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POPULATION DYNAMICS AND MOVEMENT
OF LAKE WHITEFISH IN OUTER SAGINAW BAY, LAKE HURON

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# POPULATION DYNAMICS AND MOVEMENT OF LAKE WHITEFISH IN OUTER SAGINAW BAY, LAKE HURON

By

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# ABSTRACT

## POPULATION DYNAMICS AND MOVEMENT OF LAKE WHITEFISH IN OUTER SAGINAW BAY, LAKE HURON

By

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Lake whitefish are harvested commercially from large and small-mesh trap nets throughout Saginaw Bay. This study was conducted to determine the size of the Saginaw Bay lake whitefish population, document movement patterns, and estimate population parameters. A mark-recapture study was conducted to determine both the movement patterns of the tagged fish and to obtain estimates of population size. The commercial catch was periodically assessed to determine age and size composition, age at sexual maturity, and growth rates. Tag returns indicated that this population is migratory, unlike most other whitefish studied. This finding invalidated most of the assumptions of the Petersen mark-recapture estimator, making estimates of population size unreliable. However, the observed age and size compositions, and mean age at maturity in the catch indicate that the population is experiencing a low level of exploitation.

ACKNOWLEDGEMENTS

Although there is only one author listed on the title page of this thesis, there are many others who contributed their sweat, brains and patience to make this study possible. First, I would like to thank those men and women who work so hard in every kind of weather to bring food to our tables, the commercial fishermen. Special thanks go to Tod, Randy, and Denny of the Bayport Fish Company, to Walt Opensenko, and to those fishermen on the other side of the Bay - Sandy Whyte, Bill Lentz and Dick Beardsley, for putting up with biologists on their boats and sharing their coffee and stories of the lake. The Bayport Fish Company, under the watchful eye of Forrest Williams, was instrumental in suggesting, funding and conducting this study. My fellow graduate students were almost always supportive, and were sometimes cajoled into assisting me in the cold, wet and slimy business of whitefish catch assessment and tagging. To those who now know that there is little finer than a day on the lake in November - thanks! This includes Bob Sluka, Glenn Barner and Cliffena Yellowfox, Paola (what are the big green fish?) Ferreri, Michaela (I hope I don't fall in, Sue I'm freezing) Zint, Russ (you're going to tag how many fish today?) Brown, Steve Marod, and Tim Watkins. There were also many undergraduates who were "convinced" to assist me under the promise of obtaining field experience (and never came back again), thanks also go to them. To Heather Sizek I owe a deep gratitude for she quickly, accurately and uncomplainingly aged hundreds of lake whitefish scales when I was unable to find any time to do so. Thanks also go to my committee members, Tracy Dobson, Esq. for pulling me out of the Natural Resources basement and teaching me the basics of law in our society, to Dr. Scott Winterstein who found courses for me to T.A. after my funding evaporated and even helped me in the field (November 7, 72°F, sunshine), and to Dr. Bill Whitefish Taylor whose interest in Great Lakes fisheries made all of this possible.

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# INTRODUCTION

Commercial fisheries were established in Saginaw Bay during the 1830s (Lanman 1839). The first fishing gears used on the Bay were spears, seines, and gill nets and the fisheries were concentrated near shore and in major tributary rivers. Late in the 19th century as steam power replaced sail power, fishermen moved further from shore and began using pound nets, baited hooks, and trap nets (Hile and Buettner 1959).

The Bay's fish community remained stable until the 1930s, except for the deliberate eradication of lake sturgeon Acipenser fulvescens, and introduction of the carp Cyprinus carpio (Hile and Buettner 1959). Lake herring Coregonus artedii was the predominant species sought by the commercial fishery, yielding annual harvests ranging from one to eight million pounds (Baldwin et al. 1979). Walleye Stizostedion vitreum, yellow perch Perca fulvescens, and suckers (Catostomus commersoni and Moxostoma spp.) were also abundant, each providing annual catches of almost one million pounds.

