WALLEYE STOCKS IN THE GREAT LAKES, 1800-1975: FLUCTUATIONS AND POSSIBLE CAUSES

Great Lakes Fishery Commission

TECHNICAL REPORT No. 31

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries, between Canada and the United States, ratified on October 11, 1955. It was organized in April 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: the first, to develop coordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; the second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

WALLEYE STOCKS IN THE GREAT LAKES, 1800-1975: FLUCTUATIONS AND POSSIBLE CAUSES

by

J. C. SCHNEIDER
Michigan Department of Natural Resources
Institute for Fisheries Research
Ann Arbor, Michigan 48109

And

J. H. LEACH
Ontario Ministry of Natural Resources
Lake Erie Fisheries Research Station
Wheatley, Ontario NOP 2PO

TECHNICAL REPORT NO. 31

Great Lakes Fishery Commission
1451 Green Road
Ann Arbor, Michigan 48105

February 1979

FOREWORD

The Great Lakes Fishery Commission is participating in a series of symposia whose subject matter bears on Great Lakes fisheries: Salmonid Communities in Oligotrophic Lakes (SCOL), July 1971; the Percid International Symposium (PERCIS), 24 September-5 October 1976; A Symposium on Selected Coolwater Fishes of North America, 7-9 March 1978; the Sea Lamprey International Symposium (SLIS), scheduled for l-10 August 1979; and the Stock Concept Symposium, scheduled for 1980.

After concise versions of SCOL papers had been published in the *Journal of the Fisheries Research Board of Canada* (volume 29, number 6, June 1972), it was clear that much detailed information that had been developed by the authors and refined by events at the symposium, and which would be of very considerable value to fishery workers in the Great Lakes area, would not be generally available. The Commission therefore invited the authors of case histories on seven lakes-Superior, Michigan, Huron, Erie, Ontario, Opeongo, and Kootenay-to publish full versions in the Commission's *Technical Report* series (numbers 19-25, 1973).

Similarly, after concise versions of PERCIS papers were published in the *Journal of the Fisheries Research Board of Canada* (volume 34, number 10, October 1977) the Commission asked symposium participants and authors of papers dealing specifically with Great Lakes percids whether more detailed versions of certain papers should be published for the benefit of present and future fishery workers. Based in part on the replies, the Commission authorized publication of *Technical Reports* 31 and 32: "Walleye stocks in the Great Lakes, 1800-1975: fluctuations and possible causes," by J. C. Schneider and J. H. Leach; and "Modeling the western Lake Erie walleye population: a feasibility study," by B. J. Shuter, J. F. Koonce, and H. A. Regier.

Carlos M. Fetterolf, Jr.
Executive Secretary

CONTENTS

WALLEYE STOCKS IN THE GREAT LAKES, 1800-1975: FLUCTUATIONS AND POSSIBLE CAUSES [1]

by

J. C. Schneider and J. H. Leach

ABSTRACT

Changes *in* stocks of the walleye *(Stizostedion vitreum vitreum)* in the Great Lakes from 1800 to 1975 were linked to proliferation of foreign species of fish and culturally induced sources of stress-exploitation, nutrient loading, alteration of spawning habitat, and introduction of toxic materials. During the 1800's, three small spawning stocks (and probably many others) were damaged or destroyed because of either overfishing or elimination of spawning habitat through logging, pollution, or damming.

During 1900-40, stocks gradually declined in southern Green Bay, the Thunder Bay River of Lake Huron, the North Channel of Lake Huron, the Michigan waters of Lake Superior, and the New York waters of Lake Ontario. Pollution in general, and degradation of spawning habitat in particular, probably caused the declines in the first three of these areas; in addition, the declines occurred in part during a period when rainbow smelt *(Osmerus mordax)* were increasing. Overexploitation was suspected of causing the declines in Lake Superior and Lake Ontario.

During 1940-75, stocks- declined abruptly in seven areas: Saginaw Bay (1944), northern Green Bay (1953). Muskegon River (mid-1950's), western Lake Erie (1955). Nipigon Bay (late 1950's), Bay of-Quinte (1960), and Black Bay (mid- 1960's). The decline of each stock was associated with a series of weak year classes. The stocks were exposed to various sources of stress, including high exploitation, pollution, and interaction with foreign species, which, if not important in the decline, may have suppressed recovery. Only the western Lake Erie stock recovered, partly because exploitation was reduced, and possibly because of the relatively low density of smelt and alewives (*Alosa pseudoharengus)* in the nursery areas.

Relatively stable stocks persisted in five areas: Wisconsin waters of Lake Superior, Lake St. Clair-southern Lake Huron, eastern Lake Erie, northern Lake Huron, and parts of Georgian Bay. Pollution problems were relatively minor in these areas and exploitation was light during recent decades. Apparently these stocks were also more capable than the others of withstanding the stresses exerted by alien species.

INTRODUCTION

The walleye *(Stizostedion vitreum vitreum),* like so many other fishes in the Great Lakes, has undergone dramatic changes in abundance over the past century, but especially during the last *several* decades. For example, once-large

---

1 Supported in part by Dingell-Johnson Project F-35-R, Michigan.

populations in Saginaw Bay and Green Bay are now small. On the other hand, the walleye has remained plentiful in the Lake St. Clair region. Reasons for the decline of some walleye stocks, while others have remained stable, are poorly understood. Often the combined effects of overfishing, pollution, and interaction with alien species of fish appear to have been responsible.

In this paper we review the history and present status of walleye populations in various localities in the Great Lakes (Fig. 1), giving particular attention to fluctuations in abundance induced by the activities of man (exploitation and alteration of habitat) and by interactions with other fish such as the rainbow smelt (Osmerus mordax), the sea lamprey *(Petromyzon marinus),* and the alewife *(Alosa pseudoharengus).* Trends in abundance and other relevant data needed to identify possible causes for major fluctuations in abundance are treated by lake and population in greater detail than in our earlier paper (Schneider and Leach 1977). These accounts are followed by a summary and discussion. To attempt to resolve the importance of these possible contributing factors, we have looked for sequential trends associated with invasion routes of exotic fishes, and have contrasted the characteristics of the environments in which stocks have been stable with those in which stocks have been unstable. We have also drawn certain inferences about the interactions of the walleye with other fish and with man. The term "population," as used here, refers to a spawning group or, if the data were inadequate to define such a group, to the inhabitants of a geographical area.

We have relied heavily on the comments of experienced observers and unpublished information, in addition to the published literature. Trends in abundance of walleyes have been mainly inferred from the descriptive accounts of fisheries in the early years and from the commercial catch records in later years. (All records of commercial catches have been converted to metric tons.) We believe that such records may not be precise but that they can be used to detect major changes in abundance and distribution because the walleye has been commercially important since the early 1800's. This belief is supported by a good correlation between trends in harvest and indices of abundance for walleyes in Saginaw Bay and in northern Green Bay (Hile and Buettner 1959; Hile et al. 1953). Extensive use was made of four sources: (1) commercial fish production records (Baldwin and Saalfeld 1962, and supplements), (2) detailed ledgers prepared by clerks of the Michigan State Board of Fish Commissioners (MSBFC), which are believed to reflect adequately the location, nature, and magnitude of the Michigan commercial fishery in 1891-1908, (3) records of the commercial catch by statistical districts for Ontario waters of the Great Lakes, 1956-75, and (4) detailed records of commercial catch and effort by statistical districts for the U.S. waters of the Great Lakes in 1929-69 (commercial fishing for walleyes was banned in Michigan waters after the 1969 season). The statistical districts of the Great Lakes were described by Smith et al. (1961).

In early reference materials the names "pike" and "pickerel" were sometimes applied to walleyes, northern pike (Esox lucius), saugers *(Stizoste-*

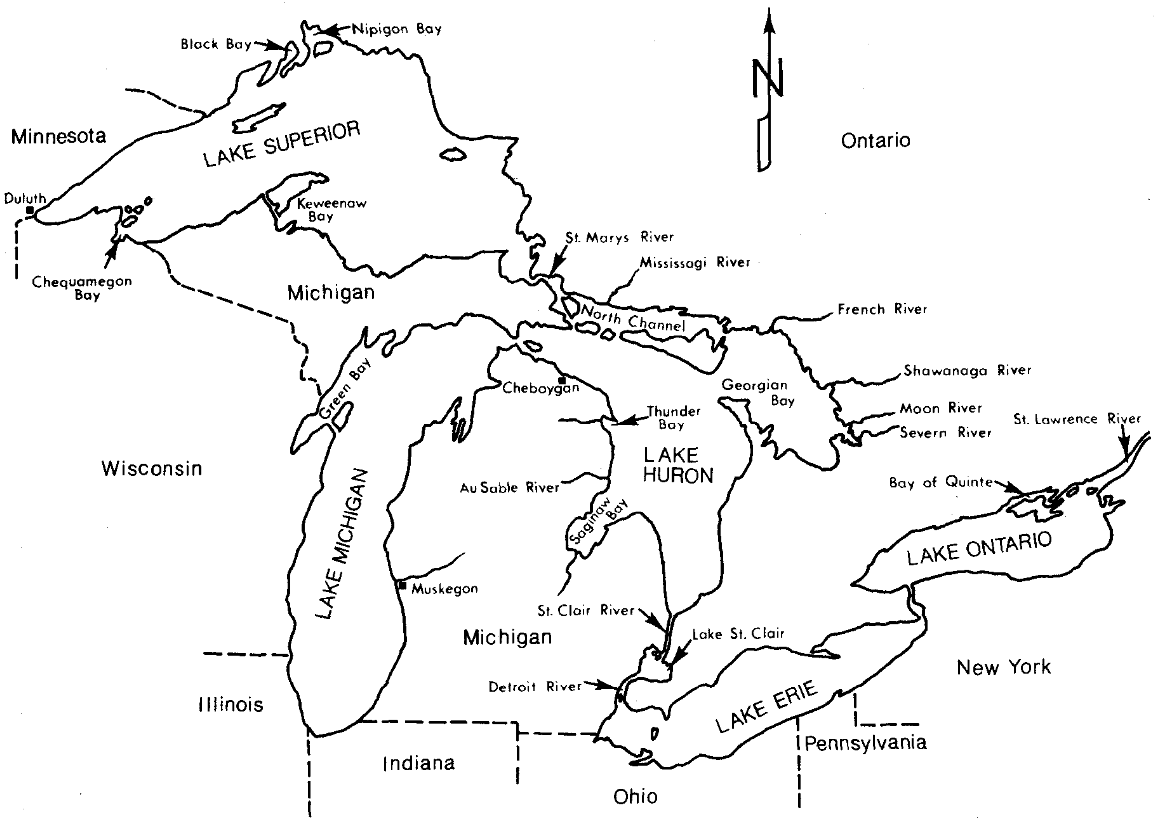

Figure 1. The Great Lakes, showing various localities mentioned in the text.

dion canadense), and blue pike *(Stizostedion vitreum glaucum).* We have deduced the identity of the species intended from context, or from contemporary or later references dealing with the same area of the Great Lakes.

LAKE SUPERIOR

The walleye populations of Lake Superior have always been relatively small and widely scattered, primarily because the amount of shallow, warm-water habitat is limited. The highest annual lake-wide catch was only 171 tons (in 1966). Most walleyes were taken from Ontario waters, principally Black Bay, and to a lesser extent, Nipigon Bay; minor populations were in Thunder Bay, Agawa Bay, Batchawana Bay, and Goulais Bay. Along the south shore of Lake Superior, walleye populations occurred in Michigan, Wisconsin, and Minnesota.

Black Bay

The recording of commercial catches according to statistical districts, which separate the major fishing areas of Lake Superior, did not begin until 1948. However, since commercial yields from Black Bay in 1948-75 accounted for 84% of the total walleye harvest from Ontario waters, we assume that the major part of the yield in earlier years (Fig. 2) also came from Black Bay. The bay is shallow (mean depth, 6 m) and provides suitable walleye habitat (Ryder 1968). Commercial harvest appeared to be fairly stable from 1910 to 1950 and then increased in the 1950's and 1960's. After a peak yield of 170 tons in 1966, the harvest dropped rapidly to nil in 1972. Commercial harvest of saugers declined at the same time.

The reasons for the decline are not entirely clear. Dymond (1944) reported the presence of rainbow smelt in Lake Superior in 1930 and in Nipigon Bay and Thunder Bay in 1940. Spawning runs of smelt into Black Bay tributaries were first observed in 1955 (R. A. Ryder personal communication) but the effects, if any, of this exotic species on the walleye have not been assessed. Ryder (1968) concluded that lamprey predation was not an important factor in the walleye decline in nearby Nipigon Bay, and the alewife can be ruled out because it did not establish a significant population anywhere in Lake Superior. An examination of water quality in Black Bay and its tributaries during the walleye decline, by field personnel of the Ontario Ministry of the Environment, revealed no contributing causes (C. A. Elsey personal communication).

R. A. Ryder (personal communication) believed that overexploitation led to the demise of the Black Bay population. Although small adfluvial spawning runs existed in the Black Sturgeon River, spawning in Black Bay occurred mainly along the northern shoreline, where adults were heavily exploited. Effort increased in the mid-1960's (Fig. 2), causing changes in the year-class structure in the commercial fishery. Essentially, the 1965 harvest consisted of only two year classes; consequently one year-class failure could have reduced the fishery by about 50%. Detailed data are not available but it

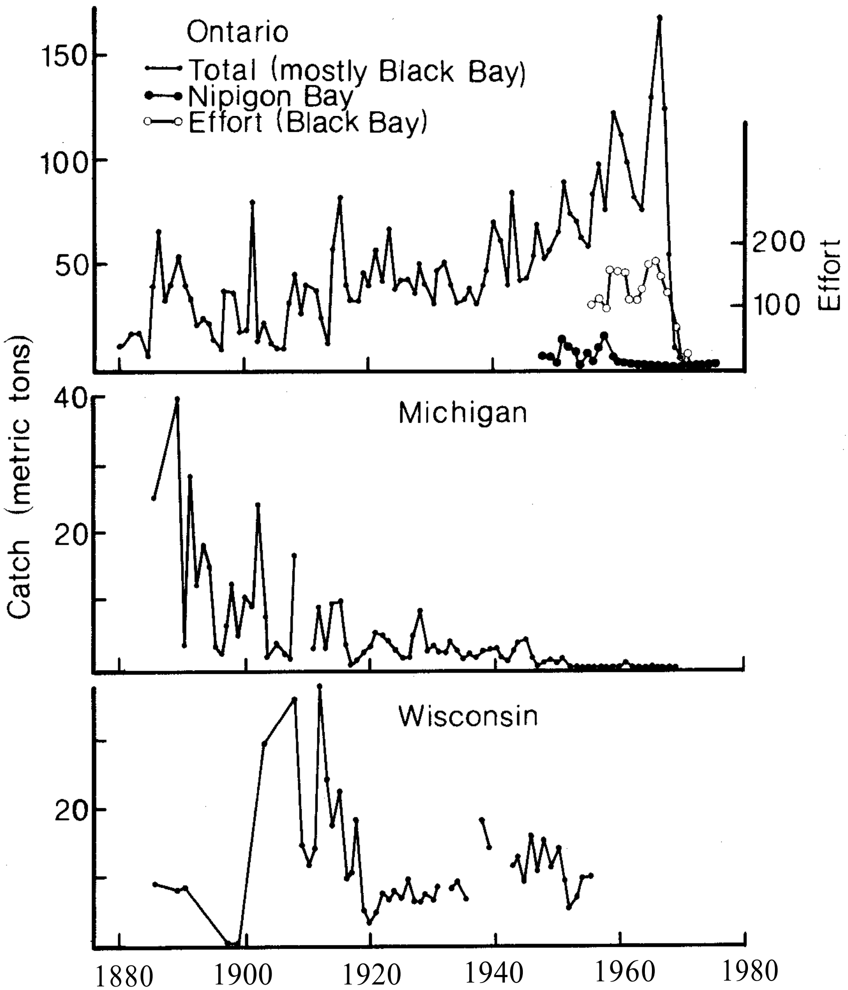

Figure 2. Commercial catches of walleyes in different regions of Lake Superior: all Ontario waters (mostly Black Bay), 1880-1975, and Nipigon Bay, 1948-75; Michigan, 18851969; and Wisconsin, 1885-1955. Upper panel also shows fishing effort (kilometers of gillnet; scale at right) in Black Bay, 1956-75.

appears that year-class success was poor in the middle and late 1960's and, in the absence of adequate recruitment, the Black Bay stock was quickly removed by the fishery.

Nipigon Bay

The walleye population in Nipigon Bay ranked second in importance in Ontario waters of Lake Superior, contributing 6% of the commercial harvest in 1948-75. Annual yield was variable in 1948-58, ranging from 2 to 16 tons (Fig. 2). From the peak of 16 tons in 1958, the commercial harvest declined to nil in 1966 and did not recover.

Ryder (1968) concluded that pollution from a kraft mill at Red Rock, Ontario, was the principal cause of the demise of the walleye population. He reasoned that the effluents from the mill disoriented spawning walleyes so that they did not return to their traditional spawning grounds in the lower Nipigon River. The abundance of white suckers *(Catostomus commersoni)* and longnose suckers *(C. Catostomus)* spawning in the Nipigon River also declined in the early 1960's. Although sucker spawning runs in the river have not occurred since 1964, it is likely that other spawning areas are being used, since both species were still common in the bay in the 1970's. Ryder believed that walleyes were unable to find alternative spawning grounds because the amount of suitable habitat in Nipigon Bay is limited. The pulp mill discharges polluted a large area of the shallow western portion of the bay. Nymphs of the burrowing mayfly *(Hexagenia limbata),* which are prime food for both young and adult walleyes, were eliminated from the outfall area (German 1968). The effluents included phenols, which were responsible for tainting the flesh of fish taken in the vicinity of the discharge plume. Other deleterious effects of the effluents were increases in suspended solids and biological oxygen demand (German 1968).

Adult walleyes remained in Nipigon Bay for several years after spawning ceased, but were gradually lost to the commercial fishery and to natural mortality. No walleyes were caught during a 1974 study of the fishes of the Red Rock area (Kelso 1977).

Ryder (1968) found that sea lamprey wounding and scarring rates of Nipigon Bay walleyes were less than 1% in 1955-57. The rate increased slightly over this period, and he reasoned that if lamprey predation was significant the natural mortality rate would increase also. However, he demonstrated a decrease in natural mortality, and concluded that lampreys did not play an important role in the decline of walleyes.

Ryder (1968) showed that fishing intensity for walleyes increased greatly in 1957 and 1958 because of the decline in the fishery for lake trout *(Salvelinus namaycush).* He estimated that the annual mortality rate from fishing increased from 0.10 in 1955 to 0.39 in 1957. However, he believed that exploitation was not a major factor in the decline because ice conditions precluded fishing during the upstream migration, and most walleyes were caught in Nipigon Bay after the spawning season.

The effect of rainbow smelt on the walleye in Nipigon Bay is not known. Smelt have been in the bay since 1940 (Dymond 1944).

Michigan

In Michigan waters the walleye was taken incidentally in nets set for lake whitefish *(Coregonus clupeaformis)* and other species. Whitefish Bay and the upper St. Marys River supported the largest populations, but some walleyes were taken along the Keweenaw Peninsula, from Huron Bay, and near Ontonagon. Spawning probably occurred in the rivers in these areas, but supporting data are scanty. Walleyes have been reported from the St. Marys, Tahquamenon, Au Train, Iron, Ontonagon, and Black rivers, and the Keweenaw Waterway.

