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The University of Michigan, Ph.D., 1975
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THE HISTORY AND IMPORTANCE OF THE RAINBOW SMELT, *OSMERUS MORDAX* (MITCHILL), IN THE LAKE MICHIGAN FISH COMMUNITY, WITH SPECIAL REFERENCE TO ITS MANAGEMENT AS A RESOURCE

by
Kitjar Jaiyen

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Fisheries)
in The University of Michigan
1975

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Professor Richard L. Patterson, Chairman
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Assistant Professor Alvin L. Jensen
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INTRODUCTION

The rainbow smelt has been the center of controversy for its possible adverse effects on the native fishes since it was introduced into the upper Great Lakes basin in the early 1900's primarily as an additional food source for the introduced Atlantic (landlocked or Sebago) salmon (Salmo salar). The decline of some native fish species such as the lake herring (Coregonus artedi) during the 1930's and the lake whitefish (Coregonus clupeaformis) in the early 1950's which coincided with the increase of the smelt, and the striking increase of these two species after the catastrophic smelt die-off in 1942-43 have suggested possible adverse effects of the smelt. However, the smelt has been increasingly used as food by piscivorous fishes, including the highly valued native and introduced trouts and, subsequently by recently introduced salmons in Lake Michigan and other lakes in the Great Lakes basin. Additionally, it has also been fairly intensively harvested by both commercial and sport fishermen. As important and controversial as it has been no suggestion for management of this fish has been made, either for the benefits of the piscivorous fishes and fishermen or for some species of fishes suspected to be affected by the smelt, until recently by Keller et al. (1974). However, in order to make the decision on whether

or not a fish species should be managed there are several criteria to be considered. These criteria include the importances of that fish--economically, biologically, and/or taxonomically--, its population condition, and the feasibility in exercising any measures in management. This study will attempt to establish a framework for decision-making in management and from all the available information to determine the possibility and direction of management of this species.

The objectives of this study are:

1) to summarize the history of introduction, establishment, dispersal, and fisheries of the rainbow smelt in Lake Michigan;
2) to assess the present status of the smelt population in Lake Michigan;
3) to determine the ecological roles, as predator, competitor, and/or prey, that the smelt is playing in the Lake Michigan fish community, and to assess the relative importance of these roles in the fish community;
4) to establish a framework for decision-making as to whether or not the fish species should be managed; and
5) to determine the possibility and direction of management of this species from the available information.

The rainbow smelt is one of less than two dozen species in the Family Osmeridae, and which are mostly marine, and all of which have an Arctic or North Temperate distribution (Hubbs and Lagler, 1958). The smelts are relatives of the salmonids--trouts and salmons, chubs, lake herring and whitefish (Scott and Crossman, 1973). In eastern North America the smelt is both marine and freshwater in the Atlantic coastal drainage from about New Jersey to Labrador; the natural landlocked populations are found in Nova Scotia, New Brunswick, Quebec, Ontario, Maine, New Hampshire, Vermont, New York, Massachusetts, and by introduction, in the upper Great Lakes and their tributary waters (Van Oosten, 1940; Hubbs and Lagler, op cit; and Scott and Crossman, op cit).

Much information from previous works on the rainbow smelt in the upper Great Lakes basin was used in this study, especially on the history of introduction, establishment, dispersal, controversy of its effects, and fisheries. Among the works included were those of Creaser (1926; 1929a; 1929b; 1932), Schneberger (1935a; 1935b; 1936; 1937), Van Oosten (1937; 1940; 1947), Wells and McLain (1973), and many others.

The experimental trawl catch data--catch (weight and numbers) per unit of effort and length-frequency distribution of the rainbow smelt taken by the 20-foot (at the headrope) bottom trawl towing for 10 minutes (or in some instances adjusted to 10 minutes) were obtained from the

Great Lakes Fishery Laboratory, U.S. Fish and Wildlife Service, Ann Arbor. The catches were taken from the depths of 3 to 50 fathoms (5 to 90 m.) during the spring and fall 1967 to 1973 from various areas of the lake, but regularly at the southern part--the areas off Saugatuck and Holland, Benton Harbor and St. Joseph, Ludington, and Waukegan.

Catch, effort, and value data from the Lake Michigan commercial smelt fishery, particularly from northern Green Bay (MM-1)[1], were obtained from the National Marine Fisheries Service, Ann Arbor; Baldwin and Saalfeld (1962) and the 1970 supplement; and the issues of "Fishery Statistics of the United States."[2]

Catch data of the smelt taken by the sport fishermen from the Michigan waters of Lake Michigan and its tributaries in 1972 and 1973 were obtained from the Michigan Department of Natural Resources, Fisheries Division.

I sampled about 385 smelt for stomach analysis from catches taken by the R/V Kaho at depths of 20, 25, 30, and 35 fathoms at the northern end of Lake Michigan off Manistique during the fall of 1973. Various food items from each stomach were identified in a petri dish under a binocular microscope (9X-60X magnification). Each food

---

[1] MM-1 and other similar codes are the statistical districts as described by Smith et al. (1961) and Hile (1962).

[2] "Fishery Statistics of the United States," 1950 to 1971, published by the U.S. Fish and Wildlife Service during 1950 to 1955, by the U.S. Bureau of Commercial Fisheries during 1956 to 1967, and by the National Marine Fisheries Service since 1968.

item from specimens captured at an equal depth was combined and measured for the total volume by water displacement in 10 cc. and 100 cc. graduate cylinders. The results of the analysis are expressed as percentage frequency of occurrence and percentage of total volume for each food item.

DESCRIPTION OF LAKE MICHIGAN

Lake Michigan, the world's sixth largest lake in both area and volume, is the only one of the Laurentian Great Lakes that lies entirely within the boundaries of the United States (Fig. 1). It is divided among four political subdivisions--the states of Michigan, Wisconsin, Illinois, and Indiana--each with complete jurisdiction over the waters within its borders. By far the greatest shares of the lake waters belong to Michigan and Wisconsin.

The open-lake waters[1] of Lake Michigan are generally typical of oligotrophic lakes. Oxygen is always near saturation and concentrations of nitrogen and phosphorus are low; total dissolved solids average 158 mg per liter and the alkalinity is 110 mg per liter (Appendix Table 1). In the inshore waters[2], however, the chemical concentrations are higher and variation is greater (Appendix Table 2), and many locations have been classified as being polluted (U.S. Dept. Interior, 1970).

---

[1]The open-lake zone lies beyond the 100-foot contour.

[2]The inshore zone lies between the shoreline and the 100-foot contour.

Figure 1. Lake Michigan and statistical districts (Adapted from Hile, 1962)

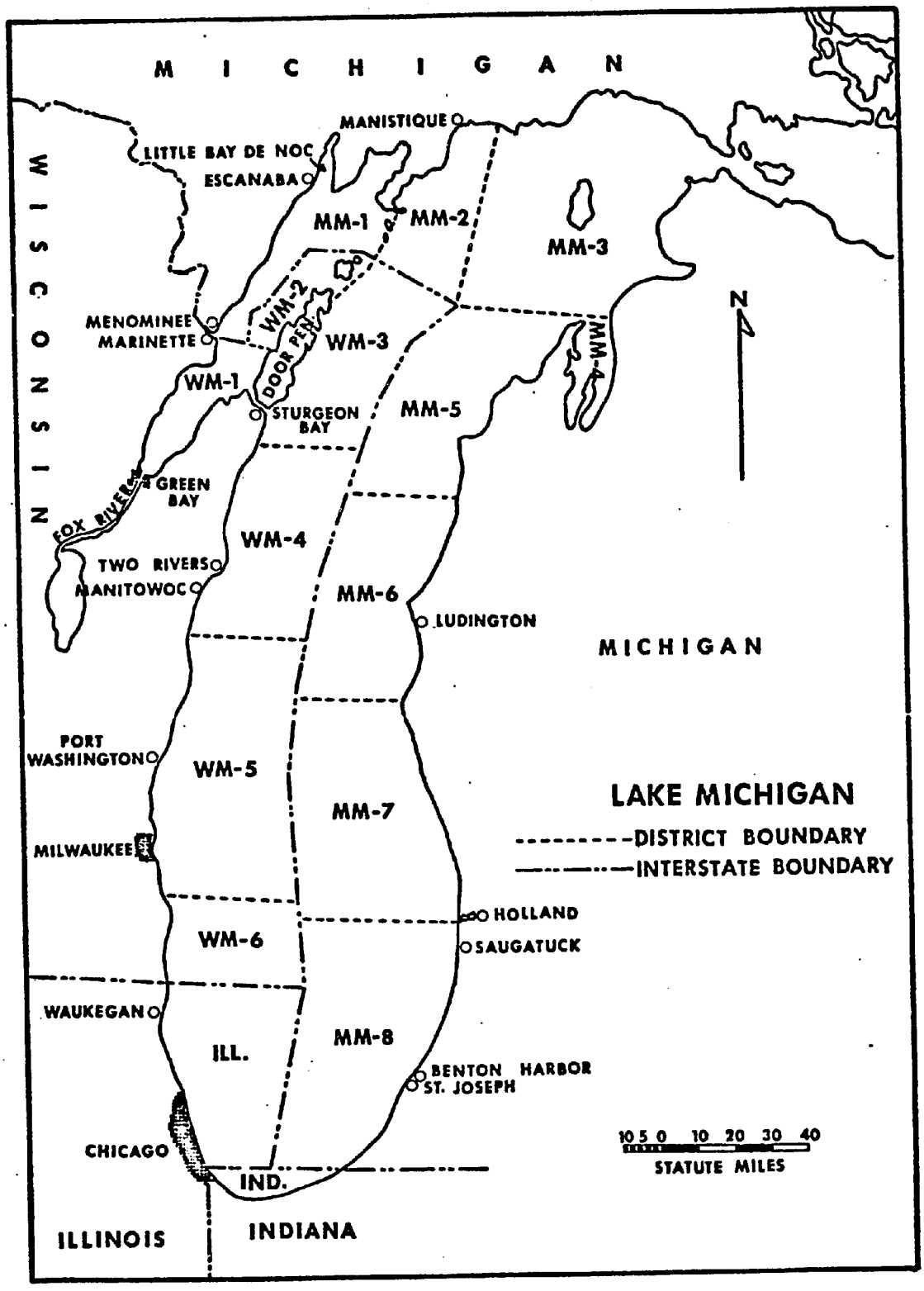

MICHIGAN
WISCONSIN
MANISTIQUE
LITTLE BAY DE NOC
ESCANABA
MM-1
MM-2
MM-3
MENOMINEE
MARINETTE
WM-2
DOOR PEN
WM-3
MM-4
WM-1
STURGEON BAY
MM-5
GREEN BAY
FOX RIVER
WM-4
TWO RIVERS
MANITOWOC
MM-6
LUDINGTON
MICHIGAN
PORT WASHINGTON
WM-5
MM-7
LAKE MICHIGAN
DISTRICT BOUNDARY
INTERSTATE BOUNDARY
MILWAUKEE
HOLLAND
WM-6
SAUGATUCK
WAUKEGAN
ILL.
MM-8
BENTON HARBOR
ST. JOSEPH
CHICAGO
IND.
10 5 0 10 20 30 40
STATUTE MILES
ILLINOIS
INDIANA

Figure 1

INTRODUCTION AND DISPERSAL OF THE RAINBOW SMELT IN THE UPPER GREAT LAKES

The occurrence of the rainbow smelt in the Great Lakes, except Lake Ontario, was the result of introduction in the early 1900's. The first attempt to introduce this fish into the upper Great Lakes basin was made in 1906 when the Michigan State Fish Commission planted a small consignment of eggs from New England into the St. Mary's River (Creaser, 1926). The purpose of this introduction was to provide food for the Atlantic ("landlocked" or "Sebago") salmon that had been planted in this river for several consecutive years (Creaser, op cit; Van Oosten, 1940). This salmon had been found to feed extensively on smelt in its native New England waters. Additional smelt plants were made in the same river and in the other Michigan inland lakes from 1909 to 1921, as Van Oosten (1937; p. 161) wrote:

> "In 1909, 1914, 1916 and 1921 an additional 37,700,000 smelt eggs were deposited in this [the St. Mary's] river. (400,000 eggs, not 2,000,000 as stated by Creaser (9), were received by the Fish Commission in 1921.) The other plants of smelt eggs recorded for Michigan are as follows:
>
> | | |
> |---|---|
> | 1912--April 4, Torch Lake, Antrim County | 6,000,000 |
> | April 6, Crystal Lake, Benzie County | 16,400,000 |
> | 1914--Huron Mt. Club, Big Bay (probably planted in Mountain Lake, Howe Lake and/or Trout Lake) | 2,000,000 |
> | 1915--Weesh-Ko-Wong Trout Hatchery, Williamsburg | 4,500,000 |

1916--Weesh-Ko-Wong Trout Hatchery, Williamsberg	2,000,000
Huron Mt. Club, Big Bay (probably planted in Mountain Lake, Howe Lake, and/or Trout Lake)	2,000,000
1921--Huron Mt. Club, Big Bay (probably planted in Mountain Lake, Howe Lake and/or Trout Lake)	200,000
March 30, Sturgeon River Power Pond, Wolverine (received from Cold Spring Harbor Hatchery, New York)	200,000."

All the smelt eggs used in the numerous plantings in the Great Lakes region were from Green Lake, Maine (Creaser, op cit), except for those planted in the Sturgeon River Power Pond, Cheboygan County, Michigan, which were from New York.

Apparently none of these introductions were successful except those made in Crystal, Howe, and Trout Lakes (Van Oosten, 1937). Although the smelt was introduced into Crystal Lake in 1912, its presence was not observed there until the spring of 1918. In 1923 it was first taken in Lake Michigan off the east shore near Frankfort, Michigan, in the vicinity of the outlet of Crystal Lake. It ostensibly derived from the successful Crystal Lake population (Creaser, 1926; 1932). Subsequently, the species made spectacular dispersal which extended throughout the Great Lakes by the mid-1930's (Fig. 2) (Creaser, 1926; Van Oosten, 1937; 1940; Dymond, 1944; and MacKay, 1958). The species reached the western end of Lake Superior near Duluth, Minnesota to complete its spread by the spring 1946 (Moyle and Hale, 1958).

The source of the rainbow smelt in the Great Lakes

Figure 2. Early dispersal of the rainbow smelt in the upper Great Lakes following the planting in Crystal Lake, Benzie County, Michigan (adapted from MacKay, 1958).

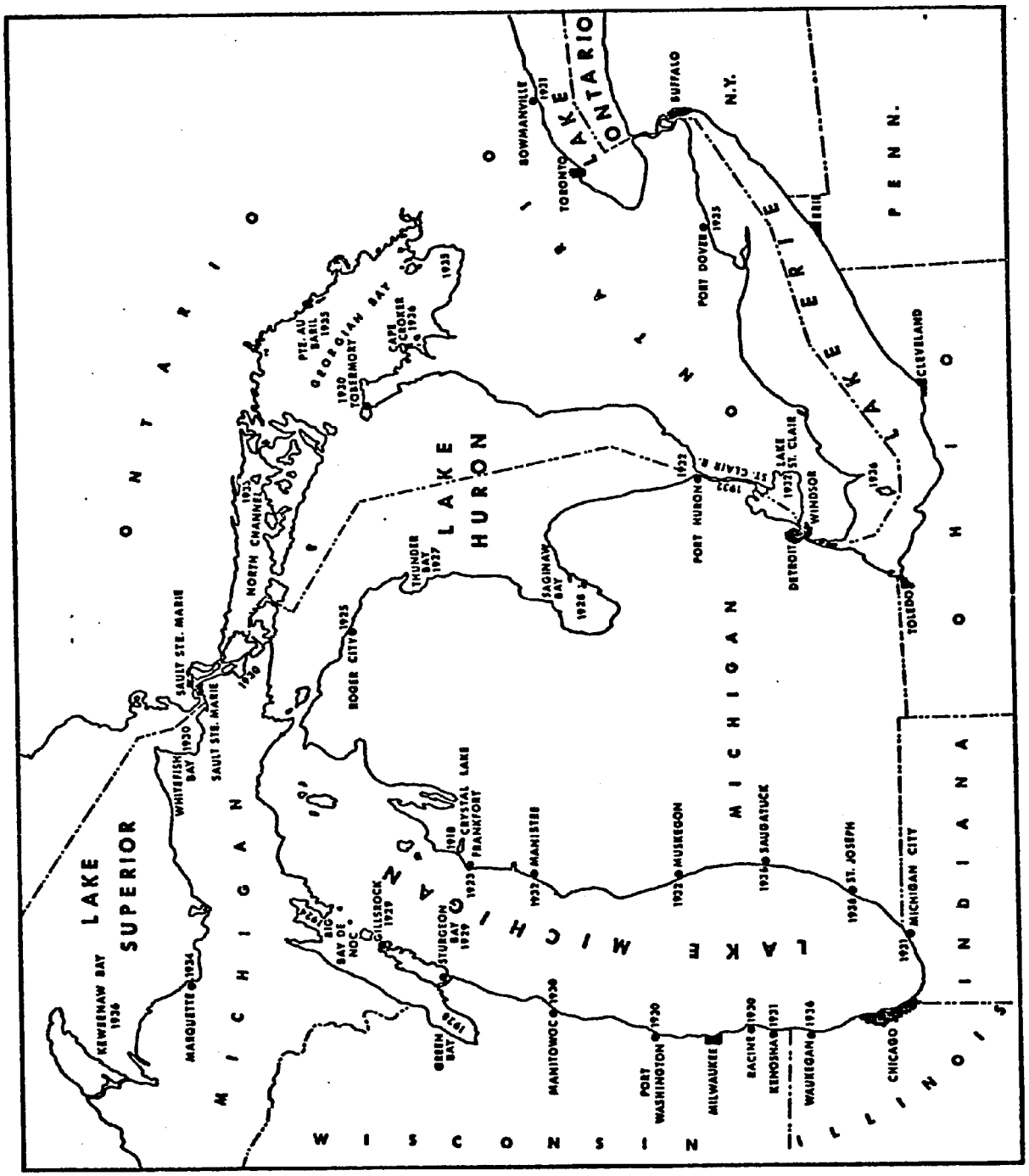

LAKE SUPERIOR
LAKE HURON
LAKE MICHIGAN
LAKE ONTARIO
LAKE ERIE
ONTARIO
MICHIGAN
WISCONSIN
INDIANA
OHIO
PENN.
N.Y.
SAULT STE. MARIE
NORTH CHANNEL
GEORGIAN BAY
THUNDER BAY
SAGINAW BAY
PORT HURON
DETROIT
WINDSOR
LAKE ST. CLAIR
ST. CLAIR R.
TOLEDO
CLEVELAND
BUFFALO
TORONTO
BOWMANVILLE
PORT DOVER
ERIE
ROGER CITY
CRYSTAL FALLS
FRANKFORT
MANISTEE
MUSKEGON
SAUGATUCK
ST. JOSEPH
MICHIGAN CITY
CHICAGO
WAUKEGAN
KENOSHA
RACINE
MILWAUKEE
PORT WASHINGTON
MANITOWOC
GREEN BAY
STURGEON BAY
GILLSROCK
BIG BAY DE NOC
MARQUETTE
WHITEFISH BAY
KEWEENAW BAY
PYE-AU BARIL
TOBERMORY
CAPE CROKER

Figure 2

other than Lake Ontario, as Van Oosten (1937) stated, is still held to be from those planted in Crystal Lake. In Lake Erie, Van Oosten (op cit) believed that the smelt in this lake migrated from southern Lake Huron and Lake St. Clair in spite of the release of aquarium-held smelt from the Belle Isle Aquarium of the City of Detroit as suggested by Creaser (1932). For Lake Superior, Van Oosten (op cit) held that the smelt reached the lake by passing upstream through the St. Mary's River rather than from the inland lakes of the Huron Mountain region. Nevertheless, it is still possible for the species to have spread into Lake Superior from these inland lakes, from the apparently unsuccessful plantings in the St. Mary's River, or from both of these sources. In Lake Ontario, there are several hypotheses for the source of the smelt, for example, from the tributaries of the St. Lawrence River (Van Oosten, 1940; MacKay, 1958), natural inhabitants of the lake (Hubbs and Lagler, 1958), and from the Finger Lakes of New York where it was introduced in the 1920's (Smith, 1972a; Scott and Crossman, 1973). It is generally believed that smelt in Lake Ontario was not from Lake Erie emigrants as it was reported in this lake in 1931, four years before it was observed in Lake Erie (Van Oosten, 1940). Cristie (1972), however, quoted Greeley (1939) in stating that the smelt was first reported in Lake Ontario in 1929. Scott and Crossman (1973), however, state that it is unlikely that the smelt occurred naturally in this lake.

POPULATION CONDITION OF THE RAINBOW SMELT IN LAKE MICHIGAN

Relative Abundance

The rainbow smelt first became abundant in Lake Michigan during the 1930's. In 1931, 400 pounds were reported taken in Green Bay from the Michigan waters, and 86,000 pounds from those of Wisconsin (Van Oosten, 1947). The principal gear used during the first few years of commercial smelt fishing was small mesh gill net. Pound nets were first reported in use for smelt from northern Green Bay (MM-1) in 1934, but there are no details of the fishing effort (number of lifts) until 1939. Since then pound nets have accounted for the greatest part (up to 100 percent) of the annual production of smelt from this area. They have also contributed the greatest part of the overall smelt catch throughout Lake Michigan. Therefore catch per unit of effort (CPE) for this gear in terms of live weight per lift of net in northern Green Bay has been used to describe the abundance of the smelt in Green Bay. CPE by pound net each year, from 1939 to 1973, was calculated using the average from the total catch and total effort for January through May--the period when all the smelt were usually taken by this gear in this area. For the southern part of the lake an index of smelt abundance has been the catch in

terms of both weight and number per 10-minute tow of the experimental bottom trawls during fall 1967 through 1973. Since the smelt shows great seasonal changes in vertical distribution, only the cruises on which trawls were operated from the shallowest to the greatest depths (or at least from 5 to 40 fathoms) were used in the calculation of CPE. If more than one cruise was conducted at any station the weighted average of CPE was computed

Green Bay

CPE for pound nets reached a peak in Green Bay in 1940 (about 470 pounds per lift). In 1941 the highest annual catch was reached as the fishing effort continued to increase (Fig. 3; Appendix Table 3). The numbers of smelt were believed to be greater during this period than in any previous or later time (Wells and McLain, 1973). The CPE declined gradually until 1943, and then abruptly in 1944 when virtually no smelt were caught. The abrupt decline of the smelt catch in 1944 was attributed to the mass mortality during fall and winter of 1942-1943. Infectious diseases of bacterial or viral origin were believed to be responsible for this mortality (Van Oosten, 1947). The die-off originated in central Lake Huron in October 1942 and spread rapidly northward and westward. It reached northern Green Bay in February 1943. Almost immediately, reduced catches were noticed (in March 1943), and no smelt

Figure 3. Catch (thousands of pounds), effort (number of lifts of pound nets), and catch per unit of effort (pounds) of the rainbow smelt taken by pound nets in northern Green Bay (MM-1) during January through May, 1939-73.