Records of the lake whitefish Coregonus clupeaformis harvest in Saginaw Bay began in 1885 (Figure 1), although information on fishing effort was not collected. During the period of 1891 - 1904 the catch had no clear trend, harvests

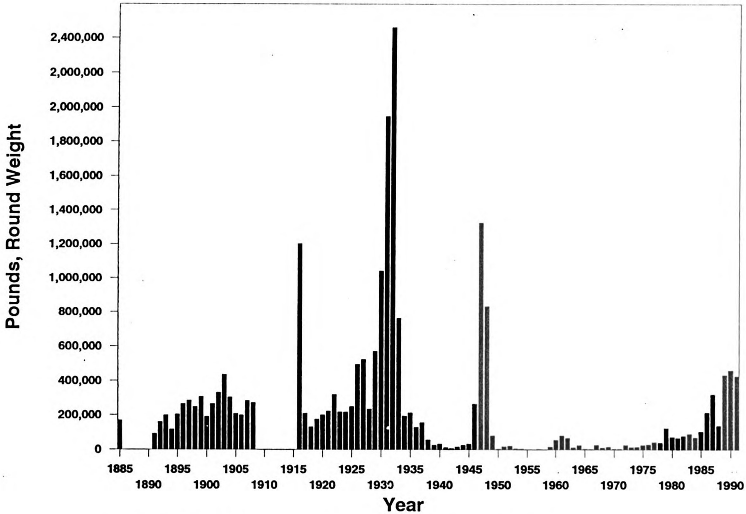


Figure 1. Saginaw Bay lake whitefish harvest, 1885 through 1991.

ranged from 92,000 to 436,000 pounds, averaging about 200,000 pounds annually. No reliable records exist for the period from 1909 - 1915. An exceptionally high catch of 1,203,000 pounds was landed in 1916. After 1916 the catch began to fluctuate drastically, and during the period of 1926 - 1929 the average annual harvest rose to 457,000 pounds. From 1930 to 1932, the average harvest increased to 1,818,000 pounds, and a record harvest of 2,463,000 pounds was landed in 1932. Harvest declined to an average of 291,000 pounds from 1933 - 1937, and fell off further to an average of 26,000 pounds from 1938 - 1945. This was followed by another sharp rise in harvest averaging 807,000 pounds during 1946 - 1948. This increase in harvest was attributed to the large year class of 1943 (Hile et al. 1953). During the 1950s, lake whitefish harvests declined to all-time lows, with harvests ranging from less than 1,000 pounds to 21,000 pounds.

The 1950s coincided with the expansion of several non-indigenous species including sea lamprey Petromyzon marinus, which preyed upon the lake whitefish, and alewife Alosa pseudoharengus and rainbow smelt Osmerus mordax, which may have competed with lake whitefish for forage and preyed upon juveniles (Christie 1974). Over-exploitation was also implicated in the declining abundance of lake whitefish and other species. Heavy exploitation during the 1930s apparently resulted from the use of deep-water trap nets with pots constructed entirely of small meshes (2.5 - 3 inches, stretched measure) resulting in heavy mortalities of juvenile fish (Van Oosten et al. 1946).

Fishing effort was reduced by a ban on gill nets and a reduction of the number of commercial licenses in the 1970s. Sea lamprey control efforts also began in the 1970s, and whitefish stocks started to rebound. Catches increased slowly throughout the 1970s, and have continued to increase throughout the 1980s and early 1990s (Figure 1; MDNR unpublished data).

The Michigan Department of Natural Resources established a new fishery policy in 1966 making the development of recreational fisheries the primary management goal for the Great Lakes. Commercial fishing was downgraded to a become a secondary, and decreasing, resource use (Keller et al. 1987). This effected the commercial fisheries in Saginaw Bay by reducing the number of licensees from 45 in 1970 to 27 in 1986, and by removing walleye and lake trout from the list of commercially harvestable species. The commercial fishery was further regulated by establishing designated fishing areas, specifying allowable gear dimensions, closing seasons for some species, and setting catch quotas for others. Gill nets, which were traditionally used to harvest both lake whitefish and lake trout, were outlawed in 1972 and gradually were replaced by less lethal trap nets, which had been modified to allow non-target and game species to be returned alive to the water.

The history of unstable lake whitefish harvests from Saginaw Bay in particular and the Great Lakes in general provided the basis of concern which led to this study. The Bayport Fish Company owners and fishermen have been harvesting lake whitefish with large-mesh deepwater trap nets in a designated area of outer Saginaw Bay (Whitefish Permit Area, Figure 2), under the auspices of a fisheries research permit issued by the Michigan Department of Natural Resources, since