Commercial catch statistics indicate a gradual decline in the walleye populations from relatively high but fluctuating levels to very low, stable levels (Fig. 2). In Whitefish Bay the highest catches (9 to 29 tons) were made in 1891-94, and in the Keweenaw area the highest catch (12.2 tons) was made in 1902. Catches in both districts dwindled to insignificance by the 1940's, irrespective of fishing effort.

Rathbun and Wakeham (1898) attributed the initial decline in the walleye catch from the U.S. waters of Lake Superior to overfishing with pound nets, noting that the number of such nets (introduced in 1863, according to Van Oosten 1938) increased from 50 in 1879 to 276 in 1893. The continued decline, and finally virtual collapse of the Michigan stocks, were most likely due to overexploitation. On the other hand, the high catches in the early years may have been due to an unusually great increase in the walleye populations-later levels being more typical. Goode (1884) reported that walleyes were "quite rare" in Whitefish Bay until they began to increase in about 1868. He also noted that fishermen in western Michigan and Wisconsin were deeply puzzled by an "immense run" of walleyes in 1879, as compared with the run of 4 years earlier. Such an unusual increase could have been triggered by the reduction of competitive inshore fishes by fishing, climatic fluctuations, or alteration of habitat. Removal of the forest cover, beginning in the 1850's, may have favored the walleye by warming the relatively cold spawning streams or stimulating productivity; conversely, reforestation during the past 50 years may have had a negative effect on walleye recruitment by cooling streams or reducing inflowing nutrients.

The Michigan walleye stocks dropped to extremely low levels before the rainbow smelt and the sea lamprey populations exploded in the 1950's (Lawrie and Rahrer 1973).

Wisconsin

In Wisconsin waters, walleyes frequent Chequamegon Bay, the Bad River, and rivers along the western shore. Early accounts by True (1887) and Goode (1884) also mentioned the Apostle Islands and Squaw and "Siscourt" (Siskiwit) bays. The combined catch data for these areas show that the walleye populations fluctuated greatly in the early years, but without a long-term trend through 1955 (Fig. 2) when commercial fishing was banned. No pronounced change occurred after that until 1972, when Indians began to intensively fish spawning grounds in the Bad River and Chequamegon Bay and those populations fell to low levels (G. R. King personal communication). The highest reported annual catches (up to 38 tons) were made after the turn of the century but the catch from a large run in 1879 (Goode 1884) was not recorded. Significantly, these populations were not adversely affected by rainbow smelt or sea lampreys. Chequamegon Bay, in particular, became a major producer of smelt, and the Brule and Bad rivers supported large runs of smelt and sea lampreys in addition to walleyes (G. R. King personal communication). A possible explanation is that many young walleyes may remain in marshes near the spawning sites and have little contact with the more limnetic smelt.

Minnesota

A spectacularly large but short-lived commercial fishery for walleyes developed near the twin cities of Duluth, Minnesota, and Superior, Wisconsin, in the 1880's. Here the habitat is more favorable (the water is shallower) along the Wisconsin shore of Lake Superior, but most of the catch was made by Minnesota fishermen during a spawning migration. In the 1870's, walleyes were dipnetted or seined from an area 16 km up the St. Louis River (Smith and Snell 1891). Also at about this time, "small" numbers were taken by hook and line through the ice on the bay (Krumlien and True 1887). In 1879, the commercial catch was 7.3 tons (True 1887). The highest reported catch, 56.6 tons, was in 1885 but only 4 years later the take was only 7.3 tons and it never again exceeded 0.5 ton (Baldwin and Saalfeld 1962). A spawning run persisted in the St. Louis River system in the 1970's, despite a long history of severe water quality problems and a large population of rainbow smelt in that area (G. R. Ring personal communication).

LAKE MICHIGAN

The largest populations of walleyes in Lake Michigan were in northern and southern Green Bay and along the eastern shore off the Muskegon River. Insofar as can be determined, only relatively small numbers ever occurred elsewhere.

Northern Green Bay

Northern Green Bay was the principal center of abundance of walleyes in Lake Michigan. In the earliest descriptive accounts, dating from the late 1870's (Goode 1884), the walleye was the third-most-important species (after lake whitefish and lake sturgeon, *Acipenser fulvescens)* in the commercial catch along both the northern and western shores of Green Bay. Along the north shore, in Bay de Noc, walleyes were taken mainly in the spring during the spawning season, whereas along the west shore, most were taken in the fall-except in the Menominee River, where they were caught during the spawning migration. After the 1890's nearly all were caught from Bay de Noc; only a few came from the area between Menominee and the Bark River.

The importance of the walleye may have dipped slightly before the end of the century, judging by the statistical records for 1891-1908, which showed that it made up no more than 8% of the total annual catch from the bay (Hile et al. 1953). The population was relatively stable in 1909-28, as may be judged from the walleye catch statistics for Lake Michigan as a whole (Fig. 3). Explicit catch records for the bay, beginning again in 1929, show that the catch increased dramatically in the late 1940's, reached a record high of 589

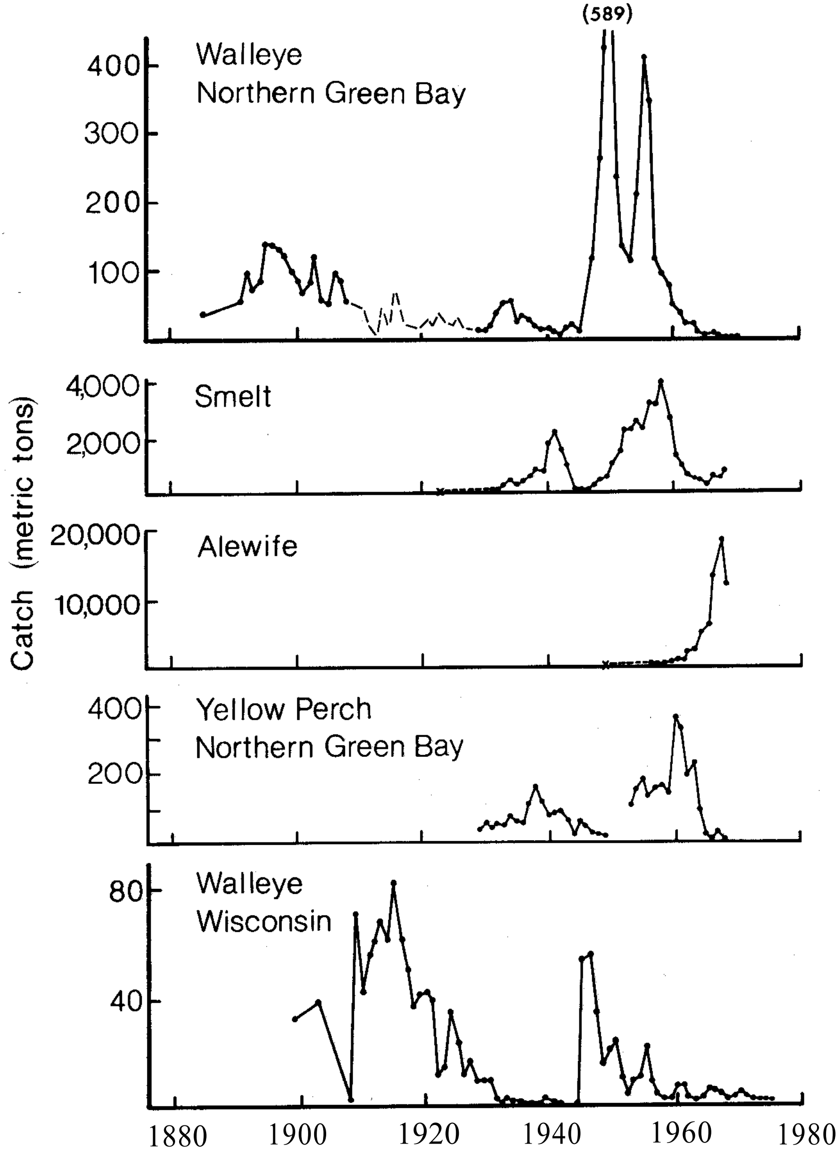

Figure 3. Commercial catches of four species in different regions of Lake Michigan: walleyes in northern Green Bay, 1885-1908 and 192969 (the dashed line for 1908-28 indicates the catch in all Michigan waters, but probably most came from northern Green Bay); rainbow smelt (mostly from Green Bay), 1931-68; alewives (lake-wide), 1956-68; yellow perch in northern Green Bay, 1929-69; and walleyes in Wisconsin waters (mostly from southern Green Bay), 1899-1975.

tons in 1950 and a lower peak in 1955, and then fell to very low levels by the mid-1960's. Commercial fishing was banned after 1969 but the population remained small through 1975.

The principal spawning grounds were in the Whitefish River and in the estuaries at the head of Little Bay de Noc, but Crowe et al. (1963) reported that much spawning took place at numerous locations in both bays as recently as the 1960's. Tagging studies by these authors established that spawning stocks were discrete.

It is unlikely that the decline in walleyes was due to pollution or to alteration of the spawning substrates, because the spawning areas were widespread and water quality in northern Green Bay as a whole did not markedly decline. Judging from fish food studies (Dodge 1968; Toth 1959), the burrowing mayfly remained plentiful in Bay de Noc (although perhaps less so than in earlier years).

The phenomenal increase in the walleye catch in northern Green Bay in the 1950's can be traced to an exceptionally strong year class in 1943, plus strong broods in 1950, 1951, and 1952 (Pycha 1961). The strong year class of 1943, in contrast to the others, arose from a relatively small adult stock. It seems more than coincidence that this strong 1943 year class of walleyes, and also those of lake whitefish and lake herring *(Coregonus artedii),* developed immediately after the 194243 mass mortality of smelt in Lake Michigan (Van Oosten 1947). Moreover, walleye recruitment became poor after smelt re-gained high abundance in Green Bay (Fig. 3), and after the alewife buildup intensified in 1953 (Wells and McLain 1973). Alewives became extremely abundant throughout Lake Michigan in the 1960's (Fig. 3). Unlike the walleye stocks in Saginaw Bay and eastern Lake Michigan (discussed later), those of Green Bay did not respond perceptibly to the initial increase in smelt, although a later study (Wagner 1972) established that smelt (as well as alewives) were an important food of walleyes in Green Bay.

It seems most likely that the poor recruitment of walleyes since 1953, and of yellow perch *(Perca flavescens)* in more recent years (Fig. 3) was primarily due to an effect of alewives and smelt on larval percids in Little Bay de Noc; however, conclusive supporting evidence is lacking. The opportunity for interaction exists because the spawning and nursery areas of these species overlap in space and time. Walleyes move inshore to spawn near the end of April, and smelt and yellow perch soon follow. Hatching of all three species begins in late May-just before the inshore migration of adult alewives in June (Wagner 1972). Adult alewives are not known to prey on the young of the other species (W. C. Wagner personal communication), but competition among the fry for zooplankton is a possibility. It is also likely that continuous grazing by alewives has permanently altered the zooplankton community in Bay de Noc, as it has in the open waters of Lake Michigan (Wells 1970). The harvest (and presumably the abundance) of yellow perch and smelt declined as the alewife population built to a peak in the late 1960's (Fig. 3), and emerald shiners *(Notropis atherinoides)* declined as well (Basch 1968). Supporting circumstantial evidence that recruitment of walleyes may have been limited at the larval stage was supplied by J. H. Peterson (personal communication). Each year, 1971-75, he incubated eggs from Little Bay de Noc walleyes in a hatchery and reared the young to fingerling size in ponds. These fingerlings, 46-89 mm long, apparently survived well after being stocked in Little Bay de Noc.

Pycha (1961) noted that total mortality of walleyes increased during the mid-1950’s. Annual mortality was also high (65%) during the late 1950’s to mid-1960’s. This estimate was calculated from pooled recapture data of W. R. Crowe (Table 1) by the method of Robson and Chapman (Ricker 1975, p. 31), excluding year-0 returns because small tagged walleyes were not fully vulnerable to the commercial fishery. This estimate is only approximate because the assumptions of constant rates of exploitation, natural mortality, and cooperation by the fishermen during the period were probably not rigorously met; nevertheless, fishing mortality or natural mortality, or both, appear to have been relatively high.

Losses to sport fishing, in particular, seemed to be high from the mid-1950’s (Pycha 1961) through the early 1960’s; on the other hand, only 8.4% of the tags from fish marked by W. R. Crowe were ever returned. From voluntary tag returns and commercial catch records, Crowe et al. (1963) estimated that roughly 420,000 walleyes were taken by anglers in 1958 and 119,000 by commercial fishermen. During the entire study, 1957-68, anglers filed 62.5% of the tag returns and commercial fishermen 37.5% (W. R. Crowe unpublished data). A high proportion of the sport catch was composed of small walleyes. In a partial creel census in 1961, 65% of the walleyes in the sport catch were less than 432 mm long, 19% were 432-456 mm, and only 16% were 457-686 mm. Judging from the maturity data provided by Balch (1952) few of the female walleyes spawned before they were caught. The minimum legal lengths in 1961 were 330 mm (13.0 inches) for the sport fishery and 394 mm (15.5 inches) for the commercial fishery.

Table 1. Numbers of tagged walleyes released in northern Green Bay, 1957-1963, and numbers returned by sport and commercial fishermen combined (W. R. Crowe unpublished data).

Release data:		Number of calendar years after release[a]								
		0	1	2	3	4	5	6	7	8
Year	Number	(Same)								
1957	770	49	33	15	1	0	0	2	0	0
1958	917	50	31	23	2	1	1	0	0	0
1959	1,981	132	65	12	5	0	0	0	0	1
1960	1,022	29	34	7	2	1	0	0	0	0
1961	1,814		16	14	6	2	1		1	0
1962	264	7	6	4	0	0	0	1	0	0
1963	147	5	1	0	1	o -	o	0	0	0
All	6,915	294	186	75	17	4	2	3	1	1

[a]For example, from the 1963 release, five tagged walleyes were recaptured in 1963, one in 1964, and one in 1966. However, for the 1957 release (only), year 0 includes re-captures for 1957 and 1958 (because these walleyes were tagged in the fall after the fishing season, rather than in the spring as in other years), year 1 includes recaptures in 1959, year 2 those in 1960, and so on.

Mortality due to sea lamprey predation was probably low. In 1961, only 3.4% of the walleyes bore lamprey scars (w. R. Crowe unpublished data). However, it should be noted that increasing mortality of walleyes in the mid-1950's coincided with declines in the commercial harvest of lake white-fish, lake herring, carp (Cyprinus carpio), and white and longnose suckers. These declines may have been caused by sea lamprey predation because the lake trout had just been eliminated, forcing the sea lamprey to turn to these less preferred species.

We do not believe that the high mortality of adult and subadult walleyes was the reason for the low recruitment that began in 1953, because the adult stock did not fall below the level that produced the phenomenal 1943 year class until the mid-1960's (Fig. 3). In the early 1960's, the walleye population still numbered in the hundreds of thousands. Census clerks recorded that 9 of 1,125 (0.8%) walleyes examined in 1960 and 3 of 147 (2.0%) examined in 1961 were tagged. By 1961, between 2,000 and 6,000 tagged walleyes were present. We surmise that adequate reproductive potential existed through at least the mid-1960's and that alewives and smelt were largely responsible for poor reproductive success of walleyes beginning in 1953.

Southern Green Bay

The early history of the fishery in southern Green Bay was synthesized from the descriptive accounts of Smith and Snell (1891), Goode (1884) and True (1887). Walleyes were harvested at the southern end of the bay and along the western shore. Major fisheries associated with spawning runs were in the Fox River and off the Oconto and Peshtigo rivers. Large numbers of walleyes also spawned in the Menominee River, where one man could spear as many as 5 barrels (545 kg) in a single night. Some spawning may have taken place in the rivers along the east shore between the cities of Green Bay and Sturgeon Bay, judging from the reported capture of "pike" (walleyes) and "pickerel" (northern pike) in seines and fyke nets in early spring, 1885.

By 1880 the walleye was believed to be declining as a result of overfishing and pollution by sawmill waste, in much the same manner (but to a much lesser extent) as the lake whitefish had declined several years earlier. However, the walleye stocks apparently did not fall to the low levels of later years. The first catch data, for 1885, listed 252 tons of "pike" and "pickerel." Judging from more detailed records in 1899 and 1903 (Baldwin and Saalfeld 1962), walleyes probably made up at least half of this total. The combined catches of walleyes and northern pike were also relatively high in 1889 (125 tons) and 1897 (212 tons).

Beginning in 1899 the catches of walleyes and northern pike were separated, but the statistics in Green Bay were not differentiated from other Wisconsin waters of Lake Michigan until 1953. Since, however, walleye fisheries in these other waters were negligible by the turn of the century, the southern Green Bay fishery is closely represented by the production from all Wisconsin waters of Lake Michigan (Fig. 3). These data show a high walleye harvest of 89 tons in 1915, a gradual decline, a slight recovery in the 1940's and 1950's (possibly as a result of immigration from northern Green Bay, judging from tag returns reported by Crowe et al. 1963), and then a nearly complete collapse. In essence, the major decline in the stock began in the 1920's.

The decline of walleyes in southern Green Bay is believed to have been caused mainly by dams and pollutants that interfered with reproduction and (to some extent) by degradation of the offshore habitat. Only the Menominee River still supported a small run of walleyes in the 1970's. Gross pollution of the Fox River reduced dissolved oxygen concentrations in the bay for at least 43 km from the river mouth, and had a pronounced effect on the benthic community (Howmiller and Beeton 1970). The once-abundant burrowing mayfly disappeared between 195.5 and 1966.

Additional stress could have been imposed by the rainbow smelt, which arrived in Green Bay in 1924 (Van Oosten 1937). Schneberger (1937) estimated that smelt had become the most abundant species in Green Bay by the mid-1930's. He noted that smelt ate many of the same foods eaten by the native species, and that they were piscivorous. In the mid-1970's the fish population of southern Green Bay was dominated by carp, smelt, and alewives. Plantings of fry and fingerlings in the early 1970's reportedly established some walleyes in Sturgeon Bay (L. Kernan personal communication).

Eastern Lake Michigan

Along the eastern shore of Lake Michigan, apparently only minor populations were associated with rivers other than the Muskegon but little can be inferred about their pristine status. Modest numbers of spawners congregated below the dam on the Big Sable River, where, from 1929 to 1955, a few (as many as 307) were netted and transported upstream annually. A few tons of walleyes were caught each year in 1891-1908 off the Kalamazoo, Grand, and Manistee rivers. The other large rivers along the southeastern shore also supported a few walleyes but later tagging studies (Crowe 1955; Eschmeyer and Crowe 1955) indicated that many, if not all, may have spawned in the Muskegon River.