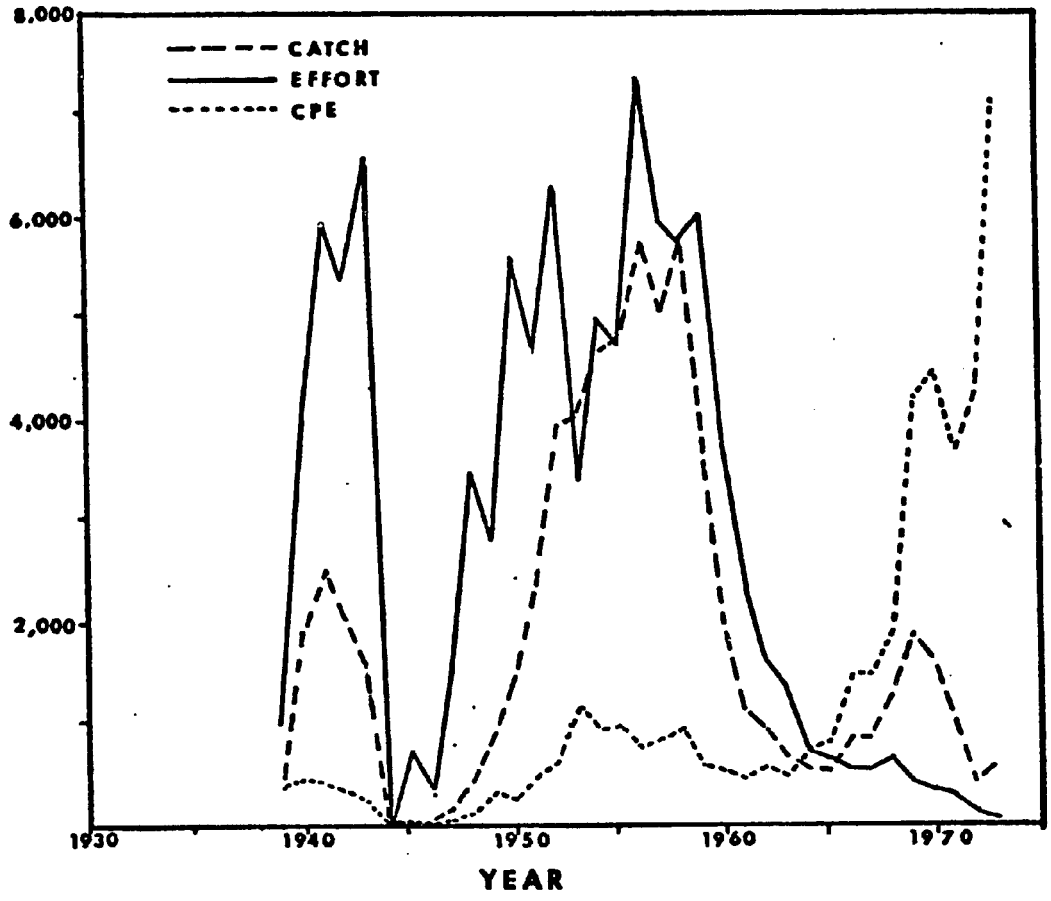

8,000
6,000
4,000
2,000
CATCH
EFFORT
CPE
1930
1940
1950
1960
1970
YEAR

Figure 3

were caught in April and May from this bay area. Van Oosten (op cit) estimated the total loss of smelt production from lakes Michigan and Huron resulting from this mortality to be about 50 million pounds.

For the first few years after the die-off, the smelt population recovered slowly with the CPE being only 33 pounds in 1945. It increased considerably and steadily from 1948 onward; reaching a peak in the mid-1950's. A high CPE coupled with considerable fishing effort in this area along with the relatively good catches from the other areas (MM-2, MM-3, WM-4 and WM-5) resulted in the highest recorded level of total smelt production (9.1 million pounds) for Lake Michigan in 1958.

Simultaneous declines of production, CPE, and fishing effort from 1959 to the mid-1960's definitely indicate the decline of the smelt population in this area. The decline of the smelt population during this period was also noted by Wells and McLain (1973), and is believed to involve a rise in abundance of the alewife (Alosa pseudoharengus) (Smith, 1970). Production of the alewife tripled in 1960 from that in 1959. In Lake Huron, as the alewife increased, the smelt also declined in abundance.

The CPE began to climb slightly in 1964 while the effort decreased by almost 50 percent from 1963. From 1966 to 1970 the CPE increased rapidly and resulted in a sharp increase in production. But the fishing effort continued to decrease during this period. With only a slight drop in

1971 the CPE rose to its highest historic level in 1973--7,098 pounds per pound-net lift. The effort in this year, however, decreased to the all time low level (98 lifts) for the years in which the smelt was fished commercially. The population of smelt undoubtedly increased from 1965 to 1969 because both catch and catch per unit of effort increased while the effort decreased. During 1969 to 1972, the population fluctuated slightly. In 1973 the population increased again. The production of 1973 increased slightly from 1972, but the CPE rose sharply along with a steady decline in effort. It is rather certain that the population of the rainbow smelt in northern Green Bay now is greater than it was in the early-to mid-1960's.

Southern Lake Michigan

The smelt has been generally less abundant in southern Lake Michigan than in Green Bay or in the northern portion of the lake. CPE in the areas off Saugatuck--Holand, Benton Harbor--St. Joseph, and Ludington fluctuated from year to year at rather low levels with an increasing trend in 1973 (Figs. 4 and 5; Appendix Table 4). In contrast, in the area off Waukegan on the west shore (where the smelt has been more abundant than on the east shore) CPE is generally increasing on high levels. The variation in the abundance of smelt in this part of the lake seems least likely to be influenced by commercial fishing pressure, as this area is fished only little.

Figure 4. Catch per unit of effort (gm/10 min.) by experimental bottom trawls in southern Lake Michigan during fall, 1967-73.

Figure 5. Catch per unit of effort (No/10 min.) by experimental bottom trawls in southern Lake Michigan during fall, 1967-73.

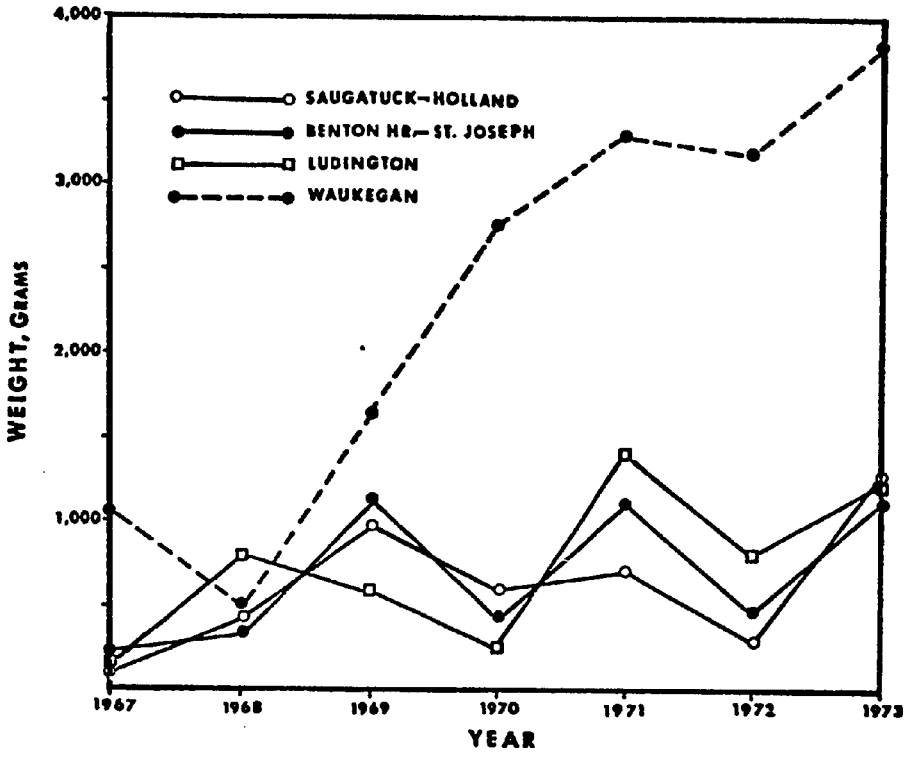


Figure 4

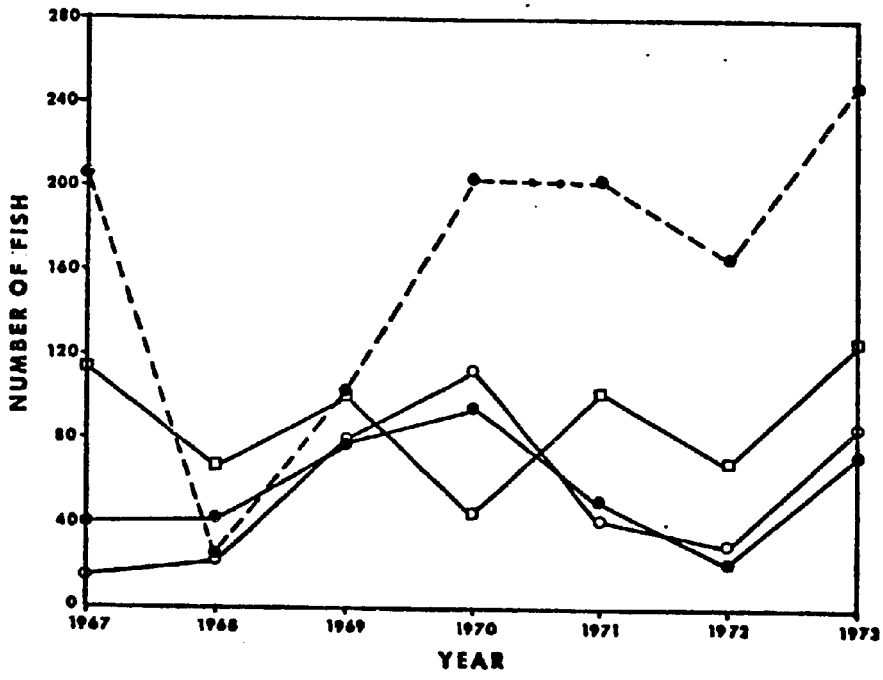


Figure 5

Standing Crop

The estimation of the standing crop or stock size of the rainbow smelt in Lake Michigan, excluding Green Bay, was based on the catch per unit of effort by the bottom trawl in the extensive sampling during fall 1973 (Appendix Table 5). The catch (grams) per 10-minute tow of the 39-foot (at head rope) trawl at a speed of 2.5 knots was converted into the weight of fish per area covered by the trawl (which is about 1.22 acres), and multiplied by the bottom area at that particular depth contour and station. The weight of the smelt at these areas was then combined to obtain the total weight. By this method it was estimated that the standing crop or stock size of the smelt in Lake Michigan, excluding Green Bay, was about 14 million kilograms or 31 million pounds. It was estimated from the logistic model, which will be discussed in a later chapter, that the current stock size of the smelt in northern Green Bay is about 70 million pounds. Therefore, the standing crop or stock size of the smelt in Lake Michigan as a whole at the present is estimated at approximately 100 million pounds.

Age Composition

The determination of the age composition of rainbow smelt in Lake Michigan was based on length frequencies of the catches taken by experimental bottom trawls from

different locations of the lake during springs and falls of recent years, and on the average total lengths of smelt in different age groups from Robinson (1973) and other studies (Appendix Table 6). However, these studies did not provide the average total lengths for the fish during the fall. Therefore, the designation of the age groups to any particular length interval during this period, except for the age-group 0 whose length distribution was distinctively separated from the rest, was somewhat arbitrary.

During the springs of the foregoing years the smelt in age-group I (yearling) were relatively abundant in the catches from the eastern shore of Lake Michigan, for example in the area off Saugatuck--Holland (Fig. 6). The spawning success was exceptionally good in the spring of 1970. This is shown by the dominance of the fish in age-group I in the catches during the spring and fall of 1971 (Figs. 6 and 9). The fish of age-groups II and III comprised the rest of the catches from this area with few older age-groups, probably up to age-group VI, recorded. Along the western shore and in the northern end of the lake, however, age-group I comprised a very small portion of the catches, for example at Waukegan (Fig. 7) and Manistique (Fig. 8). Here, the fish in age-groups II and III were the majority in the catches. Robinson (1973) found the smelt in age-groups II to IV comprised up to 90 percent of the catches from Zion and Two Rivers along the

Figure 6. Length-frequency distribution and age composition of the rainbow smelt taken by experimental bottom trawls in southeastern Lake Michigan off Saugatuck--Holland, Michigan, during spring 1971-73.

Figure 7. Length-frequency distribution and age composition of the rainbow smelt taken by experimental bottom trawl in southwestern Lake Michigan off Waukegan, Illinois, during spring 1971-73.

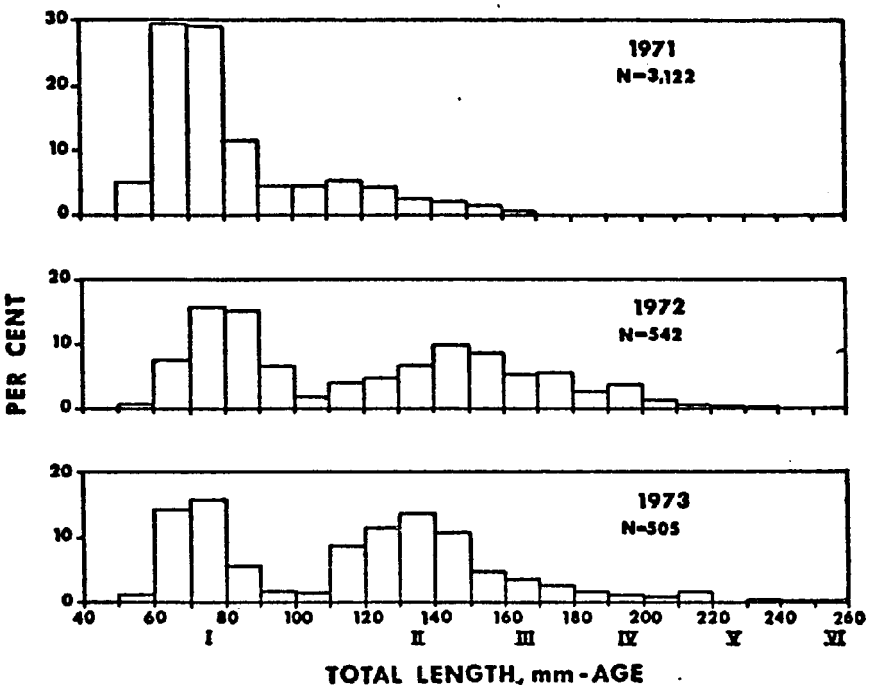


Figure 6

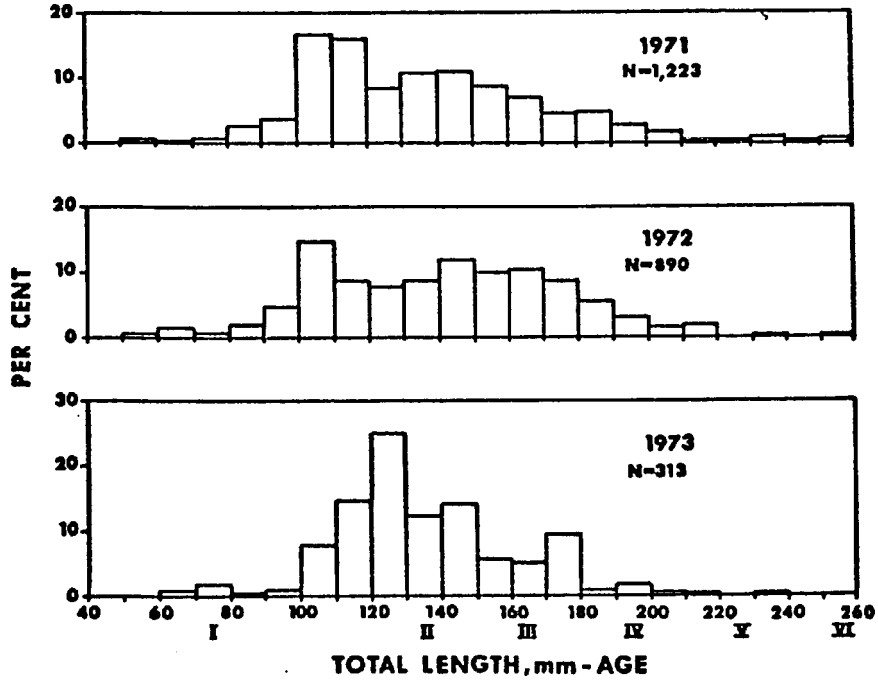


Figure 7

Figure 8. Length-frequency distribution and age composition of the rainbow smelt taken by experimental bottom trawls in northern Lake Michigan off Manistique, Michigan, during spring 1969-71.

Figure 9. Length-frequency distribution and age composition of the rainbow smelt taken by experimental bottom trawls in southeastern Lake Michigan off Saugatuck--Holland, Michigan, during fall 1971-73.

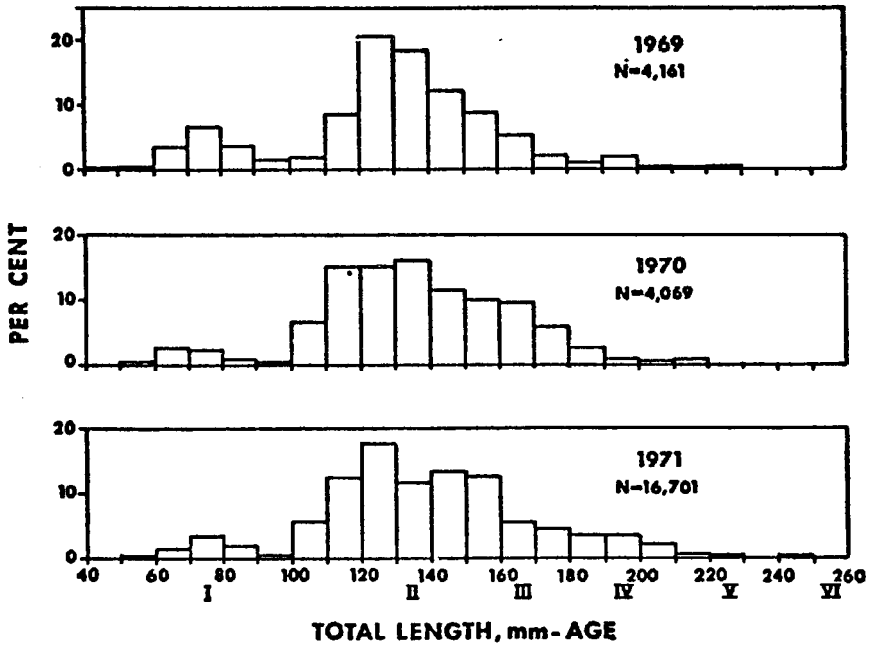


Figure 8

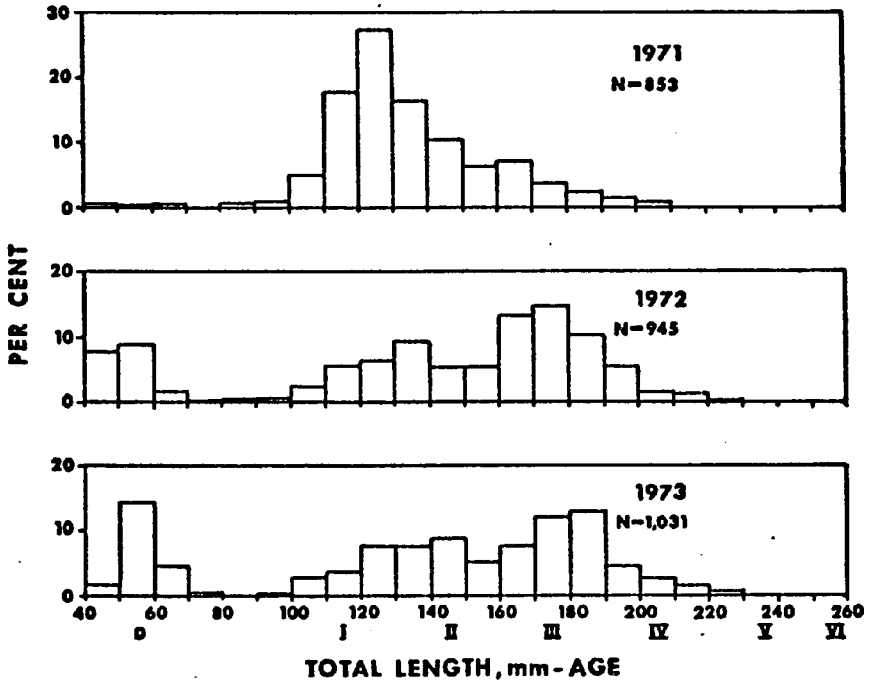


Figure 9

Figure 10. Length-frequency distribution and age composition of the rainbow smelt taken by experimental bottom trawls in southwestern Lake Michigan off Waukegan, Illinois, during fall 1971-73.

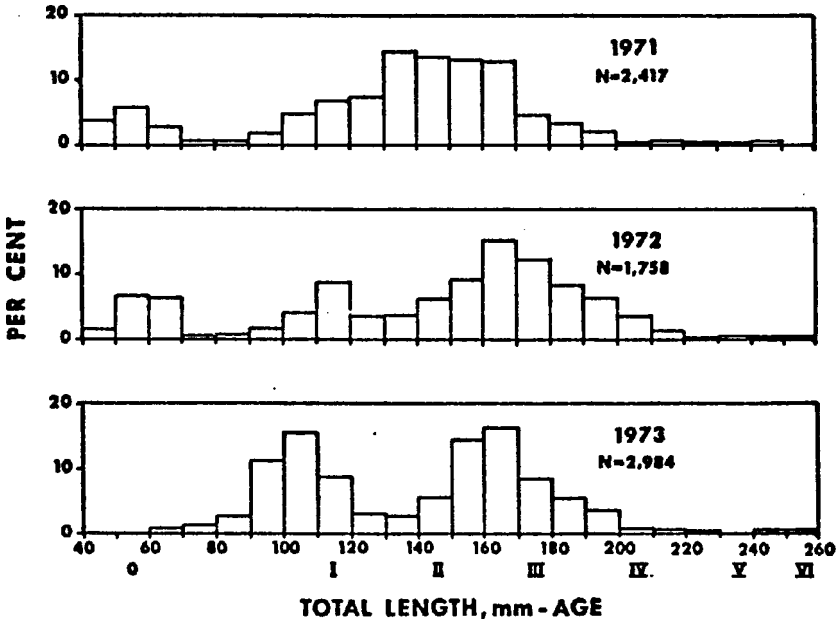

1971
N=2,417
1972
N=1,758
1973
N=2,984
PER CENT
20
10
0
40
60
80
100
120
140
160
180
200
220
240
260
0
I
II
III
IV
V
VI
TOTAL LENGTH, mm - AGE

Figure 10

western shore, and 93 percent of the catch from Escanaba in northern Green Bay in the spring 1971.

During the fall, young-of-the-year (age-group 0) were generally found in small numbers in the catches along both the eastern and western shores (Figs. 9 and 10). The fish in age-group I that were found least abundant in the catch from the western shore during the spring comprised a considerable part of the catch during the fall, however. This indicates that recruitment to the smelt population in this portion of the lake is probably as great as along the eastern shore. Nevertheless, the fish in age-groups II and III, and probably IV, were still the majority in the catches from both areas.

Keller et al. (1974) approximated the age composition of the smelt in Lake Michigan from the 1972 catch as follows: age-group I--36%; II--48%; III--11%; IV--4%; and V--1%.

SOME ASPECTS ON LIFE HISTORY OF THE RAINBOW SMELT

Habitat and Seasonal Distribution

Rainbow smelt prefers cold water, and this factor apparently restricts its distribution to the deeper portions of lakes during summer (Kendall, 1927). In the Great Lakes, the smelt prefers a water temperature of 59°F (15°C) or less, and except during the spawning season, it lives at depths ranging from 8 to 35 fathoms (15 to 64 m.) and is most abundant at 10 to 20 fathoms (18 to 36 m.) (Van Oosten, 1940). In southern Lake Michigan, in the summer of recent years the smelt has been most abundant in waters with a temperature of 43° to 57° (6° to 14°C), at a depth range of 5 to 17 fathoms (9 to 30 m.) (Wells, 1968). In northern Lake Michigan, however, the smelt is found at depths of 9 to 50 fathoms (16 to 90 m.), but is most abundant at 15 to 20 fathoms (27 to 36 m.) (Reigle, 1969).

