep. In Green Bay, smelt are found in water as shallow as 20 feet (6.5 meters) during the warm months.

Though smelt move from one depth to another, there is no evidence of general seasonal movement of the smelt population from one geographical area of the Lake to another.



Fall and Winter

Late Spring - Early Summer

Distribution of Smelt

Lake Whitefish

LAKE WHITEFISH
(Coregonus clupeaformus)

Lake whitefish were the mainstay of the early fishery in Lake Michigan. They were easily harvested in great quantity even in shore seines, the gear available to the early fishery. Whitefish were thought to be superior to lake trout in salted products, the common way of preserving fish at the time.

Once again the lake whitefish is the backbone of the commercial fishery in Lake Michigan. Today they are caught in trap nets. They are a popular restaurant menu item and smoked whitefish is available in many traditional Lake Michigan fish markets.

Lake whitefish are native to Lake Michigan and have undergone major shifts in abundance through the years. Since the 1880s commercial harvest has been a major reason for fluctuations in whitefish populations. Declines in whitefish abundance began at least as early as the 1850s along the western shore. By 1885 abundance had been severely reduced in many areas, particularly Green Bay. This decline is attributed to overfishing and pollution from sawmills. Sawdust was thrown into streams to float out into the Lake and sink. Rough bark chunks and slabs would tear and carry away nets. Sawdust smothered feeding and spawning grounds.

The popularity and importance of the whitefish led to its being the species selected for one of the early attempts of fishery managers to plant fish in the Great Lakes. The first fish hatcheries produced whitefish fry for stocking in the Great Lakes.

The lake whitefish has a very tiny, soft mouth which makes it difficult to catch on a hook. Also it keeps to deep waters. A sport fishery has never really developed for this species, although recently there has been interest in a winter sport fishery for whitefish.

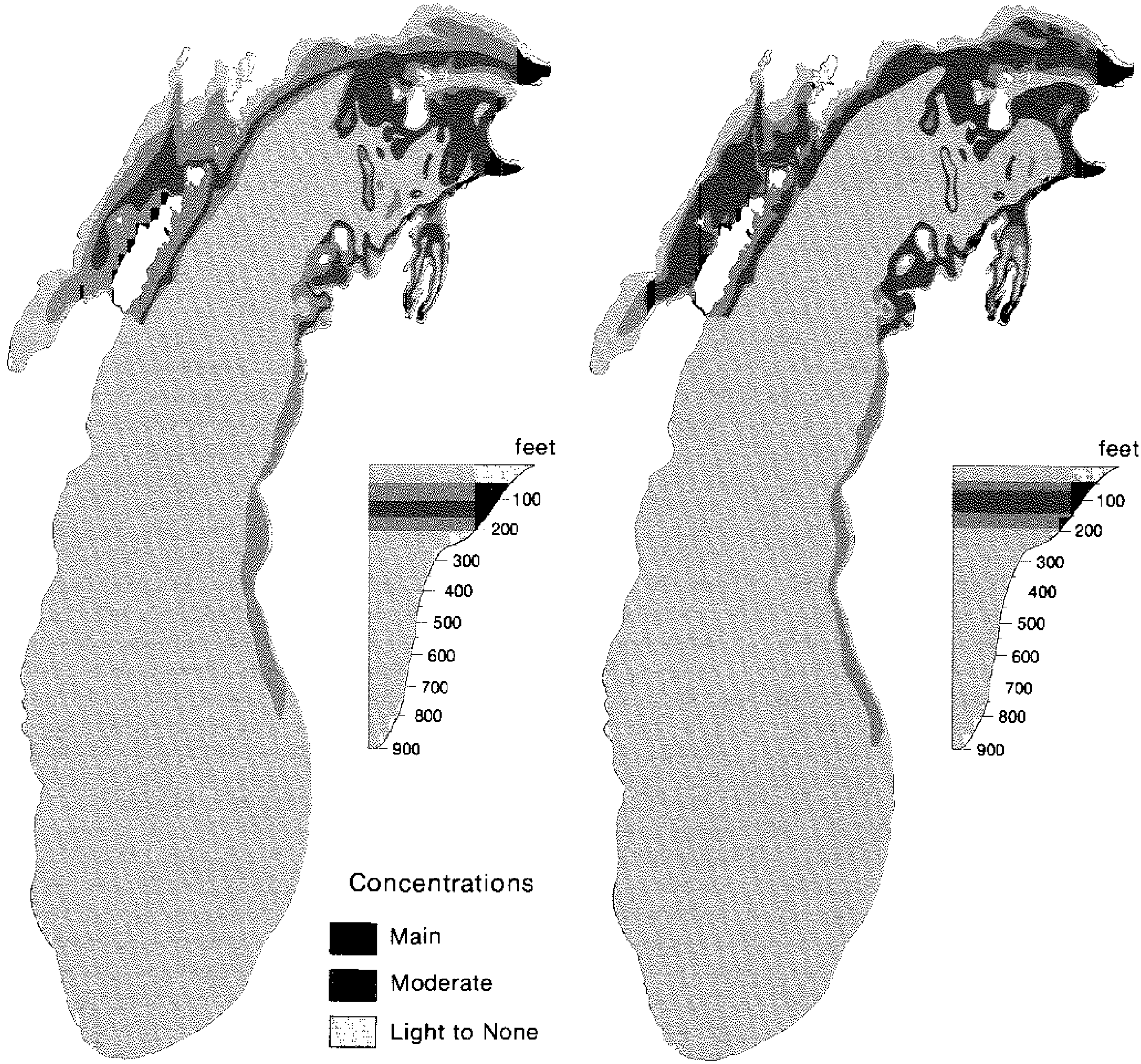
Lake whitefish eat a variety of living invertebrates. Young fish probably feed on planktonic creatures, but adults are bottom feeders; their primary foods are midge larvae and small molluscs like fingernail clams. Whitefish must eat great numbers of these tiny creatures because they grow rapidly and can reach weights in excess of 20 pounds (9 kilograms), although most whitefish are in the 2 to 5 pound (1 to 2 kilograms) range.