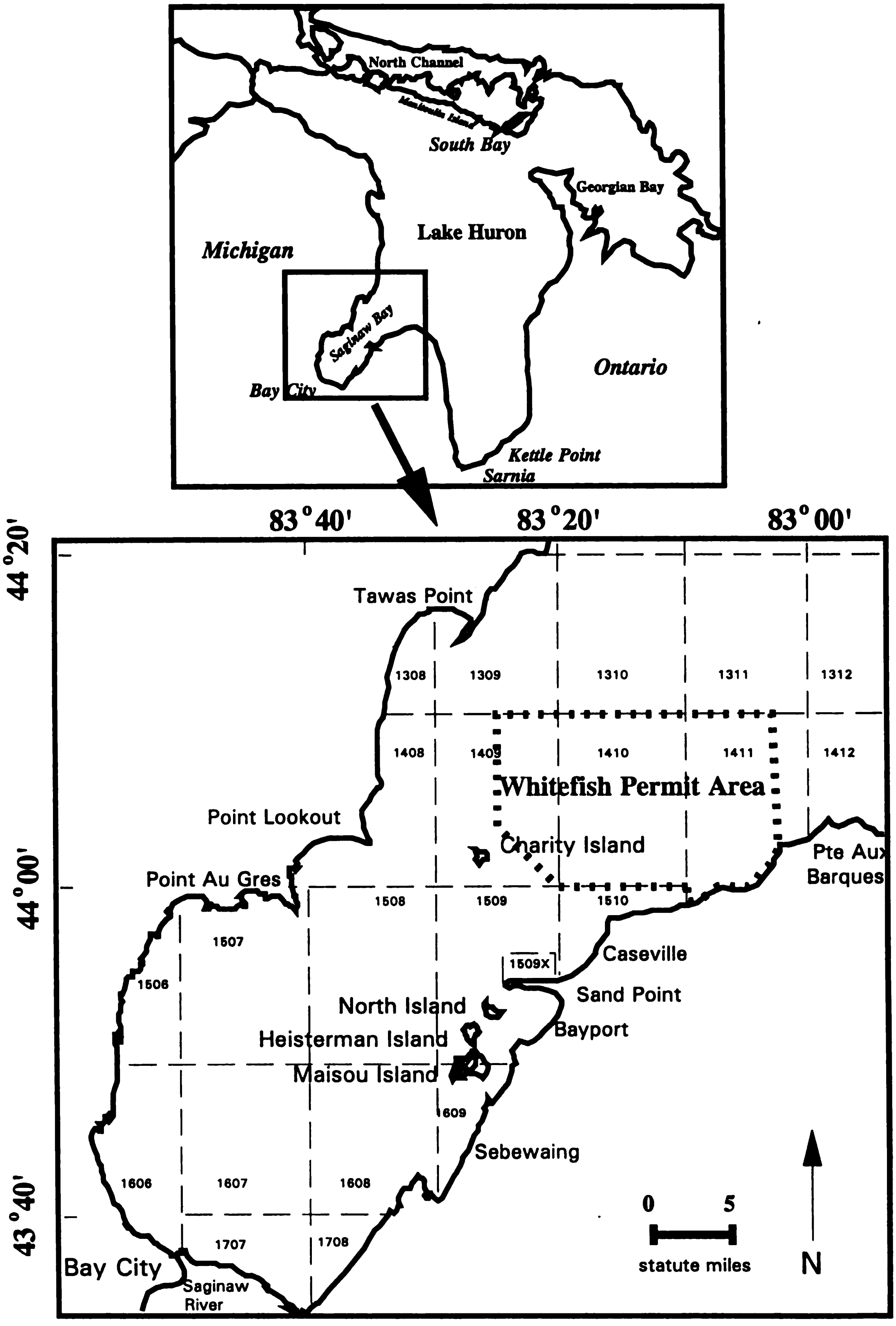


**Figure 2. Study area including management grids, Saginaw Bay, Lake Huron.**

1978. Their concern about the future stability of the whitefish populations they were harvesting led them to arrange for this study of lake whitefish population dynamics and stock movement.

## OBJECTIVES

The primary objectives of this study are to determine for Saginaw Bay lake whitefish, the population's age, sex and size structure, to estimate the population's abundance and biomass, to calculate optimal yield, and to document movement patterns from the results of a mark-recapture study.

## STUDY AREA

Saginaw Bay is an 82 km long inlet of southwestern Lake Huron on the Michigan shoreline. It is nearly equally divided into inner and outer bays by a broad shoal between Charity Island and Sand Point (Figure 2). The Bay's 2,960 $km^2$ of surface area compose 5% of the total surface area of Lake Huron. The periphery of the shallow inner Bay is mainly marshlands, and the mean inner Bay depth is 4.7 m. The maximum depth of the inner Bay is 14 m. The inner Bay is highly productive and enriched, but polluted by industrial, domestic, and agricultural waste and runoff. The Saginaw River is the major tributary to Saginaw Bay, it drains a large industrial-urban complex (16,833 $km^2$) and is the primary source of the Bay pollutants (Beeton et al. 1967). Due to frequent mixing of the shallow water column by wind and a flushing rate of 186 days (Beeton et al. 1967), dissolved oxygen levels are usually adequate for many warm-water fish species (Keller et al. 1987). Waters of the inner Bay rarely stratify. Ice cover on the inner Bay usually forms by late November and breaks up by mid-March.