Season and life stage have the greatest influence on the habitat requirements of the smelt. In southeastern Lake Michigan the smelt has been found to shift from a predominantly pelagic to a bottom existence as it grows older (Wells, 1968). Here the young-of-the-year individuals (age-group 0) live in the upper levels until fall (or very late summer) and then at least some move to the

bottom. Catches by bottom trawls, however, showed that they are most abundant at depths of 10 to 15 fathoms (18 to 27 m.). The yearlings (age-group I) may be either at mid levels (commonly in the thermocline) or on the bottom; the adults (age-group II and older) are mostly on the bottom during this period. A similar pattern of distribution was observed in the catches from northern area during fall 1973 (Appendix Table 7). In mid-winter the smelt is widely scattered from 7 to 35 fathoms (3 to 63 m.), but it abandons the deeper water by the end of winter, being most numerous at 10 to 17 fathoms (18 to 31 m.). In spring the adults move to the shore and streams to spawn, and after the spawning period, in mid-spring, they move back to the lake at depths of 3 to 20 fathoms (5 to 36 m.).

Similar patterns of habitat and seasonal distribution have also been observed in other waters of the Great Lakes; for example, Saginaw Bay, Lake Huron (Gordon, 1957), eastern Lake Erie (Ferguson, 1965), the Apostle Islands region, Lake Superior (Dryer, 1966), and Gull Lake, Michigan (Burbidge, 1969). MacCallum and Regier (1970), however, observed that the adult smelt in the central basin of Lake Erie were in the thermocline with the yearlings during the summer, and this was because the hypolimnion became deoxygenated.

The smelt also exhibits diel distribution. In eastern Lake Erie, Ferguson (1965) reported that during the day the

adult smelt were concentrated near the bottom at 25 fathoms (45 m.), but by late afternoon they started to disperse away from the bottom; during the night they remained dispersed and invaded the epilimnion. After daylight they again concentrated close to the bottom. Emery (1973) found that the larvae of the smelt in Little Dunk's Bay in Goergian Bay, Lake Huron, were most abundant during the day at the depths of 2 to 4 meters, but during the night they distributed throughout the water column to a depth of 15 meters with concentration at 2 to 3 meters above the bottom.

In addition to the impact of season and life stage on the distribution of the smelt, environmental factors, such as water temperature, lake basin configuration, currents, food concentration, and other factors may also influence the local densities.

Food Habits

Of 381 stomachs of the smelt that I subsampled from catches taken by experimental bottom trawl at depths of 20, 25, 30, and 35 fathoms in northern Lake Michigan near Manistique during fall 1973, the percentage of empty stomachs range from 14 for the fish at 20 fathoms to 28 for the fish at 35 fathoms (Table 1). *Mysis* occurred most frequently of all food organisms and comprised the greatest part of total food in the stomachs at all depths. Amphipods (*Pontoporeia*), copepods (*Limnocalanus*), cladocerans, isopods, and

Table 1

Fall food of the rainbow smelt in Lake Michigan off Manistique, Michigan, expressed as percentage frequency of occurrence and percentage of total volume (in parenthesis)

Item	At 20 f.	At 25 f.	At 30 f.	At 35 f.
Number of stomachs	64	81	119	117
Number empty	9	16	23	33
Crustaceans				
Mysidacea	100(100)	100(90)	96(88)	95(70)
Amphipoda	12 (<1)	31(10)	11(2)	11(3)
Copepoda	4 (<1)	-	21(2)	11(2)
Cladocera	9 (<1)	-	2(<1)	1(<1)
Isopoda	-	-	1(<1)	-
Fish	-	-	8) 3(8)	7(25)
Molluscs	-	-	-	3(<1)

molluscs occurred far less frequently and together comprised only a small part of the food. Fishes were found in the stomachs of smelt caught at depths of 30 to 35 fathoms where large smelt made up most of the catch (Appendix Table 7). Most of the identifiable fishes were young smelt.

The dominance of Mysis, both in terms of frequency and quantity, in the smelt stomachs that I examined agrees with many previous findings for this fish in Lake Michigan and in other Great Lakes waters: Lake Michigan and in the deep waters of Crystal Lake, Michigan, Creaser (1929a); Green Bay of Lake Michigan, Schneberger (1935a; 1937); South Bay of Lake Huron, Baldwin (1950); and in western Lake Superior, Moyle and Hale (1938), Hale (1960), Anderson (1969), and Anderson and Smith (1971). Other crustaceans--amphipods, copepods, cladocerans, ostracods--were found to be the major food items of the smelt in Lake Erie (Price, 1958; Gordon, 1957; 1961; Ferguson, 1965); in Gull Lake, Michigan (Burbidge, 1969); in St. Louis Bay, Lake Superior (Seifert, 1972); Black Brook, New Hampshire (Hoover, 1936); and in Echo Lake, Maine (Lackey, 1969). The replacement of Daphnia pulex by D. dubia, and the disappearance of Leptodora kindtii, following the introduction of smelt was observed in Harvey Lake, Pennsylvania, and this is believed to be due to the differential

utilization of these cladocerans by the smelt (Reif and Tappa, 1966).

Other food items that were found to be utilized by the smelt to a lesser extent include molluscs, insects (nymphs, larvae, and pupae), oligochaetes, algae, fish eggs, and fishes. The utilization of fishes has caused a great deal of controversy regarding possible effects of predation. Few studies, however, have shown that smelt feed considerably on fishes, for example, Creaser (1926) and Beckman (1942) in Crystal Lake, Creaser (1929b) in Mountain Lake, Michigan, and Foltz and Norden (1974) in Lake Michigan. Most other studies indicate that fishes become an important part of smelt food only in particular periods (for example, in shallow waters of Crystal Lake during summer, Creaser, 1926), and most of them were young smelt (Schneberger, 1937; Hale, 1960; Gordon, 1961; Price, 1963; Ferguson, 1965; Anderson, 1969; Burbidge, 1969). Cannibalism on young has also been observed for smelt outside the Great Lakes region (Kendall, 1927; Greene, 1930). Foltz and Norden(op cit) found that smelt fed considerably on young of the alewife during late spring and summer and became principally cannibalistic on its own young during fall.

From the above studies we may conclude that the rainbow smelt feed principally on crustaceans (Mysis, amphipods, copepods, cladocerans, ostracods, isopods) along

with, but to a lesser extent, on other food items. Fishes are eaten less frequently and, generally, in smaller quantities than crustaceans, and most of them are young smelt. Only in certain places and seasons do fishes become the major part of smelt diet. No game or commercial fish species have been found in smelt stomachs in significant numbers. An adequate explanation for this, perhaps, can be taken from Kendall (1927; p. 316):

> ". . . under no natural conditions are they a menace to young trout and salmon, for the young of the latter two species do not occur in the deep water resort of the smelt, and the smelt is not seeking food when it ascends streams to spawn, where young trout and salmon occur."

This statement was supported by the later studies by Schneberger (1937) and Burbridge (1969). This circumstance can undoubtedly be applied to the young of many other important species in Lake Michigan as well.

Biotic Potential

Biotic potential is the capability of a population of an organism to produce biomass. This potential is a function of the number of young produced per female (reproductive rate) and the age at first reproduction (mean generation time). The greater the number of young produced per female, and/or the younger the female when it first reproduces, the higher the biotic potential will be. Thus, in the broad sense, biotic potential is equivalent to the intrinsic rate of natural increase.

The reproductive rate may be determined from the fecundity and the number of times the female reproduces throughout its life (longevity). Age at first reproduction is obviously a key factor in the biotic potential of an organism, as cited above. Details of experiments and discussion of this matter can be found in many references, such as Watt (1968) and Krebs (1972). Nikolsky (1963) discussed in some detail the calculation of an index for the biotic potential, or as he called it, the "reproductive capacity."

The rainbow smelt has a relatively short life and becomes sexually mature at an early age. In the Great Lakes, the oldest smelt reported was in age-group VII (Bailey, 1964; Robinson, 1973), and the earliest spawning is at the end of the second year (Creaser, 1926; 1929a; Schneberger, 1935b; Van Oosten, 1940; Beckman, 1942; Baldwin, 1950; Moyle and Hale, 1958; Hale, 1960; and Bailey, 1964). Similar observations have been reported from the waters outside the Great Lakes (Greene, 1930; and McKenzie, 1958; 1964). Generally, it is also the fish of age-group II that comprise the majority of the spawning population; but there are exceptions such as those observed by Creaser (1929a) and Bailey (op cit), where smelt of age-group III were the majority. The spawning of smelt age-group I was also reported outside the Great Lakes (Greene, op cit; and Warfel et al.,

1943). After spawning once the smelt will continue to spawn thereafter throughout its life, as indicated by the occurrence of the older groups, up to age-group VII in the spawning population (Bailey, 1964).

Although small, the smelt is a prolific fish. In Crystal Lake, Michigan, an average of 25,102 eggs was found per female ranging from 185 to 195 mm, and up to 43,125 eggs were found in one specimen 232 mm long (Langlois, 1935). In South Bay, Lake Huron, the average number of eggs of females 140 to 221 mm long was 20,570 (Baldwin, 1950), and 31,338 eggs per female 185 to 221 mm long in western Lake Superior (Bailey, 1964). Interestingly, these two studies also showed that the number of eggs per female declines in some large fishes. In Maine, a smelt 177 mm long was found to contain 5,893 eggs (Kendall, 1926); in New Hampshire, the number of eggs per female (104 mm average length) ranged from 1,700 to 7,000 (Hoover, 1936); and in the Miramichi River, New Brunswick, the number of eggs per female ranged from 8,500 in a fish 127 mm long to 69,600 in a fish 200 mm long; the relationship between the fecundity and the length of the smelt in this river is a logarithmic function (McKenzie, 1964).

It is obvious that the rainbow smelt has a high biotic potential and therein may lie the explanation for the rapid recovery of the population after the 1942-43 mass mortality.

ECOLOGICAL ROLES OF THE RAINBOW SMELT IN THE LAKE MICHIGAN ECOSYSTEM

The rainbow smelt has many and broad interrelationships with many factors of the Lake Michigan ecosystem (Figure 11). In this ecosystem, solar energy is trapped by phytoplankton through the photosynthetic process which in turn supports the zooplankton, benthos, and other organisms. As described in the previous section, the smelt receives most of its energy through zooplankton (copepods, cladocerans, ispods), benthos (Mysis, Pontoporeia, insect larvae, and molluscs). Some adults also feed on fishes. In the smelt population, the individual fish is divided into two compartments according to the paths of the energy or biomass lost and gained--immature, including the young-of-the-year and the yearling (age-groups 0 and I), and adult (age-groups II and older). The energy or biomass of the smelt population as a whole is ultimately "lost" to natural mortality, to fishing mortality, or transferred by predation to salmonids and other piscivorous fishes. Although at the present time we have no reports of disease or parasites for the smelt in Lake Michigan, the previous mass mortality of 1942-43 was apparently caused by a disease, and the occurrence of the protozoan parasite (Glugea hertwigi) among the smelt in Lake Erie suggests

Figure 11. Generalized diagram of the rainbow smelt population in Lake Michigan showing biomass, energy, and nutrient flows, and influences of some related factors.

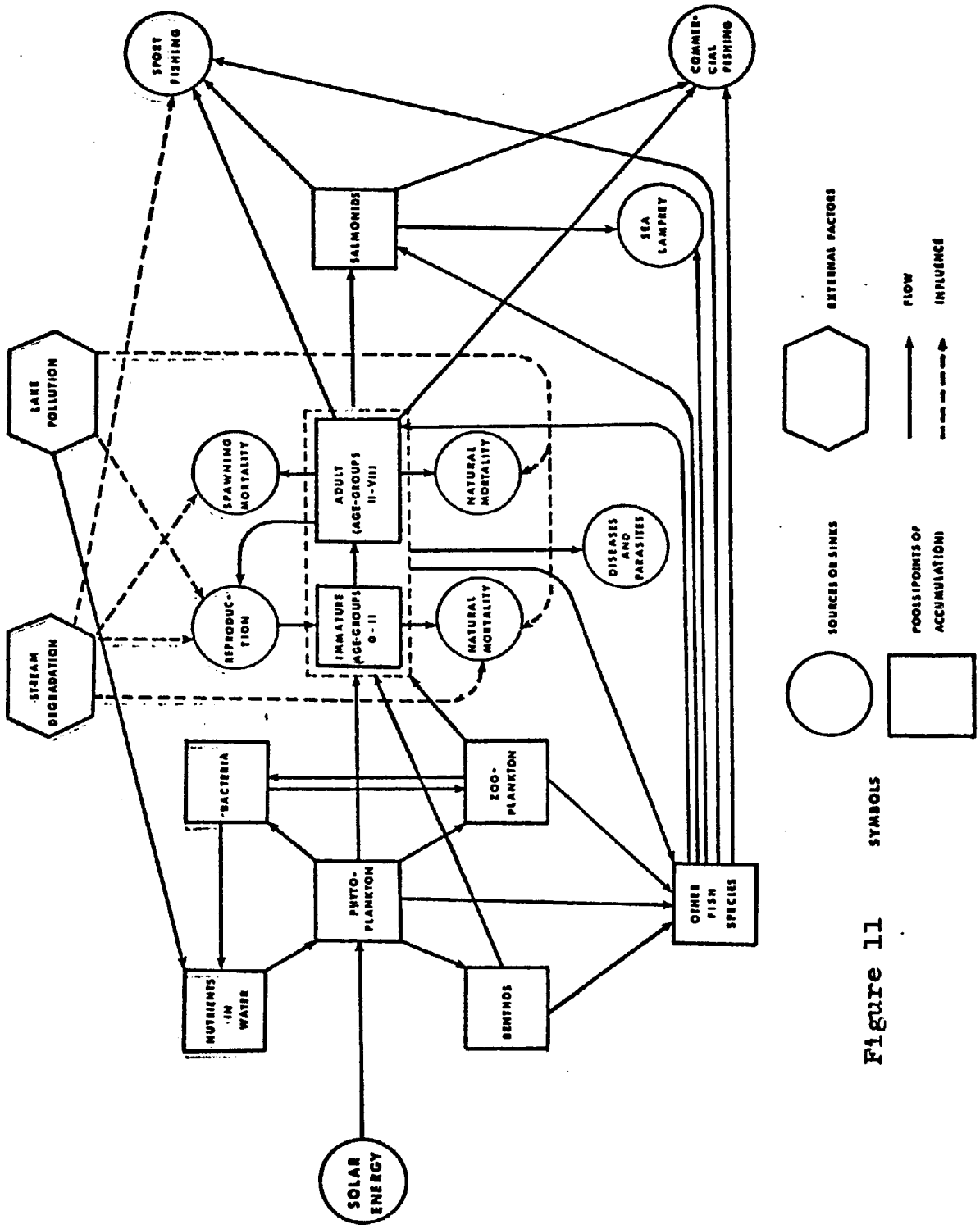

SPORT FISHING
COMMERCIAL FISHING
SALMONIDS
SEA LAMPREY
LAKE POLLUTION
STREAM DEGRADATION
SPAWNING MORTALITY
ADULT (AGE-GROUPS II-VIII)
NATURAL MORTALITY
DISEASES AND PARASITES
REPRODUCTION
IMMATURE AGE-GROUPS 0-II
NATURAL MORTALITY
BACTERIA
ZOO-PLANKTON
PHYTO-PLANKTON
OTHER FISH SPECIES
NUTRIENTS IN WATER
BENTHOS
SOLAR ENERGY
EXTERNAL FACTORS
FLOW
INFLUENCE
SOURCES OR SINKS
POOLS (POINTS OF ACCUMULATION)
SYMBOLS

Figure 11

that disease and parasite can be a cause of significant loss of energy or biomass of the smelt population in Lake Michigan.

Only in adults (adult compartment, Fig. 11), however, is energy lost to reproduction (shedding of eggs and sperm), spawning mortality due to the struggle of reproduction, and to sport fishing. The spawning mortality is separated from overall natural mortality since it occurs only among the adults during the spawning season. The mortality may be caused by land predators (certain birds and mammals) or from the exhaustion of the spawning migration and reproductive activity (during which feeding apparently ceases) making them more susceptible to disease, parasites, extremes of weather, etc. Pronounced mortalities of the smelt at or shortly after the spawning season have been observed in Lake Erie (Nepszy and Dechtiar, 1972), and in waters outside the Great Lakes (Kendall, 1926; McKenzie, 1964). Furthermore, since only the adults migrate to spawn along beaches and in streams, they alone are subject to mortality due to sport fishing.

Energy or biomass of immature smelt is transferred to adult smelt through growth and also through cannibalism by the adults. The immature fish, however, gained energy or biomass from the adults in the reproductive tissues (eggs and sperms) which started them.

The smelt in Lake Michigan is a competitor for food with some fishes, e.g., lake herring, lake whitefish, since the zooplankton and benthos are also used by these species; it is a predator since it feeds on some other fishes, such as the alewife; it is also a prey to many piscivorous fishes--lake trout, coho salmon, chinook salmon. This is not unusual phenomenon in nature but, from the point of view of population dynamics, assessment is required of the relative importance of these roles. In their assessment, information is used from this study and many previous studies on the food habits, seasonal distribution, and the abundance of food.

Information in the food habits of the fishes at various life stages and at different times of the year is a basic but not complete index of their possible interactions, competition and predation. The fishes may distribute to different areas or depths of the waters during various times of the year, and, therefore, utilize food from different sources. This will certainly lessen their possible interaction. Analyses of areal and bathymetric distribution of the various life history stages of the fishes throughout the year enable one to understand the potential of the competition for food, as well as the competition for space, activity level in predation, and likelihood of being prey. These two pieces of information may indicate the possibility of the interaction among the

fishes, but the degree of the interaction, particularly the competition for food, however, will also depend on the abundance of food. The greater the abundance of food is, the less the possible competition for it among the fishes concerned will be. The abundance of the alternative food items may also reduce the predatory potential of the fishes.

Food habits and seasonal distribution of the rainbow smelt were discussed in detail in the previous sections. For the abundance of food, the two important food organisms for the smelt in Lake Michigan, Mysis and Pontoporeia, seem to be relatively abundant now as they were in the past. Pontoporeia comprises about 70 percent by volume of the benthic organisms in Lake Michigan (U. S. Dept. Interior, 1966). It was found to be more abundant in 1964 than in 1931 and 1932 in the southern two-thirds of the lake (Robertson and Alley, 1966). For Mysis, except for the distinctly higher standing crop in summer 1970 as compared with summer 1971 that was observed in the southeastern portion of the lake (Reynolds and DeGraeve, 1972), no annual variation in the abundance in Lake Michigan has been reported.

To evaluate the ecological roles played by the smelt, as predator, competitor, and/or prey, and their importance to the Lake Michigan fish community, the above information as well as the information from the other

previous studies will be analyzed.

As Predator

Early suspicions of adverse effects of the smelt on native fishes of the upper Great Lakes centered on possible predation. The wide mouth of the smelt, and its sharp and long teeth, convinced many observers of this possibility. Some of them, as reported by Schneberger (1935a), described the fish as being an enemy of the lake trout (Salvelinus namaycush), lake whitefish, lake herring, and chubs (Coregonus spp.) by consuming immense quantities of fry and young of these species. Others even claimed that the smelt ate millions of minnows and lake trout eggs (Anon., 1952). However, based on the food habits, it is clear that the major food items of the smelt in Lake Michigan, as well as in the other lakes of the Great Lakes, are crustaceans. Fishes, and other food items excluding crustaceans, make up only a small portion of the smelt diet, both in terms of frequency and quantity; and the majority of fish eaten was young smelt.

The most recent study of the food habits of the smelt in Lake Michigan (Foltz and Norden, 1974) now shows that the alewife is used considerably by the smelt, especially during late spring and summer. Other fishes reported as having been eaten in Lake Michigan or other of the Great Lakes include shiners (Notropis spp.), the rock bass

(Ambloplites rupestris), yellow perch (Perca flavescens) chubs, burbot (Lota lata), and lake trout (Creaser, 1926; 1929a; 1929b; 1932; Schneberger, 1935a; 1937; Beckman, 1942; Baldwin, 1950; Hale, 1960; Gordon, 1961; Anderson, 1969; and Anderson and Smith, 1971). On first view the presence of valuable commercial and sport fishes in this list may appear to be cause for alarm, but the number of these fishes taken by the smelt is very small. For example, Creaser (1926) found only one individual from Lake Michigan that had a supposed lake herring in its stomach; Schneberger (1935a) found only two of 835 smelt stomachs from Green Bay to contain lake trout; and Hale (1960) encountered only three small lake trout in 1,065 smelt stomachs from western Lake Superior. Anderson (op cit), furthermore, concluded in his study that the smelt was insignificant as a predator on coregonid eggs.

From the foregoing, however, the piscivorous potential of the smelt in Lake Michigan must be recognized. Nevertheless, the abundance of other food items, as recognized by Price (1963), and the different patterns of the seasonal distribution between the smelt and the young of the other species, as stated by Kendall (1927) and Burbridge (1969), must minimize the significance of its predatory role on the populations of other fishes.

As Competitor

Besides its predatory make-up, the smelt was early thought also to have the potential to compete for food with many species of fishes in Lake Michigan and in others of the Great Lakes--for example, with the lake whitefish (Creaser, 1926), lake herring (Creaser, 1929b), and lake trout (Schneberger, 1935a; Moyle and Hale, 1958). Even in the larval stage it was suspected of competing for food with the larvae of lake herring (Anderson, 1969; and Anderson and Smith, 1971). And because of its abundance and capability of feeding on a variety of foods it was alleged to compete with young of all fish species associated with it, as well as with adults of some kinds (Creaser, 1929a; Gordon, 1961).

In view of this concern, it is interesting to note that no studies, except that of Anderson (1969), have shown actual effect of competition for food on the populations of these fishes. It is true that the smelt feeds principally on Mysis and Pontoporeia which are also fed on by some other species such as lake whitefish, lake herring, and bloater (Coregonus hoyi). The alewife also feeds importantly on Pontoporeia (Morsell and Norden, 1968). Lake Trout in the Great Lakes, although classified as a piscivore, feeds primarily on Mysis and Pontoporeia during its first year of life and transfers to a diet mostly of fish when 4 to 6 years of age (Smith, 1972a). However,

for the smelt to be classified as a competitor of the lake trout (or any other fish) would not only require similar food habits, but similar temporal and spatial distribution and also, perhaps, a food supply that is "limited."

With lake herring and lake whitefish

The decline of only two species of fishes, the lake herring and the lake whitefish, both of which along with the smelt are distributed in the shallow and intermediate depths of Lake Michigan (U.S. Dept. Interior, 1966) are believed to be affected, at some periods, by the smelt (Wells and McLain, 1973). But the steady declines of the herring and whitefish populations occurred prior to the smelt having become established in Lake Michigan and are attributed to heavy exploitation (Wells and McLain, op cit). Nevertheless, after the catastrophic smelt die-off of 1942-43, there was unusual success of the following few year classes resulting once more in high production of these two species. In addition, the subsequent declines in production which coincided with the resurgence of smelt to considerable abundance by the early 1950's suggested some possible adverse effects of the smelt to these two species. How the smelt could have influenced the decline of the lake whitefish is not clear, but presumably it could have been through competition for food, since Mysis is a favorite food of both lake whitefish and smelt. The competition for planktonic food with lake herring fry,

or predation on them or both by the smelt were suggested by Wells and McLain (1973) as being the cause of the decline of the lake herring. From the food habit studies by Schneberger (1935a; 1937), only a few young of these two species were found in smelt, and none was found in the recent study by Foltz and Norden (1974). Anderson (1969) indicated that the smelt in western Lake Superior was insignificant as a predator on coregonid eggs. Therefore, it remains possible that competition for food rather than predation by the smelt might have contributed to the decline of these two species; a similar suggestion was made by Anderson (op cit) for the decline of lake herring in western Lake Superior. To what extent the smelt contributed to the decline of these two species to the present low levels in Lake Michigan in comparison with the effects the sea lamprey on the lake whitefish, and the alewife on the lake herring, is not known. The increase of the lake whitefish in the 1960's, however, has been attributed to lessened sea lamprey predation (Wells and McLain, op cit).