The walleye population "homing" to spawning grounds in the lower Muskegon River seemingly expanded to an all-time high in the present century. The walleye is native to the Muskegon system, but little can be deduced about the original status of the adfluvial stock because the early development (in about 1838) of an extensive logging industry and the lack of a shipping channel inhibited growth of the fisheries until the 1880's (MSBFC 1890). Judging from the descriptive accounts of Goode (1884) and Smith and Snell (1891) and the commercial catch statistics for the eastern shore of Lake Michigan (Fig. 4), the walleye stock was at a low level until about 1907. The increase occurring after that date may have been related to the completion of Newaygo Dam in 1900 - perhaps spawning grounds were improved because bedload sediments (which must have been high then as a result of deforestation) were trapped in the new impoundment. Later the commercial harvests fluctuated greatly; catches exceeded 20 tons in the mid-1930's, in 1946 (mainly due to large catches off St. Joseph, Michigan), and in 1952. The

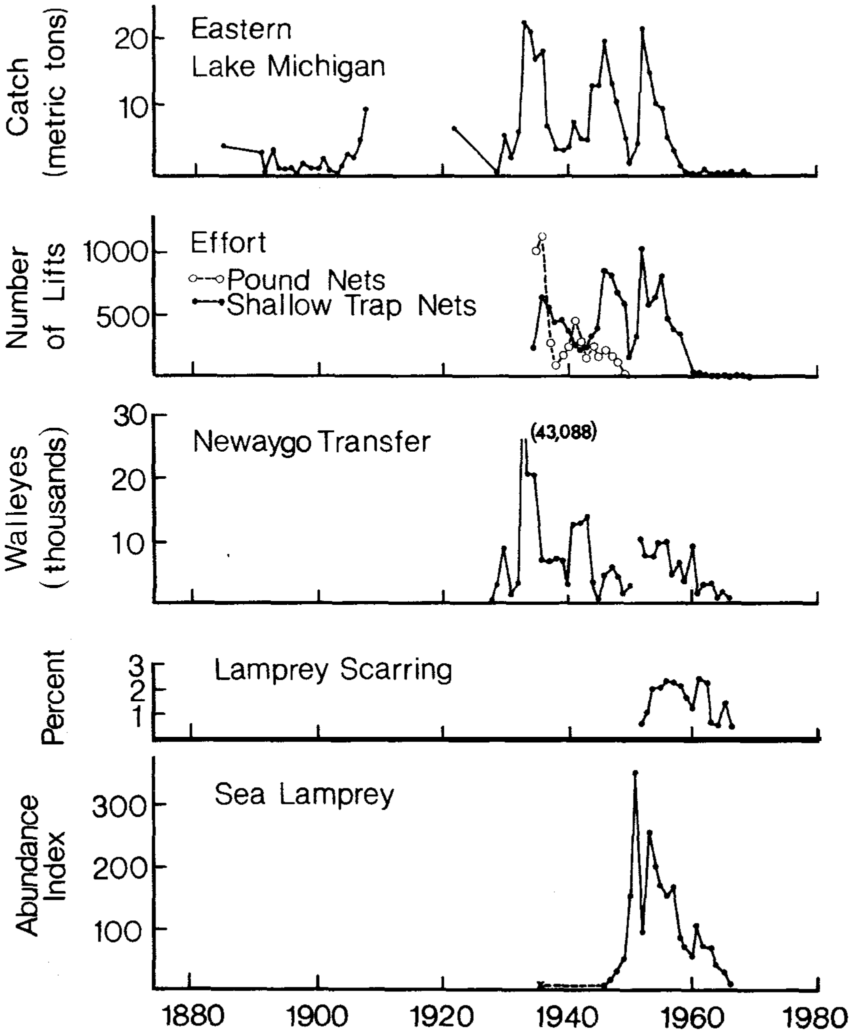

Figure 4. Lake Michigan: commercial catches of walleyes in eastern Lake Michigan (statistical districts MM-6, MM-7, and **MM-8),** 1885-1969; associated fishing effort (number of pound - net or trap-net lifts) in eastern Lake Michigan, 193569; number of walleyes caught in the Newaygo transfer, Muskegon River, Michigan, 192866; sea lamprey scarring rates for walleyes in the Muskegon River run, 195266; and abundance indices (percentages of mean number of adults counted in tributary streams) for sea lampreys, 194666 (Smith 1968).

fishery first reached a modern-day low in 1959 and was officially closed in 1970.

Additional population data were obtained during the migration to the spawning grounds below Newaygo Dam, 63 km up the river. Dip nets were used to capture adults below the dam at Newaygo and, in an operation known as the "Newaygo transfer," they were moved to five upstream impoundments to provide sport fishing. The Newaygo transfer began in 1923 and ended after the 1966 season because the run had dwindled. The records of numbers of walleyes transferred, kept from 1928 to 1966, are a rough index of the size of the spawning run (Fig. 4). However, catches were influenced by water levels (a normal high level favoring a high catch) and, after 1935, the imposition of a limit of 10,000 fish or 15 days of effort. The largest run was probably in 1933, when 43,088 walleyes were transferred. Crowe (1955) estimated runs of 114,000 walleyes in 1953 and 139,000 in 1954. In 1975 the run included only about 2,000 fish (J. C. Schneider unpublished data). Hip nets captured 6.7% of the estimated run in 1953 and 5.6% in 1954 (Crowe 1955), and these low catch rates are believed to be typical of other years.

Commercial exploitation appears to have been a minor factor in the decline of this stock for at least three reasons. First, fishing effort did not increase perceptibly-taking into account the shift from pound nets to trap nets in 1949 and the tendency for effort to vary with walleye abundance (Fig. 4). (The catch in gillnets was always small.) Second, a comparison of the estimates of the size of the spawning run in 1953 and 1954 (Crowe 1955) with the commercial catches in those years, indicate that exploitation was relatively low. Assuming, as Crowe did, that the walleyes in the commercial catch averaged 1.18 kg each, about 13,300 (15,690 kg+ 1.18) walleyes were taken in 1953 and 9,320 in 1954. Exploitation was then 12% (13,300 ÷ 114,000) in 1953 and 7% in 1954. Exploitation was even lower if the commercial catch included immature fish, or adults from other spawning populations. Third, the collapse of the offshore fishery preceded the collapse of the spawning run. A strong run occurred as late as 1960, well after the fishery had plummeted (Fig. 4). The collapse of the fishery was only partly due to the decline in the walleye stock; a decrease in fishing effort was also a contributing cause. Effort decreased because lake whitefish, the major species sought with impounding gear, reached low levels by 1957 (after a peak in the early 1950's).

The demise of the whitefish in southeastern Lake Michigan was partly due to sea lamprey predation (Wells and McLain 1973), and lampreys may also have had a limited effect on the walleye. Lamprey scarring rates recorded for walleyes in the spawning run, 1952-66, increased somewhat in the mid-1950's following the extermination of the lake trout, and decreased in the 1960's as the lamprey population was reduced (Fig. 4). However, the highest scarring rate was only 2.4%, and furthermore, the walleye population did not rebound after sea lampreys were reduced and a large lake trout population was reestablished. In addition, the size and age distribution of walleyes of the Muskegon River run in the critical years of 1958-62 (Tables 2 and 3) did not indicate unusually high mortality among large or old fish that would be expected to result from sea lamprey predation. On the contrary, as the population declined, both growth rate and the average size of fish in the population increased. For example, the mean length of age VII females, which were well represented in each run, increased from about 525 mm in 1955-57 to 544 mm in 1958 and to more than 635 mm in 1960-74.

Table 2. Length-frequency distributions (percent) and mean lengths (mm) of male and female walleyes in the Muskegon River run, 1947-75 (T = < 0.05%).e

Sex and total leneth (mm)	Year												
	1947	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1972-75[b]
Male													
280-329		-	1	T	-	-	T		1	6	3	1	1
330-380	5	5	13	12	4	1	6	-1	1	29	16	1	14
381-431	14	39	43	55	30	15	44	14	2	4	33	11	15
432482	25	47	27	22	51	36	23	43	19	3	17	31	9
483-532	37	5	13	8	13	38	17	24	43	29	6	19	
533-583	16	3	2	2	2	8	9	16	25	24	19	27	128
584-634	2	1	1	T	T	2	1	2	8	4	5	10	25
635-684	1	T	T	T	T	-	-	T	1	1	1	-	15
>684	-	-	-	-	-	-	-	-	T	-	-		1
Mean length	485	439	427	422	447	478	447	480	514	467	450	499	522
Number of fish	672	1,125	894	1,354	742	151	533	671	401	72	79	114	158
Female													
280-329					-	-	-	-	-	-	-	-	-
330-380		T	-	-	-		-	- .		-	1	-	-
381431		T	-	T	T	T	T			-	-		
432482	1	18	5	5	12	4	3	- 6	-1	-	-	- 4	- 2
483-532		54	43	30	50	35	17	40	19	5	10	23	3
533-583	30	17		38	26	50	40	22	41	34	7	20	5
584-634	35	5	45	23	9	10	32	19	20	38	48	15	26
635-684	22	3	1	2	2	1	7	10	16	17	27	25	26
>684	4	2	1	2	T	-	1	3	3	6	7	13	38
Mean length	589	518	536	553	526	528	569	553	578	602	620	595	652
Number of fish	1,059	1,110	1,332	1,276	1,125	690	696	226	848	179	84	252	86

[a]**Unpublished** data for 1947 from Eschmeyer (1947), and for 1953-75 from the Michigan Department of Natural Resources.
b Data for 1972, 1974, and 1975 combined.

Table 3. Age-frequency distribution (percent) of mature walleyes in the Muskegon River run, 1947-76.[a]

Age group	Year and (in parentheses) number of fish									
	1947 (125)	1955 (153)	1956 (101)	1957 (151)	1958 (103)	1960 (101)	1962 (163)	1972 (51)	1974 (57)	1975 (133)
			–		–			4	–	
III	-2	3	–	1	–	-	25	10	8	15
IV	8	9		3	6	-6	11	25	16	16
V	16	29	4	2	7	31	3	12	23	13
VI	31	15	8	4	15	14	5	18	5	6
VII	21	15	30	29	17	20	22	21	16	13
VIII	15	12	49	48	26	24	26	8	23	20
IX	6	11	9	11	15	5	4		5	12
X	1	5	-	1	7	–	2	2	2	5
> x	-	1	-	1	7	–	2	-	2	-

[a]Unpublished data from Eschmeyer (1947) and the Michigan Department of Natural Resources.

The decline and continued low level of the Muskegon River spawning population can be traced to poor recruitment. Some recruitment occurred every year in 1937-75 but it decreased markedly after 1955. The last large run, in 1960, was composed mostly of fish of the 1952-55 year classes (Table 3). The population peak in the early 1950's was probably supported largely by a strong year class in 1948 or 1949, since large numbers of juveniles were seen by anglers on Muskegon Lake (near the mouth of the Muskegon River) in the winter of 1950-51. The other population peaks were most likely supported by strong year classes that developed in the late 1920's and late 1930's. The strong year classes seem to have been produced in years when the adult population was low, and in about a IO-year cycle (Fig. 4). However, the strong year classes anticipated in the late 1950's (and later) did not develop.

The decline in recruitment cannot be attributed to the quality of the walleye eggs or spawning grounds. Through the early 1960's walleyes from the Muskegon River run were used as a source of eggs for state fish hatcheries. The quality of the eggs did not change over the years and the hatching rate remained near 33% (J. R. Hammond personal communication). The rate was similar in test lots of eggs hatched in 1975 (L. E. Mrozinski personal communication). Furthermore, no improvement in recruitment was detected after the removal of the Newaygo Dam in 1969 gave the adults access to an additional 19 km of apparently suitable spawning habitat.

Mounting enrichment and industrial pollution in Muskegon Lake could have affected survival of walleye fry and juveniles, but the evidence is inconclusive. Heavy metals concentrated in the lake sediments, but toxins do not appear to have been critically high in the water. The water in the Muskegon River itself is of high quality.

Important changes in the fish fauna of Muskegon Lake and eastern Lake Michigan probably affected walleyes. Rainbow smelt first appeared along the eastern shore in 1923 (Van Oosten 1937). Fluctuations in their abundance were probably similar to those of the population in Green Bay (Fig. 3). The buildup of the walleye population in the 1930's was perhaps partly due to the additional forage provided by the expanding smelt population. Smelt played no role in the decline of walleye recruitment, however, because they have always been sparse in the Muskegon Lake nursery area. (The movements of walleye fry hatched in the river were not studied; we presume on the basis of Priegel's [1970] study in the Wolf River, Wisconsin, that most fry drift downstream to Muskegon Lake immediately after hatching in May.)

The most likely cause of the decline and continued low abundance of walleyes was the invasion and continued high abundance of the alewife. Although sparse in Lake Michigan as a whole until the 1960's (Fig. 3), the alewife began swarming into the Muskegon and adjacent river systems in about 1958. The peak concentration period for alewives-late May to August-overlaps with the critical period for walleye fry and fingerlings. Competition for food may be the primary interaction, although predation could also be important.

The gizzard shad (Dorosoma cepedianum) may have contributed to the continued low abundance of walleyes. The first gizzard shad was taken near Muskegon Lake in 1953 (Miller 1957), and a significant population was probably established in the 1960's. They concentrate in the warmwater plume of a power plant located in the presumed nursery area for walleye fry.

Other inshore fishes probably adversely affected by the alewife were the white bass (Morone chrysops), emerald shiner, and yellow perch. The white bass, once common to all the river-mouth lakes along the eastern shore, also fell to extremely low population levels in the 1950's (Michigan Department of Natural Resources unpublished data). Wells and McLain (1973) reported that the emerald shiner, never common in Muskegon Lake but once abundant in other river mouths, became sparse in the early 1960's. These authors blamed the alewife for the drop in yellow perch recruitment throughout Lake Michigan, beginning in the early 1960's.

The decrease in walleyes also coincided with an increase in the incidence of lymphocystis (perhaps including skin sarcomas which produce similar warts-Walker 1958) on walleyes in the spring run, from less than 1% in 1951-54 to a peak of 13.9% in 1961. Increases in lymphocystis infections were also observed before walleye population declines in Nipigon Bay (Ryder 1961) and Saginaw Bay (Hile 1954), and Hile (1954) noted that infected fish weighed less than healthy ones of similar length. However, we doubt that lymphocystis caused these declines because Ryder (1961) gave convincing evidence, based on tag returns, that the natural mortality of infected walleyes was no higher than that of uninfected fish, and because no decline occurred in another population with a relatively high infection rate of 15.1% (Johnson 1971).

Although the alewife appears to have been the principal indirect cause for the decline of the walleye in southeastern Lake Michigan, the combined effects of other stresses cannot be ignored. Sea lamprey predation, commercial fishing, and marginal water quality have already been mentioned. Anglers claimed another 7 to 16% of the annual run (Crowe 1955; Eschmeyer and

Crowe 1955) bringing the total fishing rate up to 14 to 28%. The Newaygo transfer (6%), with its associated spawn-taking operation, must also be included.

Other Lake Michigan stocks

Information about the fish stocks along the western shore of Lake Michigan is sparse because the stocks had been greatly altered by overfishing, pollution, and dams by the time the first description of the fisheries was made (Milner 1874; Smith and Snell 1891). Goode (1884) reported that walleyes were formerly "quite plentiful" near Racine, Wisconsin, and that some were taken near Milwaukee; and Smith and Snell (1891) listed a small catch off Manitowoc in 1885. Nelson (1878) noted an unusually large run in the Calumet River at Riverdale, Illinois, in 1875.

Some walleyes taken commercially along the north shore probably came from the Manistique River system. The highest recorded catch (3.9 tons) was in 1907. The catch was less than 0.5 ton annually from 1929 through the 1940's and fell to zero in the 1950's, but recovered somewhat in the late 1960's. It is not known if a large population of walleyes (as well as lake sturgeon-Whitaker 1892) occurred there before the damming of the Manistique River and pollution from the extensive lumbering industry.

LAKE HURON

A number of important walleye stocks have existed in Lake Huron. The Saginaw Bay population, the second largest in the Great Lakes, not only supported an annual yield that occasionally exceeded 700 tons, but also contributed to fisheries 90km away in Thunder Bay, Michigan. Harvests sometimes surpassed 50 tons in Thunder Bay; in the northwestern section of the lake (Statistical District MH-1); in the North Channel, Ontario; and in Georgian Bay, Ontario. The Au Sable River area in Michigan had a relatively small population of walleyes. (The still prominent walleye fishery in southern Lake Huron is discussed in a later section on the St. Clair River and Lake St. Clair.)

Saginaw Bay

Fisheries were established in the Saginaw Bay area in the 1830's (Lanman 1839). Four types of commercial fisheries for walleyes eventually developed: a seine fishery in or near certain rivers during the spawning migration; a fyke net fishery in the Saginaw River and its tributaries during the winter; an angling fishery through the ice on the inner part of the bay; and an offshore impounding net fishery. The river fisheries declined as spawning runs into the tributaries dwindled in the early 1900's, but the offshore fishery remained productive into the 1940's.

Pound nets and trap nets were the most effective gear for the offshore fishery. The most productive fishing grounds (and also the major spawning

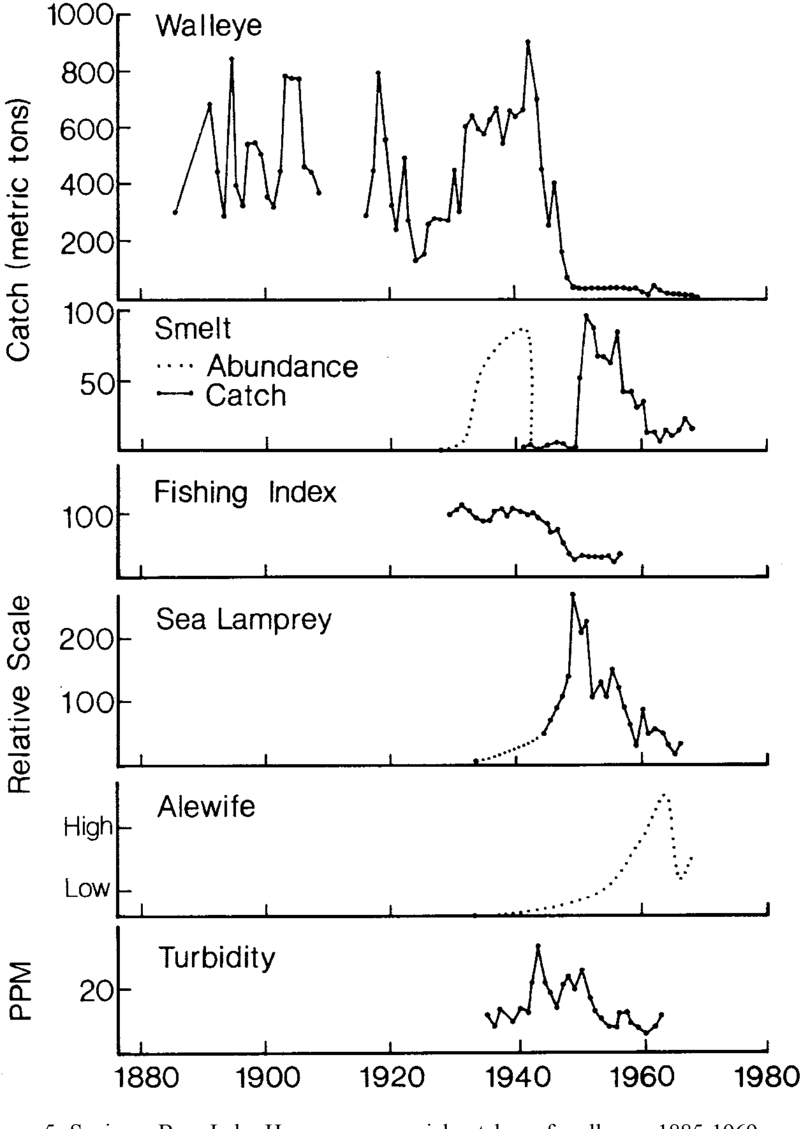

Figure 5. Saginaw Bay, Lake Huron: commercial catches of walleyes, 1885-1969; probable relative abundance (dotted line) of rainbow smelt (Van Oosten 1937, 1947), and commercial catches (solid line), 192868; commercial fishing intensity index (percentages of 1929-43 mean) for walleyes, 1929-56 (Hile and Buettner 1959); abundance indices (percentages of mean number of upstream migrating adults counted at the Ocqueoc River weir) for sea lampreys, 194466 (Smith 1968); probable relative abundance of alewives, 1933-58 (Miller 1957; Aron and Smith 1971); and turbidity (parts per million) of bay water, 1935-58 (Bay City Water Treatment Plant unpublished data).

grounds) were along the edges of the inner bay as far as 32 km from the Saginaw River mouth, and on Coreyon Reef, a shallow bar extending from the mouth of the Saginaw' River to the Charity Islands (Anonymous 1883; MSBFC 1890). Large catches were made during the spring spawning migration and smaller catches during a fall migration into the bay (Hile and Buettner 1959). Some walleyes were taken from the outer bay during the summer, especially after the introduction of the deep-water trap net (Van Oosten et al. 1946).