The outer Bay has a mean depth of 15.6 m and a maximum depth of 40.5 m. Seventy percent of the Bay's total volume is contained in the deeper outer Bay (Beeton et al. 1967). The outer Bay's periphery contains few marshes, rocky shores are predominantly found on the east side and sand beaches line much of the western shore. Outer Bay water mixes with Lake Huron proper, resulting in dissolved oxygen conditions of nearly 100% saturation during summer stratification (Keller et al. 1987) and abundant cold water fish populations.

The Bay has several small islands including the Charity Islands in the central outer Bay, three islands south of Sand Point (North, Heisterman, and Maisou Islands) which enclose shallow Wildfowl Bay. A distinctive feature of the Bay's bathymetry is the Coryeon Reef, a shallow sand and gravel bar stretching nearly the entire length of the Bay in a north-eastern direction.

The harvest of lake whitefish in Saginaw Bay is divided into two fisheries, the large mesh trap net fishery of the Whitefish Permit Area in the outer bay, which targets lake whitefish, and catch incidental to the harvest of yellow perch and catfish from small mesh trap nets set in the inner bay. The inner bay incidental lake whitefish harvest is seasonal, with peak harvests during early spring and late fall coinciding with congregations of lake whitefish on shoals during spring when water temperatures are unithermally cool, and similar shoal crowding during the fall spawning season (Scott and Crossman 1975).

Commercial fishing for lake whitefish within the Whitefish Permit Area is permittted during the period from January 1 to October 31 and December 1 to December 31 with the following restrictions on seasonal use of gear. Up to ten large mesh trap nets (pot mesh not less than 11.43 cm)or nine large mesh trap nets and one small mesh menominee trap net may be fished from January 1 through June 30, from September 26 through Occtober 31, and from December 1 through December 31. From July 1 through September 25, no more than five large mesh trap nets or four large mesh trap nets and one small mesh menominee trap net may be fished. These permit terms are subject to annual renewal and revision of specific provisions.

## METHODS

### Length and Weight

Net run samples of the commercial catch (all legal and sub-legal lengths included) were assessed seasonally for length, weight, sex, maturation, and age information during the summer of 1989 through the fall of 1991 (Table 1). Total length was measured to the nearest millimeter, and weight was measured to the nearest 25 grams during 1989 and spring of 1990 using a spring balance, and to the nearest gram beginning in the summer of 1990 using a more precise electronic balance. When rough lake conditions prevented accurate weighing, net run samples were brought to shore and measured.