With lake trout

Depth distribution of juvenile lake trout is shallow to intermediate, similar to that of smelt (U.S. Dept. Interior, 1966). In Lake Superior, they were most abundant at 20 to 29 fathoms (36 to 52 m.) which is in the range of the smelt distribution, 10 to 39 fathoms (18 to 70 meters) (Dryer, 1966). And, as stated previously, their primary

foods are also Mysis and Pontoporeia, like the smelt, it is therefore indeed possible that the smelt may compete with the young trout for these food organisms. How much this will affect the trout population in Lake Michigan is not known, but the smelt itself is a considerable part of food of these young trout, and the proportion increases directly with increasing size of the lake trout in Lake Michigan (Wright, 1968).

With bloater

For the bloater, although its foods are also Mysis and Pontoporeia (Wells and Beeton, 1963), the competition for food with smelt may not be great due to a low level of habitat sharing. The bloater is a deepwater fish and occurs in the greatest numbers from 12 to 50 fathoms (22 to 92 m.) in southern Lake Michigan areas where the smelt is most abundant at 5 to 17 fathoms (9 to 31 m.) (Wells, 1968). In the vicinity of the Apostle Islands, Lake Superior, bloater distribution is even deeper. Here the largest numbers are usually taken at 40 to 59 fathoms (72 to 106 m.), whereas the smelt are most abundant at 10 to 39 fathoms (18 to 70 m.) (Dryer, 1966). Moreover, during winter and spring while the smelt moves up to the shallows the bloater still lives in the greatest depths; and during the summer when the smelt moves to the deeper portion of the lake the bloater migrates into shallow areas (data from Dryer, op cit; and Wells, op cit).

With alewife

The interaction between the smelt and the alewife is very interesting. Both species are very abundant in Lake Michigan. Pontoporeia, one of the two most important food items of the smelt, is also the major item of alewife diet. It is not known to what extent smelt competition for food will affect the alewife population. The alewife, however, has been suspected of causing the decline of the smelt population in Lake Michigan in the 1960's (Smith, 1970).

As Prey

Thus far we have emphasized the possibilities that the smelt may compete for food with other valued fishes or prey on their young. Now we may do the opposite, i.e., consider the smelt when it is preyed upon by the other fishes. As stated earlier, the rainbow smelt was first planted into the upper Great Lakes as a forage fish for the introduced Atlantic salmon. Although the salmon failed then to establish, the native piscivorous, lake trout readily took the smelt as one of its major food items. The acceptability of the smelt is shown by Schneberger (1936; p. 3) who described the food of lake trout in Green Bay as follows: "Upon examination of their stomachs, it is not uncommon to find three and four smelt 8 inches long." And from late April to December the lake trout in northern Green Bay was found to subsist almost

entirely on smelt (Schneberger, 1937). The smelt in Green Bay, then, was also preyed upon, but to a lesser extent, by the yellow perch and the burbot.

In addition to the species of fishes presented here as predators of the smelt, it had been suggested that during the early period of the establishment virtually every piscivorous fish in the Great Lakes would consume the smelt if given opportunity (Van Oosten, 1940). Many later studies have supported this statement and added positive details of understanding to the predator-prey relationships in this large ecosytem.

In Lake Superior, adults of the lake trout fed heavily on the smelt, especially during the months of March to June (Hale, 1960). On a year round basis, smelt made up nearly two-thirds of the total volume of food of the lake trout (Dryer et al., 1965), with slightly greater proportions being taken by individuals longer than 38 cm. in the vicinity of the Apostle Islands (Griswold and Smith, 1973).

In Lake Michigan, smelt occurred in 28 percent of the immature lake trout stomachs, and comprised about 20 percent by volume; and the consumption of the smelt by the lake trout increased directly with the increasing size of the lake trout (Wright, 1968). In Little Bay de Noc, in northern Green Bay, the smelt comprised 76, 8, and 45 percent of the total food of the northern pike (Esox

lucius), respectively, during spring, summer and fall (Wagner, 1972). It also comprised 94 and 25 percent of the total weight of food in the walleye (Stizostedion vitreum vitreum) during the spring and fall, and 96 percent in the burbot and 100 percent in the bowfin (Amia calva) during spring. The individual smelt that had been preyed upon ranged from 6 to 25 cm. Similar results were found in a later study in the same area by Peck (1974).

Salmon recently introduced in the upper Great Lakes, namely, the coho salmon (Oncorhynchus kisutch) and the chinook salmon (Oncorhynchus tshawytscha), have also taken the smelt as a major part of their food, and the overall rates of consumption appear to be increasing. According to Rybicki (1973), in 1969 only 5 percent of the coho salmon studied were found to feed on smelt; this rate increased to 11 percent in 1971. Similarly, the rate of smelt consumption by the chinook salmon increased from 3 percent in 1969 to 30 percent in 1971.

The alewife was pointed to by Smith (1970) as possibly a major predator on larvae of the smelt, and this may have contributed to the decline of the smelt population as that of the alewife increased.

Conclusion

In conclusion, the rainbow smelt in Lake Michigan can be competitor for food, predator on young fish (including smelt) and prey for many piscivorous fishes. It is not

unusual for an organism to play more than one such role in an ecosystem. The important point is which one of these roles is more important to the community in terms of resource management. The effects of the smelt on the native fishes of Lake Michigan by competition for food, by predation, or by both, remain uncertain because there are other factors involved in the population fluctuations of these fishes. Previously noted, for example, have been the sea lamprey as a factor on the whitefish, the alewife on the lake herring, and the heavy exploitation on both species. But with all, it is clear that the smelt is useful as food for many piscivorous fishes in Lake Michigan, especially the salmonids. As it is the goal of the states around Lake Michigan to restore and augment the fisheries of this lake by planting millions of salmonids in it, the smelt could become increasingly important to the fish community and to the manager by serving as the food source for these fishes, especially the inshore species such as brook trout (Salvelinus fontinalis), brown trout (Salmo trutta), and rainbow trout (Salmo gairdneri) (Smith, 1970), although there is concern that its instability might provide a less productive and reliable forage base than the previous complex of native species (Smith, 1972b).

The smelt may also be a stabilizing factor as an alternative food source for those salmonids which now

depend heavily on the alewife for food (e.g., lake trout, coho salmon, chinook salmon), especially when there are sudden, even catastrophic, declines in population abundance of the alewife. Furthermore, smelt by its abundance, and distribution in Lake Michigan may serve as a buffer to predation upon the young of more valuable sport and commercial fishes. This possibility has been noted since the early period of smelt establishment. For example, it was believed that the smelt might help relieve the chub population from lake trout predation (Schneberger, 1936). At present, in Little Bay de Noc of northern Green Bay, the low predation of northern pike and walleye on yellow perch and other small game fishes, and the insignificant predation of resident piscivorous fishes on the planted coho salmon smolts are attributed to smelt serving as a buffer (Wagner, 1972; Peck, 1974).

THE RAINBOW SMELT FISHERIES OF LAKE MICHIGAN

Commercial Fishery

The rainbow smelt first entered the commercial fishery in 1931 when 400 pounds were reported taken in Green Bay from Michigan waters, and 86,000 pounds from those of Wisconsin (Van Oosten, 1947). The production then rose sharply to the million-pound level for all of Lake Michigan in 1934 (Fig. 12; Appendix Table 8). Following a slight decrease in 1935, the production then continued to increase steadily to reach its first highest recorded level of 4.8 million pounds in 1941. During the interval 1931 to 1939, the catch from the Wisconsin waters of Lake Michigan, mainly of Green Bay where the smelt fishery developed first, contributed the greatest part of the production (Van Oosten, op cit). The catch from the Michigan waters first became the major part of the total production in 1940, and has held the dominant position ever since. Total production declined slightly after the peak until 1943, and then fell abruptly in 1944 as a result of the die-off in 1942-43. A total of only 5,000 pounds of smelt were reported taken in this year. The production recovered quickly afterward and increased sharply to the second peak, the highest level of all time (9.1 million pounds), in

1958. This was followed by a sharp decrease until 1965 when slightly less than one million pounds were taken. The decline of the production during the late 1950's to the mid-1960's was the result of a reduced market demand and a decline in the population (Wells and McLain, 1973). Production increased again to 2.5 million pounds in 1969, and then decreased sharply to 745,000 pounds in 1972. The fluctuation of the production during this period may be due to the fluctuations in the population. In 1973 the production was only slightly higher at 867,284 pounds. The smelt production increased sharply in 1974 as the result of increased demand for export; in the first half of this year the production (about 1.7 million pounds) was nearly double the 1973 production.

The largest part of the annual commercial production of smelt in Lake Michigan has traditionally come from Green Bay with the northern area (MM-1) generally contributing the major part. The other areas of Lake Michigan that produced sizable catches of smelt were Wisconsin waters of southern Green Bay (WM-1), Michigan waters of the northern portion of the lake (MM-2 and MM-3), and the west shore areas from the tip of Door Peninsula to Milwaukee, Wisconsin (WM-3, WM-4, and WM-5) (Appendix Table 9). However, now only a few areas still produce considerable amounts of smelt annually, namely northern and southern Green Bay (MM-1 and WM-1), and the area around Two Rivers (WM-4).

Figure 12. Total commercial production of the rainbow smelt of Lake Michigan, 1931-73.

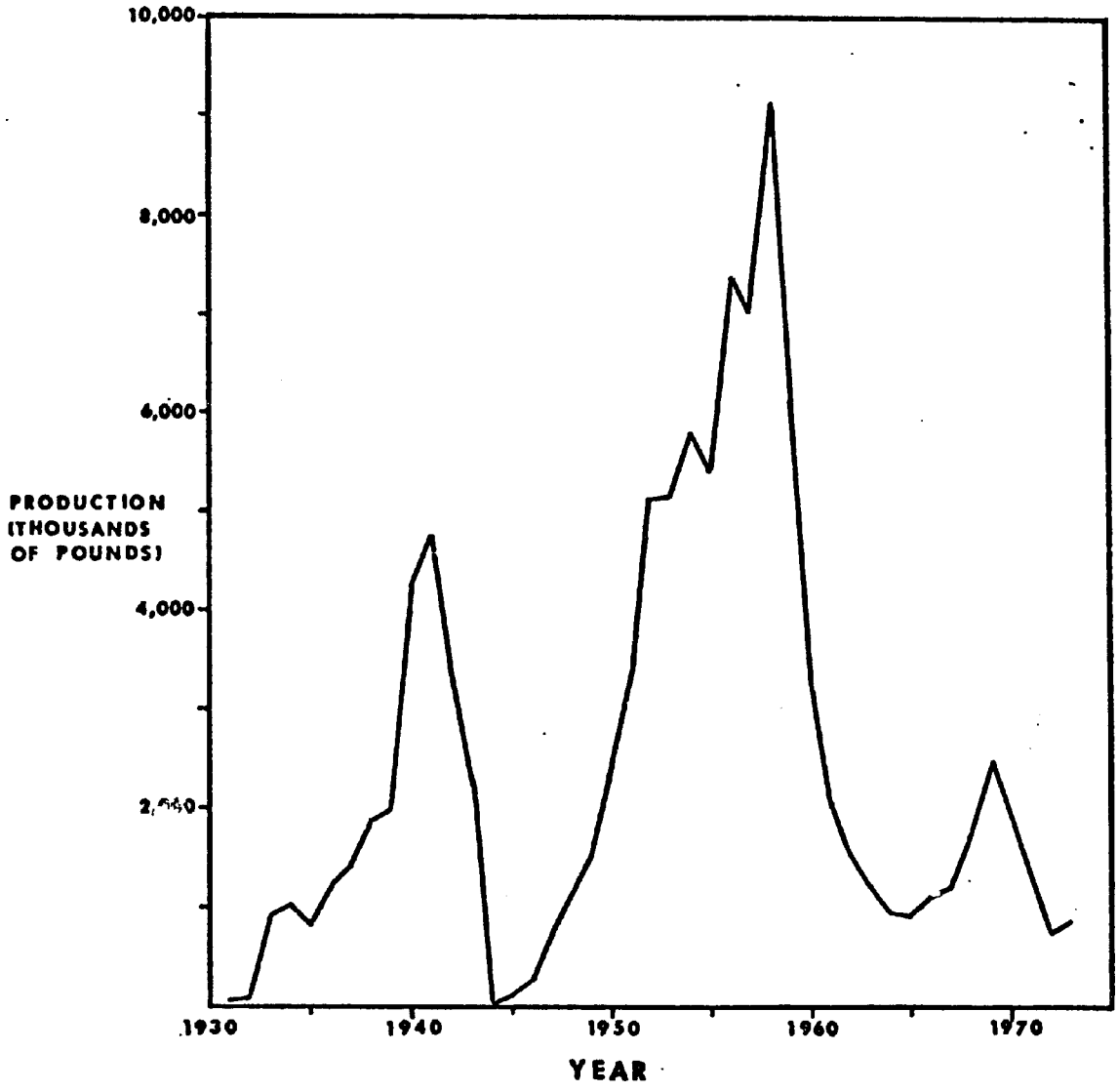

10,000
8,000
6,000
4,000
2,000
PRODUCTION
(THOUSANDS
OF POUNDS)
1930
1940
1950
1960
1970
YEAR

Figure 12

The major gear used in the commercial smelt fishery are small (one-inch stretch) mesh gill nets, pound nets, and bottom trawls. Gill nets and pound nets have been used widely since the beginning of the fishery, and they have contributed the greatest part of the annual production. Both are operated almost entirely during the winter months under the ice. Before the smelt die-off in fall and winter 1942-43 monthly catches increased from January to March and then fell away sharply in April, with March being the most productive month (Van Oosten, 1947). This condition held until 1951. Based on the catch recorded for pound nets in northern Green Bay, since 1952 the catch has been generally highest in April (Appendix Table 10).

Both gill nets and pound nets were extensively used in all fishing areas during the high production years of the 1950's. In Little Bay de Noc of northern Green Bay, the center of smelt production, the pound nets once numbered in the hundreds and were located for miles along the shore (Swanson, 1955). Now only a few pound nets are operated here and in a few other areas (WM-1 and WM-4). However, they still account for the greatest part of the annual production. Simultaneously, gill nets have lessend in numbers and production, although they are used in more areas than the pound nets.

Bottom trawls were introduced into the commercial smelt fishery in the late 1950's, first in Wisconsin waters

and then in those of Michigan. They are operated during the early spring (April), but are sometimes also fished in the early fall. Their catch had been considerable until recently. In northern Green Bay the catch by bottom trawls was as high as 357,400 pounds in 1968, but in 1972 and 1973 the catch was only 400 pounds. Now, only in the Wisconsin waters do the bottom trawls still produce a sizable catch each year.

As stated earlier, the smelt population in Lake Michigan, particularly in northern Green Bay, had decreased in abundance from the late-1950's to the mid-1960's. This also was recognized by Wells and McLain (1973). Smith (1970) attributed this decrease to the increase of the alewife. However, the catch per unit of effort of smelt by pound nets began to increase in the mid-1960's (Fig. 3) while the alewife was still very abundant, probably more abundant than in the above period. Alewife production reached a peak in both Green Bay and Lake Michigan in 1967 when total catch was 42 million pounds (Baldwin and Saalfeld, 1962). So if the alewife indeed was the major causative factor in the decline of the smelt during the late-1950's and mid-1960's the smelt should not have increased during the mid- to late-1960's. I believe that fishing pressure has had considerable effect on the smelt population of Green Bay, probably more so than the alewife or any other factors. Fishing pressure was very

intense during the 1950's. At Escanaba in northern Green Bay alone, as stated earlier, the pound nets numbered in the hundreds and were located for miles along the shore. More than 7,000 lifts of pound nets were recorded in 1956, just before the smelt began to decline. Gill nets and trawls were also numerous. Thus, over-fishing could have been a strong factor in the decline. The latter explosive increase of the alewife also could have helped to accelerate the decline of the smelt population. The increase of the smelt population from the mid-1960's on, when the fishing effort was declining and the alewife was still very abundant, helps confirm the importance of fishing pressure on smelt population dynamics.

The results from the application of the logistic or Schaefer's model by using the catch, catch per unit of effort, and effort data of pound net catches in northern Green Bay from 1950 to 1971 (Appendix Table 3) also support my hypothesis on the significant effect of fishing on the smelt population. The general formula of this model is as follows:

$$\frac{dB}{dt} = kB - \frac{kB^2}{K} - FB$$

where,

B = Biomass or population size
k = Constant
K = Carrying capacity or maximum population size
F = Fishing mortality

At equilibrium, $\frac{dB}{dt} = 0$

$$FB = kB - \frac{kB^2}{K} = Y_e, \text{ when } Y_e \text{ is an equilibrium yield (or catch)}$$

$$F = qf$$

where, q = Catchability coefficient

f = Effort

$$B = \frac{Y}{F} = \frac{Y}{qf} = \frac{U}{q}$$

where, U = Catch per unit of effort

From the general formula we can derive the equations for the relationships between the equilibrium yield and effort, and between the effort and catch per unit of effort as follows:

$$Y_e = Kqf - \frac{K(qf)^2}{k}$$

$$f = \frac{k}{q}\left(1 - \frac{U}{Kq}\right)$$

The details of the model, its application and calculation can be found in Schaefer (1954; 1957) and Pella and Tomlinson (1969). The results of the calculation are shown in Figs. 13-16. It is rather clear that during the 1950's the smelt population in northern Green Bay (MM-1) was over-exploited. The population was held at levels much lower than that which can produce maximum sustainable yield (Fig. 13). The catch (yield) points during this period are along the ascending (left) part of the stock-production curve. From 1956 to 1958 the population was exploited even more. The yields taken were more than

could be sustained by the population, as shown by the catch points of these years lying to the left side of the stock-production curve. And this, I believe, led to the decline of the population in the early to mid-1960's. The over-exploitation is also shown in Figs. 15 and 16. Here the levels of fishing effort were higher than that which would produce the maximum sustainable yield, and similarly, in 1956 to 1958 the fishing effort was even greater than that which would produce the equilibrium yield, as shown by the points lying to the right side of the equilibrium curve and line.

The smelt population began to decline in 1959, and continued declining until 1963. The fishing effort, however, was still at a high level in 1959, but has decreased drastically since 1960 due to the reduced market demand of the smelt, and, probably, also due to the response of the fishermen to the decrease of the catches. The smelt population increased slightly from 1964 to 1968, then increased sharply from 1969 to 1970. Although it may be shown (Fig. 15) that smelt fishing during 1961 to 1968 was at an under-exploitation level (points on the left side of the optimum level), the relatively low population during this period indicates over-exploitation (Fig. 13). From 1969 to 1971, however, it seems likely that the smelt population in northern Green Bay was underexploited. This situation may also hold at the present time. With the current levels of fishing effort the smelt population in northern Green Bay

Figure 13. Relationship between population size and estimated equilibrium yield of the rainbow smelt in northern Green Bay

Figure 14. Estimated population size of the rainbow smelt in northern Green Bay, 1950-71

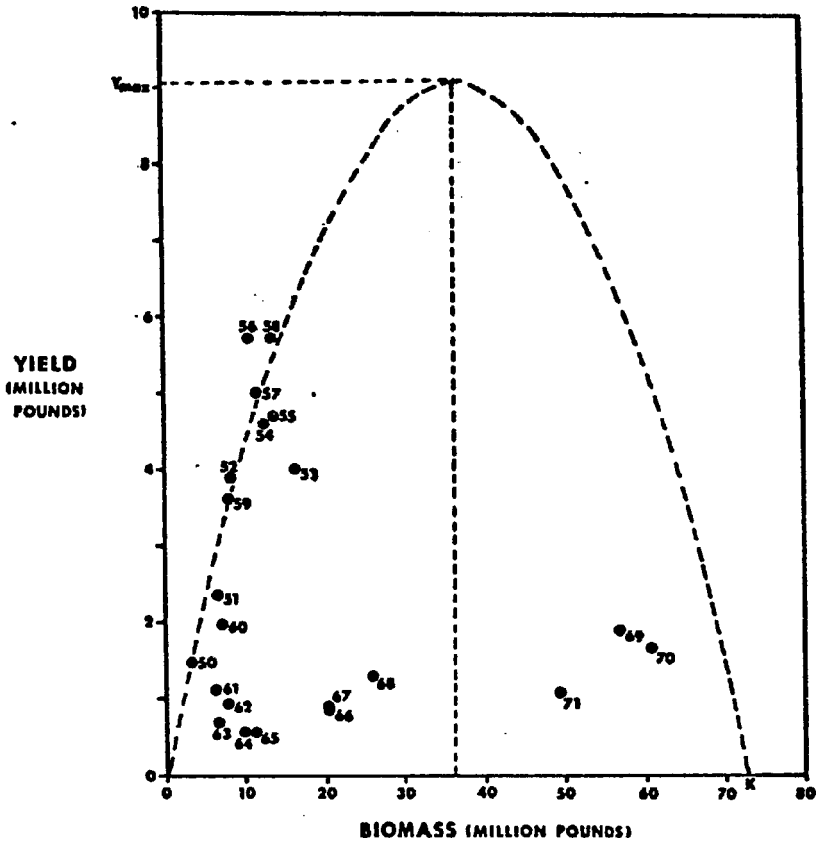


Figure 13

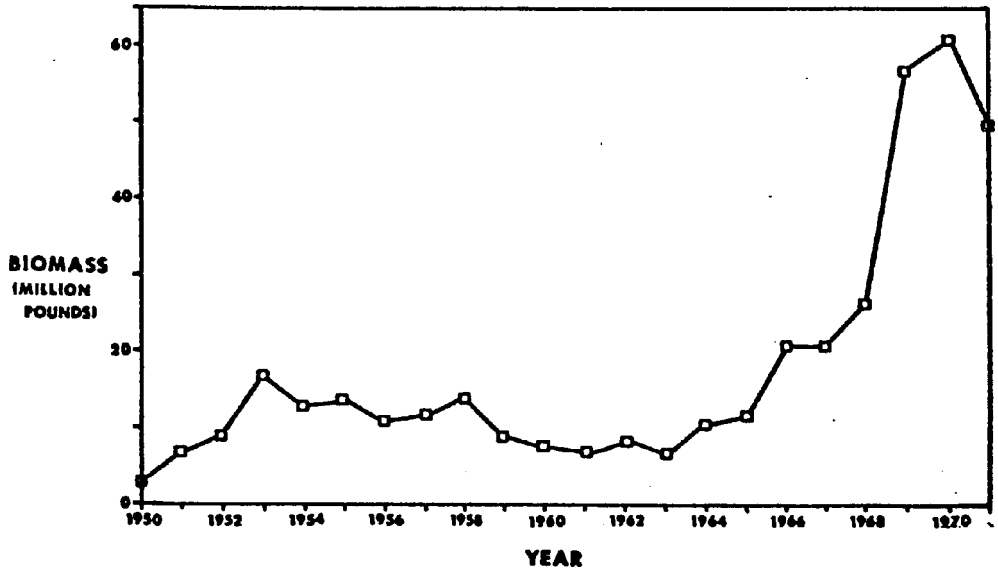


Figure 14

Figure 15. Relationship between fishing intensity and estimated equilibrium yield.