Adult lake whitefish average about 17 to 22 inches (435 to 559 millimeters). The average age is about 10 to 16 years. Whitefish spawn in November and December, usually in water less than 25 feet (8 meters) deep. They need very cold water for incubation of their eggs. Developing very slowly in the icy water, whitefish eggs require as long as 150 days to hatch. Larval whitefish remain near shore until mid-summer of their first year before moving into deeper, cooler water. Whitefish eggs are often used for caviar.

The peak commercial harvest was recorded in 1879, the first time that fishery production figures were kept, at 12 million pounds. By 1892 production had dropped to 2.8 million pounds. Another production peak occurred around 1930 and again in the late 1940s. Whitefish reached a low point in the period 1955 to 1960. The sea lamprey was a major factor in this decrease. In the hey-day of the lamprey, their effect on whitefish was not so great as on the lake trout, their favorite target. But with the virtual elimination of the lake trout by 1950, sea lamprey began preying on whitefish. Competition from smelt may have been a factor in the whitefish decline in the 1950s, but the alewife apparently did not play a major role in the whitefish decline.

Today the popular whitefish fishery is closely regulated, but concern has been raised in some areas about Native American harvests of whitefish. Intensive fishing by Indians in waters of northeastern Lake Michigan has reduced whitefish numbers drastically in that region according to the Michigan Department of Natural Resources.

The main concentrations of whitefish are in waters between 60 to 120 feet (20 to 39 meters). The preferred water temperatures range from 54° to 56°F (12°to 13°C). Moderate concentrations occur from 120 to 180 feet (39 to 59 meters) and in waters slightly shallower than 60 feet (20 meters). Aside from a significant population in the vicinity of Grand Haven, Michigan, few whitefish are taken in the southern half of the Lake. The most heavily fished commercial areas are northern Green Bay, and Big and Little Bay de Noc and the northeastern waters of Lake Michigan.



Winter

Summer

Distribution of Lake Whitefish

Conclusions

SUMMARY

Where are fish found in Lake Michigan? What factors determine where various species are likely to be found? How do these distributions change daily, weekly and seasonally? How is the present fish community different from past years?

This publication answers these questions. It explains where individual species of fish concentrate in Lake Michigan and why. It analyzes eight species of fish for various seasons of the year pointing out *main*, *moderate* and *light* concentrations, and it relates these patterns to the natural factors which determine locations and concentrations of the various species. The main factor is water temperature. Other physical factors involved are surface currents, upwelling, and water depths especially as they affect temperature. Food supplies, competition from other species, and some other influences are also discussed.

The publication also describes changes in the distribution patterns through recent history of the Lake. Many changes in the fish community have been directly or indirectly the result of human actions in Lake Michigan and the surrounding Great Lakes basin.

Most species currently present in the Lake are native stocks. In recent decades several important species have been introduced to the Lake, notably the salmon. Several others, sea lamprey and alewives, were inadvertently admitted to the Lake through human alterations of Great Lakes channels to the ocean.

Alterations in water quality are the major human influence currently affecting Lake Michigan fish.

Temperature

Together with food availability and spawning, temperature explains most fish distribution patterns in Lake Michigan. The major exception is spawning when salmon will tolerate higher than usual temperatures to reach spawning streams.