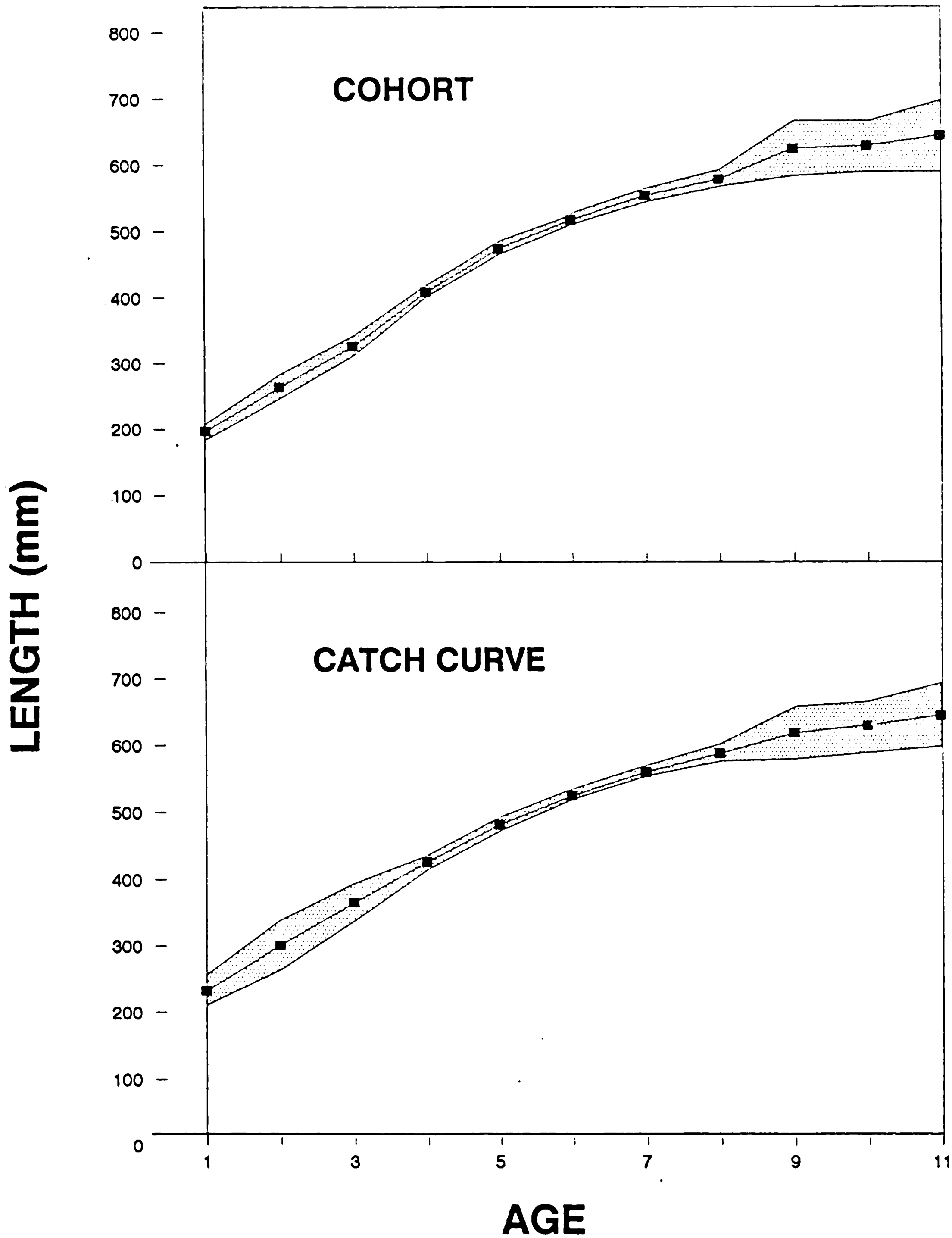


**Figure 3. Back-calculated lengths at age for cohort and catch curve samples of lake whitefish collected from the commercial trap net harvest in Saginaw Bay, Lake Huron during 1989 (n=536, 95% confidence intervals indicted by bands).**

**Sex and Maturation**

Samples were classified as either immature or mature based upon gonadal development, including size of ovaries, eggs and testes. Sex and maturation were determined by visual examination of the gonads. Samples collected during the spawning season were further classified as either "M1", ripe, or spawning. Mature females were described as "M1" if small ovaries with few mature eggs were observed, indicating that this was the first spawning season for that particular fish. Female fish were described as "ripe" if their eggs were mature but not yet loose in the ovary. "Spawning" was used to describe mature female fish whose eggs were easily expressed. Male fish were not as easily classified due to the variation in testes size. Mature male fish can be generally described as having relatively large testes compared to the thin, string-like gonads of immature fish, although it was impossible to determine the first year of maturity for male fish. During the spawning season, mature male fish were considered ripe if milt was easily expressed.

**Age and Growth**

Scales from sub-samples of the weighed and measured fish were removed from the left side of the fish in the area between the lateral line and the anterior portion of the dorsal fin. Ages of whitefish were determined from the collected scales by counting the annuli of projected scales (van Oosten 1923). Age determinations were made by the author and an assistant and were checked for accuracy by comparing the results each obtained. Age determinations were also compared to the results obtained by another experienced scale-reading technician.

Measurements of the distances between the focus and each annuli on scale samples collected during spring of 1989 were used to back-calculate lengths at age (Carlander 1981; Smale and Taylor 1986). The Fraser-Lee back-calculation method was used to estimate back-calculated lengths at age for catch curve and cohort samples (Figure 3).