Figure 16. Relationship between fishing intensity and catch per unit of effort under equilibrium condition.

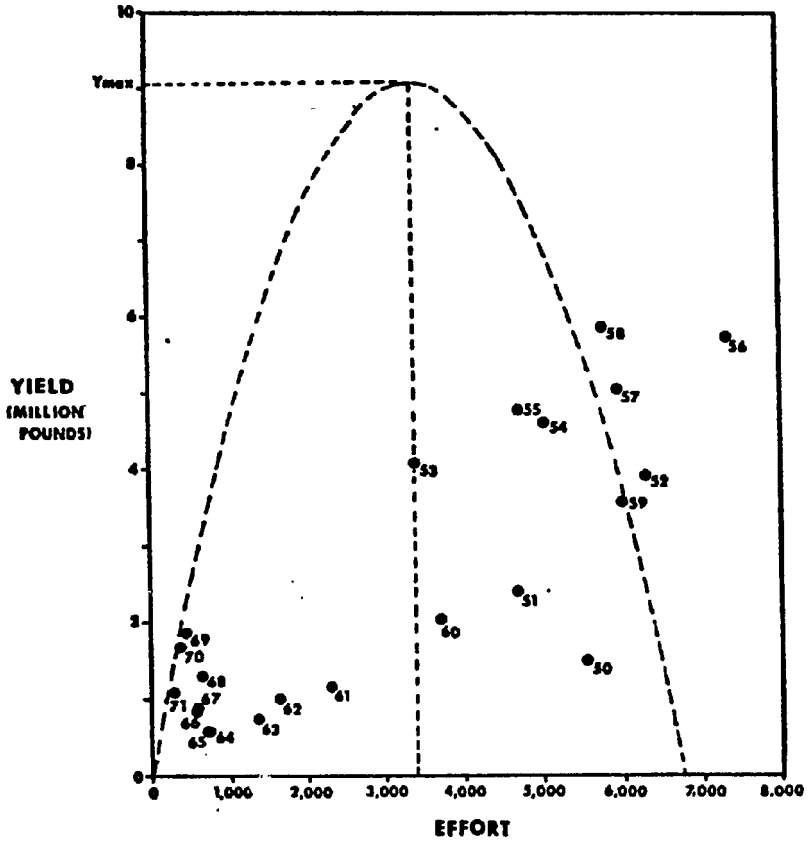


Figure 15

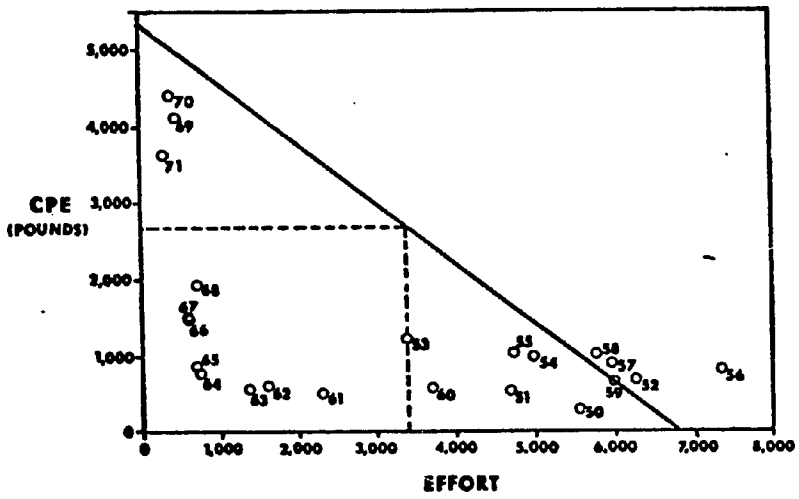


Figure 16

presently should be around 70 million pounds.

Theoretically, the relationship between effort and catch per unit of effort is a straight line, as shown by the estimated line of equilibrium (solid line) in Fig. 16. The unusually low values of CPE during the 1960's may be due to a time lag for the smelt population, which was very low in the early 1960's, to respond to the drastic decrease in fishing effort. Also, this condition probably was prolonged by the tremendous increase in the alewife population in the mid-1960's. The high values of CPE from 1969 to 1971 indicate an increase in the smelt population in response to low fishing effort.

From this model it was estimated that the carrying capacity or the maximum population size (K) of the smelt in northern Green Bay is about 73 million pounds, and the maximum sustainable yield (Ymax) is about 9 million pounds, at the population size of 36.5 million pounds (half of the carrying capacity) and the fishing effort of 3,400 pound net lifts. Therefore, at the present level of population abundance, about 9 million pounds (the maximum sustainable yield) may be harvested annually without damaging the population.

The present low level of commercial fishing also reflects the significant reduction in the mortality rate of the smelt population in northern Green Bay. At Escanaba, in 1941, during the high fishing intensity period, the instantaneous rates of mortality of smelt estimated from

the catch curve (data from Van Oosten, 1947) were high, 1.13 for fish between age-groups II and III, and 3.17 for fish between age-groups III and IV (Table 2; Fig. 17). The dominance of fish in age-group II, the first age-group to enter the pound net fishery, and the relatively few older age-groups in the catch also indicated the possibility of over-exploitation during this period. In 1971, however, the instantaneous rates of mortality estimated from the catch curve (data from Robinson, 1973) were exceptionally low, only 0.52 for fish between age-groups III and IV, and 1.32 for fish from age-groups IV through VII. The fish in age-group III were most abundant; and more older age-groups, up to age-group VII, were found in the catch in this year. This seems to indicate that the smelt population in northern Green Bay, at present, may be underexploited.

The estimation of the instantaneous rate of mortality (i) of rainbow smelt from the descending right limb of the catch curve was done by the following equation:

$$Z = 2.3026 \left| (\log_{10} n_t - \log_{10} n_{t-1}) \right|$$

where n_t = number or percentage of fish in age-group t

n_{t-1} = number or percentage of fish in age-group t-1

2.3026 = constant to convert the common logarithmic value to natural logarithmic value

Table 2

Estimated mortality rates for the rainbow smelt from different areas of Lake Michigan using the catch curves

Areas	Years	Ages or lengths	Mortality rate	
			instantaneous	annual
Escanaba[1]	1941	II-III	1.13	0.68
		III-IV	3.17	0.96
Escanaba[2]	1971	III-IV	0.52	0.40
		IV-VII	1.32	0.73
		130 mm.+	0.92	0.60
Saugatuck[3]	1972-73	140 mm.+	1.32	0.73
Ludington[3]	1971-72	140 mm.+	1.39	0.75
Manistique[3]	1971	120 mm.+	1.22	0.70
Two Rivers[2]	1971	140 mm.+	1.25	0.71

[1]Data from Van Oosten (1947)

[2]Data from Robinson (1973)

[3]Data from the experimental bottom trawl catches

Figure 17. Catch curves for the rainbow smelt taken by pound nets near Escanaba in northern Green Bay, Michigan in 1941 (data from Van Oosten, 1947), and in 1971 (data from Robinson (1973).

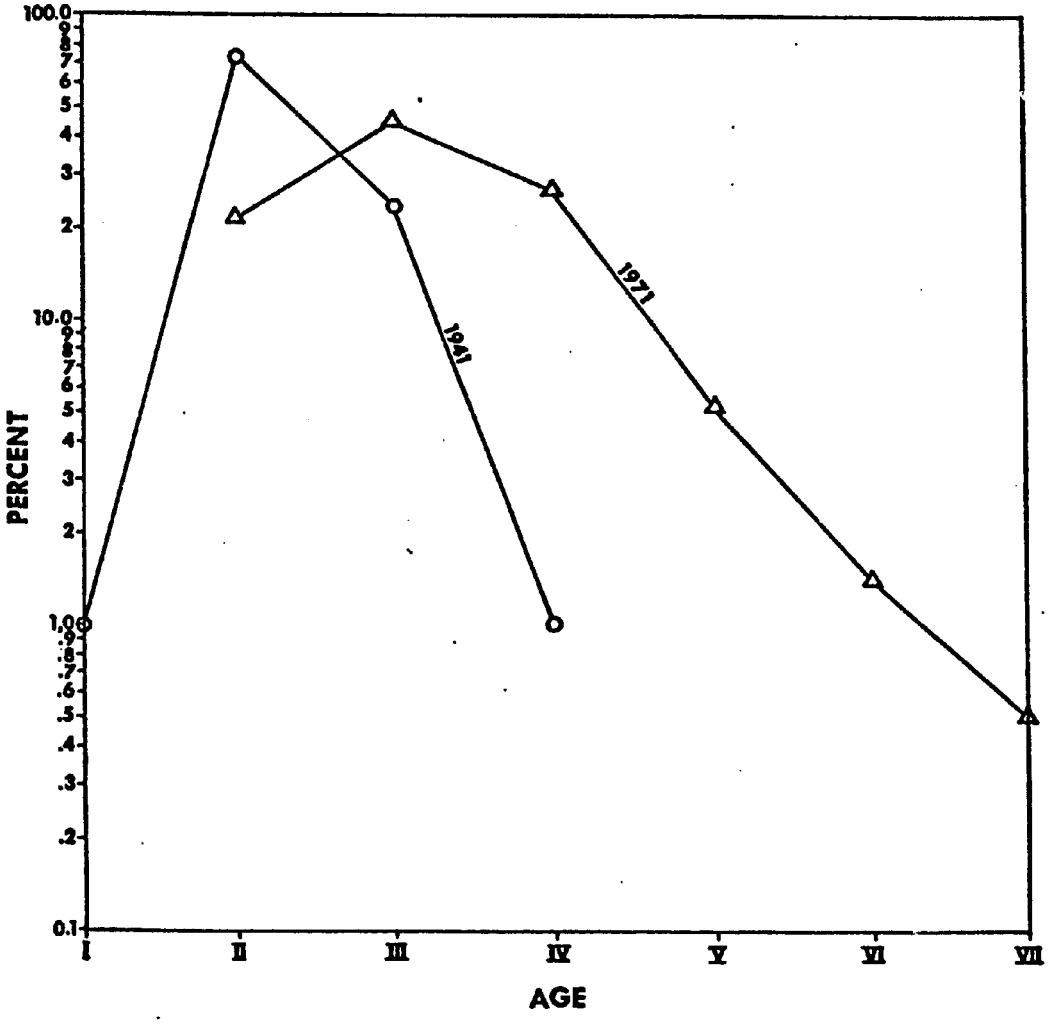


Figure 17

The annual rate of mortality (a) was, then, calculated by the equation

$$a = 1.0 - e^{-Z}$$

The details of this method are discussed fully by Ricker (1958).

The instantaneous rate of mortality for smelt collected near Escanaba in 1971 estimated from a catch curve based on length frequency (data from Robinson, 1973) was considerably lower than that previously estimated from a catch curve based on age. It was estimated to be about 0.92 for fish 130 mm. and larger (age-groups II and older) (Table 2; Fig. 18). This is because the fish in age-groups II and III also were included in the calculation.

The estimation of the instantaneous rate of mortality using the catch curve based on length frequency was done from the equation,

$$Z = 2.3026\ Z'k$$

where,

Z' = slope of the regression line of the descending right limb of the catch curve with the sign changed.

k = slope of the regression line of mean total length and age.

2.3026 = constant.

The annual mortality rate (a) was calculated from the above equation.

The limitation and details of application of this method can be found in Ricker (1958).

The relationship between the mean total length and age, based on the data from Robinson (1973), is almost a straight line (Fig. 19) which indicates the relatively constant growth rate of the smelt from age-group II through VI.

The estimation of mortality rates of smelt in other areas of Lake Michigan, including Saugatuck, Ludington, Manistique, and Two Rivers, was done by using catch curves based on length frequencies from the catches taken by experimental bottom trawls (Appendix Table 11; and Robinson, 1973). At Saugatuck and Ludington where the commercial smelt fishery has been very small or practically non-existent the instantaneous rates of mortality for smelt 140 mm. and larger (age-groups II and older) were 1.32 and 1.39, respectively (Table 2; Fig. 20). The relatively high mortality rates in these areas, which may be considered as due solely to natural mortality, may lie the explanation for the generally low abundance of smelt in this part of the lake. At Manistique and Two Rivers where smelt has been little to moderately harvested by commercial fishermen, and its abundance is greater than along the eastern shore, the instantaneous rates of mortality were slightly lower--1.22 for smelt 120 mm. and larger at Manistique, and 1.25 for smelt 140 mm. and larger at Two Rivers (Table 2, Fig. 21).

Figure 18. Catch curve based on length frequency for the rainbow smelt taken by pound nets near Escanaba in northern Green Bay, Michigan in 1971 (data from Robinson, 1973). Broken line is the regression line.

Figure 19. Relationship between the mean total lengths and ages of the rainbow smelt from Lake Michigan (data from Robinson, 1973). Broken line is the regression line.

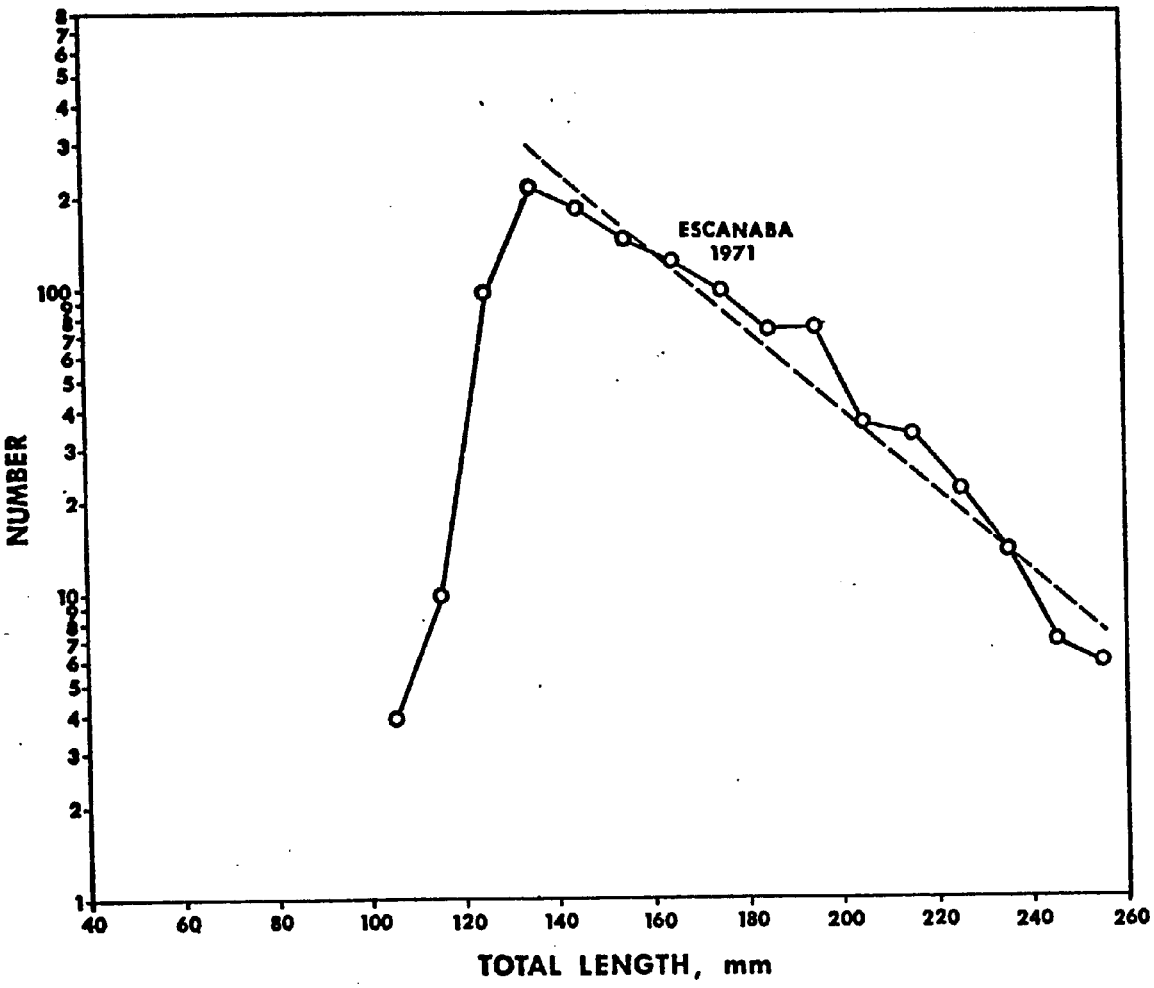


Figure 18

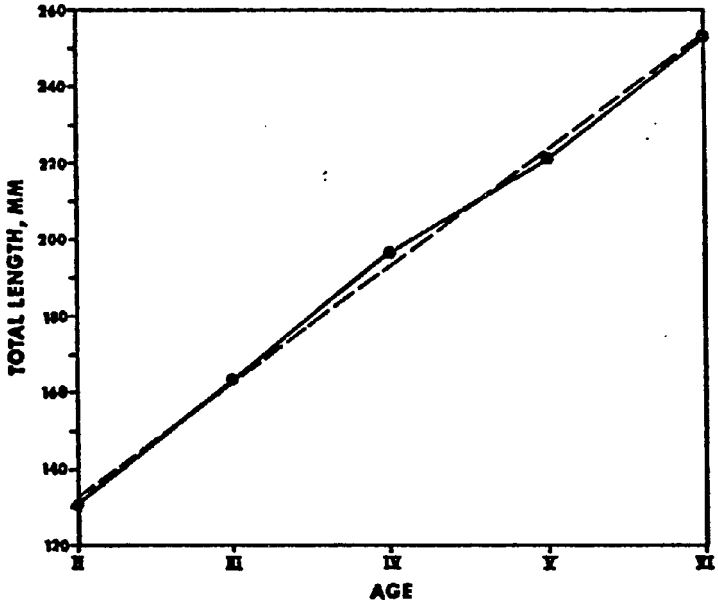


Figure 19

Figure 20. Catch curves based on length frequencies for the rainbow smelt taken by experimental bottom trawls near Saugatuck, Michigan, in 1972-73, and near Ludington, Michigan in 1971-72. Broken lines are the regression lines.

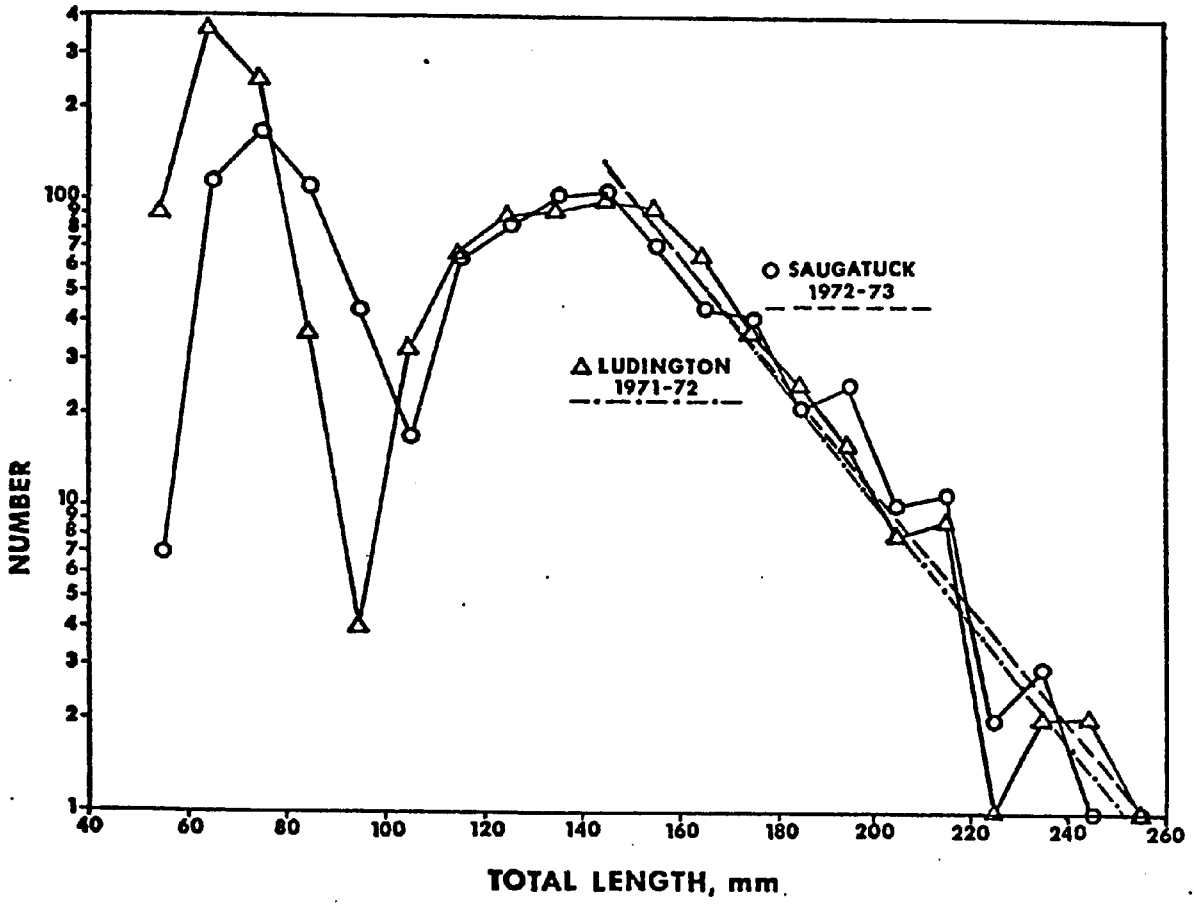

NUMBER
TOTAL LENGTH, mm
O SAUGATUCK
1972-73
Δ LUDINGTON
1971-72
40
60
80
100
120
140
160
180
200
220
240
260

Figure 20

Figure 21. Catch curves based on length frequencies for the rainbow smelt taken by experimental bottom trawl near Manistique, Michigan in 1971, and by bottom trawls near Two Rivers, Wisconsin in 1971 (data from Robinson, 1973). Broken lines are the regression lines.