Lake Michigan has a seasonal temperature cycle. Each species has preferred temperatures for every activity from feeding to spawning. As water temperatures in the Lake change through the seasons, fish will move about to their preferred temperatures. The maps in this publication show those portions of Lake Michigan with preferred temperatures for various species through the year.

Bottom depth temperatures proved to be the most useful guide to seasonal species distributions. The authors relied on statistics from research trawls for information about depths and temperatures. Although bottom depths and temperatures do not correlate exactly over the entire Lake, depths and corresponding temperature variations provided the basis for establishing three zones of concentration—*main, moderate* and *light to none.* The bottom depths were especially valuable for determining where fish were likely to be concentrated in the warm season (late spring through early fall); most fish species are located in water layers nearer the bottom during this time of year. Even during the cold months, most species concentrate mainly at or near the bottom because these are areas where food is most readily available.

Small localized changes in water temperatures are important in determining where fish might be found within the broader concentration zones. Wind changes often alter surface water currents, especially during the summer. These changes in location of warm surface water cause corresponding changes in the locations of the fish preferring these warm waters. Marked changes in water temperature which occur in strong upwellings bring about major changes in locations of many species for a short time. Yellow perch is an example of a species which shifts with changing temperatures; other species, for example alewives, respond little to rapid shifts in water temperature. Inability to adjust to these temperature changes is implicated in the spring alewife dieoffs.

Changes in the Fish Community

Since human settlement of the Lake Michigan region, people have relied on fish from the Lake for food. Commercial fishing was one of the early economic activities in the region beginning at least by 1843. Human uses of the Lake and the land surrounding it have had major impacts on the fish community. As human development of the region increased, many changes occurred in the species composition of Lake Michigan fish. Cutting of the forests in the region increased turbidity through soil erosion. Wastes from saw mills were dumped in bays and at rivermouths emptying into the Lake, covering fish spawning grounds and food supplies. Through the years, cities, industries and agricultural activities added pollutants to the Lake reducing water quality in some areas, and altering the types of fish which could survive in those areas. Commercial fish harvests also influenced fish species. Harvests have always been concentrated on a few high value species. Until the turn of the century whitefish was the most popular species, with lake trout replacing it in value until the 1950s. Today whitefish is again the backbone of the Lake Michigan commercial fishery, being the most valuable species, while alewives are the largest part of the harvest in terms of poundage.

A major disruption of the native community of Lake Michigan fish was touched off in the 1940s when the sea lamprey, an invader from the Atlantic Ocean, established a population in Lake Michigan. By 1956, lamprey had virtually eliminated lake trout in Lake Michigan. The disappearance of the major predator fish like the lake trout cleared the path for a tremendous growth in alewives, another species which invaded from the Atlantic Ocean. The dominance of the Lake Michigan fish biomass by alewives since the 1950s is another major influence on present fish distribution patterns. Alewives affect other fish in two ways; they crowd out other species requiring the same locations and temperatures; and they are the major food of some large fish. Thus, the distribution of fish which feed on alewives will follow alewife distributions. Through the course of the year, alewives inhabit practically all water zones in the Lake. Wherever alewives are during the year, they bring about intense competition for space and food. Inability to compete with alewives has greatly reduced numbers of yellow perch, chubs and lake herring. The only species that may not be affected is the deep water sculpin which inhabits the same deep water zones all year. Other species such as the coho salmon have flourished because the alewives provide abundant food. Coho and other predators have kept the alewife numbers reduced in the last fifteen years.

With the population explosion of alewives and the absence of large predators in the Lake, the stage was set for salmon stocking. The Michigan Department of Natural Resources launched the program in the 1960s. Pacific species of coho and chinook salmon were planted in Lake Michigan and have been extremely successful there. The plantings have touched off growth of a sport fishery unmatched in the world. The fishery and the service industry which supports it are important economic contributors in Michigan and Wisconsin.

Future Distribution Trends

Lake Michigan fish have gone through many changes in the last 150 years. Some stability appears to have been reached in the present fish community. To maintain current levels of fish stocks and the present composition of species, fishery managers must do several things. First, the predator-prey balance of alewives and salmon and lake trout must be maintained. This requires stocking enough lake trout and salmon to replace the sport fishery take. Also, the current controversy over Native American fishing rights must be resolved to prevent damage to lake trout and whitefish stocks. Furthermore, Lake Michigan water quality must be kept high and improved in problem areas. Also other uses of land and water in the Lake Michigan basin must be carried out in ways that do not interfere with maintenance of the fish stocks.

Fish in Lake Michigan are a major resource for food and recreation. Understanding the distribution patterns and the factors which control them will help citizens, politicians, commercial fishers, anglers and researchers forge public policies that will ensure viable fish communities in Lake Michigan for the future.