## Movement Patterns

Whitefish were captured from trap nets set at or near spawning locations during the fall of 1989 and 1990 (Figure 4) and tagged with serially-numbered Floy anchor tags (FD-68B). Tagging occurred during the November spawning closure and was completed by 14 November. The fish were brought to the surface in trap nets, removed with dip nets and placed in aerated tanks on deck. Individual fish were removed by hand from the tanks, quickly measured, examined for sea lamprey wounds, tagged and then released back into the lake. Only fish in good condition were tagged, using a fabric-gun applicator to place the T-bar anchor between the interneural bones of the dorsal fin. Fish which were judged to be in poor condition were returned to the lake untagged. Tags were inserted at the anterior edge of the dorsal fin on the fishes' left side after removal of a few scales from the insertion site. A randomly chosen sub-sample of fish were similarly marked and a second tag was placed at the posterior edge of the dorsal fin on the right side of the fish. During November of 1989, 2,500 fish were tagged, and 2,351 fish were tagged in

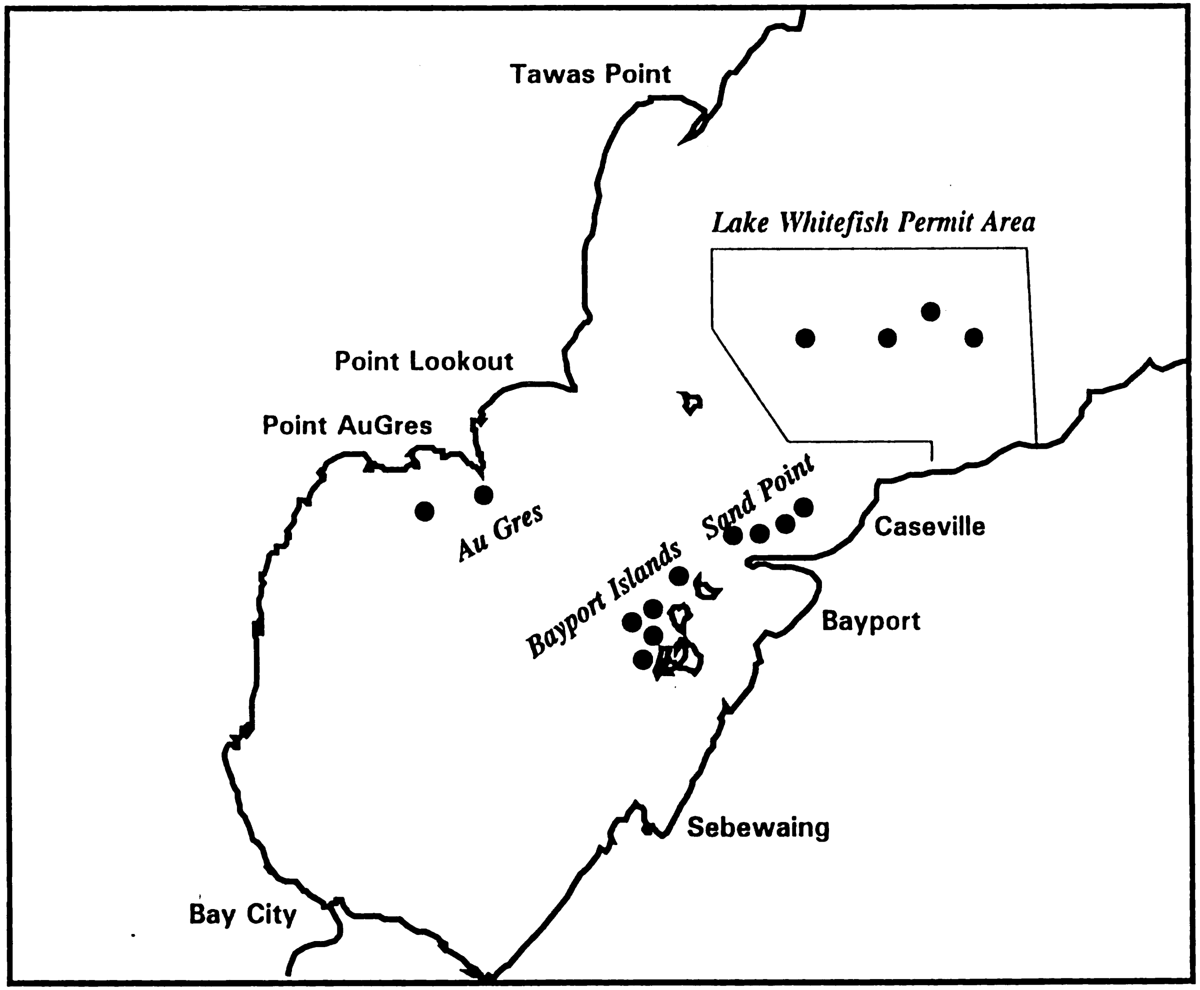


Figure 4. Lake whitefish tagging sites, Saginaw Bay, Lake Huron.