The commercial statistics, which are a composite of the various walleye fisheries, show that the catch from Saginaw Bay fluctuated widely, but without a long-term trend, until it reached a low point in the mid-1920's (Fig. 5). The catch then increased to a record high of 930 tons in 1942, but declined precipitously to a record low in 1949-64, and then collapsed. Commercial fishing for walleyes was prohibited after 1969.

An abrupt increase in the catches of saugers in the 1920's and 1930's was the first indication of changes in the bay. The sharp increase may have been a response to decreases in populations of walleyes and yellow perch, or to increased productivity or turbidity in the bay. Growth of yearling and older walleyes began to increase in the early 1930's and continued to do so, irrespective of fluctuations in walleye abundance (Hile 1954; Great Lakes Fishery Laboratory unpublished data). The improved growth of the walleyes was coincident with the initial buildup of the smelt population (Fig. 5), as we have reconstructed it from the observations of Van Oosten (1937), and was probably due, in part, to utilization of smelt for food.

The relatively high commercial catch of walleyes in 1932-43 resulted from a combination of three factors: high walleye abundance, improved growth, and reduced minimum size limits. The last two factors made a greater proportion of the stock available to commercial fishing. The minimum size limit was reduced from 680 g (approximately 432 mm) to 419 mm in 1933, then to 404 mm in 1939.

We argue in a later section that the combination of faster growth and lower size limit surely resulted in increased harvest of immature walleyes; however, the subsequent collapse of the stock was probably not initiated by overfishing. The size structure of the population during the 1940's was skewed toward large walleyes and does not suggest that overfishing was then taking place (Table 4). Also, fishing effort remained stable from 1929 to 1943 (Fig. 5) and catch-effort did not increase significantly when the size limits were reduced (see Appendix Table 3 of Hile and Buettner 1959). However, commercial fishing placed added stress on the population after the decline began: by 1950, catch had dropped 96% but effort only 62%. This heavy exploitation, coupled with very poor recruitment, caused the stock (and its reproductive potential) to decline rapidly.

Hile and Buettner (1959) noted the similarity in the declines of the walleye and the lake trout and postulated that sea lamprey predation was the primary cause of both. The sea lamprey population of Lake Huron did increase markedly in the 1940's, according to Smith's (1968) data on the adult run at the Ocqueoc River weir, in the northern part of the lake (Fig. 5). However, lamprey scarring of walleyes appears to have been inconsequential

Table 4. Length-frequency distributions (percent) of walleyes in the catch of Saginaw Bay (Bay Port) commercial fishermen during spawning runs, 1927-58 (T = <0.5%).[a]

Total length (mm)	Year and (in parentheses) number of fish													
	1927 (131)	1929 (604)	1943 (288)	1948 (427)	1949 (210)	1950 (262)	1951 (363)	1952 (185)	1953 (180)	1954 (119)	1955 (130)	1956 (236)	1957 (350)	1958 (385)
173-241	-	-	-	-	-	-	48	-	—	—			—	1
242-272	—	—	—	—	-	—	11	-	2	—	2	2	—	1
213-307	-	-	-	-	-	—	2	—	T	-	1	14	1	T
308-338	-	-	-	-	-	2	5	1	T		11	19	7	T
339-373	1	-	1	1	-	3	6	13	2	-8	35	8	35	5
374-406	3	T	12	1	1	14	6	39	13	2	-	6	30	15
407-439	21	18	42	3	10	11	7	24	12	7	1	14	17	27
440-472	27	14	21	4	8	7	2	10	29	8	8	14	5	22
473-503	18	22	9	7	4	4	3	7	29	13	4	6	1	17
504-533	11	13	4	13	6	3	1	2	4	23	7	3	2	7
534-564	8	13	5	30	13	7	1	-	2	22	9	4	1	1
565-597	2	8	1	30	18	10	1	1	1	12	7	3	1	1
598-632	5	5	—	1	26	15	2	-	T	-	11	1	T	1
633-665	-	4		4	8	11	2	1	1	1	2	6	T	1
666-699	3	3	1		2	6	2			1		—		—
>699	1	T	T	2	4	7	1	2	3	3	2	T	1	1

a Data for 1927, 1929, and 1943 from Hile (1954); unpublished data for other years courtesy of U.S. Fish and Wildlife Service, Great Lakes Fishery Laboratory, Ann Arbor, Michigan.

(Shetter 1949; H. J. Buettner and M. Keller personal communications), and the size structure of the population did not become truncated (Table 4), as would occur if lampreys were selectively killing the larger fish. On the contrary, larger walleyes predominated during the late 1940's, when the sea lamprey was at its peak and after the lake trout had already been virtually exterminated.

Bather, the size structure reflects poor recruitment. After the strong year classes in 1940 and 1943, only moderate-sized year classes in 1950 and 1954 (and possibly one or two others in the late 1950's) slowed the downward trend. As in northern Green Bay, the strong year class in 1943 was hatched in the spring after a massive die-off of smelt (Van Oosten 1947); on the other hand, only weak year classes were produced during the next 6 years, even though smelt remained sparse (Fig. 5).

The decline in walleye abundance was accompanied by an increase in yellow perch, suckers, and especially carp (Hile and Buettner 1959). The increase in yellow perch was greater than indicated by the catcheffort index because declining growth rate was altering the size structure of the perch population (El-Zarka 1959). The abundance of catfishes (mostly channel catfish, *Ictalurus punctatus)* increased also, but the increase began during the 1930's (Hile and Buettner 1959), possibly as an early response to changes in water, quality. The alewife first reached significant numbers in Saginaw Bay in the early 1950's (Fig. 5). We suspect that these species hindered walleye recruitment in later years, but that they were not the primary cause for the decline. An attempt to aid the remnant walleye population by planting 50 million fry in 1972 and again in 1973 failed (R. Haas personal communication).

Commercial fishermen claimed that pollution from the Saginaw River and other tributaries was responsible for the decline of the Saginaw Bay walleye fishery. This view was supported by Beeton (1969) and is supported by us. Schneider (1977) detailed the circumstantial evidence. A wide variety of pollutants could have been involved, but it seems likely that those that led to an alteration of the substrate on the walleye spawning grounds were the most important. A report on Lake Huron by the U.S. Fish and Wildlife Service (1969) supported this opinion. Measurements made by employees of the Bay City water treatment plant showed that the turbidity of the bay increased greatly during the 1940's, the period when walleye recruitment began to fail (Fig. 5).

Intensive studies in the 1950's documented the adverse effect of Saginaw River water on the benthos of the inner bay (Schneider et al. 1969). The burrowing mayfly was still present then (though perhaps less abundant than formerly), but was greatly reduced in 1955 or 1956 and became scarce by 1965. Depletion of dissolved oxygen in the bottom waters of the inner bay, serious enough to kill perch confined in trap nets, was first observed in the early 1970's during midsummer calms of 2 or 3 days (R. Manor personal communication), but undoubtedly began years earlier.

Au Sable River

The Au Sable River area of Lake Huron (Statistical District MH-3) supported a moderate-sized walleye fishery until the 1940's (Fig. 6). The walleye was usually taken incidentally with lake whitefish, lake trout, and lake herring; nevertheless, annual catches were as high as 33.5 tons in the early 1900's and may have been higher before 1885, the year when the first detailed statistics were collected (Smith and Snell 1891). In 1876, for example, a single lift of 13 tons was made off Iosco County (Otis 1948).

The fishery operating out of the Au Sable River port began in 1848 (Otis 1948), peaked at 42 boats in 1865, and then declined abruptly to 6 boats in 1871 (Milner 1874). This decline in fishing effort was probably due to depletion of the stocks of target species by fishing, coupled with the effects of pollution from sawmills. An extensive lumbering industry began there in 1865, peaked in 1890, and ended at about the turn of the century (Miller 1966; Otis 1948). In 1887 and again in 1893, sawmill wastes were blamed for ruining the whitefish fishing grounds (True 1887; MSBFC 1895).

Logging must have had a severe impact on fish populations that spawned in the river during the spring. The adults, eggs, and young would be subjected to abrasion from floating logs and suffocation from large amounts of suspended bark and eroded soil. The Michigan grayling *(Thymallus arcticus* tricolor) eventually became extinct, perhaps in part for this reason.

By the turn of the century the walleye runs must have been small, because seiners operating in the lower end of the Au Sable River and along the shore of Iosco County took only 278 kg of walleyes in 1899 (Townsend

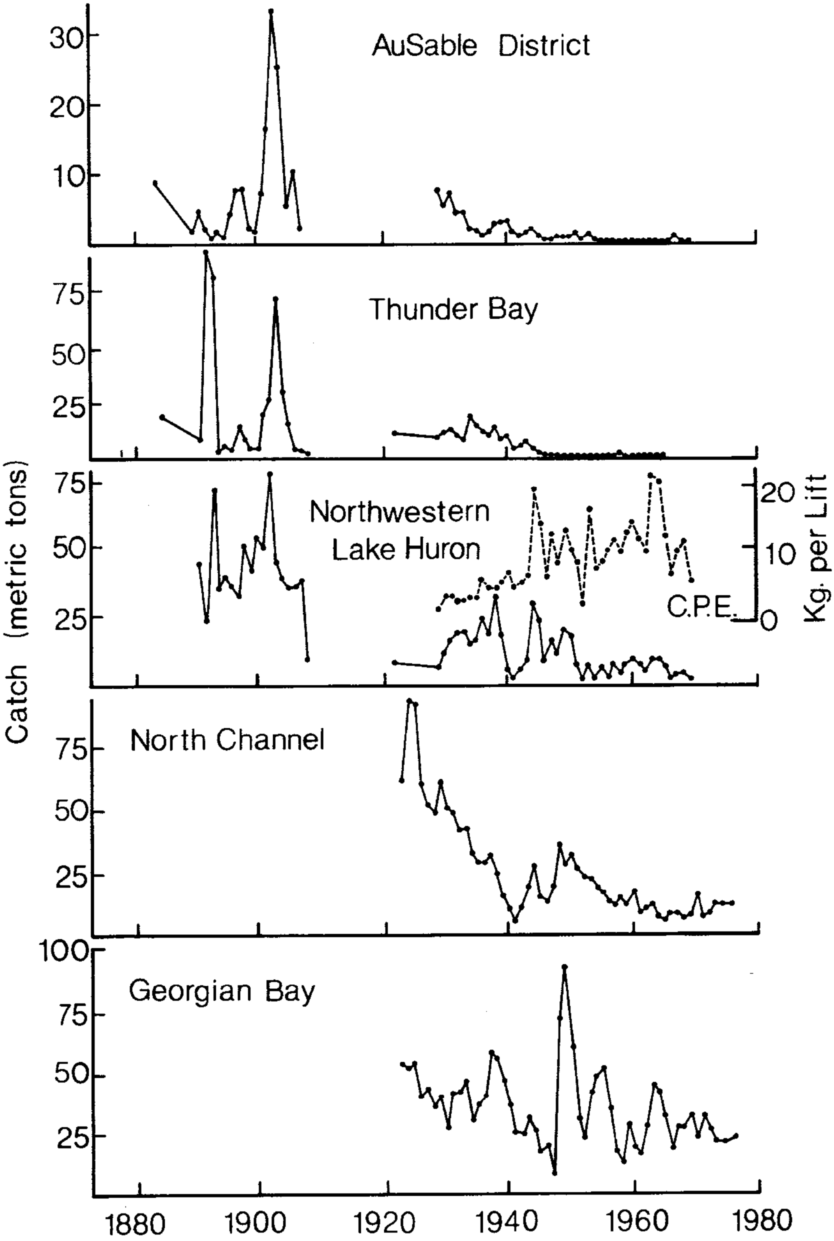

Figure 6. Commercial catches of walleyes in different regions of Lake Huron: Au Sable district (MH-3), 1891-1969; Thunder Bay (MH-2), 1891-1969; northwestern Lake Huron (MH-1), 1891-1969; North Channel, 1923-75; and Georgian Bay, 1923-75. Inset, center panel, shows the walleye catch per unit of effort (CPE) for shallow trap nets in northwestern Lake Huron, 192949.

1902) and none in 1903 (Alexander 1905). However, H. D. McKinley, an early settler, recalled that before construction of the hydroelectric dams (beginning in 191 I), lake sturgeon and many large "pickerel" (probably walleyes) ascended the river 146 km in the spring, to the mouth of the North Branch of the Au Sable River (Miller 1966). Fish transfer records in a series of biennial reports of the Michigan Department of Conservation (1934-58) suggested that the walleye run at the lower dam had become negligible by the 1930's and that only a few walleyes ascended a tributary stream to the Van Etten Dam in the 1950's.

Although the Au Sable River once supported a spawning population of walleyes, data collected since 1891 offer at least three indications that the walleyes fishery of the area depended strongly on the Saginaw Bay stock: (1) the two fisheries failed concurrently, (2) the year-to-year fluctuations of catch during 18951908 were in synchrony ($r = 0.82$) and (3) since 1929 (and possibly before) the largest catches in this district were made after-not during-the spawning season. However, the trends in the walleye catch in the two areas were dissimilar in 1929-42-waning in MH-3 and increasing in Saginaw Bay. We believe that the catch data for MH-3 in those years were not a true indicator of walleye abundance because the walleye catch was strongly influenced by major changes in the fishery for lake whitefish. A new gear, the deep trap net, which was fished at depths greater than 21 m from 1930 to 1934, not only took tremendous numbers of whitefish (Van Oosten et al. 1946) but also increased the take of walleyes by 43%. The whitefish fishery then declined. When it recovered in the late 1940's, the catch of walleyes did not recover, indicating that the walleye stock was gone.

Thunder Bay

The history of the fishery in the Thunder Bay area (Statistical District MH-2) is similar to that of the fishery in the Au Sable River district. Lake whitefish and lake trout were the principal species but substantial numbers of walleyes were taken in some years. The peak recorded catch, 95.2 tons, was in 1892, but usually the annual catch was less than 18 tons (Fig. 6).

Possibly larger catches were made between 1854, the year the pound net was introduced to the area, and 1885, the year of the first detailed records. In 1874, for example, a single lift yielded 3,000 walleyes (Goode 1884). By 1879, the fisheries, in general, were thought to be down by one-third, compared with those of 10 years before (Krumlien and True 1887). In 1885, it was noted that walleyes appeared to have replaced lake trout in the catch, that they made up 50% of the pound-net catch, and that they had already been "fished down" to an average size of 680 g (MSBFC 1887). The walleye sustained an important fishery in May and June, and especially in September (Goode 1884).

Other events that probably reduced the abundance of walleyes were degradation of the environment by the logging industry (logging began here in 1844-Powers 1912) and blockage of spawning migrations by a dam 1.6 km above the Thunder Bay River mouth (the first dam was built in 1863-Fuller 1926). It was repeatedly charged that both the whitefish and walleye had been driven away from this once-famous fishing ground by wastes from sawmill industries and woodworking factories, and by the towing of timber rafts down the Thunder Bay River (MSBFC 1888, 1895).

Unpublished data and records of observations in the files of the Michigan Department of Natural Resources suggest that a spring run of walleyes into the Thunder Bay River persisted in 1925 but not in the 1930's. (The whitefish run was reportedly gone by 1925.) Pollution of the river and bay from a paper mill, a tannery, and a cement factory probably administered the coup de grace to the spawning population. The rainbow smelt, which began to spawn in the river in 1932 (Van Oosten 1937), appeared in this area at about the time the walleye disappeared.

The summer and fall walleye fishery continued in this district, supported by recruits from the Saginaw Bay stock. Like the walleye catch in the Au Sable area, the catch in Thunder Bay was influenced by changes in fishing gear after 1928; however, it clearly collapsed with the Saginaw Bay population (cf. Figs. 5 and 6). A strong correlation (r = 0.69) between the catch in Thunder Bay and Saginaw Bay was evident as far back as 18951908. Perhaps Saginaw Bay was always the source of most of the walleyes in the district.

Northwestern Lake Huron

The fisheries of northwestern Lake Huron (Statistical District MH-1) are among the oldest in the Michigan waters of the Great Lakes (Whitaker 1892). The Straits of Mackinac and Sault Ste. Marie were important Indian fishing grounds when the voyageurs arrived in the 1600's. The trading posts established there eventually served as nuclei for the earliest commercial fisheries. Lake whitefish and lake trout were the principal species but "pickerel" (probably walleyes) were also reported at the "Soo." The highest reported walleye catch for this district was 81.2 tons in 1902 (Fig. 6). Larger catches may have been made in the 1870's or 1880's. In 1885, for example, 87.9 tons of "pike and pickerel" (walleyes and northern pike) were caught from part of this district (Smith and Snell 1891).

The largest concentration of walleyes in MH-1 was at the lower end of the St. Marys River in the vicinity of Detour. The lake whitefish was the principal species here, and at one time (1893) this area was considered to be the best fishing ground for whitefish in U.S. waters (Rathbun and Wakeham 1898). The first catch statistics (1891-1908) showed an average walleye catch of 31.3 tons, which was 80% of the walleye catch in MH-1. Rathbun and Wakeham (1898) stated that most of the walleyes were taken in pound nets set in shallow water during the summer, but that good catches were sometimes made in early May. However, a drop in catch occurred about 1909 (Fig. 6) when the St. Marys River and a principal spawning area, Lake Munuscong, were closed to commercial fishing. The relative abundance of walleyes was stable from 1909 to 1929 (Westerman and Van Oosten 1937). In 1929-69, the catch for the district as a whole fluctuated, largely because of reduced fishing effort during World War II and the general collapse of the Lake Huron fisheries. Samples at index stations indicated that the walleye stocks of MH-1 remained in good condition through 1975 (R. L. Eshenroder personal communication).

Catch-effort data (Fig. 6) indicate that the abundance of walleyes increased in northwestern Lake Huron in 1929-69, irrespective of the expansion of the sea lamprey population and other changes in the fish population (Fig. 5). The increased catch of walleyes during the 1930's corresponds to the buildup of the smelt population. The first smelt were seen in 1925, and large spawning runs were established in tributary streams by 1936 (Van Oosten 1937). The alewife did not become extremely abundant in this district, as compared with its abundance in other areas. It probably reached peak numbers here, as elsewhere in the upper Great Lakes, in the early 1960's.