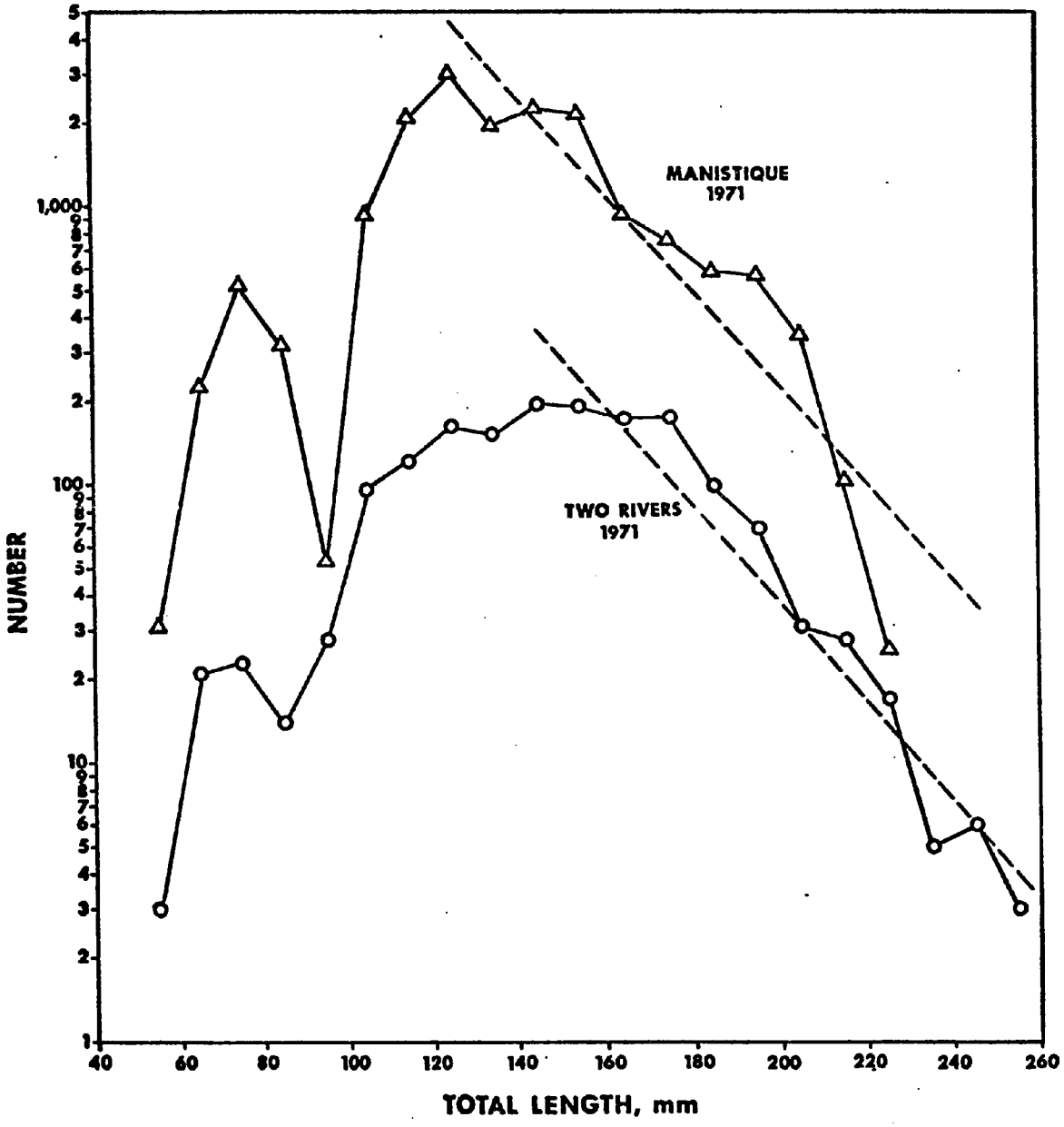

MANISTIQUE
1971
TWO RIVERS
1971
NUMBER
TOTAL LENGTH, mm
1,000
100
10
1
40
60
80
100
120
140
160
180
200
220
240
260

Figure 21

Sport Fishery

Fishing through the lake ice during fall and winter and dipping along the lake shore and in the lower reaches of streams during the spring spawning runs have been a fairly popular sport in the Lake Michigan basin since smelt was first established. It was estimated that about 125,000 pounds of smelt were taken by hook-and-line fishing in 1936 (Van Oosten, 1940). In the past, several northern Michigan communities, namely, Beulah, Boyne City, East Jordan, Menominee, and Escanaba, set up smelt festivals during the spawning runs. These festivals attracted tens of thousands of visitors each year (Mich. Dept. Conserv., 1936). In fact, smelt dipping used to be the largest source of smelt production. In Green Bay it was estimated that during the 1935 spawning run, 447 tons of smelt were taken from the Marinette River, Wisconsin (Schneberger, 1936), and in the spring of 1936 about 3,250 tons of smelt were taken from the Menominee River at Marinette, Wisconsin, and 1,460 tons from the streams in Menominee and Delta counties, Michigan by dipping (Schneberger, 1937). In the spring of 1939 these two counties produced about 5.3 million pounds of smelt by dipping, and possibly a comparably large quantity was produced in Wisconsin waters (Van Oosten, 1940). The total commercial production from Lake Michigan in 1936 and 1939 was only 1.2 and 2.0

million pounds, respectively. It was said that dipping during the spawning runs produced, at least, as many pounds as the commercial fishermen harvested during the entire winter (Bower, 1954).

The high production by sport fishermen is probably due to the concentration and abundance of smelt, as well as to the relatively high efficiency of dip netting. For example, it was reported that in Wisconsin streams during the peak of the runs two men sometimes dipped out as many as 10 tons in an evening (Patterson, 1948). Unfortunately, at time of high abundance, the greatest part of the catch by sport fishermen was wasted because of the glut (Van Oosten, 1940).

Smelt dipping in the past not only has accounted for the greatest portion of the total production of smelt in Lake Michigan waters but it also has provided great sport to fishermen. Furthermore, this fishery helped the economic conditions of several northern Michigan communities both indirectly and directly through the festivals that were established. Now, smelt dipping in Lake Michigan is less popular and less advertised than it was in the past. This may be due partly to the low market demand. Nevertheless, a considerable quantity of smelt still is taken annually by sport fishermen. In 1973 about 36,810 sport fishermen spent about 95,850 angler days in Michigan waters of Lake Michigan dipping for smelt, yielding about 1.8

million pounds of fish (Jamsen, 1974). The catch is about twice the commercial catch, and increased about three times from the 1972 catch of 532,100 pounds (Jamsen, 1973). The large portion of the catch has come from the northern part of the lake, in counties such as Manistee, Emmet, Mackinac, and Delta, and from the waters near and in such tributary streams as Carp Lake River, Ford River, Leland River, Bark River, and Brewery Creek in Grand Traverse Bay.

Present catches by sport fishermen are believed to be more fully utilized than in the past, although there is no way of knowing the amounts used for family consumption or sold to the market.

Market

When the rainbow smelt was first commercially harvested in Lake Michigan during the 1930's, the fishermen were very skeptical of the market value of this fish. Therefore, they sometimes mixed smelt with lake herring when selling to wholesalers (Bjerg, 1935). However, during winter, the price per pound of smelt was sometimes higher than lake herring (Bjerg, op cit). The smelt was sold either fresh or frozen. Fresh fish were packed, iced top and bottom, and shipped to markets as far away as New York, Boston, Cleveland, Detroit, and Chicago (Van Oosten, 1940). There is no figure available on how many of these fish were used for human consumption or animal food. It

is generally understood that during the winter, when other fishes were scarce and smelt could be caught by pound nets under the ice, it would be sent to distant markets without appreciable deterioration and used mostly for human consumption. The price of smelt to the fishermen during this period might be as high as 15 cents per pound, although the average price was only 3 to 4 cents per pound (Van Oosten, op cit). During the spring when the greatest numbers of smelt and other fishes were caught both by the commercial and sport fishermen, the largest part of the catch would be used as the animal food. The price of smelt to the fishermen during such times was very low, seldom more than 2 cents per pound; sometimes they were even rejected (Van Oosten, op cit).

The market for the rainbow smelt of Lake Michigan was best during the 1950's, after the recovery from the mass mortality in 1942-43. It is during this period, in 1958, that smelt production reached its highest recorded level of 9.1 million pounds. The market demand for smelt as human food was high, as indicated by several processing plants at Escanaba in northern Green Bay, Michigan (Swanson, 1955). However, Lake Michigan was not the only smelt producer. The smelt production from Canadian waters of Lake Erie was considerable, and increased steadily. Nevertheless, the processing plants in Ontario also bought smelt from Lake Michigan (LaRue Wells, personal

communication). The major part of the catch during the 1950's, however, was used as animal food, especially for mink and as canned cat food; mink ranchers using the largest part (Euers, 1960).

The sharp drop in smelt production from 1959 to 1965, as pointed out earlier, is believed to be the result of both a reduced market demand and a decline in the smelt population. During this period the smelt production in Lake Erie increased tremendously and reached its highest level of 19 million pounds in 1962, nearly all (96 percent or more) being from the Canadian waters. The increase of smelt production from Lake Erie not only competed for the market with the smelt from Lake Michigan, but the Ontario processing plants also stopped buying the smelt from Lake Michigan (LaRue Wells, personal communication). The market was even worse during the mid-1960's when mink ranchers decreased their use of fishes from the Great Lakes due to reports of complications in reproduction when mink was fed with Lake Michigan fishes. A study has shown that mink fed with Lake Michigan coho salmon, bloater, and yellow perch, although not with smelt, had reproductive failure plus a high mortality rate in both kits and adults (Aulerich, Ringer, and Iwamoto, 1973). Polychlorinated biphenyls in the fish, possibly synergized by DDT which was also present, were suggested in this study as being at least in part responsible for this problem. The antimetabolite,

thiaminase, which is contained in several species of fish including the alewife is also believed to cause a similar problem (U.S. Dept. Interior, 1966).

Thus many interrelated factors, including the decline of the smelt population, have forced many operators to quit smelt fishing. In northern Green Bay, Delta County, Michigan, there were about 200 licensed fishermen who employed 500 extra men during the 1950's, and all depended to a certain degree on smelt to earn a living (Swanson, 1955). At present this number is greatly reduced. For example, in the winter 1974, there were only two fishermen operating pound nets in Little Bay de Noc (M. H. Patriarche, personal communication), where formerly there were many. Similar decreases in the number of fishermen and in fishing activity for smelt are believed to have occurred throughout the Lake Michigan basin.

There are, however, several reasons for believing that the demand for smelt of Lake Michigan will increase again, perhaps in the near future. First, the high price for meat may force people to consume more fish. Second, the smelt population in Lake Erie is declining and may be soon greatly reduced by the infestation of a protozoan parasite, Glugea hertwigi (Smith, 1972b). Third, the export of coarse fishes from the Great Lakes is feasible and may also soon increase. For example, in winter 1974, Japan ordered about 4 million pounds of coarse fishes

from Green Bay alone, apparently for human consumption, and paid 5 cents a pound (H. J. Buettner, personal communication). The usual price for smelt is 2 to 4 cents a pound. It is likely that smelt will comprise the largest part of this order. The production of smelt in 1974 has already responded to this increase in demand. The commercial catch from January to July 1974 reached 1.7 million pounds, about twice the 1973 production.

INFORMATION SYSTEM FOR MANAGEMENT DECISIONS ON THE RAINBOW SMELT IN LAKE MICHIGAN

It was an objective of this study to gather the available data and information that would facilitate decision making as to whether or not the smelt population in Lake Michigan should be managed. Several criteria for decision making will be formulated for fish in general with the hope that they could be applied to other species as well. In the process, the needs for certain additional information will be identified and related to management measures in the event they are to be exercised.

Information is of course the basis for management. Managers use information to make decisions that lead to a satisfaction of the objectives of the enterprise. Without information there can be no real management, only guesswork. In fishery management two steps of decision are generally made; one is the decision to institute management, and the other is to select the measure(s) to be used in accomplishing the goal(s) of the activity. For example, when a fishery manager has decided to release fish fingerlings into a lake in order to increase the production of that lake, he has already passed these two steps of decision. First, he has determined that the production of this lake can be increased, and then he has chosen stocking (species,

time, place, fish size, number of fingerlings) as the overall method in the face of the several other ways to increase the production. Any exercise of fisheries management that we have seen usually takes place after the second decision has been made. In many instances the first step of decision making is obvious. The manager uses an intuitive mental model in taking it. For example, in the sea lamprey control program in the upper Great Lakes, where it was obvious that this lamprey was destructive to many native fishes, the first decision on whether or not to control it was intuitive. The second decision on what kinds of control should be practiced took considerable research to reach. In other instances, however, when there are many variables or factors involved, and the interactions among these variables are complex, the manager may have to use a great deal of complicated information in order to make his decisions. This is when the application of an information system is most advantageous.

In this study the emphasis has been placed on the first step of decision--whether or not the rainbow smelt in Lake Michigan should be managed. Nevertheless, at both of the steps of management decision, the pattern of the information system is simple and direct (Fig. 22).

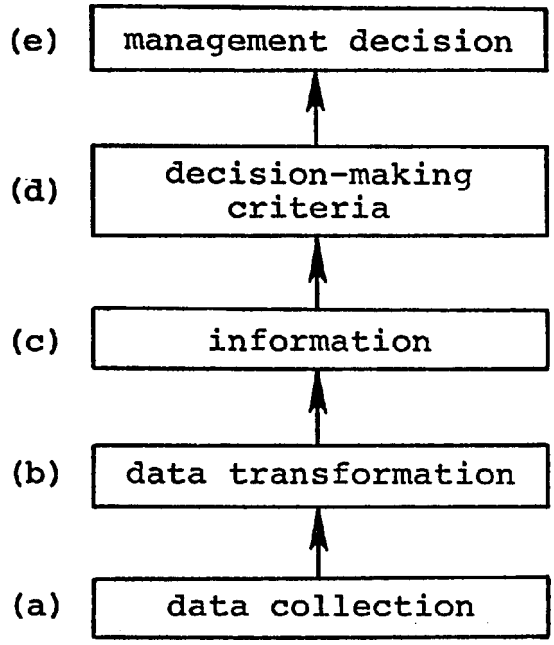


Figure 22. Diagram of information system for management decision making

Data are the raw form of information. As such, they may not tell us much about the relationship among variables. In a well planned study aimed at decision making, the required data should be specified, and the data collection techniques should be specifically prescribed before they are sought in the field. The transformation of the data can be only tabulation, or it may be transformed in complex operations of modeling, simulation, or other such techniques.

The data of the present study encompasses the aspects of life history, ecological roles, population condition, and fisheries of the rainbow smelt in Lake Michigan which have been described in the previous sections, including the collection and transformation of these data and information.

Although fishery management has different definitions, the objective seems to be generally agreed upon--to obtain the maximum sustainable physical yield in terms of weight or numbers of fish taken. This concept has been challenged by some economists, for example Crutchfield (1965), for its practicality. They argue that the greatest physical yield does not necessarily provide the greatest revenue, or the greatest profit, or the greatest employment, and that any of the latter objectives may be more desirable. They have proposed instead the objective of maximizing the net economic yield which is defined as the

greatest surplus of return over the full cost of capital and labor to be used. The restriction of entry into a fishery and the use of the most efficient gears available are suggested most often as the measures to attain this economic goal of management. In some fisheries the total catch will not be changed more than 10 to 15 percent whether there is management action or not, whereas appropriate action could reduce cost by 50 percent or even more (Gulland and Robinson, 1973). In commercial fisheries the latter is obviously a desirable goal of the management.

Recently, the Sport Fishing Institute adopted this economical concept which they called the optimum sustainable yield and urged it to be substituted for the former solely biological goal of maximum sustainable yield (The Sport Fishing Institute, 1974). This concept guides fishery management regimes as follows (p. 1):

> "Optimum sustainable yield refers to the largest net economic return consistent with the biological capabilities of the stock, as determined on the basis of all relevant economic, biological, and environmental factors. Most international agreements state as their basic objective maximizing sustainable yields from the stocks. The maximum sustainable yield is achieved when the annual catch is at the highest level (in terms of number or weight of fish caught) which can be sustained without harming the reproductive ability of the stock. However, many experts believe that use of the maximum sustainable biological yield objective in fisheries management may lead to substantial economic waste and may ignore important environmental relationships between stocks from which yields cannot be maximized simultaneously. It seems more desirable therefor to adopt the objective of optimum sustainable yield defined to include

> biological, economic, and environmental factors as the guideline for fishery management in an extended fishery zone and over anadromous species of fish."

However, in spite of its sound logic, the optimum concept is still challenged by some experts for its international applicability. Since the physical yield of this concept is usually below the maximum sustainable yield (Crutchfield, 1965), this concept is said to make sense for the industrialized countries, but as long as people in developing countries go hungry, and the production of food resources remains below the maximum level and cannot be made up by imports, a level of fishery resource exploitation below the maximum sustainable yield does not seem to be justifiable on a global basis (Onarheim, 1973).

The preceding discussion deals with management of commercial or food fisheries. In sport fishery management many costs and values cannot be measured in terms of weight of fish or dollars as in the commercial fishery. The catch is the big part but not the only part of value fishermen receive from their sport. Relaxation, esthetic enjoyment, social experience, and quality of sport are also elements of value, but these usually are associated with the catch. The cost includes the license to fish, tackle, travel, time, which are social, economic, and psychological functions. This makes it difficult to use the standard cost-value curve for determining the level of maximum net economic yield in the sport fisheries.

In the Great Lakes, the Michigan Department of Natural Resources established a management policy in 1966 that stated (Keller et al., 1974; p. 73):

> "The broad goal of our Great Lakes fisheries program is to manage these waters for maximum development of both sport and commercial fishing. There is room for both, and there is no reason to predict at this time that one must be sacrificed for the other. However, in some areas of the Great Lakes and for some species of fish, it is entirely possible that conflicts between sport and commercial fishing interests may arise. In such instances we believe the commercial interest must be subordinated to the recreational interest. In other words, development of the sport fishery must be our primary management goal when there is a choice to be made."

It is not quite clear what the "maximum development of commercial fishing" really means. It can mean the development or management to obtain either the maximum physical yield or maximum economic yield.

In making a decision of management for any fish species it is not always that the manager wishes to maximize or optimize the yield of the particular species being managed. He may wish indirectly through managing one species to maximize or optimize the yield of another. For example, the smelt was introduced into the upper Great Lakes to benefit the Atlantic salmon. It is also possible that the decision of managing a certain fish species may not be because of its economic value or its involvement with other species at all. For example, the Michigan protection of the lake sturgeon (Acipenser fulvescens) from commercial fishing during the 1929-1950 and its

classification for restricted use as a game fish in 1958 was to protect a fish that was becoming rare to the extent that its survival seemed endangered.

From the above discussion it is apparent that in making a decision of management of any fish species, it is not only that we want to maximize or optimize the yield of that particular fish, but also that we may want to manage it because of its effects on the other more desirable species, its natural significance, or taxonomic importance. Therefore, I propose the following criteria to use in decision making for the management of any fish species (Fig. 23).

Evaluation will be made at each of these three points in the decision-making process (I, II, and III in Fig. 23) before the management decision can be made. Various types of information are required at each of these points for the evaluation as follows:

I. Importance of a Fish Species

At this step the fish is evaluated for economical, biological, and natural importances. The fish may possess one, or two, or three of these qualities.

A. Economical importance. The fish is evaluated not only for its contribution to the sport and/or commercial fisheries (cost and value), but also its interference with other fishing operations or other human interests.

Figure 23. Criteria (points of evaluation) for the decision making on whether or not a fish species should be managed.

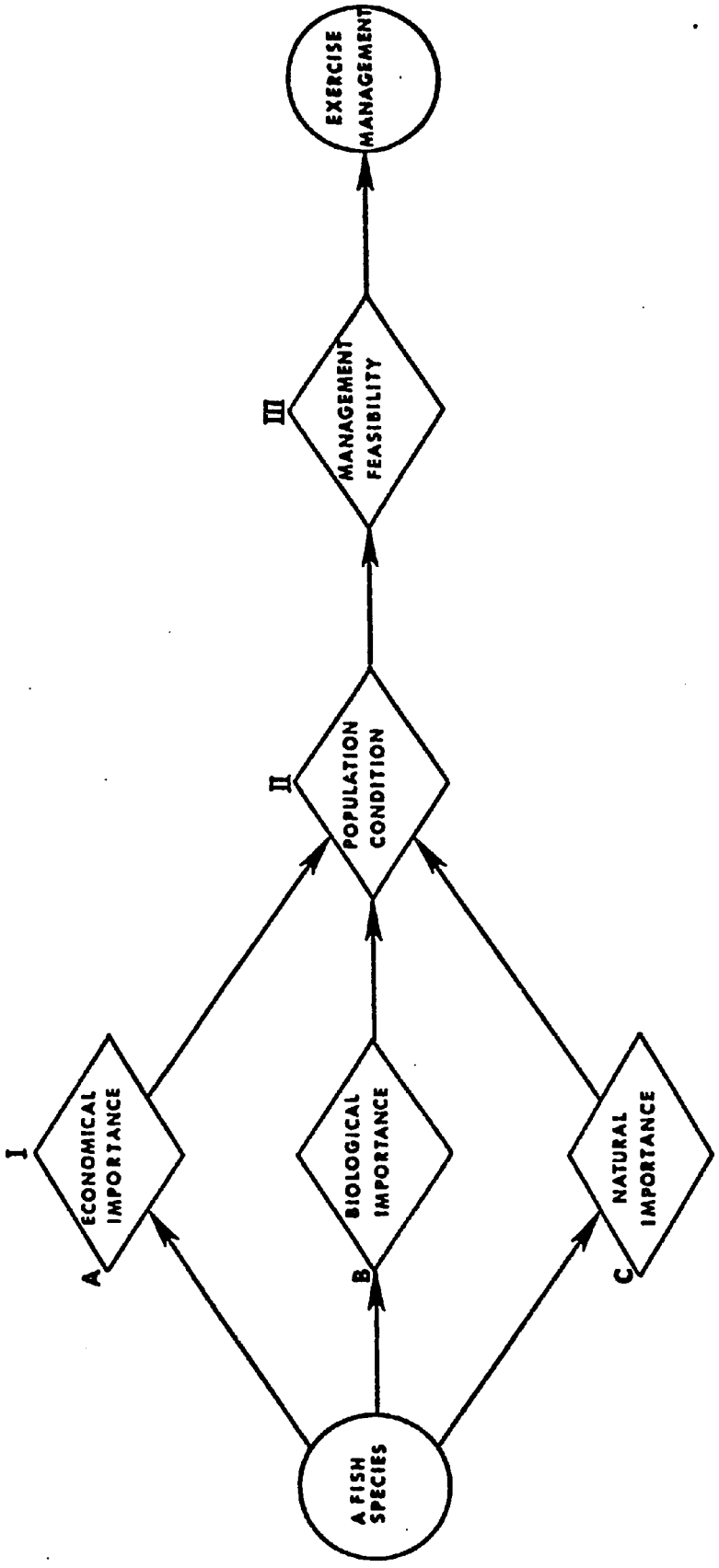

EXERCISE MANAGEMENT
III
MANAGEMENT FEASIBILITY
II
POPULATION CONDITION
I
A
ECONOMICAL IMPORTANCE
B
BIOLOGICAL IMPORTANCE
C
NATURAL IMPORTANCE
A FISH SPECIES

Figure 23

Different kinds of information are obviously needed for the evaluation.

1) Cost and value to the commercial fishery. The value of the annual catch related to the cost of the fishing operations will show how much profit the fishermen receive from fishing for this species. This information is very useful for the manager's understanding the relationship between cost and value, and the condition of the fishery so that he will be able to decide at what level fishing pressure should be maintained in order to obtain the maximum benefit (optimum sustainable yield). For the rainbow smelt, as discussed earlier, it was fished intensively during the 1930's through the 1950's. The presently low production is due mainly to the restricted market demand, but this situation may soon be changed by the possible increase in demand for export.

2) Cost and value to the sport fishery. Cost and value related to the sport fishery are more difficult to measure than for the commercial fishery since they cannot be assessed only in term of dollar spent or pounds of fish taken. They involve many other factors such as time, relaxation, esthetic enjoyment, social experience, quality of sport, all of which contain psychological elements. Another feature that makes the sport fishery different from the commercial fishery is that a large part of cost of fishing supports private enterprise--hotels, restaurants,

boat and fishing tackle manufacturers, etc. These costs are certainly good for the economy of communities and state. A much smaller cost, the license revenue, supports the sport fishery management activity of the state. Therefore, the objective of the sport fishery is to introduce more effort to the point where the fishermen's profit is zero and the interest in fishing levels off or declines. Generally, the fishery manager would like to have more fishermen participate and spend more money in the fishing. However, he will also have to raise the value of the fishing to accommodate these fishermen by making fishing more enjoyable, e.g., catching more fish. Therefore, the importance of the fish in the sport fishery may be measured by the number of fishermen who participate and the money they spend on their sport.

Smelt dipping was a popular sport in the Lake Michigan basin during the 1930's through the 1950's. Tens of thousands of people used to participate in the smelt festivals each year. Although presently it seems less popular and less advertised than in the past, a considerable number of fishermen still go smelt dipping each spring.