Table 1. Whitefish sampling dates, locations, gear types, and measurements taken, 1989 - 1991.

| DATE | NUMBER SAMPLED | LOCATION | GEAR[a] | MEASUREMENTS[b] |
|---|---|---|---|---|
| 1989 | | | | |
| 07-18 | 151 | Permit Zone | TN-L | 1, 2, 3, 4, 5 |
| 08-01 | 144 | Permit Zone | TN-L | 1, 2, 3, 4, 5 |
| 08-09 | 104 | Permit Zone | TN-L | 1, 2, 3, 4, 5 |
| 10-20 | 101 | Heisterman Is. | TN-S | 1, 2, 3, 4, 5 |
| 10-20 | 106 | Permit Zone | TN-L | 1, 2, 3, 4, 5 |
| 10-30 | 86 | Permit Zone | TN-L | 1, 2, 3, 4 |
| 10-30 | 100 | Heisterman Is. | TN-S | 1, 2, 3, 4 |
| 1990 | | | | |
| 05-03 | 126 | Permit Zone | TN-L | 1, 2, 3, 4 |
| 05-31 | 90 | Permit Zone | TN-L | 1, 3 |
| 05-31 | 199 | Permit Zone | TN-L | 1, 2, 3, 4, 5 |
| 05-31 | 110 | Permit Zone | TN-L | 1, 2, 3, 4 |
| 05-31 | 48 | Permit Zone | TN-L | 1, 2, 3 |
| 06-11 | 64 | Permit Zone | TN-L | 1, 2, 3, 4 |
| 07-10 | 78 | Permit Zone | TN-L | 1, 2, 3 |
| 07-24 | 134 | Permit Zone | TN-L | 1, 2, 3, 4 |
| 08-16 | 29 | Permit Zone | TN-L | 1, 2, 3, 4 |
| 10-16 | 58 | Masiou Is. | TN-S | 1, 2, 3, 4 |
| 10-30 | 66 | Sand Point | TN-S | 1, 2, 3, 4 |
| 10-30 | 69 | Heisterman Is. | TN-S | 1, 2, 3, 4 |
| 11-08 | 148 | Au Gres | TN-S | 1, 2, 3, 4 |
| 1991 | | | | |
| 04-25 | 104 | Permit Zone | TN-L | 1, 2, 3, 4, 5 |
| 05-16 | 100 | Permit Zone | TN-L | 1, 2, 3, 4, 5 |
| 05-20 | 99 | Bay City | TN-S | 1, 2, 3, 4 |
| 06-20 | 113 | Permit Zone | TN-L | 1, 2, 3, 4 |
| 07-02 | 103 | Permit Zone | TN-L | 1, 2, 3, 4 |
| 07-03 | 100 | Permit Zone | TN-L | 1, 2, 3, 4 |
| 09-28 | 41 | Pt. Austin | TRAWL | 1, 2, 3, 4, 5 |
| 10-11 | 48 | Permit Zone | TN-L | 1, 2, 3, 4 |
| 10-11 | 21 | Sand Point | TN-S | 1, 2, 3, 4 |
| 10-11 | 86 | Masiou Is. | TN-S | 1, 2, 3, 4 |

[a]TN-L = deepwater large-mesh trap net, TN-S = shallow small-mesh trap net, TRAWL = 39' bottom trawl

[b]1 = length, 2 = weight, 3 = scales, 4 = sex and maturity, 5 = annular measurements

November 1990 (Table 2).

During March and April of 1990, sub-legal size (<19") whitefish were tagged using smaller "fine-fabric" Floy anchor tags (FD-68B with "fine fabric" monofilament). Due to difficulties encountered in locating sufficient numbers of small fish, suspected high mortalities of these fish, and incomplete recruitment of the small whitefish to the fishing gear, spring tagging was not continued in 1990.

All commercial fishermen operating in the surrounding waters of Saginaw Bay, northern Lake Huron, and southern Ontario were notified annually of the study by mail. All major whitefish fishermen were visited several times to keep them informed of the study and to request that tag recaptures be recorded and reported. The Bayport Fish Company is the primary wholesale fish-buyer and was the primary collector of fish tags from the area.

Tags which were returned from within the study area with information on the date and location of recapture were used to document the movement patterns of fish in the study area.