Smaller walleye populations and fisheries existed in other parts of Statistical District MH-1. Catches as high as 9.3 tons were recorded in 1891-1908 from the Les Chenaux-St. Ignace area. Possibly much larger catches were made earlier (Smith and Snell 1891). These fish may have been strays from the Detour area (the catches in these two areas were weakly correlated, r = 0.494) or perhaps the Pine and Carp rivers supported small spawning populations at that time.

Along the south shore of MH-1, annual walleye catches averaged 4.8 tons but rose as high as 19.4 tons in 1891-1908. It is doubtful that the catch was much higher in preceding years because the fishery at Cheboygan developed relatively late-in the 1880's (Rathbun and Wakeham 1898). Walleye recruits were supplied by the Cheboygan River and perhaps also by the Ocqueoc River, since some walleyes were taken from Hammond Bay (at the mouth of the river) in the early years. Goode (1884) reported that 0.6 ton was taken in one pound net set for 2 nights in Hammond Bay.

The Cheboygan River walleye run has endured a long history of abuse from dams, logging, sawmills, a tannery, and a paper mill. The lower end of the river was dammed in 1847, the year after the first settlers arrived (Powers 1912). A boat lock was installed in 1868 but upstream fish migration remained hindered. In 1903 the walleye run must have been negligible, as none were reported caught in the seine and trap-net fisheries for suckers at the river mouth (Alexander 1905). A small walleye run appeared sometime later, and from 1931 to 1949 an average of 1,240 walleyes were netted below the dam each spring and transferred to upstream waters by the Michigan Department of Conservation. The transfer operation was discontinued because the benefits did not seem to justify the costs, but the run still continued in the 1970's. During the last year of the transfer (1949) it was noted by a cooperating commercial fisherman that white suckers were "pretty well marked-up" by sea lampreys, but no comment was made about scars on walleyes (Michigan Department of Natural Resources unpublished data). In this same year, the sea lamprey run in the Ocqueoc River peaked (Fig. 5). Tagging studies have shown that some of the transplanted walleyes, and some of the adult walleyes native to the lakes and rivers of the Inland Waterway, pass the Cheboygan Dam en route to Lake Huron (Eschmeyer and Crowe 1955). It is likely that many native fry and juveniles migrate downstream from a major spawning area in the Black River, a tributary of the Cheboygan River.

North Channel

Walleye stocks have been centered in three locations in the North Channel: (1) the St. Joseph Channel and St. Joseph Island area in the west, (2) centrally in the Mississagi River and Serpent River area, and (3) McGregor Bay, at the eastern end of the channel. Commercial catches of walleyes in the North Channel declined gradually from a peak of 94 tons in 1924 to 6 tons *in* 1941, recovered somewhat in the 1940's, and averaged about 10 tons in 1960-75 (Fig. 6).

Little is known about the biology of North Channel walleyes, except for the Mississagi stock, which was studied in the 1960's by Payne (1965). This population spawned in the lower Mississagi River and in a 250-m stretch of the Blind River between the channel and a dam. Additional spawning occurred on shoals along the shore of the North Channel. Most walleyes matured at age IV (males) or age V (females). Tagging studies showed that most of the Mississagi River walleyes remained within a 10-km radius of the river mouth. For ages III-VI, estimated natural mortality was 30% and fishing mortality 27%; about 74% of the fishing mortality resulted from angling. Because of the moderately high total mortality and highly variable year-class strength, virtually no fish over age VII were found, and the fishery has depended on occasional strong year classes.

The St. Joseph Channel stock was considered to be fairly stable but was not large (N. R. Payne personal communication). Commercial fishing was banned in part of the St. Joseph Channel in 1947. The decline in the McGregor Bay stock may have been caused by acid pollutants (Spangler et al. 1977). There was little or no recruitment in the 1970's, and the few remaining walleyes were large. The sport fishery was light and commercial fishing was prohibited.

Reasons for the almost steady decline in North Channel walleyes in the 1930's are not clear. It may have been partly due to the loss of a spawning stock in the Spanish River because of paper mill pollution. The decline occurred at about the time rainbow smelt became established, but the only obvious interaction of walleyes with smelt (and alewives) in the North Channel was predation by walleyes on the two forage species. The smelt was the predominant food in May and the alewife in summer (Spangler et al. 1977). The sea lamprey was not considered to be important in the mortality of North Channel walleyes.

Georgian Bay

The main walleye stocks spawn along the eastern shore of Georgian Bay in the French River, the Shawanaga River-Groundhog Island area, the Moon River, and the Severn River. Commercial catches of Georgian Bay walleyes have fluctuated around an annual mean of 36 tons for the past 50 years, with no obvious trend (Fig. 6). Some information on the ecology of Shawanaga-Groundhog and Moon River stocks is available, and studies on the French River and Severn River stocks were under way in 1975.

Shawanaga River-Groundhog Island stocks

Zimmerman (1967) who studied these adjacent stocks, showed that one population spawned in the Shawanaga River and the other on the shoals around Groundhog Island. Little mixing (4.2%) took place. Year-class strength varied considerably in both stocks. In the 1960's the Groundhog Island stock was in trouble and declining, whereas the Shawanaga River stock remained in good condition.

The difference in the two stocks was probably caused by fishing. The Shawanaga River stock, which was exploited only by anglers, had an average total mortality of 32.5% for ages IV to IX. On the other hand, the Groundhog Island stock, which was exploited commercially, suffered an average total mortality of 60.4% for the same age classes. The Shawanaga River stock included walleyes up to age XIV, whereas the Groundhog Island stock included few walleyes over age VII. Groundhog River walleyes entered the commercial fishery at age IV and were virtually eliminated after age V. Since most males matured at age IV and females at age V, there was little escapement of spawners. A better balanced age structure was restored in the 1970's as a result of successful year classes and greater restriction of commercial fishing (N. R. Payne personal communication).

Moon River stock

Walleyes of this stock, studied by Winterton (1975) in the late 1960's to early 1970's, dispersed from the Moon River spawning site north to the Sandy Island area off Parry Sound and south to the Watchers Island area. These migrations over the "commercial fishing restricted line" (a line extending along the eastern shore of Georgian Bay from the Huronia District in the south to the French River in the north, east of which commercial fishing was not allowed) exposed the walleye to commercial gillnet fisheries in both areas. Angling was centered in the Moon River Island area. Fishing mortality was light during the study period, as evidenced by an average total mortality of 34% and the presence of walleyes up to 17 years old.

As in other Georgian Bay walleye stocks, year-class strength varied considerably. A very strong year class developed in 1960 and moderately strong ones in 19.55, 1959, and 1965. Flow volume of the Moon River and (to a lesser extent) water temperature were correlated with year-class strength.

Walleyes fed mainly on rainbow smelt during the spring and on smelt and alewives during the other seasons. The sea lamprey wounding rate in 1968-72 was less than 1%, and Winterton concluded that lampreys were not an important cause of walleye mortality.

Other Georgian Bay stocks

The French River stock appeared to be stable in 1975 and was not threatened by the angling fishery (N. R. Payne personal communication). The Severn River stock was limited by the availability of suitable spawning habitat.

Although not large, the stock was viable and had a low total mortality rate. The Nottawasaga River stock was also small but stable; angling was confined mainly to the river.

SOUTHERN LAKE HURON, LAKE ST. CLAIR, AND CONNECTING WATERS

The walleye stocks of southern Lake Huron, the St. Clair River, and Lake St. Clair intermingle. Tagging studies have Indicated that many walleyes that spawned in the Thames River of Lake St. Clair later moved up the St. Clair River to southern Lake Huron, and that there was interchange between these areas and the Detroit River and western Lake Erie (Ferguson and Derksen 1971; Wolfert 1963). Descriptions of the early fisheries indicate that there were spawning migrations into the Detroit River (presumably up from Lake Erie) and into the St. Clair River (presumably down from Lake Huron).

Southern Lake Huron

The walleye stock of southern Lake Huron sustained a lake fishery that produced up to 227 tons, in addition to a fishery in the St. Clair River. The lake fishery was concentrated at the lower end of the basin, principally in Ontario waters. This stock was still strong in 1970, when commercial fishing was banned in Michigan and suspended in Ontario because of mercury contamination.

The walleye catch in the southern Lake Huron fishery seemed to be much higher in early than in later years. For example, George Clark (MSBFC 1875) recalled that at Fort Gratiot (just north of Port Huron) in 183042, he packed an average of 800-1,200 barrels (87-131 tons) of walleyes per year (in addition to those eaten and sold fresh), and that other fishermen averaged nearly the same amount. For comparison, Clark estimated that the catch from the-same area in 1874 was no more than 50 barrels. Concern was expressed in the mid-1880's (MSBFC 1887) because the whitefish run in the St. Clair River had fallen to nearly zero, and because the mesh size of seines had been reduced, with the result that one-third of the walleyes caught weighed less than 680 g each. On the Ontario side, seines were outlawed in 1894 because their use destroyed so many small walleyes (Rathbun and Wakeham 1898). Pound nets, fyke nets, and trap nets later became the principal gears of the lake fishery.

More recent trends in the walleye stock of southern Lake Huron (Fig. 7) can be deduced from explicit Michigan commercial catch records for Statistical Districts MH-5 and MH-6 for 1891-1908, 1922 (Sette 1925), and 1929-69, and Ontario records for "Lake Huron proper" (Baldwin and Saalfeld 1962) for 1923-69. (Records of catch by Ontario districts, available since 1956, show that nearly all walleyes taken from the main body of Lake Huron came from southern districts.) The walleye catch fluctuated strongly in the earliest years of record, perhaps reflecting the dependence of an intensive fishery on strong year classes. Records of harvest and catch per unit of effort indicate

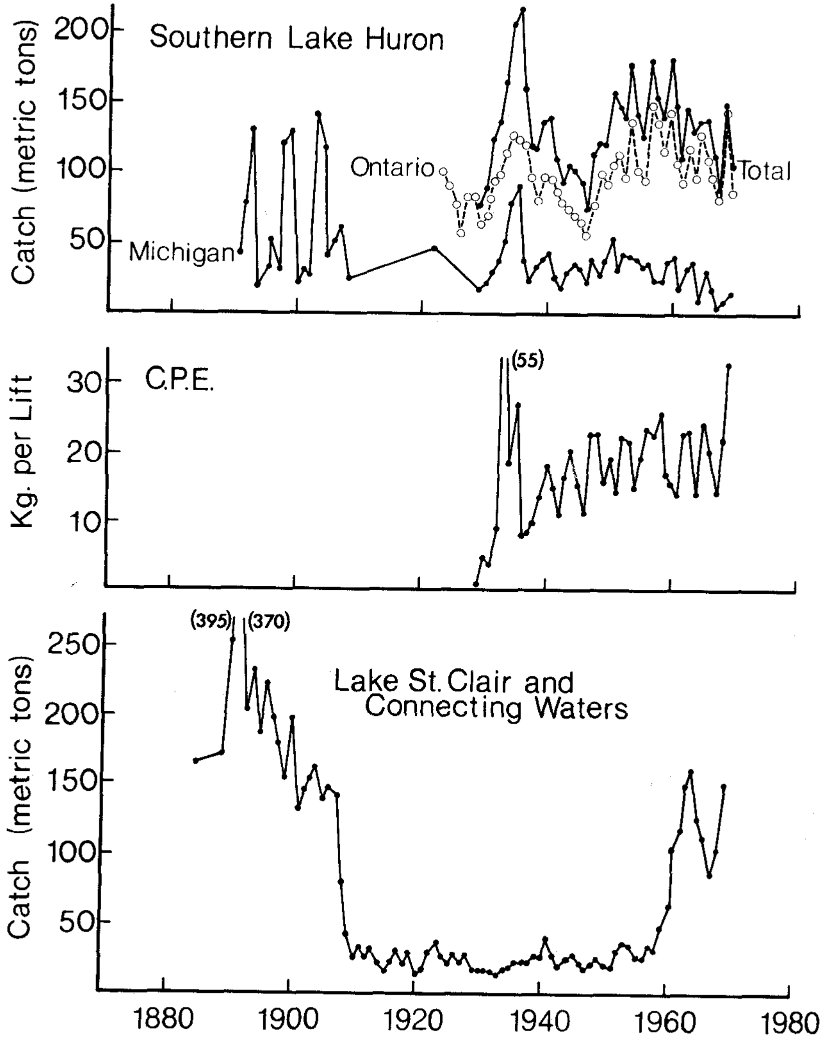

Figure 7. Commercial catches of walleyes in Michigan (statistical districts MH-5 and MH-6) and Ontario (Lake Huron proper) waters of southern Lake Huron, 1891-1969; walleye catch per unit effort (CPE) for shallow trap nets in District MH-6, 192969; and commercial catches of walleyes in Lake St. Clair and connecting waters, 1885-1969.

that the population remained relatively stable after 1905, except for a marked increase in the mid-1930's (Fig. 7). Rainbow smelt were not seen here until 1932 (Van Oosten 1937), but possibly they were numerous enough to stimulate the increase in the walleye population. The later fluctuations in abundance of smelt, alewives, and sea lampreys (Fig. 5) had no obvious effect on the southern Lake Huron stock, possibly because the St. Clair River-Lake system acts as a spawning refuge for the walleye. At Port Huron, as in Lake Michigan, alewives were most likely responsible for the loss of the extensive bait fishery for emerald shiners.

St. Clair River

The St. Clair River walleye stock has always been large and closely linked to the stock in southern Lake Huron. The commercial fishery on the U.S. side of the river operated from 1812 (Van Oosten 1938) to 1908; sport fishing remained important through 1975. According to ledgers kept by the State of Michigan, after the Lake St. Clair commercial fishery was curtailed, over 90% of the catch from "Lake St. Clair and connecting waters" came from commercial seining and angling in the St. Clair River. (The State of Michigan estimates for 1891-94 and 1906 were much lower than the suspiciously high federal *estimates* [Fig. 7] given by Baldwin and Saalfeld [19621.) We believe this fishery exploited a discrete walleye population that spawned in the St. Clair River, in addition to walleyes returning from breeding grounds in the Thames and Sydenham rivers and possibly elsewhere. Michigan and Ontario hatcheries obtained walleye eggs in the 1880's and 1890's from commercial seiners operating along the entire length of the St. Clair River. It was clearly recorded (MSBFC 1895) that the run always began in May-in contrast to the March-April run in the Thames River. Presumably spawning was delayed in the St. Clair River because the water discharged from Lake Huron was colder than that in the Thames. In the 1970's, considerable numbers of walleye fry were captured from the St. Clair River near Marysville (R. Benda personal communication), indicating that walleyes still spawn in the river channel or at the outlet of Lake Huron. Many of these fry would be swept by the current into Lake St. Clair.

Lake St. Clair

The commercial walleye fishery in Lake St. Clair, centered mainly along the east shore, exploited spawning runs in the Thames and Sydenham rivers. Large numbers of walleyes were also taken along the west shore, especially near the mouth of the Clinton River, until commercial fishing was curtailed in the early 1890's. The Ontario fishery was stable from 1910 to the 1960's (Fig. 7), when fishing effort and (seemingly) walleye abundance increased (Johnston 1977). The fishery was closed in 1970 because of mercury contamination. Johnston noted that the apparent increase in walleyes coincided with the near extinction of the sauger and cited evidence for introgressive hybridization.

Because of its shallowness and warm water, Lake St. Clair did not attract exotic species of fish as readily as did the Great Lakes proper. The sea lamprey did not linger there; however, some rainbow smelt are present and alewives have become abundant seasonally-the adult alewives in spring and the young in summer (Johnston 1977; R. Haas personal communication). Further expansion of the alewife population may adversely affect the percids.

Detroit River

The Detroit River walleye run was apparently overfished with seines by the mid-1800's-although this is difficult to comprehend in a river so swift and large. In the First Biennial Report of the Michigan State Board of Fish Commissioners, George Clark recalled (MSBFC 1875): "In the Detroit River, about a mile below Woodward Avenue, in the month of May, 1829, and a number of years after, S. Gilliot caught and packed five hundred barrels [54 tons] yearly of walleyed pickerel, besides what were used and sold fresh." The fishery dwindled to such a low level by the mid-1880's that Canadian fish culturists began collecting walleye eggs from the St. Clair River instead (Regier et al. 1969). The quality of the Detroit River water had already begun deteriorating, but not enough to affect the (later) operation of the State Hatchery at Detroit or to stop the runs of lake whitefish and lake herring. A sport fishery for walleyes persisted and is believed to have improved with the recovery of the walleye in Lake Erie during the 1970's.

LAKE ERIE

Comprehensive overviews of Lake Erie and its fish populations were recently published by Regier et al. (1969), Regier and Hartman (1973), Hartman (1973), and Leach and Nepszy (1976). Our purpose here is to briefly summarize the changes in the walleye population of Lake Erie and their possible causes. There are at least two discrete populations, a traditionally large one occupying the western and central basins and a relatively small one in the eastern basin.

Western Lake Erie

The western half of Lake Erie long sustained the best walleye fishery in the Great Lakes, if not in the world. Commercial harvest was relatively stable at about 1,000 tons from 1885 to 1939 (Baldwin and Saalfeld 1962). Walleye catches then increased almost steadily until 1954 and sharply after 1954, to nearly 7,000 tons in 1956 - the record year (Fig. 8). By 1969, however, the catch had dropped precipitously to 213 tons. The population recovered after commercial fishing was banned in 1970.

The western basin was a prime breeding and nursery area. Adults were attracted to the spawning grounds from areas as far away as the central basin to the east and Lake Huron to the north, and large numbers of young walleyes were contributed to the western basin from the Lake St. Clair region-mainly from the Thames River (Wolfert 1963; Ferguson and Derksen 1971). In Lake Erie proper, most spawning in recent decades occurred on reefs among the islands because pollution, sedimentation, and damming had destroyed or damaged spawning grounds in the Detroit, Huron, Maumee, Sandusky, Cuyahoga, and Grand rivers, and also at a number of alongshore breeding sites (Langlois 1945; Regier et al. 1969; Busch et al. 1975). The remaining spawning grounds were sometimes adequate, as evidenced by the

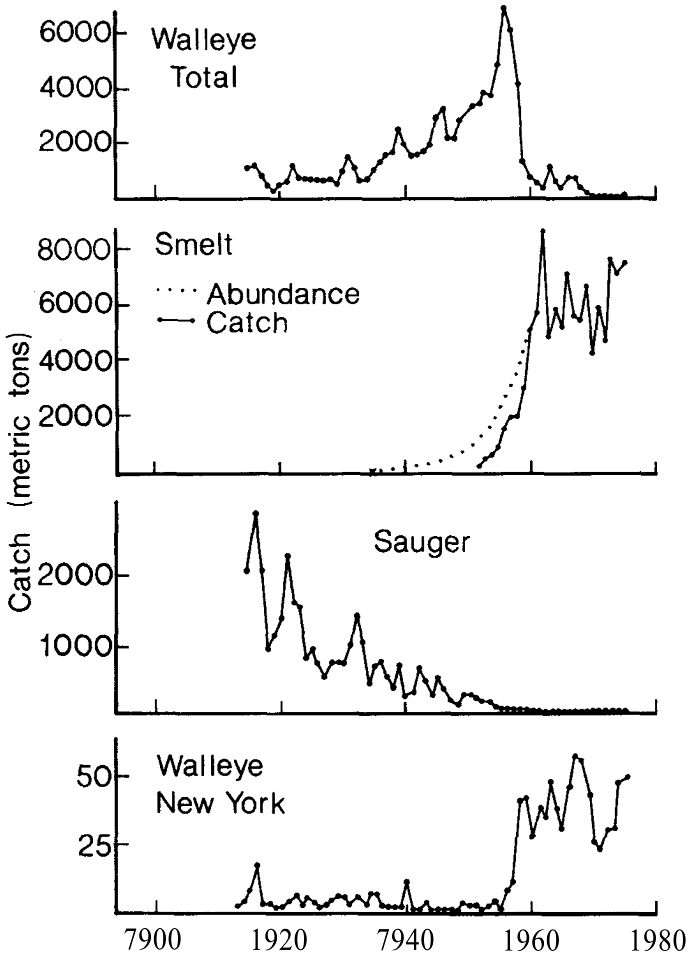

Figure 8. Lake Erie: commercial catches of walleyes lake-wide (mostly the western stock), 1915-75; catches of rainbow smelt lake-wide, 1952-75 (the probable abundance of smelt is indicated by the dotted line); catches of saugers lake-wide, 1915-75; and catches of walleyes from New York waters (eastern stock), 1913-75.

maintenance of a large walleye population even after many breeding sites were lost. However, as Regier et al. (1969) pointed out, recruitment could become more variable because a poor hatch at one spawning ground might not be offset by good hatches at other localities.