3) Interference with other activities. This type of information may be important for some fish species even though it may never be the critical point that determines whether a species is to be managed. For example, the alewife, in addition to fouling gill nets set for other

fishes, often causes problems when it is concentrated along shore in spring by clogging intakes of steel mills, power plants, and municipal water filtration plants. It also seasonally dies in huge numbers and collects in windrows on the beaches which makes an unpleasant sight and may create a health hazard.

B. Biological importance. The interrelations of one particular fish species with other associated species are also an important criterion to be used in management decision-making. A fish may not have an economical importance by itself, but it may be the predator, competitor, and/or prey to the more desirable fish species. Its biological importance to the fish community will finally become economically important to man, the major sink of the aquatic ecosystem. The information base for this criterion is the evaluation of the ecological roles, as done in the previous section. However, another kind of information, fish behavior, is also important and should be included in this point of evaluation. When one species of fish becomes dominant among the others it may not be only that it preys on, or competes for food with these fishes, it may be also that its aggressiveness, territoriality, or other behavior interferes with the activities of the other fishes. From studies in the laboratory or in the field one would hope to draw more definite conclusions about such behavior and to interpret the effects on other fishes.

C. Natural importance. The measure taken to protect some birds, mammals, or other animals from extinction have been known generally for a long time. These animals may not have great economical or biological values, but they may be the endemic species, or the only living members of some particular taxonomic groups. Their extinction may mean a great loss to studies in natural history, taxonomy, and evolution. More than 300 species and subspecies of fishes were listed as in a threatened condition, and among these, 30 species and subspecies were listed as nationally endangered (Miller, 1972). In Lake Michigan, the largest deep water ciscoes, Coregonus nigripinnis and C. johannae, and two of intermediate-size, C. alpenae and C. zenithicus, are probably extinct (Wells and McLain, 1973). The lake sturgeon, once commonly found, has also become very scarce. Now it is declared by the U. S. Department of Interior and the state of Michigan as an endangered species. Some measures have been taken to protect this fish from further decline, such as the closure of the commercial fishing during 1929-1950, and the declaration of it as a game fish in 1958, as previously stated. These measures may have been based at least in some part on its natural or taxonomical values, since it does not have much economical value at present. It is a native species of this basin, although it does occur elsewhere in the United States and Canada.

II. Population Condition

It is obvious that for any fish species its economical, biological and natural importance, as previously evaluated, depend greatly on its population size. And the change of population size of a fish can be related not only to the change in fishing pressure, but also to changes in the environment, or in the abundance of food, competitors, predators, and diseases and parasites. Additionally, the degree of change in population size depends importantly on the biotic potential of a fish species to respond to changes in the above factors. Therefore, information on 1) the population condition, 2) the changes of these related factors and their effects on a fish population, and 3) the biotic potential of a fish species will enable the fishery manager to decide whether or not any measure(s) should be taken to achieve the management goal(s).

In addition to a) the present population status, b) the fishing pressure, c) the abundance of food, and d) the biotic potential, all of which were previously discussed, following are types of information required at this point of evaluation:

A) Environmental factors. Two factors are considered to have the important effects on the smelt population in Lake Michigan, namely, stream degradation and lake pollution.

(1) Stream degradation. As previously described, smelt ascends tributary streams to spawn during the early spring. Some of the older and larger individuals may also spawn on sand or gravel beaches or shoals (Creaser, 1926; Van Oosten, 1940; Leivense, 1954). The characteristics of smelt spawning streams include considerable current and gravel or coarse sand bottom (Creaser, op cit; Langlois, 1935; and Van Oosten, op cit). Variations of the spawning site were observed outside the Great Lakes in the Main lake tributaries (Rupp, 1959). All streams feeding into Lake Michigan were potentially or actually spawning streams. The heaviest runs, however, usually have occurred in the streams of the northern part of the lake and of Green Bay. Now many of the other tributary streams of Lake Michigan are polluted from heavy and multiple use engendered by industrial and metropolitan development. Of several large streams presently found to be polluted by one or more sources (Appendix Table 12), some such as the Marinette, Menominee, and Escanaba rivers used to be important smelt spawning streams.

Smelt does not ascend the streams very far for spawning (e.g., only a few hundred feet at Cold Creek, Crystal Lake--Creaser, 1926), and usually stops at the first rapids or falls with a drop of one foot or more (Baldwin, 1950; Hale, 1960). Because of this behavior, any obstructions in the lowest reaches of streams reduce the spawning ground available to smelt and result in dense

schools of the spawners and high density of the eggs deposited. Such conditions not only make it difficult for smelt to spawn but also increase their vulnerability to predators, diseases and parasites. A high density of the eggs deposited furthermore has an adverse effect on the hatching success (Needler, 1943; McKenzie, 1944; 1947; and Rochschild, 1961). Obstructions in the spawning stream were once blamed for causing the decline of smelt production in the Miramichi River, New Brunswick (McKenzie, 1944). Other causes of stream degradation may include soil erosion, siltation, and flow conversion.

2) Lake pollution. Various types of pollutants, ranging from the sawdust, bark, and slabs during the lumbering era, to fertilizers, pesticides, domestic and industrial wastes, and thermal effluents of present day have been discharged into Lake Michigan. However, since this lake is large, with the exception of Milwaukee Harbor and some inshore and river-mouth areas, there is little evidence of general overall and extensive deterioration of water quality throughout the lake (U.S. Dept. Interior, 1966). This is not to say that Lake Michigan has not changed. Concentrations of several major ions (calcium, sulfate, chloride, and sodium and potassium) and total dissolved solids along with pesticides have increased, but at a constant and low rate. Without acceleration of this rate and with reduction in use of persistent pesticides such as

DDT, significant effects on the smelt component of the fish community throughout most of the lake are not expected for a considerable length of time. The past fluctuations of commercial fish production from Lake Michigan have been related much more closely to biological and economic factors than to water quality.

Although, as pointed out earlier, the water quality of the open water of Lake Michigan has only a relatively small documented change, most of the harbors and river mouths are polluted, and some areas off the river mouths, the inshore areas in southern Lake Michigan, and southern Green Bay, also show strong evidence of pollution. This may have some effect on the smelt population because the young live in the shallow areas near the shore before moving to the intermediate depths, and the adult smelt move up to these areas in the winter prior to entering the streams to spawn in the early spring. Pollution could indeed make these areas unsuitable for the young to live and unattractive for the adults to enter.

Weather, another environmental factor, may of course have significant influence on the smelt population. In streams extreme daily water temperature fluctuation (as much as 7°F) can cause mortality in the smelt eggs (Rothschild, 1961). But since weather varies unpredictably from year to year, it is not included in the present considerations.

B. Abundance of competitors. Several important species of fishes known to feed considerably on Mysis or Pontoporeia, or both, include the young lake trout, lake herring, lake whitefish, bloater, and alewife. However, all of these fishes except the alewife are in relatively low abundance and none has really shown a significant increase in recent years. The alewife, since the 1967 die-off of the population, seems to be holding at a relatively stable level in a lower abundance than before the wave of mortality (E. H. Brown, personal communication). At this level of abundance alewife may not have much influence on smelt, even if competition for food does not exist between the two species. When alewife was in great abundance in the mid-1960's smelt had already begun to increase.

The bloater population began to increase in the mid-1960's as the result of lessened sea lamprey predation, and the reduction of food competition with alewife (Wells and McLain, 1973), but now it is seriously declining (E. H. Brown, personal communication). Moreover the seasonal distribution of bloater differs from that of smelt and seems thereby to minimize the possibility of competition with smelt.

The lake whitefish which also recovered during the 1960's from sea lamprey predation (Wells and McLain, 1973), is also in a stable level as shown by the commercial production from Lake Michigan in the last few years.

C. Abundance of predators. Numerous piscivorous fishes in Lake Michigan have preyed on smelt. Many of them, however, are now greatly reduced in abundance; for example, lake trout, walleye, and yellow perch. However, intensive planting of hatchery-reared salmonids, a principal method used in attempting to rehabilitate the Great Lakes fisheries, may have some impact on the smelt population. From 1965 to 1972 nearly 41 millions salmonids (mostly fingerlings and yearlings) were planted into Lake Michigan and its tributaries (Appendix Table 13). These included lake trout, coho salmon, chinook salmon, and Atlantic salmon. Other salmonids, including rainbow trout, brown trout and brook trout, have also been planted in recent years, but in smaller numbers. The catches of these salmonid fishes by sport fishermen are very impressive (Appendix Table 14). The planting of these hatchery-reared salmonids is expected to continue, and, in fact, to increase, and many of these fishes have been reported to spawn in the natural waters.

D. Diseases and parasites. Another factor that can affect a fish population is the occurrence of diseases or parasites. This factor may not have great effect on many other fishes, but for smelt in the upper Great Lakes it is perhaps the most important one. It was estimated that the total loss of smelt from the 1942-1943 die-off in lakes Michigan and Huron, allegedly caused by some disease, was

about 50 million pounds (Van Oosten, 1947). Furthermore, the present infestation of the microsporidian paraside, Glugea hertwigi, in smelt in Lake Erie which results in an unusually severe postspawning mortality (Nepszy and Dechtiar, 1972) may soon greatly reduce the smelt population in this lake (Smith, 1972b). Although at present no Glugea infestation has been reported in the smelt population in Lake Michigan, it could spread to there.

III. Management Feasibility

From the foregoing points of evaluation (Fig. 23) the fishery manager should be able to know the importance(s) or value(s) of a fish species, and its present condition of population. From such knowledge he should then be able to decide whether or not, and how to undertake management. Fishery management may be divided into three types depending on the importance and the population condition of a fish species, as follows:

1. To expand the utilization of a fish population.
2. To maintain or improve a fish population (and its harvest).
3. To control or eliminate a fish population.

The first and second types of management are taken for a fish species that has commercial, recreational, or forage values. Their classical objective is to obtain maximum sustainable yield in either physical or economic units and

sometimes, to protect a fish species that has a natural value from extinction. The third type of management is to regulate the unwanted or nuisance fish.

The first type of management is taken for a population in which the utilization rate, by fishing or predation, is below the population biotic potential, or below the point of maximum or optimum sustainable yield in a commercial fishery, or the point where the fishermen's benefit is zero in a sport fishery. The action taken in this type of management is the expansion of utilization of a fish population by encouraging more harvest.

The second type of management is undertaken for a fish population in which the utilization rate is at or over the level sustainable by a population, i.e., it exceeds the levels of maximum or optimum yield. To sustain the maximum or optimum yields of a population and to prevent its decline, three measures are usually taken:

1) Restriction on utilization--limitations on time, region, size and number of fish, gear, effort, etc. for fishing.
2) Artificial propagation and stocking of fish--hatching or raising fish and releasing them in fishing waters to compensate for losses in the population from heavy utilization.
3) Habitat improvement--preservation, restoration, or augmentation of habitats favorable for the

fish including the increase of food sources, control of predators and competitors, etc.

However, even with the foregoing measures in hand, before setting up a program for management the fishery manager has to consider the following categories to see if the program is feasible:

1) Existing project(s) of management schemes dealing directly or indirectly with a fish species being assessed. The fishery manager may not want to set up a new management measure if there are other projects which have already dealt with the fish species of concern and if he can exercise an adequate measure in management through these existing projects.

2) Conflicts of interest, policy, or regulations with public, other projects, agencies, or states involved. Again the fishery manager may have to consider if the objectives or procedures of this project are within the policy of the agency and do not conflict with the interests of the public, or the policy and regulation of the other agencies or political entities involved.

3) Availability of information. More information on life history and other related factors of a fish species, other than those that have been used in the foregoing criteria, may be needed before a project of management can be formed. Such needed information may include fish distribution, growth rate, mortality rate, behavior, etc.

4) Availability of budget, facilities, and personnel. It is obvious that the fishery manager needs sufficient funds, facilities, and personnel to implement any management project. Therefore, he will need to see if these things are available for the proposed project.

5) Cost and benefit of exercising the project. This is a most important, yet often neglected, category that the fishery manager has to consider before setting up a project of management. The cost of the project will include not only the total money, facilities, or personnel used in the project, but also the opportunity cost, the cost of using commodities which otherwise might be used by other projects.

From this framework the fishery manager will be able to know the importance or value of a fish species being considered, its population status, and the direction and feasibility of exercising any management measures about it.

DETERMINATION OF THE STRATEGY OF MANAGEMENT FOR THE RAINBOW SMELT IN LAKE MICHIGAN

In the previous chapter, a framework to be used in the decision-making for management of a fish species was established; the criteria were formed, and the types of information required for each of these criteria were identified. In this chapter the attempt will be made to determine whether or not the rainbow smelt in Lake Michigan should be managed, and, if so, what strategy of management should be taken, by utilizing all the information gathered and analyzed in the previous chapters. The discussion, therefore, will follow the steps in the decision-making framework in the previous chapter.

First, we have to determine the importance of the rainbow smelt to see if it is worthwhile to consider exercising any measures in management.

As described earlier, the rainbow smelt has been harvested by both the commercial and sport fishermen. Although the value of the annual commercial catch of the smelt may not be substantial comparing to the other species (Appendix Table 8), it may be considered as an important additional source of income for the commercial fishermen. Smelt fishing usualy is done during the winter when the fishing activities for other species are slow or nonexistent. With

the encouraging possibility of an increased demand, mainly due to export and to the changing U. S. economy, smelt fishing could become more important to fishermen than at any time in the past. In the first half of 1974 the value of smelt from the commercial fishery was the highest in the past ten years. With the reduction in numbers of fishermen due to the new Michigan regulation to limit the entry of commercial fishermen, and the increased demand for smelt, it is expected that the surviving fishermen could obtain more individual benefit from the commercial smelt fishery than in the past. No cost of the commercial smelt fishing is available at the present study.

In the sport smelt fishery, the 1973 figures--about 36,810 fishermen spent 95,850 angler days in smelt dipping in Michigan waters of the Lake Michigan basin, which yielded 1.8 million pounds of fish--indicate that it is still fairly popular. In this activity the fishermen may also receive money from selling their catches to the market in addition to the enjoyment of the fishing activity, and the fish taken for family consumption. Although the total value of the sport smelt fishery and the revenue it contributes to the communities and state have never been determined they would be substantial.

There have long been reports of the smelt causing serious problems in the commercial fishing industry in Lake Michigan by becoming entangled in the gill nets in great

numbers and by preventing the capture of other more desirable species (Schneberger, 1936; Van Oosten, 1940; Patterson, 1948; and Euers, 1960). Such events have usually occurred during the summer and fall months. In many areas of Lake Michigan it was impossible to use gill nets to catch perch, chub, and lake herring because of this problem. Fishermen who tried to fish for perch during the summer were sometimes forced to pick out 1,000 pounds of the smelt to obtain 100 pounds of perch. And the smelt taken this way were usually badly decomposed, and frequently damaged the nets. This condition forced some fishermen to cease gill-net operations during this part of the year which certainly had some effect on the economy of the fishery. However, this problem is likely less serious now than it was in the past because gill nets are prohibited in many areas of the lake and because the numbers of commercial fishermen have been restricted as parts of the measure taken to restore the fishery resource of Lake Michigan by the states around the lake.

The adverse effects of the rainbow smelt on some native fishes (e.g., lake herring, lake whitefish), either through predation or competition, or both, have never been clearer demonstrated because there were also some other obviously more important factors--the fishing intensity, the sea lamprey, and the alewife, involved in the declines of these native species. However, smelt has been fed

extensively on by many piscivorous fishes in Lake Michigan, including the highly valued trouts and salmons. Moreover, it also serves as a buffer between the piscivorous fishes fishes and some small game fishes, and as a stabilizing factor by being the alternative food source for many piscivorous fishes that now depend heavily on the alewife. At present, there is not report of interference by smelt on other fishes.

The rainbow smelt in Lake Michigan is an introduced species and therefore its presence in these waters does not have any natural importance. At a few points in its natural range, as in New Jersey, however, where it is presently listed as an endangered species (Miller, 1972), its natural importance would be great.

Thus far I have concluded that the rainbow smelt in Lake Michigan has a moderate economic importance by being harvested by the commercial and sport fishermen, and it has a high biological importance to the Lake Michigan fish community by serving as a forage base. Therefore, it is worthy of further consideration of management.

Second, we have to determine the present population condition and the possible change of the population due to changes of some related factors.

As previously discussed, the rainbow smelt population in Lake Michigan is increasing in abundance, and it is now

underexploited by the commercial fishery, particularly in northern Green Bay (MM-1). This condition is not expected to change in the near future due to relatively low market demand of smelt, and the new regulation to limit the entry of the commercial fishermen. Although the sport fishery yielded about twice the commercial production in 1973, its production is still much lower than during the 1930's through 1950's. With this level of production the sport fishery may not have much effect on the smelt population presently or in the near future.

For the two important environmental factors, stream degradation and lake pollution, we do not have complete information on their conditions and the impacts upon the smelt population. Although it seems clear that all of smelt spawning streams and many shallow areas of Lake Michigan are less favorable to smelt than they were in the past, they probably do not affect greatly the smelt population, when considering the existence of several pollution-sensitive salmonids in this lake and by judging the grave pollution condition of Lake Erie and the great abundance of smelt.

Among several biological factors that are considered to have important influences on the smelt population, the abundance of food and competitors may not have a significant effect. Two food organisms (Mysis and Pontoporeia) are still relatively abundant. Of various species of

fishes that are potential competitors with smelt, only the alewife is still relatively abundant. At its present level of abundance the alewife may not have a significant influence on the smelt, even if competition for food does exist between the two species.

The abundance of predators, particularly the planted salmonids, may have some impact on the smelt population. The abundance of these salmonids may soon increase due to more plantings, the possibility of some species becoming self-sustained, and the virtual elimination of the sea lamprey. Nevertheless, at the present, these predators may not have much effect on the smelt, because their abundance is still not great, and the alewife, another very important food item for these fishes, is still relatively abundant.

Another biological factor that may have some sudden effects on the smelt population in Lake Michigan is the occurrence of diseases and parasites, particularly the microsporidian parasite, Glugea hertwigi. This parasite is spreading among the smelt in Lake Erie. Although at the present no such parasite has been reported in the smelt population in Lake Michigan, it could spread there.

The early maturity, high fecundity, and repetitive spawning indicate that smelt has a high biotic potential. This means the smelt population can produce the biomass to replace losses and create a surplus for utilization in a

relatively short period of time. This quality will certainly help stabilize the population condition.

I am led to conclude that, at present, the rainbow smelt population in Lake Michigan, particularly in northern Green Bay, is underexploited, and that it will continue to increase, except in the event of the disease or parasite infestation. And since it was concluded that the smelt has moderate economical importance and high biological importance, two directions in fishery management, namely, that of maintaining or improving the population (and its harvest), and that of controlling or eliminating the population, can be eliminated. The remaining direction in management that we should consider for the smelt population in Lake Michigan at present is to expand the utilization of it.

Third, we have to consider the management strategy. How much can we do in managing this fish? Should we set up a new management program aiming to expand the utilization of its population? Although at present we do not have much information in several categories that we previously established for considering the management feasibility, I have concluded that we may not be able to do much about the increase of utilization of the smelt population in Lake Michigan at the present time or in the near future because of the following:

1) The smelt presently has a rather low market demand. It will be uneconomical to increase the production without an improved market.

2) If the demand of the smelt increases, as we expect in the near future, the existing commercial fishermen will certainly exert more effort to harvest this fish, and, furthermore, the sport fishermen who are not under commercial fishery regulation will also increase in numbers in response to the increased market demand. All of these will occur with or without a management program.

3) There are other management programs in Lake Michigan that are directly and indirectly involved in expanded utilization of the smelt population. The directly involved programs are the lake trout rehabilitation, and the introduction of several salmonids. The indirectly involved program concerns sea lamprey control. The first two programs include the intensive plantings of hatchery-reared fingerlings and yearlings of these salmonids (lake trout, rainbow trout, brown trout, brook trout, coho salmon, and chinook salmon). Most of these fishes feed considerably on smelt. In general these programs have been very successful. Although through 1972 no natural-spawned juvenile lake trout have been found in Lake Michigan (Great Lakes Fish. Comm., 1973) and the annual plantings still contribute the greatest part of the production of these salmonids, some have become self-sustaining in many areas

(i.e., rainbow trout, brown trout, brook trout) and other have established natural reproduction (e.g., coho salmon, chinook salmon) (Latta, 1974). The sea lamprey which caused the decline of many native fishes, including lake trout, in Lake Michigan has been greatly reduced, although not completely eliminated. This is indicated by the decline in numbers of wounds and scars on the lake trout, the increase in the lake whitefish and rainbow trout populations, and overall growth and survival of planted salmonids (Great Lakes Fish. Comm., 1973). As these programs become more progressive, the sea lamprey should be controlled more fully, and some of the salmonids could be more abundant as self-sustaining populations than now. In this event, the utilization of smelt in Lake Michigan will certainly be greater than at present.

Although, as I concluded earlier, no new management program aiming to expand the utilization of the smelt population in Lake Michigan is proposed here, there are a few recommendations concerning this objective that should be made. Recently Keller et al. (1974) recommended that the commercial smelt fishery be confined to Green Bay (northern part, MM-1, for state of Michigan), by using selective gear such as smallmesh pound and trap nets with no size limit, and a liberal catch quote in 1974. They also recommended quotes of 2, 1.5, and 1 million pounds for 1974, 1977, and 1980, respectively. I agree with the

location recommended, since the greatest part of the catches has been traditionally from this area. However, I think the catch quote should be greater than recommended. In this study it is shown that the smelt population in northern Green Bay is presently underexploited, and up to 9 million pounds, the maximum sustainable yield, may be harvested without damaging the population. Therefore, I recommend that the commercial catch quota of smelt be liberal depending on market demand, and use of some other selective gear, such as mid-water and bottom trawls which have been used successfully on Lake Erie and in Lake Michigan during the 1960's, also be allowed.

Nevertheless, smelt also will be increasingly used by the salmonids. And the development of sport fishery is a primary management goal of the states around Lake Michigan. As the forage requirements of these salmonids increase in the future, a cut back of the catch quota should be considered.

SUMMARY

1. The rainbow smelt, Osmerus mordax (Mitchill), was first introduced into the upper Great Lakes basin in the St. Mary's River in 1906, primarily as an additional food source for the introduced Atlantic salmon (Salmo salar). Of several subsequent introductions into this river and other Michigan inland lakes, it was only in Crystal, Howe, and Trout lakes that smelt became established. Smelt were collected first from Lake Michigan in 1923; these apparently were descendents from the Crystal Lake population. Subsequently, the smelt made a spectacular dispersal throughout the upper Great Lakes in the mid-1930's.

2. The relative abundance of rainbow smelt in northern Green Bay, as indicated by the catch per unit of effort by pound nets, began to increase in the mid-1960's after a steady decline from the late 1950's. The population then increased sharply, and, except for slight fluctuations from 1970 to 1972, reached its highest level in 1973. In the southern part of the lake, however, from 1967 to 1973 the relative abundance of smelt using CPE by experimental bottom trawls as an index fluctuated from year to year at relatively low levels on the eastern shore, and had an increasing trend on the western shore.

3. The standing crop or stock size of the rainbow smelt in Lake Michigan in 1973 was estimated to be about 100 million pounds--about 30 million pounds in Lake Michigan excluding Green Bay estimated from CPE by experimental bottom trawl, and about 70 million pounds in Green Bay estimated from the logistic or Schaefer's model.

4. Young-of-the-year (age-group 0) and yearling (age-group I) smelt were found in most catches by experimental bottom trawls in Lake Michigan in recent years. Age-group I was dominant in catches from the southeastern part of the lake during the spring, but less abundant in catches from the southwestern and northern parts. Age-groups II and III comprised the greatest part of all catches, with a very small fraction belonging to older age-groups, probably up to age-group VI.