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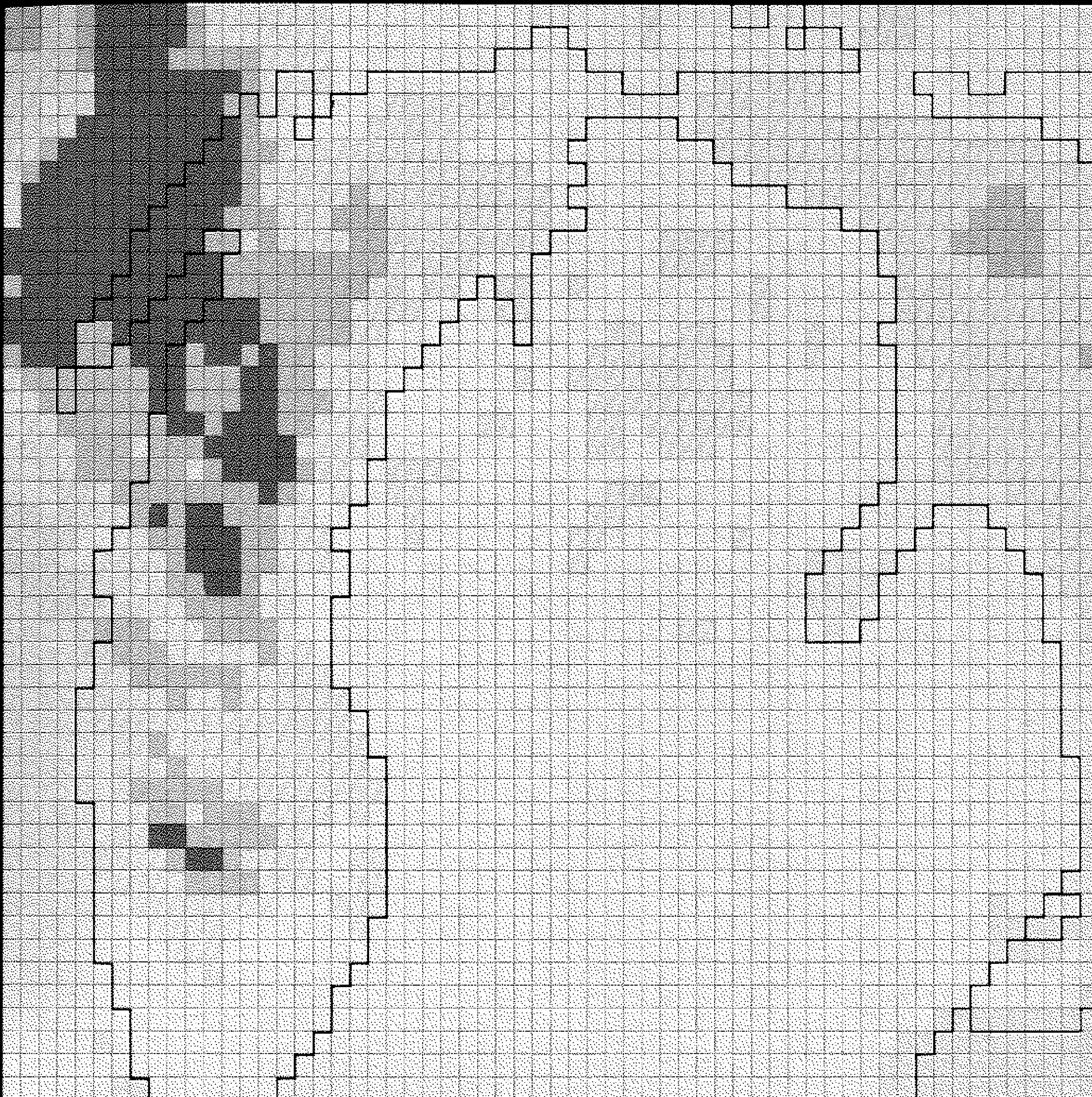

Warmer than 71° F
64° to 71° F
56° to 63° F
48° to 55° F
40° to 47° F
33° to 39° F
Cooler than 33° F

Lake Michigan's Surface Temperatures
7 a.m. EST, June 25, 1979

Overnight, the land rapidly lost heat absorbed from the previous day's bright summer sun; it appears much cooler in this map. Deep water, however, absorbs and gives up the sun's heat more slowly than earth (a phenomenon called "thermal inertia"), so the lakes' color patterns have not changed much from one map to the next. The coldest areas, shown in purple, are clouds.

These GOES images were provided through the courtesy of Dr. Stuart Gage, Department of Entomology, Michigan State University.