A preponderance of weak year classes after 1954, plus intensive removal of immature and adult fish by the commercial fishery, led to the decline of the walleye population (Parsons 1970, 1972; Busch et al. 1975). Indirectly, poor walleye recruitment was attributed to a combination of three principal stresses: (1) increased exploitation in Canadian waters, causing a decrease in reproductive potential; (2) the onset of periodic depletion of dissolved oxygen in the hypolimnion in the western and central basins, resulting in a loss of habitat and a valuable food organism, the burrowing mayfly; and (3) the development of a large population of rainbow smelt in the central basin (Regier et al. 1969; Hartman 1973; Leach and Nepszy 1976). We suspect that rainbow smelt exerted stress on larval walleyes by preying on them or competing with them (or both) as they drifted into the central basin from the spawning reefs in the island area, as suggested by Regier et al. (1969).

Smelt first appeared in Lake Erie in 1935 (Van Oosten 1937). They became abundant in the central and eastern basins by the early 1950's, when they appeared in the fishery (Fig. 8) and very abundant by 1960, when trawling operations were started (MacCallum and Regier 1970). Walleyes in the western part of the central basin fed on them extensively (Price 1963; Wolfert 1966).

The rise of the walleye in western Lake Erie between the late 1930's and 1956 was probably causally related to the decline of the sauger (Fig. 8) the rise of the rainbow smelt, and accelerated eutrophication. Apparently the gain in walleye production resulted from an improvement in recruitment rather than an increase in growth (Regier et al. 1969). Growth of age II and III walleyes improved in the mid-1950's, probably because of reduced intraspecific competition (resulting from intensive harvest), as proposed by Regier et al. (1969) and perhaps in part because of the abundance of smelt for forage. However, recruitment of both the walleye in the western basin and the blue pike in the central and eastern basins began to fail regularly after smelt became very abundant. The blue pike appeared to be extinct by about 1971 and the future of the walleye became uncertain because few large year classes were produced. There is no evidence that smelt affected either species, but their predation on other fish and on the food of other fish (zooplankton) has been established (Price 1963). Apparently, a complete collapse of the walleye stock was barely averted by the timely occurrence of environmental conditions favorable for recruitment and the preservation of adequate brood stock by the moratorium on commercial fishing. In the future, a relatively large brood stock should be maintained to compensate for the negative effects of smelt and marginal environmental conditions on walleye recruitment.

Since 1960, walleye recruitment has been linked to weather on the island reefs. Steadily rising temperatures and few storms during the incubation and post-hatching period have favored the formation of strong year classes (Busch et al. 1975). However, the poor recruitment of walleyes during the critical years of 1955-61 probably cannot be explained as a chance occurrence of temperatures unfavorable to the incubation of eggs and survival of fry. In four of those years (1955, 1958-60) average April-May air temperatures at Monroe, Michigan, were 2.0 to 6.7 Celsius degrees above normal.

The alewife and the sea lamprey cannot be blamed for the decline of the walleye in Lake Erie because they never reached high levels there. The population of emerald shiners, an important forage species for the walleye, remained nearly stable.

Eastern Lake Erie

A small population of walleyes is centered in the New York waters of the eastern basin. From 1915 to 1957 the New York commercial catch was only about 4 tons per year, but in 1958-75 it was 22-57 tons per year (Fig. 8). The population may have been even larger in the 1870's and 1880's, judging from the descriptions of Goode (1884) and a catch estimate of 398 tons in 1885 (Baldwin and Saalfeld 1962); however, these data may be unreliable because the identification of walleyes, blue pike, and saugers was often confused (Rathbun and Wakeham 1898). The increase in walleye catch in the 1950's seemed to represent a real increase in the available stock because total fishing effort was nearly stable (although possibly redirected from blue pike to walleyes). The increase could be a reaction to reduced competition from blue pike or to increased forage provided by rainbow smelt. Walleye recruitment was nearly stable until the 1970's despite a large population of smelt in the eastern basin, possibly because smelt did not concentrate near the walleye nursery areas along the New York shore. However, recruitment became irregular in the early 1970's, and there is concern about the future of the stock.[2]

LAKE ONTARIO

Walleyes were almost exclusively confined to the shallower, eastern end of Lake Ontario; few occurred along the narrow north and south shoals or at the west end, where the blue pike predominated. Blue pike were also common at the east end, where about one-fourth of the New York commercial catch was taken (Rathbun and Wakeham 1898). The major walleye stock was in the Bay of Quinte (Christie 1973) but a population also existed in New York waters.

Bay of Quinte

The walleye stocks spawning in the Bay of Quinte supported commercial catches as high as about 75 tons in 1922 and 1958 (Fig. 9). An important sport fishery developed in the 1950's; estimated annual catches were as high as 39,000 walleyes (Christie 1972). The population became negligible after the passage of the strong 1959 year class.

Spawning occurred in the lower reaches of tributaries and along rocky shores of the bay. Young walleyes lived in the bay for 3 years, then began an annual summer migration into the Eastern Outlet Basin of Lake Ontario. The fish migrated to the lake after spawning, and returned to the bay in early autumn. Young walleyes were continually available to the sport fishery in the bay. Adult walleyes were vulnerable to the commercial fishery in the lake during summer and in the bay during autumn. However, few adults were

2 In 1977, the fishery was highly dependent on the 1971 year class (K. Muth personal communication).

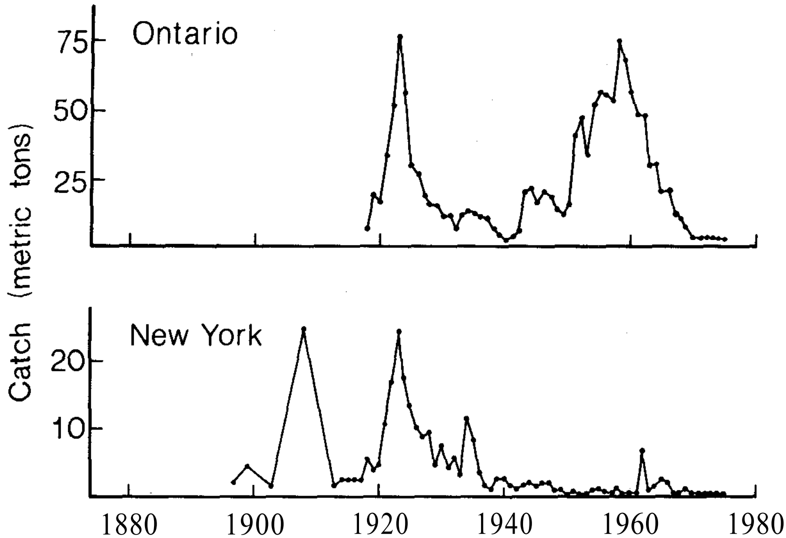

Figure 9. Lake Ontario: commercial catches of walleyes from waters of Ontario (Bay of Quinte stock), 1918-75; and New York, 1897-1975.

caught in summer and, according to Christie (1973), the total rate of exploitation was relatively low.

Year-class strength in Bay of Quinte walleyes was variable; strong year classes occurred in 1948, 1952, 1955, and 1959, and weak ones in 1949, 1950, 1951, 1956, and 1958; the 1953 year class was almost a total failure. Payne (1963) correlated year-class success with above-normal April temperatures but found that it was, also affected by May-June temperatures.

It is not clear why walleyes became more abundant in the late 1940's and 1950's. Christie (1973) pointed out that this period was characterized by higher spring water temperatures, which favored walleye production throughout the Great Lakes. He also speculated that eutrophication may have enhanced the survival of walleyes by increasing the supply of food for juveniles and by reducing other predators. He also noted that the increase in walleyes coincided with the increase in rainbow smelt. Payne (1963) found that smelt were the second-most-important food item in the walleye diet (next to alewives).

Reasons for the decline of walleye recruitment in the Bay of Quinte are not obvious. Although water quality was deteriorating in the 1960's, the proliferation of white perch *(Morone americana)* was probably a more important factor (Hurley and Christie 1977). Christie (1973) pointed out that the last successful year classes of walleyes coincided with the beginning of the rise in the white perch population in the bay. He suggested that white perch may have contributed to the decline of the major walleye stocks by preying on their eggs or larvae. The last walleye stock to decline was in the Trent River, where white perch were less abundant than elsewhere in the bay.

Moreover, walleyes were little affected in West Lake (near the Bay of Quinte), where white perch were not abundant. Christie (1973) concluded that there was a direct relation between the stress imposed on a walleye population and the degree of instability in an area invaded by white perch.

Payne (1963) found that the alewife was the major food of Bay of Quinte walleyes of age I and older. Although alewife abundance fluctuated between 1958 and 1971 (Christie 1973), this forage base was never lost to the walleye. On the other hand, the decline of this walleye stock cannot be related to excessive levels of rainbow smelt, alewives, or sea lampreys: Spawning runs of smelt into the walleye nursery areas in the Bay of Quinte ended in the late 1950's; the alewife has been abundant in the Bay of Quinte since the 1800's; and the sea lamprey may be native to the lake (Christie 1973).

New York

In U.S. waters of Lake Ontario, the ancestral walleye spawning grounds were generally described as being in the shallows and rivers of the east end (Smith 1892). More specifically, Rathbun and Wakeham (1898) mentioned Chaumont and Three Mile bays (some eggs for the state hatchery at Clayton came from Three Mile Bay), and possibly areas around the islands and at the head of the St. Lawrence River. Spawning did not occur near Black River or in Black Bay because of pollution from mills. Although it is not certain that these accounts excluded the blue pike, the location (inshore) and time (just after ice-out) of the fisheries leave little doubt that they referred to the walleye. In addition, the Cape Vincent National Fish Hatchery collected ripe walleyes in the tributary to Mud Bay (D. M. Bouton personal communication). In recent decades the only important spawning areas were in the St. Lawrence River (W. A. Pearce personal communication).

The commercial fisheries in the New York waters of Lake Ontario, developed in the early 1800's, probably peaked just after mid-century, and had been largely depleted by the time of the first fishery surveys in the 1870's. The walleye fisheries may have followed a similar trend, but the decline was not as severe. Rathbun and Wakeham (1898) and Christie (1973) suggested that the early seine fisheries greatly reduced the inshore stocks of lake whitefish, and it is likely that some highly vulnerable spawning stocks of walleyes suffered a similar fate. Seining began in 1807 and was in general use in the Oswego-Cape Vincent area from the 1830's to the 1860's (Rathbun and Wakeham 1898). Walleyes were sought immediately after ice-out-suggesting that the spawning runs were the target of the fishery. The introduction of gillnets in 1847 probably had little impact because pound nets (first used in 1850), and later (1875) trap nets, became the principal gears for walleyes.

In the late 1870's, Goode (1884) reported that the walleye was "fairly common" at Oswego and became more abundant to the east, the main fishery being near Chaumont and Sackets Harbor. The walleye fishery at Port Ontario (at the mouth of the Salmon River) had already declined, reputedly (and probably) due to overfishing with pound nets. Much of the fishing effort near Chaumont and Sackets Harbor was then directed at the alewife, whose numbers had increased enormously since 1873. The alewife had become the chief forage of walleyes, causing their average size to increase to 1.8 kg (Smith 1892). As early as 1877 it was believed that alewives had caused “pike,” black bass, and trout to increase and whitefish and “cisco” (lake herring) to decrease (True 1887).

By the 1890’s the other species had declined so much that walleyes and blue pike had become the most valuable species (Smith 1892). The walleye was then protected from commercial fishing within 1.6 km of shore-except at Chaumont Bay-and by a closed season in April. Records of the walleye catch after 1897 showed peak catches of 22 tons in 1908 and 1923, and then a gradual decline to about 1 ton per year (Fig. 9). The peak in the Bay of Quinte population in the late 1950’s was not reflected in the New York catch.

The rise of walleye stocks in eastern New York waters in the 1920’s and the later decline resemble the trends in lake whitefish, lake trout, and burbot *(Lota lota)* in the eastern basin as a whole. Christie (1973) attributed the fall of whitefish, lake trout, and burbot to a combination of overfishing with gillnets and increased predation by sea lampreys, but we doubt that the same factors were responsible for the decline of the walleye. Few walleyes were caught in gillnets, and the limited data on number of trap nets in use suggest little change in 1932 as compared with 1903. Furthermore, two to three times as much gear was fished in the 1885-1890 period. The effect of lamprey predation on this walleye population is not known; however, the catch of walleyes from the Bay of Quinte stock and the catch of blue pike from the eastern basin were seemingly unaffected-at least until well after lamprey scarring rates on whitefish began to increase in 1953 (Christie 1973).

Other fish could have reduced walleye recruitment, but the blame cannot be assigned to any one species. As noted earlier, the alewife was abundant near the spawning areas long before the New York walleye stock declined. Christie (1973) believed that the alewife may have reached peak abundance before 1900 and that no appreciable change had occurred thereafter, except for a slight dip in the 1920’s. The buildup of smelt (in the 1940’s) and of white perch and yellow perch (in the 1960’s) came relatively late (Christie 1973).

DISCUSSION

The foregoing reviews of 21 specific walleye stocks (including many spawning populations) are summarized in Table 5. The dates of major decline shown are subjective estimates for stocks that declined gradually; for other stocks more specific dates have been assigned, based either on year-class strength or on an abrupt decrease in walleye abundance. Our judgments as to the principal and contributing stresses responsible for the declines of stocks are based largely on circumstantial evidence. Although the characteristics and problems of each stock are unique, there are similarities.

Of these 21 walleye stocks, only 5 relatively stable ones persisted in the mid-1970’s: (1) in Wisconsin and Minnesota waters of Lake Superior, (2) in parts of northwestern Lake Huron, (3) in Georgian Bay, (4) in the southern

Table 5. Summary of stresses affecting walleye stocks in the Great Lakes, and approximate dates of major population declines.[a]

		Source of stress								
					Alteration of spawning habitat		Alien species			
Stock	Year of major decline[b]	Exploitation	Nutrient loading	Toxic materials	Sedimentation	Restructuring	Smelt	Sea lamprey	Alewife	White Perch
Lake Superior										
Black Bay	M 1960's	XX	–	–	–	–	P	P	–	–
Nipigon Bay	L 1950's	X?	–	XX	–	–	P	P	–	–
Michigan	G 1900's	XX?	–	–	–	–	(P)	(P)	–	–
Wisconsin	None	–	–	–	–	–	P	P	–	–
Minnesota	L 1800's	XX	(P)	(P)	(P)	–	(P)	(P)	–	–
Lake Michigan										
Green Bay										
Northern	1953	X	P	–	–	–	X	P	XX	–
Southern	G 1920's	X	X	P	XX	XX	X	(P)	(P)	–
Eastern	M 1950's	P	P	P	–	–	P	P	XX	–
Lake Huron										
Saginaw Bay	1944	X	XX	P	XX	P	(P)	P	X	–
Au Sable River	L 1800's	P	–	–	XX	X	(P)	(P)	(P)	–
Thunder Bay River	G 1920's	P	–	–	XX	X	P	(P)	(P)	–
Northwestern	None	P	–	P	P	P	P	P	P	–
North Channel	G 1930's	P	–	X	X	P	P	P	P	–
Georgian Bay	None	P	–	–	–	–	P	P	P	–
St. Clair Area										
Southern Lake Huron-St. Clair River	None	P	–	P	–	–	P	P	P	–
Lake St. Clair	None	P	P	P	P	–	P	–	P	–
Detroit River	M 1800's	XX?	P	(P)	P	P	–	–	–	–
Lake Erie										
Western	1955	XX	XX	P	X	X	X	P	P	P
Eastern	None	P	P	?	–	–	P	P	P	P
Lake Ontario										
Bay of Quinte	1960	P	X	?	P	–	P	P	P	XX
New York	G 1920's	XX?	P	?	X?	?	(P)	P	P	(P)

[a]XX = major factor in the decline; X = minor factor in the decline; P = present; (P) = not important factor in the decline but may have prevented recovery of the stock.
b M = mid; L = late; G = gradual.

Lake Huron-Lake St. Clair complex, and (5) in eastern Lake Erie. Furthermore, the future of three of these-Lake Superior, southern Lake Huron-Lake St. Clair, and eastern Lake Erie-is uncertain. All of the stable stocks seem to have been exploited rather lightly, especially over the past few decades, and perhaps were better able to withstand stresses added by the activities of new species of fish. The abundance of sea lampreys, smelt, and alewives ranged from low to high within the areas occupied by these stocks; pollution problems were relatively minor.

Among the walleye stocks that have declined, many relatively small spawning populations were damaged during the 1800's, presumably because of overfishing, destruction of spawning habitat by logging or pollution, or obstruction of spawning migrations by dams. That certain runs were able to survive this era Seems miraculous.

Five walleyes stocks declined gradually in the first 40 years of this century, as though their habitats were slowly degrading: the populations in Michigan waters of Lake Superior, southern Green Bay, the Thunder Bay River, the North Channel, and the New York waters of Lake Ontario. Causes for their declines cannot be confidently assigned; however, for southern Green Bay and Thunder Bay there was good evidence of pollution, and for Michigan waters of Lake Superior we speculate that a gradual change in environment may have occurred. Degradation of spawning grounds was a possibility in the other areas, too. Overexploitation was suspect (largely by default) in two areas, but it could not be substantiated by data on fishing effort. For the stocks in southern Green Bay, the North Channel, and the Thunder Bay River, the decline of walleyes and the rise of rainbow smelt were somewhat correlated.

The remaining discussion focuses mainly on the seven walleye stocks that fell abruptly in 1940-75, the period when the fish composition of the Great Lakes was altered drastically. By contrast, walleye populations in many inland lakes in the Great Lakes region were more or less stable in this period, suggesting that the cause or causes of instability were restricted to the Great Lakes. For each stock the decline can be traced to a series of weak year classes. Stresses came from moderate to intensive exploitation, water quality problems ranging from light to severe, and varying degrees of interaction with exotic fishes-any of which, if they played no important part in the decline, may have suppressed recovery. Only one stock (that in western Lake Erie) recovered, and it was favored by the relatively low density of smelt and alewives in the nursery areas and closure of the commercial fishery.