5. The rainbow smelt is distributed in waters over the shallow to intermediate depths of Lake Michigan. It shifts from a predominantly pelagic to a bottom existence as it grows older. The young-of-the-year individuals (age-group 0) live in the upper levels until fall (or very late summer) and then at least some move to the bottom; the yearlings (age-group I) may be either at the mid levels (commonly in the thermocline) or near the bottom; the adults (age-groups II and older) are mostly near the bottom during this period. The adults, then, leave the deep part of the lake by the end of winter, and move to

the shore and streams in the early spring for spawning.

6. In Lake Michigan, as in other large lakes, the food eaten by the rainbow smelt is generally dominated by Mysis, a crustacean of the Order Mysidacea. Other food organisms that were found eaten by smelt but in far less frequency and volume include amphipods (Pontoporeia), copepods, cladocerans, isopods, molluscs, and fishes. Fishes that were eaten by smelt usually were young smelt; however, recently young alewives (Alosa pseudoharengus) were found to comprise a considerable part of the smelt diet, particularly during late spring and summer.

7. The rainbow smelt has a high biotic potential. It becomes sexually matured at an early age, first spawning at the end of the second year (age-group II), and continues spawning thereafter throughout its life. It is a prolific fish, having approximately 20,000 to 30,000 eggs per female. As many as 69,600 eggs were found in smelt 200 mm long.

8. Many species of native fishes, including the highly valued lake trout (Salvelinus namaycush), have been suspected of being preyed upon by the rainbow smelt. However, several food habit studies have revealed that none of these fishes was eaten in large numbers by the smelt. Although the piscivorous potential of the smelt still has to be recognized, the abundance of other food items, and the different patterns of seasonal distribution between

smelt and the young of native fishes may have minimized its predatory role.

9. Of several species of fishes in Lake Michigan that feed on Mysis and Pontoporeia, the major food items of smelt, only the lake herring (Coregonus artedi) and lake whitefish (C. clupeaformis) are believed to be affected by the smelt, probably through food competition during some periods. However, there were some other important factors involved in the decline of these two species, e.g., high fishing intensity, and the occurrence of the sea lamprey (Petromyzon marinus) and the alewife.

10. Although the Atlantic salmon failed to become established in the upper Great Lakes in the early 1900's, many native piscivorous fishes, including lake trout, have readily accepted the rainbow smelt as one of their major food items. The recently introduced salmonids, namely, the coho salmon (Oncorhynchus kisutch) and chinook salmon (O. tshawytscha), also have utilized the smelt as an important part of their food, and the rates of consumption are increasing. Presently the smelt is even more important than in the past, because it is one of only a few species that remains abundant enough to serve as a significant forage base; another is the alewife.

11. The rainbow smelt first entered the commercial fishery in 1931 in Green Bay, and had been harvested extensively until the late 1950's. The greatest part of the

annual production generally has been from pound nets and gill nets operated in Green Bay during the winter months. Production of smelt reached its highest level (9.1 million pounds) in 1958. A subsequent sharp decline in production until the mid-1960's was the result of a reduced market demand and a decline in the smelt population. Production increased and decreased again from 1969 to 1972 and probably was due to fluctuations in population size. It increased slightly in 1973, and increased sharply in 1974--about 1.7 million pounds were reported in the first half of the year, which was the result of the increased demand for export.

12. The results of the application of the logistic or Schaefer's model indicated that the decline of the rainbow smelt population in Green Bay from the late-1950's to the mid-1960's was caused by overexploitation, however, the alewife population explosion may have accelerated and prolonged the decline. The smelt population presently is underexploited.

13. The importance of fishing pressure on the smelt population also was shown by a significant reduction of mortality rates in the smelt population of Green Bay from the high intensity fishing period of the early 1940's to the present period of low fishing intensity.

14. Smelt dipping along the lake shore and at the mouths of streams during the spring spawning runs was a

popular sport during the 1930's through the 1950's. It not only provided a great sport to the fishermen and improved the economy of several northern Michigan communities through the establishment of smelt dipping festivals, but also contributed the largest part to the total smelt production from Lake Michigan. Now, smelt dipping is less popular which may be due partly to the low market demand for the smelt. In 1973, a total catch of 1.8 million pounds was reported taken by sport fishermen.

15. The rainbow smelt has been used both for human consumption and animal food, with the latter, particularly for mink, using the greater part of the production. The market for Lake Michigan smelt was best during the 1950's which resulted in the highest production occurring during this period. The decline in the demand for smelt since the 1960's is the result of competition from smelt production from Lake Erie, and reports of reproduction problems in mink fed with Lake Michigan fishes. However, this demand may be reversed, perhaps in the near future, due to (1) high meat prices causing people to consume more fish, (2) the decline of the smelt population in Lake Erie caused by the infestation of a protozoan parasite, and (3) an increased demand for exportation of smelt.

16. In fishery management generally there are two steps of decision making; one is the decision to institute management, and the other is to select the measure(s) to

be used in accomplishing the goal(s) of the activity. In either step much information may be needed before the decision can be made. In this study the emphasis has been placed on the first step--whether or not the rainbow smelt in Lake Michigan should be managed.

17. Three criteria, namely, the importance of a fish species, population condition, and management feasibility, were formed, and the types of information required by each of these criteria were identified in order to evaluate the rainbow smelt and its population in Lake Michigan.

18. From the available information it was concluded that the rainbow smelt in Lake Michigan has a moderate economic importance by providing sizable catches to both the commercial and sport fisheries, and it has a high biological importance to the Lake Michigan fish community by serving as a forage base. Its population is presently increasing and underexploited by the commercial fishery, particularly in northern Green Bay, and this condition is not expected to change in the near future, except in case of disease or parasite infestation.

19. No particular management program aiming to expand the utilization of the smelt population was proposed, however. This is because of 1) the presently low market demand of smelt, 2) the expected increase of fishing pressure from the existing commercial fishermen and the newcoming sport fishermen as demand increases in the future,

and 3) increased predation on smelt by salmonids as the existing management programs--rehabilitation of lake trout, introduction of salmonids, and sea lamprey control--progress.

20. Presently, the quotas for the commercial fishery should be liberal. Up to 9 million pounds a year are recommended. Other selective gear such as mid-water and bottom trawls also should be allowed in fishing. However, if forage requirements by salmonids increases in the future, a cut-back of the commercial catch should be considered.

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APPENDIX

Appendix Table 1

Chemical characteristics measured in the open-lake portion of Lake Michigan in 1962-63 (U.S. Dept. Interior, 1970). (Values for average and range are in milligrams per liter unless otherwise indicated; NS not sampled; ND not detectable at sensitivity of test.)

Characteristic	Number of Samples	Average	Range
Dissolved oxygen	1,080	12	8.4-17
Saturation (percent)	497	102	73-152
BOD	NS	-	-
NH_3-N	429	0.06	ND-0.50
NO_3-N	595	0.13	ND-0.65
Organic-N	313	0.19	ND-0.52
Total solids PO_4	388	0.02	ND-0.14
SiO_2	299	2.5	0.6-5.5
Na	321	3.9	2.7-6.5
K	325	1.1	0.4-2.0
Dissolved solids	417	155	100-240
Specific conductance (micromhos per centimeter)	918	260	185-345
pH (pH units)	1,040		7.5-8.9
Alkalinity	858	110	75-130
Ca	395	33	25-40
Mg	318	12	8-16
Cl	607	6.5	3.3-11
SO_4	561	20	12-30
Phenols (micrograms per liter)	NS	-	-

Appendix Table 2

Chemical characteristics measured in inshore of Lake Michigan in 1962-63 (U.S. Dept. Interior, 1970) (Values for average and range are in milligrams per liter unless otherwise indicated; ND not detectable at sensitivity of test.)

Characteristic	Number of samples	Average	Range
Dissolved oxygen	2,541	10	3.7-16
Saturation (percent)	1,701	102	43-148
BOD	730	1.4	ND-8.6
NH_3-N	1,751	0.13	ND-1.4
NO_3-N	1,654	0.14	ND-0.90
Organic-N	529	0.21	0.01-0.70
Total PO_4	1,382	0.04	ND-5.0
SiO_2	645	1.7	0.4-4.4
Na	400	4.0	1.8-7.5
K	453	1.2	0.5-3.8
Dissolved solids	976	175	86-810
Specific conductance (micromhos per centimeter)	2,452	285	33-1130
pH (pH units)	2,113		6.4-9.3
Alkalinity	2,169	105	70-210
Ca	616	35	17-40
Mg	898	12	7-14
Cl	1,611	7.1	1.5-94
SO_4	1,547	20	10-76
Phenols (micrograms per liter)	1,033	2	ND-32

Appendix Table 3

Catch (thousands of pounds), effort (number of lifts of pound nets), and catch per unit of effort (pounds) of the rainbow smelt taken by pound nets in northern Green Bay (MM-1) during January through May, 1939-73

Year	Catch	Efforts	CPE
1939	376	930	404
1940	1,872	3,959	473
1941	2,475	5,882	421
1942	2,008	5,380	373
1943	1,582	6,530	242
1944	5	--	-
1945	26	767	33
1946	9	394	23
1947	137	1,542	89
1948	412	3,480	118
1949	896	2,820	318
1950	1,495	5,550	269
1951	2,359	4,706	501
1952	3,919	6,286	623
1953	4,068	3,408	1,194
1954	4,624	5,046	916
1955	4,757	4,757	1,000
1956	5,738	7,337	782
1957	5,039	5,950	847
1958	5,742	5,788	992
1959	3,610	6,012	600
1960	1,997	3,712	538

Appendix Table 3 (continued)

Year	Catch	Efforts	CPE
1961	1,126	2,313	487
1962	965	1,632	591
1963	691	1,372	504
1964	541	720	751
1965	555	674	824
1966	854	570	1,499
1968	1,282	670	1,914
1969	1,867	450	4,150
1970	1,632	367	4,447
1971	1,055	292	3,613
1972	496	116	4,274
1973	696	98	7,098

Appendix Table 4

Weight (grams) and number (in parenthesis) of the rainbow smelt taken per 10-minute tow of the experimental bottom trawls in southern Lake Michigan during fall, 1967-1973

Station	1967	1968	1969	1970	1971	1972	1973
Saugatuck--	89	410	971	593	700	269	1,261
Holland	(16)	(23)	(81)	(113)	(42)	(31)	(86)
Benton Harbor--	239	346	1,118	412	1,102	449	1,104
St. Joseph	(41)	(41)	(79)	(96)	(51)	(21)	(73)
Ludington	108	782	567	249	1,391	799	1,217
	(114)	(68)	(100)	(45)	(102)	(68)	(128)
Waukegon	1,044	484	1,636	2,754	3,288	3,175	3,813
	(208)	(27)	(104)	(203)	(202	(166)	(250)

Appendix Table 5

Catch (grams) of the rainbow smelt per 10-minute tow of the experimental bottom trawls at various stations around Lake Michigan during fall 1973

Depth (fathoms)	Sauga-tuck	Benton Harbor	Luding-ton	Frank-fort	Manis-tique	Sturgeon Bay	Port Washington	Wauke-gon
5	167	67	18	167*	10	167*	167*	573
10	306	611	51	530	255	135	9,588	2,552
15	7,560	5,439	935	1,360	390	20	12,550	11,238
20	677	1,475	10,810	3,770	189	30	1,347	8,991
25	29	155	2,100	902	10,737	85	1,454	4,225
30	64	28	465	255	29,556	1,200	164	710
35	85	49	90	80	12,110	4,165	6	850
40	55	37	34	70	4,260	47	754*	775
45	198*	198*	11	82	198*	198*	660	38
50	76*	76*	36	60	76*	113	91	82

*Values for the unsampled or no-catch depths obtained by averaging the values of the same depths of the other stations

Appendix Table 6

Average sizes (length, mm) for the rainbow smelt of different age groups from various waters

Waters	Age-group							
	0	I	II	III	IV	V	VI	VII
In the Great Lakes basin								
Crystal Lake, Mich.[1]	-	-	177.8	228.6	254.0	288.9	-	-
Crystal Lake, Mich.[2]	-	92.0	156.9	171.0	-	-	-	-
Crystal Lake, Mich.[3]	-	111.1	177.8	184.1	209.5	-	-	-
Green Bay, Wisc.[4]	-	-	177.8	254.0	304.8	355.6	-	-
Green Bay, Mich.[5]	-	132.0	203.2	210.8	266.7	-	-	-
South Bay, Lake Huron, Ont.[6]	-	-	137.1	154.9	182.9	-	-	-
South Bay, Lake Huron, Ont.[7]	-	-	149.8	170.2	193.0	-	-	-
Western Lake Superior, Minn.[8]	-	-	158.7	179.8	228.6	238.7	259.0	-
Western Lake Superior, Minn.[9]	-	-	154.9	182.9	215.9	-	276.9	309.0
Gull Lake, Mich.[10]	60.2	149.8	163.2	188.2	197.7	186.5	-	-
Zion, Lake Michigan, Ill.[11]	-	91.4	129.5	162.5	190.5	216.0	264.0	-
Two Rivers, Lake Mich. Wis.[12]	-	83.8	132.0	162.5	195.5	226.0	251.5	-
Escanaba, Green Bay, Mich.[11]	-	-	132.0	165.0	203.0	226.0	243.8	251.5
Other places								
Lake Champlain, N.Y.[13]	157.0	208.0	239.0	269.0	289.0	296.0	-	-
Great Bay, N.H.[14]	-	86.0	144.9	171.0	220.0	-	-	-
The Miramichi River, N.B.[15]	-	-	141.0	166.0	187.0	207.0	221.0	-
Mooselookmeguntic Lake, Me.[16]	-	-	127.0	177.8	228.6	248.9	-	-
Matamek Lake, Quebec[17]	16.0	73.6	114.4	190.7	217.7	243.3	256.8	270.0

[1] From Creaser (1926), total length, early spring collection.

[2] From Creaser (1929a), standard length

[3] From Beckman (1942), total length, summer collection

[4] From Schneberger (1937), total length, early spring collection

[5] From Van Oosten (1947), total length, winter collection

[6,7] From Baldwin (1950), fork length, spring and summer collections, respectively

[8] From Hale (1960), total length, early spring collection

[9] From Bailey (1964), total length, early spring collection

[10] From Burbidge (1969), total length, year round collection

[11] Robinson (1973), total length, early spring collection

[12] Robinson (1973), total length, spring and late fall collection

[13] From Greene (1930), total length, large race, winter collection

[14] From Warfel et al. (1943), total length, early spring collection

[15] From McKenzie (1958), from tip of snout to last scales on peduncle, year round collection

[16] From Rupp (1959), total length, early spring collection

[17] From Saunders and Power (1970), fork length, summer collection

Appendix Table 7

Length-frequency distribution of the rainbow smelt taken by experimental bottom trawl at different depths in northern Lake Michigan off Manistique, Michigan, during fall 1973

Size-group (mm)	Depth (fathoms)							
	5	10	15	20	25	30	35	40
40 - 49	3	3	0	0	1	0	0	0
50 - 59	5	70	10	4	0	3	0	1
60 - 69	2	137	58	10	3	1	2	0
70 - 79	0	27	66	25	2	1	2	2
80 - 89	0	0	6	15	5	2	3	1
90 - 99	0	0	4	8	13	9	9	7
100 - 109	0	0	3	6	155	37	13	49
110 - 119	0	0	1	3	227	123	48	40
120 - 129	0	0	2	0	189	213	40	56
130 - 139	0	0	0	2	160	427	144	96
140 - 149	0	0	0	0	88	617	166	74
150 - 159	0	0	1	0	42	218	171	83
160 - 169	0	0	0	0	0	133	57	37
170 - 179	0	0	0	0	4	19	39	15
180 - 189	0	0	1	0	0	19	9	3
190 - 199	0	0	1	0	0	0	4	0

Appendix Table 8

Commercial production (thousands of pounds), value (dollars, and average price per pound (cents) of the rainbow smelt in Lake Michigan, 1931-1974

Year	Production	Value	Avg. Price per Pound
1931	86	4,383	5
1932	98	3,313	3
1933	909	18,051	2
1934	1,031	16,080	2
1935	835	25,920	3
1936	1,202	37,227	3
1937	1,428	67,536	5
1938	1,854	55.242	3
1939	1,991	78,352	4
1940	4,209	126,263	3
1941	4,775	178,336	4
1942	3.353	145,005	4
1943	2,225	242,619	11
1944	5	296	7
1945	101	9,842	10
1946	267	31,490	12
1947	786	139,168	18
1948	504	65,562	13
1949	1,540	147,663	10

Appendix Table 8 (continued)

Year	Production	Value	Avg. Price per Pound
1950	2,417	230,676	10
1951	3,399	222,123	7
1952	5,111	316,050	6
1953	5,181	209,095	4
1954	5,811	170,494	3
1955	5,416	153,614	3
1956	7,368	263,686	4
1957	7,024	216,234	3
1958	9,102	273,118	3
1959	6,004	205,086	3
1960	3,267	110,288	3
1961	2,152	76,160	4
1962	1,546	46,993	3
1963	1,203	43,272	4
1964	969	29,911	3
1965	927	31,534	3
1966	1,111	36,709	3
1967	1,224	40,279	3
1968	1,789	56,182	3
1969	2,481	65,638	3
1970	1,977	44,803	2
1971	1,344	34,877	3
1972	705	24,378	3
1973	886	17,509	2
1974*	1,672	69,571	4

*From the Michigan waters during January through July, and the Wisconsin waters during January through May.

Appendix Table 9

Production (thousands of pounds) of the rainbow smelt from various major areas of Lake Michigan, 1950-73

Year	Michigan			Wisconsin				
	MM-1	MM-2	MM-3	WM-1	WM-2	WM-3	WM-4	WM-5
1950	1,624	1	1	785	6	*	1	*
1951	2,440	1	2	946	8	*	*	*
1952	4,018	-	1	1,036	8	*	2	24
1953	4,146	2	6	942	20	12	5	36
1954	4,707	26	16	904	29	24	44	41
1955	4,829	*	5	455	23	7	27	27
1956	5,753	103	15	827	8	7	580	47
1957	5,125	187	57	533	66	2	985	40
1958	5,833	214	89	1,427	17	162	1,254	74
1959	3,682	180	19	642	5	133	1,221	106
1960	2,030	122	3	443	3	47	364	203
1961	1,128	97	2	337	3	1	354	216
1962	973	87	12	1	2	2	271	34
1963	771	146	1	110	*	1	104	16
1964	648	126	22	83	6	1	53	21
1965	592	-	-	214	2	1	6	2
1966	1,013	*	-	74	1	2	9	7
1967	1,023	71	*	63	3	1	53	4
1968	1,656	-	2	89	*	*	38	1
1969	2,039	1	-	268	*	*	135	14
1970	1,693	*	7	166	*	*	108	1
1971	1,066	*	17	37	*	1	175	*
1972	594	2	7	26	*	*	63	*
1973	699	3	3	92	4	*	58	2

*Less than 500 pounds

Appendix Table 10

Production (thousands of pounds) of the rainbow smelt taken by pound nets in northern Green Bay (MM-1) during January through May, 1950-73

Year	January	February	March	April	May
1950	10	302	805	270	107
1951	128	705	782	661	82
1952	374	978	1,159	1,253	155
1953	104	769	1,153	2,034	8
1954	289	1,266	829	2,085	155
1955	136	945	1,140	2,504	32
1956	525	776	1,380	1,586	1,471
1957	354	620	808	3,138	119
1958	219	595	1,031	3,871	25
1959	479	240	700	820	1,371
1960	33	189	453	1,032	291
1961	51	152	291	630	2
1962	34	52	149	252	479
1963	24	38	77	466	87
1964	10	32	26	433	40
1965	5	29	106	100	315
1966	1	42	18	793	-
1967	1	7	37	714	112
1968	29	31	29	1,194	-
1969	*	15	21	1,639	192
1970	-	*	25	1,262	345
1971	*	1	6	406	641
1972	-	*	2	1	492
1973	-	2	1	689	3

*Less than 500 pounds

Appendix Table 11

Length-frequency distribution of the rainbow smelt taken by the experimental bottom trawls from different areas in Lake Michigan during the spring

Length-intervals (millimeter)	Saugatuck		Ludington		Manistique
	4/26/72	4/25/73	5/21/71	5/18/72	5/27/71
50 - 59	2	5	90	1	31
60 - 69	41	72	353	14	223
70 - 79	85	80	219	26	521
80 - 89	82	28	24	13	314
90 - 99	36	8	3	1	53
100 - 109	10	7	25	7	932
110 - 119	21	44	61	7	2,056
120 - 129	26	57	77	12	2,958
130 - 139	35	68	70	21	1,948
140 - 149	53	54	73	25	2,231
150 - 159	46	25	63	30	2,128
160 - 169	28	17	48	18	928
170 - 179	30	12	26	11	765
180 - 189	14	7	15	10	582
190 - 199	20	5	12	4	563
200 - 209	6	4	5	3	341
210 - 219	4	7	8	1	101
220 - 229	2	0	1	0	25
230 - 239	1	3	2	0	0
240 - 249	0	1	1	1	1
250 - 259	0	1	0	1	0
Total	542	505	1,176	206	16,701

Appendix Table 12

Primary sources of pollution, Michigan and Wisconsin tributary streams of Lake Michigan (U.S. Dept. Interior, 1966)

Wisconsin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Fox			x			x	x					x		x	x	x			x
Oconto			x				x	x		x				x				x	
Peshtigo			x					x		x				x	x				
Menominee							x					x		x					
Sheboygan			x			x	x	x		x				x	x	x	x		
Root		x					x			x		x	x		x				
Manitowoc			x					x		x				x					
Twin	x	x	x	x	x			x											
Kewaunee			x			x	x	x											
Ahnapee						x	x		x										
Milwaukee	x	x	x				x			x	x	x	x	x	x	x			

Michigan	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Grand	x					x	x					x		x			x		
Muskegon												x		x			x		
Pere Marquette										x									
Kalamazoo							x					x		x					
St. Joseph							x					x							
Manistique														x					
Boardman							x			x									
Escanaba														x					
Manistee														x					

1 - Gravel pit washings
2 - Metal platings
3 - Dairy wastes
4 - Slaughter house wastes
5 - Whey wastes
6 - Milk processing
7 - Municipal sewage
8 - Cheese factories
9 - Packing plants
10 - Canning plants
11 - Creosote wastes
12 - General industrial wastes
13 - Silt
14 - Paper mills
15 - Storm sewers
16 - Sulfite wastes
17 - Oil, phenols
18 - Brewery wastes
19 - Sugar beet wastes

Appendix Table 13

Annual plantings (in thousands) of salmonids in Lake Michigan, 1965 - 1972 (Great Lakes Fishery Commission, 1973)

Year	Lake Trout*	Coho salmon*	Chinook salmon**	Atlantic Salmon***	Total
1965	1,274	--	--	--	1,274
1966	1,717	660	--	--	2,377
1967	2,424	1,732	802	--	4,958
1968	1,876	1,201	687	--	3,764
1969	2,001	3,280	718	--	5,999
1970	1,960	3,543	1,904	--	7,407
1971	2,343	2,750	2,317	--	7,410
1972	2,926	2,620	2,032	10	7,588
Subtotal	16,521	15,786	8,460	10	40,777

* Yearlings

** Fingerlings

*** Two-year fish

Appendix Table 14

Estimated* effort (angler days) and catch of salmonids by anglers in Michigan waters of Lake Michigan (Great Lakes Fishery Commission, 1973)

Year	Effort	Catch			
		Lake Trout	Salmon	Other Salmonids	Total
1968	508,437	144	86,379	2,985	89,508
1969	1,217,000	93,000	378,000	167,000	638,000
1970	2,062,620	244,890	713,860	577,300	1,536,050
1971	2,932,720	311,040	870,740	561,860	1,743,640
1972	1,517,590	373,150	720,290	406,980	1,500,420

*Estimates cover open waters of the lake and tributaries.