Listed in approximate order according to the date (in parentheses) when recruitment began to fail, these seven stocks are as follows: Saginaw Bay (1944), northern Green Bay (1953), eastern Lake Michigan (mid-1950's), western Lake Erie (1955), Nipigon Bay (late 1950's), Bay of Quinte (1960), and Black Bay (mid-1960's). The 1950's was an especially disastrous period. There is only a hint of a sequential pattern, beginning in Lake Michigan in the **mid-19503** (if it is acknowledged that pollution was the problem in Saginaw Bay) and ending in Lake Ontario and Lake Superior in the 1960's. The only exotic fish that had an analogous pattern of dispersal and is common to all areas is the rainbow smelt; however, we are confident that the smelt was not entirely responsible for the collapse of all of these stocks.

The smelt has had effects on the walleye that were both positive and (probably) negative. Catches in many commercial walleye fisheries (Saginaw Bay, eastern Lake Michigan, southern Lake Huron, western and eastern Lake Erie, Bay of Quinte, and Black Bay) increased while smelt were becoming established. The walleye population in Green Bay (and possibly in Georgian Bay) did not respond immediately, but did expand as the smelt stocks rebuilt following the heavy smelt die-off in the winter of 194243. In Saginaw Bay the smelt forage probably improved walleye growth, but in western Lake Erie growth was constant and recruitment increased. The importance of smelt in the diet of walleyes was established in western Lake Erie, Bay of Quinte, and North Channel, Georgian Bay, and northern Green Bay.

Evidence for negative effects of smelt on the walleye is purely circumstantial. Poor walleye recruitment in Green Bay, western Lake Erie, and elsewhere was associated generally with high smelt abundance and, conversely, a strong year class was produced in the upper Great Lakes when smelt abundance fell sharply in 1943. Smelt are voracious, and could have a severe impact on fish communities in which they are not native and which are being subjected to other stresses. A seemingly small effect of individual smelt on pelagic larval walleyes, or their food, would be magnified greatly at the population level because smelt attain high densities. On the other hand, both species now coexist in certain areas of the Great Lakes and in certain inland lakes. These situations should be closely examined to determine if walleye fry are buffered from the influence of smelt in some way.

The same arguments apply to the alewife. They are piscivorous at times, reportedly eating their own young and those of yellow perch (Sibley and Rimsky-Korsakoff 1931; Rhodes et al. 1974). In southern Lake Michigan, larval alewives made up as much as 76% of the food of adult alewives in September (Rhodes et al. 1974). Since alewife larvae up to 32 mm long have been found in alewife stomachs, they are obviously capable of eating walleyes, which are only 8 mm long at hatching. It is more likely that alewives compete with plankton-feeding fishes, including young walleyes. In addition, they restructure the plankton community (Wells 1970). Evidence that the alewife has had an impact on many species in the Great Lakes was presented by Smith (1970). The emerald shiner seems to have been especially sensitive and may be a useful indicator of the condition of the walleye's environment. The shiners were severely reduced in Lake Michigan, and there the superabundance of alewives was the most likely explanation for the loss of walleye recruitment. Emerald shiners were not greatly affected by alewives in western Lake Erie, and there the walleye was able to make a comeback. On the other hand we are unable to explain why alewives had no obvious effect on the two walleye populations in Lake Ontario. There, as elsewhere, the alewife became an important food for walleyes.

The sea lamprey has had a severe impact on many Great Lakes fishes but we doubt that it played a significant role in the decline of the Great Lakes walleye. Scarring and wounding rates were very low-less than 3.5% in the four populations for which we have reliable data-and it seems unlikely

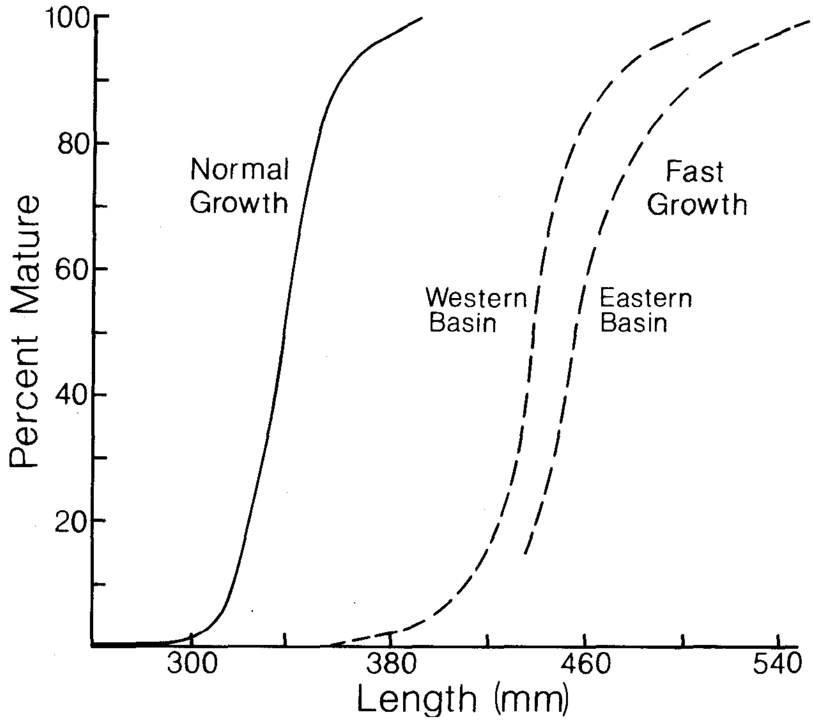

Figure 10. Relation between total length and percentage maturity for female walleyes in Lake Erie under conditions of normal growth in 1927-33 (solid line) and fast growth in 1964-66 (broken line). Data for 1927-33 from Deason (1933) and for 1964-66 from Wolfert (1969).

that many walleyes died during lamprey attacks. A laboratory study by Farmer and Beamish (1973) indicated that the walleye is low on the lamprey's preference list and that lampreys select their hosts according to size. Therefore we believe that the walleye would not have been heavily attacked until preferred species became sparse, and believe that large walleyes would have been selected over small ones. Supporting data from Muskegon River walleyes show that lamprey scarring rates increased after lake trout were eliminated from Lake Michigan (Fig. 4) and that scarring rates increased with walleye size as follows: 330-432 mm, 0.4%; 433-533 mm, 2.6%; and 534-762 mm, 5.3% (Michigan Department of Natural Resources unpublished data). Furthermore, the recent collapses in walleye populations were caused primarily by poor recruitment-not poor survival of adults. Also, in Oneida Lake, New York, the walleye and sea lamprey have coexisted for many years; the walleye population is dense, and its natural mortality rate is among the lowest reported (Forney 1967).

The white perch is the latest exotic to invade the Great Lakes and has already been implicated in the collapse of one walleye stock (Bay of Quinte). Further trouble is expected from this species if it continues to spread through the Great Lakes (Busch et al. 1977).

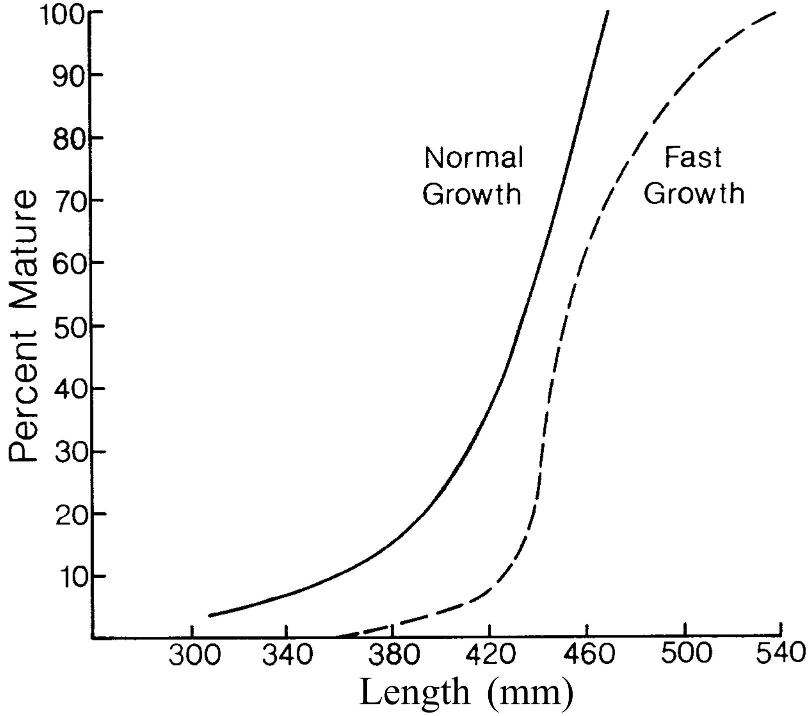

Figure 11. Relation between total length and percentage maturity for female walleyes in Saginaw Bay under conditions of normal growth in 1930 (solid line) and fast growth in 1943 (broken line). Data from Hile (1954).

The sauger, extremely scarce in the Great Lakes in 1975, was a sensitive indicator of water quality changes in western Lake Erie and Saginaw Bay. In both areas, sauger stocks plummeted before those of the walleye. In Black Bay, which has no recognized pollution problem, the sauger declined at the same time as the walleye. We wonder if the recent disappearance of saugers from Lake St. Clair, followed by the abrupt increase in walleyes, an increase in alewives, and a possible decline in emerald shiners, is a harbinger of things to come.

Exploitation played a major role in the decline of certain walleye stocks in the past several decades, when it was combined with other perturbations, such as the effects of pollution and exotic fishes. Intensive exploitation reduces the reproductive potential of a population and increases its dependency on stable recruitment. In western Lake Erie the walleye population was barely able to recover from the effects of seven successive weak year classes. Other populations (northern Green Bay, eastern shore of Lake Michigan, and Saginaw Bay) seemingly had an adequate spawning stock for a

Table 6. Commercial catch of percids from the Great Lakes in 1975 as compared with peak years, 1929-75.[a]

Lake and species	Peak: Year	Peak: Catch (metric tons)	Peak: Percent of total catch	1975: Catch (metric tons)	1975: Percent of total catch	Reduction in catch in 1975 (%)
Ontario						
Walleye	1958	76	7	2	<1	97
Blue pike	1952	294	22	0	0	100
Yellow perch	1970	455	31	299	22	34
Erie						
Walleye	1956	6,988	20	114	<1	98
Blue pike	1936	14,562	55	0	0	100
Yellow perch	1969	15,044	56	4,593	26	69
Huron						
Walleye	1942	1,071	18	126	5	88
Yellow perch	1961	767	14	368	16	52
Michigan						
Walleye	1950	612	5	2	<1	99
Yellow perch	1964	2,647	22	360	2	86
Superior						
Walleye	1966	171	4	1	1	99

a Catch data from Baldwin and Saalfeld (1962), and supplements.

decade after the decline began, yet did not produce a large year class. It is difficult to judge how large a brood stock should be protected from the fishery and for how long, because the effects of weather on recruitment tend to obscure the relation between stock and recruitment.

Indirectly, the factors that increase walleye growth, such as eutrophication or a new forage species such as the smelt or alewife, increase the impact of the fishery on walleye recruitment. As growth rate increases, a fishery takes more walleyes before they mature. This surely occurred in western Lake Erie and Saginaw Bay. In Lake Erie (Fig. 10), for example, a fishery selective for walleyes longer than 394 mm (the highest size limit actually imposed) would have taken no immature females in the period when growth was normal (as in 1927-28, when two growing seasons were required for walleyes to reach a length of 212 mm-Deason 1933); but later all the females in the catch could have been immature when (1) growth was fast (e.g., in 1960 walleyes reached a length of 368 mm in two growing seasons-Parsons 1970) and (2) exploitation was intensive. A similar shift in the size-maturity relation occurred in Saginaw Bay (Fig. 11) but there the shift was not as marked because the increase in growth was less (after two growing seasons, lengths of females were 277 mm in 1926-30 and 305 mm in 1943-Hile 19.54). Clearly, the proper management strategy in both fisheries would have been to increase the minimum size limit or reduce the harvest.

The depressed condition of the percid fisheries in each of the Great Lakes in 1975, as compared with peak years of the past, is clearly evident from the statistics in Table 6. The commercial catch of walleyes was down by 88 to 100%, yellow perch by 34 to 86% and blue pike by 100% (this species being apparently extinct). These data faithfully reflect the present low abundance of percids, except for the areas where fisheries were curtailed to protect the stocks. Conservative management policies will be needed to preserve the remaining stocks in the unstable Great Lakes environment; pollution must be reduced to restore habitats; and special management techniques will be needed to reestablish spawning populations of walleyes already lost, because the homing tendency of walleyes hinders recolonization through natural dispersal.

ACKNOWLEDGMENTS

Most of the unpublished data and observations used in this report were obtained from H. J. Buettner of the U.S. National Marine Fisheries Service, J. I. Ridgley of the Fisheries Branch of the Ontario Ministry of Natural Resources, the Great Lakes Fishery Laboratory of the U.S. Fish and Wildlife Service, and the files of the Ontario Ministry of Natural Resources and the Michigan Department of Natural Resources. We are grateful for the assistance of many colleagues, especially the following: D. M. Bouton, W. J. Christie, W. R. Crowe, P. H. Eschmeyer, C. M. Fetterolf, Jr., W. L. Hartman, G. R. Ring, W. C. Latta, S. J. Nepszy, M. H. Patriarche, N. R. Payne, W. A. Pearce, J. H. Peterson, R. A. Ryder, and S. H. Smith. The manuscript was typed by M. S. McClure and L. F. Coulter; drafting was by A. D. Sutton.

REFERENCES

ALEXANDER, A. B.
1905. Statistics of the fisheries of the Great Lakes in 1903. Pages 643-731 *in* Report of the U.S. Bureau of Fisheries 1904. Department of Commerce and Labor, Washington, D.C.

ANONYMOUS.
1883. History of Bay County Michigan, with illustrations and biographical sketches of some of its prominent men and pioneers. H. R. Page & Co., Chicago. 281 pp.

ARON, W. I., and S. H. SMITH
1971. Ship canals and aquatic ecosystems. Science 174: 13-20.

BALCH R. E.
1952. The age and growth of the yellow pikeperch *Stizostedion vitreum vitreum* (Mitchill) in the Green Bay waters of Lake Michigan. M.S. Thesis, Michigan State Univ., East Lansing. 75 pp.

BALDWIN, N. S., and R. W. SAALFELD.
1962. Commercial fish production in the Great Lakes 1867-1960. Great Lakes Fish. Comm. Tech. Rep. 3. 166 pp., and Supplement covering the years 196168. 1970.90 pp.

BASCH, R. E.
1968. Age, growth and food habits of the spottail shiner, *Notropis hudsonius* (Clinton) in Little Bay de Noc, Lake Michigan. M.S. Thesis, Michigan State Univ., East Lansing. 53 pp.

BEETON, A. M.

1969. Changes in the environment and biota of the Great Lakes. Pages 150-187 in Eutrophication: causes, consequences, correctives. Proceedings, Symposium, National Academy of Sciences, Washington, D.C.

BUSCH, W.-D. N., D. H. DAVIES, and S. J. NEPSZY.

1977. The establishment of white perch, *Morone americana* (Gmelin), in Lake Erie. J. Fish. Res. Board Can. 34:1039-1041.

BUSCH, W.-D. N., R. L. SCHOLL, and W. L. HARTMAN.

1975. Environmental factors affecting the strength of walleye (Stizostedion *vitreum* vitreum) year-classes in western Lake Erie, 1960-1970. J. Fish. Res. Board Can. 32: 1733-1743.

CHRISTIE, W. J.

1972. Lake Ontario: effects of exploitation, introductions, and eutrophication on the salmonid community. J. Fish. Res. Board Can. 29:913-929.

1973. A 'review of the changes in the fish species composition of Lake Ontario. Great Lakes Fish. Comm. Tech. Rep. 23. 65 pp.

CROWE, W. R.

1955. Numerical abundance and use of a spawning run of walleyes in the Muskegon River, Michigan. Trans. Am. Fish. Soc. 84(1954):125-136.

CROWE, W. R., E. KARVELIS, and L. S. JOERIS.

1963. The movement, heterogeneity, and rate of exploitation of walleyes in northern Green Bay, Lake Michigan, as determined by tagging. Int. Comm. N.W. Atl. Fish. Spec. Publ. **4:38-41.**

DEASON, H. J.

1933. Preliminary report on the growth rate, dominance, and maturity of the pike-perches (Stizostedion) of Lake Erie. Trans. Am. Fish. Soc. 63:348-360.

DODGE, K. E.

1968. Food habits of the yellow perch, *Perca* flavescens (Mitchill), in Little Bay de Noc, Lake Michigan. M.S. Thesis, Michigan State Univ., East Lansing. 48 pp.

DYMOND, J. R.

1944. Spread of the smelt *(Osmerus* mordax) in the Canadian waters of the Great Lakes. Can. Field-Nat. 58: 12-14.

EL-ZARKA, S. E.-D.

1959. Fluctuations in the population of yellow perch, *Perca flavescens* (Mitchill), in Saginaw Bay, Lake Huron. U.S. Fish Wildl. Serv. Fish. Bull. **59:365-415.**

ESCHMEYER, P. H.

1947. Observations on certain waters of the Muskegon River drainage, with particular reference to the annual transfer of adult yellow pikeperch. Mich. Dep. Conserv., Inst. Fish. Res. Rep. 1142. 145 pp.

ESCHMEYER, P. H., and W. R. CROWE.

1955. The movement and recovery of tagged walleyes in Michigan, 1929-1953. Mich. Dep. Conserv., Inst. Fish. Res. Misc. Publ. 8. 32 pp.

FARMER, G. J., and F. W. H. BEAMISH.

1973. Sea lamprey *(Petromyzon* marinus) predation on freshwater teleosts. J. Fish. Res. Board Can. 30:601-605.

FERGUSON, R. G., and A. J. DERKSEN.

1971. Migrations of adult and juvenile walleyes *(Stizostedion vitreum vitreum)* in southern Lake Huron, Lake St. Clair, Lake Erie, and connecting waters. J. Fish. Res. Board Can. 28: 1133-l 142.

FORNEY, J. L.

1967. Estimates of biomass and mortality rates in a walleye population. N.Y. Fish Game J. 14: 176-192.

FULLER, G. N.

1926? Historic Michigan: local histories of several Michigan counties. National Historical Association, Dayton, Ohio. 454 pp.

GERMAN, M. J.

1968. Biological survey of Nipigon Bay. Ontario Water Resources Commission Report, Toronto. 17 pp. (Mimeo.).

GOODE, G. B.
1884. Natural history of useful aquatic animals. Part III. The food fishes of the United States. Pages 163682 in G. B. Goode, ed. The fisheries and fishery industries of the United States, Section I-Text. U.S. Comm. Fish Fish. U.S. Government Printing Office, Washington, D.C. 895 pp.
HARTMAN, W. L.
1973. Effects of exploitation, environmental changes, and new species on the fish habitats and resources of Lake Erie. Great Lakes Fish. Comm. Tech. Rep. 22. 43 PP.
HILE, R.
1954; Fluctuations in growth and year-class strength of the walleye in Saginaw Bay. U.S. Fish Wildl. Serv. Fish. Bull. 56:7-59.
HILE, R., and H. J. BUETTNER.
1959. Fluctuations in the commercial fisheries of Saginaw Bay, 1885-1956. U.S. Fish Wildl. Serv. Res. Rep. 51. 38 pp.
HILE. R.. G. F. LUNGER. and H. J. BUETTNER.
1953.' Fluctuations in the fisheries of State of Michigan waters of Green Bay. U.S. Fish Wildl. Serv. Fish. Bull. 54: l-34.
HOWMILLER, R. P., and A. M. BEETON.
1970. The oligochaete fauna of Green Bay, Lake Michigan. Proc. Conf. Great Lakes Res. (Int Assoc. Great Lakes Res.) 13:15-46.
HURLEY, D. A., and W. J. CHRISTIE.
1977. Depreciation of the warmwater fish community in the Bay of Quinte, Lake Ontario. J. Fish. Res. Board Can. 34:1849-1860.
JOHNSON, F. H.
1971. Numerical abundance, sex ratios, and size-age composition of the walleye spawning run at Little Cut Foot Sioux Lake, Minnesota 1942-1969, with data on fecundity and incidence of lymphocystis. Mimi. Dep. Nat. Resour. Fish. Invest. Rep. 315. 9 PP.
JOHNSTON, D. A.
1977. Population dynamics of walleye *(Stizostedion vitreum vitreum)* and yellow perch *(Perca flavescens)* in Lake St. Clair, especially during 1970-76. J. Fish. Res. Board Can. 34: 1869-1877.
KELSO, J. R. M.
1977. Density, distribution, and movement of Nipigon Bay fishes in relation to a pulp and paper mill effluent. J. Fish. Res. Board Can. 34:879-885.
KRUMLIEN, L., and F. W. TRUE.
1887. The fishing grounds of the Great Lakes. Pages 117-132 in The fishing grounds of North America. The fish and fisheries of the United States, Section III. U.S. Government Printing Office, Washington, D.C.
LANGLOIS, T. H.
1945. Water, fishes, and cropland management. Trans. N. Am. Wildl. Conf. 10: 190-196.
LANMAN, J.
1839. History of Michigan: civil and topographical in a compendius form with a view of surrounding lakes. E. French, New York. 397 pp.
LAWRIE, A. H., and J. F. RAHRER
1973. Lake Superior: a case history of the lake and its fisheries. Great Lakes Fish. Comm. Tech. Rep. 19. 69 pp.
LEACH, J. H., and S. J. NEPSZY.
1976. The fish community in Lake Erie. J. Fish. Res. Board Can. 33:622-638.
MacCALLUM, W. R., and H. A. REGIER.
1970. Distribution of smelt, *Osmerus mordax,* and the smelt fishery in Lake Erie in the early 1960's. J. Fish. Res. Board Can. 27:1823-1846.
MICHIGAN DEPARTMENT OF CONSERVATION.
1934-58. Biennial reports of the Department of Conservation, 7 to 18, for the fiscal years 1933-34 to 1957-58. Michigan Department of Conservation, Lansing.

MICHIGAN STATE BOARD OF FISH COMMISSIONERS.
1875. First biennial report, 1873-4. 46 pp.
1887. Seventh biennial report, 1884-1886. 80 pp.
1888. Eighth biennial report, 1886-1888. 66 pp.
1890. Ninth biennial report, 1888-1890. 92 pp.
1895. Eleventh biennial report, 1892-1894. 60 pp.
MILLER, H. L.
1966. The old Au Sable. William B. Eerdmans Publishing Co., Grand Rapids, Michigan. 180 pp.
MILLER, R. R.
1957. Origin and dispersal of *the* alewife, *Alosa pseudoharengus,* and the gizzard shad, *Dorosoma cepedianum,* in the Great Lakes. Trans. Am. Fish. Soc. 86(1956):97-111.
MILNER, J. W.
1874. Report on the fisheries of the Great Lakes; the result of inquiries prosecuted in 1871 and 1872. Pages 1-78 *in* U.S. Commission of Fisheries Report for 1872-73 (Part 2).
NELSON, E. W.
1878. Fisheries of Chicago and vicinity. Pages 783-800 *in* U.S. Commission of Fish and Fisheries Report for 1875-76.
OTIS, E. M.
1948. Their yesterdays, Au Sable and Oscoda, 1848-1948. (Published by author). 62 PP.
PARSONS, J. W.
1970. Walleye fishery of Lake Erie in 194362 with emphasis on contributions of the 1942-61 year-classes. J. Fish. Res. Board Can. 27:1475-1489.
1972. Life history and production of walleyes of the 1959 year-class in western Lake Erie, 195962. Trans. Am. Fish. Soc. 101:655-661.
PAYNE, N. R.
1963. The life history of *the* yellow *walleye, Stizostedion, vitreum* (Mitchill) in the Bay of Quinte. M.A. Thesis, Univ. Toronto. 40 pp.
1965. A progress report on Mississagi River walleye study, Sault Ste. Marie District. Ontario Department of Lands and Forests, Toronto. 29 pp. (Mimeo.).
POWERS, P. F.
1912. A history of northern Michigan and its people. Lewis Publishing Co., Chicago. 1355 pp.
PRICE, J. W.
1963. A study of the food habits of some Lake Erie fishes. Bull. Ohio State Biol. Surv., New Ser. 2:1-89.
PRIEGEL, G. R.
1970. Reproduction and early life history of the walleye in the Lake Winnebago region. Wis. Dep. Nat. Resour. Tech. Bull. 45, 105 pp.
PYCHA, R. L.
1961. Recent changes in the walleye fishery of northern Green Bay and history of the 1943 year class. Trans. Am. Fish. Soc. 90:475-488.
RATHBUN, R., and W. WAKEHAM.
1898. Report of the joint commission relative to the preservation of the fisheries in waters contiguous to Canada and the United States. House Exec. Doc. No. 315, 54th Congress, 2nd session. 1897. Washington, D.C. 178 pp.
REGIER, H. A., V. C. APPLEGATE, and R. A. RYDER.
1969. The ecology and management of the walleye in western Lake Erie. Great Lakes Fish. Comm. Tech. Rep. 15. 101 pp.
REGIER, H. A., and W. L. HARTMAN.
1973. Lake Erie's fish community: 150 years of cultural stresses. Science 180:1248-1255.
RHODES, R. J., D. A. WEBB, and T. S. McCOMISH.
1974. Cannibalism by the adult alewife *(Alosa pseudoharengus)* in southern Lake

Michigan. Proc. Conf. Great Lakes Res. (Int. Assoc. Great Lakes Res.) 17:593-595.
RICKER, W. E.
1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bull. 191. 382 pp.
RYDER, R. A.
1961. Lymphocystis as a mortality factor in a walleye population. Prog. Fish-Cult. 23: 183-186.
1968. Dynamics and exploitation of mature *walleyes, Stizostedion vitreum vitreum,* in the Nipigon Bay region of Lake Superior. J. Fish. Res. Board Can. 25: 1347-1376.
SCHNEBERGER, E.
1937. The biological and economic importance of the smelt in Green Bay. Trans. Am. Fish. Soc. 66(1936):139-142.
SCHNEIDER, J. C.
1977. History of the walleye fisheries of Saginaw Bay, Lake Huron. Mich. Dep. Nat. Resour., Fish. Res. Rep. 1850. 16 pp.
SCHNEIDER, J. C., F. F. HOOPER, and A. M. BEETON.
1969. The distribution and abundance of benthic fauna in Saginaw Bay, Lake Huron. Proc. Conf. Great Lakes Res. (Int. Assoc. Great Lakes Res.) 12:80-90.
SCHNEIDER, J. C., and J. H. LEACH.
1977. Walleye *(Stizostedion vitreum vitreum)* fluctuations in the Great Lakes and possible causes, 1800-1975. J. Fish. Res. Board Can. 34:1878-1889.
SETTE, 0. E.
1925. Fishing industries of the United States, 1923. Pages 141-359 *in* Report of the U.S. Commission of Fisheries for 1924 (Appendix IV).
SHETTER, D. S.
1949. A brief history of the sea lamprey problem in Michigan waters. Trans. Am. Fish. Soc. 76 (1946):160-176.
SIBLEY, C. K., and V. RIMSKY-KORSAKOFF.
1931. Food of certain fishes in the watershed. Pages 109-120 *in* A biological survey of the St. Lawrence watershed. Suppl. 20th Annu. Rep., N.Y. Conserv. Dep. (1930).
SMITH, H. M.
1892. Report on the’ fisheries of Lake Ontario. Pages 177-215 *in* U.S. Fish. Commission Bull. 10 (1890).
SMITH, H. M., and M. P. SNELL.
1891. Review of the fisheries of the Great Lakes in 1885. Pages 3-333 in U.S. Fish Commission Annual Report for 1887.
SMITH, S. H.
1968. Species succession and fishery exploitation in the Great Lakes. J. Fish. Res. Board Can. 25:667-693.
1970. Species interactions of the alewife in the Great Lakes. Trans. Am. Fish. Soc. 99:754-765.
SMITH, S. H., H. J. BUETTNER, and R. HILE.
1961. Fishery statistical districts of the Great Lakes. Great Lakes Fish. Comm. Tech. Rep. 2. 24 pp.
SPANGLER, G. R., N. R. PAYNE, and G. K. WINTERTON.
1977. Percids in the Canadian waters of Lake Huron. J. Fish. Res. Board Can. 34: 1839-1848.
TOTH, R. J.
1959. Studies on the life history of the yellow perch, *Perca* flavescens (Mitchill) in Big Bay de Noc, Lake Michigan. M.S. Thesis, Michigan State Univ., East Lansing. 86 pp.
TOWNSEND, C. H.
1902. Statistics of the fisheries of the Great Lakes. Pages 575657 *in* U.S. Commission of Fish and Fisheries Report of the Commissioner for the year ending June 30, 1901.

TRUE, F. W.
1887. The fisheries of the Great Lakes. Pages 631673 *in G.* B. Goode, ed. The fisheries and fishery industries of the United States, Section II, Part 17. U.S. Comm. Fish Fish., U.S. Government Printing Office, Washington, D.C.
U.S. FISH AND WILDLIFE SERVICE.
1969. Fish and Wildlife as related to water quality of the Lake Huron basin: a special report on fish and wildlife resources, 1969. Report of the Regional Directors, Bureau of Commercial Fisheries and Bureau of Sport Fisheries and Wildlife. 134 pp.
VAN OOSTEN, J.
1937. The dispersal of smelt, *Osmerus mordax* (Mitchill), in the Great Lakes region. Trans. Am. Fish. Soc. 66(1936):160-171.
1938. Michigan's commercial fisheries of the Great Lakes. Mich. Hist. Mag. 22(1):107-145.
1947. Mortality of smelt, *Osmerus mordax* (Mitchill), in Lakes Huron and Michigan during the fall and winter of 1942-1943. Trans. Am. Fish. Soc. 74(1944):310-337.
VAN OOSTEN, J., R. HILE, and F. JOBES.
1946. The whitefish fishery of lakes Huron and Michigan with special reference to the deep-trap net fishery. U.S. Fish Wildl. Serv. Fish. Bull. 50:297-394.
WAGNER, W. C.
1972. Utilization of alewives by inshore piscivorous fishes in Lake Michigan. Trans. Am. Fish. Soc. 101:55-63.
WALKER, R.
1958. Lymphocystis warts and skin tumors of walleyed pike. Dep. Biol., Rensselaer Polytechnic Inst., Rensselaer Rev. Graduate Stud. No. 14. 5 pp.
WELLS, L.
1970. Effects of alewife predation on zooplankton populations in Lake Michigan. Limnol. Oceanogr. 15:556-565.
WELLS, L., and A. L. MCLAIN.
1973. Lake Michigan: man's effects on native fish stocks and other biota. Great Lakes Fish. Comm. Tech. Rep. 20. 55 pp.
WESTERMAN, F. A., and J. VAN OOSTEN.
1937. Report to the Michigan State Senate on the fisheries of Potagannissing Bay, Michigan. Michigan Department of Conservation, Lansing. 82 pp.
WHITAKER. H.
1892. Early history of the fisheries on the Great Lakes. Trans. Am. Fish. Soc. 21:163-179.
WINTERTON, G. K.
1975. Structure and movement of a spawning stock of walleye, *Stizostedion vitreum vitreum* (Mitchill), in Georgian Bay. M.S. Thesis, Univ. Guelph, Ontario. 95 pp.
WOLFERT, D. R.
1963. The movements of walleyes tagged as yearlings in Lake Erie. Trans. Am. Fish. Soc. 92:414-420.
1966. Food of young-of-the-year walleyes in Lake Erie. U.S. Fish Wildl. Serv. Fish. Bull. 65:489-494.
1969. Maturity and fecundity of walleyes from the eastern and western basins of Lake Erie. J. Fish. Res. Board Can. 26:1877-1888.
ZIMMERMAN, J. F.
1967. Georgian Bay walleye project progress report 1967 and six year summary report of walleye trapping and tagging on Georgian Bay, 1962-1967. Ontario Department of Lands and Forests, Toronto. 77 pp. (Mimeo.).

GREAT LAKES FISHERY COMMISSION

TECHNICAL REPORT SERIES

No. 1. Use of 3-triflutormethyl-4-nitrophenol as a selective sea lamprey larvicide, by *Vernon C. Applegate, John H. Howell, James W. Moffett, B. G. H. Johnson,* and *Manning A. Smith.* May 1961. 35 pp.

No. 2. Fishery statistical districts of *the* Great Lakes, *by Stanford H. Smith, Howard J. Buettner,* and *Ralph Hile.* September 1961. 24 pp.

No. 3. Commercial fish production in the Great Lakes 1867-1960, by *Norman S. Baldwin* and *Robert W. Saalfeld.* July 1962. 166 pp.
Supplement covering the years 1961-68. 1970. 90 pp.

No. 4. Estimation of the brook and sea lamprey ammocete populations of three streams, *by Bernard R. Smith* and *Alberton L. McLain.* September 1962. Pages 1-18.
A photoelectric amplifier as a dye detector, *by Wesley J. Ebel.* September 1962. Pages 19-26.

No. 5. Collection and analysis of commercial fishery statistics in the Great Lakes, *by Ralph Hile.* December 1962. 31 pp.

No. 6. Limnological *survey* of Lake Erie 1959 and 1960, *by Alfred M. Beeton.* November 1963. 32 pp.

No. 7. The use of alkalinity and conductivity measurements to estimate concentrations of 3-trifluormethyl-4-nitrophenol required for treating lamprey streams, *by Richard K. Kanayama.* November 1963. 10 pp.

No. 8. Synergism of 5,2'-dichloro-4'-nitro-salicylanilide and 3-trifluormethyl-4-nitrophenol in a selective lamprey larvicide, *by John H. Howell, Everett L. King, Jr., Allen J. Smith,* and *Lee H. Hanson.* May 1964. 21 pp.

No. 9. Detection and measurement of organic lampricide residues, *by Stacy L. Daniels, Lloyd L. Kempe, Thomas J. Billy,* and *Alfred M. Beeton.* 1965. 18 pp.

No. 10. Experimental control of sea lampreys with electricity on the south shore of Lake Superior, 1953-60, *by Alberton L. McLain, Bernard R. Smith,* and *Harry H. Moore.* 1965. 48 pp.

No. 11. The relation between molecular structure and biological activity among mono-nitrophenols containing halogens, *by Vernon C. Applegate, B. G. H. Johnson,* and *Manning A. Smith.* December 1966. Pages 1-19.
Substituted nitrosalicylanilides: A new class of selectively toxic sea lamprey larvicides, *by Roland J. Starkey* and *John H. Howell,* December 1966. Pages 21-29.

No. 12. Physical limnology of Saginaw Bay, Lake Huron, *by Alfred M. Beeton, Stanford H. Smith,* and *Frank F. Hooper.* September 1967. 56 pp.

No. 13. Population characteristics and physical condition of alewives, *Alosa pseudoharengus,* in a massive dieoff in Lake Michigan, 1967, *by Edward H. Brown, Jr.* December 1968. 13 pp.

No. 14. Limnological survey of Lake Ontario, 1964 (five papers), *by Herbert E. Allen, Jerry F. Reinwand, Roann E. Ogawa, Jarl K. Hiltunen,* and *LaRue Wells.* April 1969. 59 pp.

No. 15. The ecology and management of the walleye in western Lake Erie, by Henry *A. Regier, Vernon C. Applegate* and *Richard A. Ryder,* in collaboration with *Jerry V. Manz, Robert G. Ferguson, Harry D. Van Meter,* and *David R. Wolfert.* May 1969. 101 pp.

No. 16. Biology of *larval* sea lampreys *[Petromyzon marinus)* of the 1960 year class, isolated *in the* Big *Garlic River, Michigan,* 196065, *by Patrick J. Manion* and *Alberton L. McLain.* October 1971. 35 pp.

No. 17. New parasite records for Lake Erie fish, *by Alex* O. ***Dechtiar.*** April 1972. 20 pp.

No. 18. Microbial degradation of the lamprey larvicide 3-trifluoromethyl-4-nitrophenol in sediment-water systems, *by Lloyd L. Kempe.* January 1973. 16 pp.

No. 19. Lake Superior-A case history of the lake and its fisheries, *by A. H. Lawrie* and *Jerold F. Rahrer.* January 1973. 69 pp.

No. 20. Lake Michigan-Man's effects on native fish stocks and other biota, *by LaRue Wells* and *Alberton L. McLain.* January 1973. 55 pp.

No. 21. Lake Huron-The ecology of the fish community and man's effects on it, *by A. H. Berst* and *G. R. Spangler. January* 1973. 41 pp.

No. 22. Effects of exploitation, environmental changes, and new species on the fish habitats and resources of Lake Erie, *by W. L. Hartman.* April 1973. 43 pp.

No. 23. A review of the changes in the fish species composition of Lake Ontario, *by W. J. Christie.* January 1973. 65 pp.

No. 24. Lake Opeongo-The ecology of the fish community and of man's effects on it, *by N. V. Martin* and *F. E. J. Fry.* March 1973. 34 pp.

No. 25. Some impacts of man on Kootenay Lake and its salmonoids, *by T. G. Northcote.* April 1973. 45 pp.

No. 26. Control of the sea lamprey *(Petromyzon* marinus) in Lake Superior, 1953-70, *by Bernard R. Smith, J. James Tibbles,* and *B. G. H. Johnson.* March 1974. 60 pp.

No. 27. Movement and recapture of parasitic-phase sea lampreys *(Petromyzon marinus)* tagged in the St. Marys River and Lakes Huron and Michigan, 196367, *by Harry H. Moore, Frederick H. Dahl,* and *Aarne K. Lamsa.* July 1974. 19 pp.

No. 28. Changes in the lake trout population of southern Lake Superior in relation to the fishery, the sea lamprey, and stocking, 1950-70, *by Richard L.* ***Pycha*** and *George R. King.* July 1975. 34 pp.

No. 29. Chemosterilization of the sea lamprey *(Petromyzon marinus), by Lee H. Hanson* and *Patrick J. Manion.* July 1978. 15 pp.

No. 30. Biology of larval and metamorphosing *sea* lampreys *(Petromyzon marinus)* of the 1960 year class in the Big Garlic River, Michigan, Part *II,* 1966-72, *by Patrick J. Manion* and *Bernard R. Smith,* October 1978. 35 pp.