**Abundance and Biomass**

Population abundance (N) and biomass estimates were made using the Petersen mark-recapture method, where

$$N = M * C / R$$

and, M = the number of legal-sized fish tagged in year 1

C = the number of fish caught by the fishery in year 2

Table 2. Location and number of lake whitefish tagged from trap nets in Saginaw Bay, Lake Huron, during 1989 and 1990.

| Location | Date | Trap net size | Number Tagged |
|---|---|---|---|
| Permit Zone | | Large | |
| | 11-07-89 | | 204 |
| | 11-13-89 | | 172 |
| | 04-16-90 | | 41 |
| | 05-04-90 | | 32 |
| | 11-02-90 | | 74 |
| | | Total | 523 |
| Sand Point | | Small | |
| | 11-09-89 | | 374 |
| | 11-12-89 | | 263 |
| | 11-13-89 | | 68 |
| | 04-16-90 | | 25 |
| | 11-03-90 | | 216 |
| | 11-10-90 | | 419 |
| | | Total | 1365 |
| Heisterman Island | | Small | |
| | 11-04-89 | | 168 |
| | 11-13-89 | | 518 |
| | 11-14-89 | | 733 |
| | 11-03-90 | | 262 |
| | 11-09-90 | | 804 |
| | 11-14-90 | | 203 |
| | | Total | 2688 |
| Au Gres | | Small | |
| | 04-12-90 | | 209 |
| | 11-08-90 | | 373 |
| | | Total | 582 |
| | | Grand Total | 5158 |

R = the number of tags recaptured in year 2

Mean individual weights were estimated using a weighted mean weight of legal-sized fish from the small and large-mesh trap net catches (432 and 483 mm minimum legal lengths respectively) sampled throughout the fishing season. This mean was used to convert the catch (C) from weight to numbers. M was corrected for tag loss during the study period to meet one of the assumptions of the Petersen method. Annual rates of tag loss were estimated from a Mayfield instantaneous tag loss rate calculated from the number of tags lost to days exposed for the double-tagged sub-sample (Bart and Robson 1982; White 1983). Annual catch was corrected for recruitment during the season by subtracting an estimate of the fractions of the catch which grew to legal size for the large-mesh and small-mesh trap net fisheries. Confidence intervals were estimated using the Poisson estimator. Total instantaneous mortality rates were estimated from the slopes of the descending limbs of catch curves constructed by plotting the natural logarithms of frequency against age, and from cohort analysis (Ricker 1975).

Annual survival (S) estimates were calculated from the following equation:

$$S = (R_{12} * M_2) / (R_{22} * M_1)$$

where: $R_{12}$ = Recaptures in 1991 from tagging in fall 1989

$R_{22}$ = Recaptures in 1991 from tagging in fall 1990

$M_1$ = Number of fish tagged in fall 1989

$M_2$ = Number of fish tagged in fall 1990 and recaptures were corrected for tag loss.

Annual mortality (A) was calculated from survival as:

$$A = 1 - S$$

Exploitation rates (u) were calculated as:

u = # of recaptures/ # of tagged fish, corrected for tag loss.

Instantaneous estimates of total mortality (Z), fishing mortality (F), and natural mortality (M) (Ricker 1975) were be calculated as:

$$Z = -\ln (S)$$

$$F = (u)*(Z) / A$$

$$M = Z - F$$

## Optimal Yield

Optimal yield for the 1990 fishing season was estimated by multiplying abundance and average biomass estimates of each age class by the optimal rate of instantaneous fishing mortality for exploited whitefish populations (Clark and Smith 1984).

# RESULTS

## Length and Weight

Mean weights at age of lake whitefish in 1990 and 1991 from combined samples of large and small trap net catches were similar. However, the 1989 samples were heavier at ages three through nine years (Figure 5). The greater average weights observed in 1989 are probably attributable to the lack of spring samples during that year. Regression of mean weight at age on ln age yielded an equation which can be used to predict weight at age. Figure 5 includes only those ages for which samples were collected in each of the three years. During 1991, one one-year old fish and seven two year-old fish were sampled from the spring trap net fishery and two twelve year-old fish were also sampled (Table 3). The mean weights at age of these age groups were not included in the regression due to the lack of representation in each year, the variability of weight at age in juvenile fish, and the difficulties of aging whitefish accurately at ages greater than ten years.

Mean lengths at age of lake whitefish in 1989, 1990, and 1991 from combined samples from large and small trap net catches were more similar than were weights. However, the trend observed in 1989 weight data was also observed in mean lengths at age, with fish sampled in 1989 being longer than mean lengths at age observed in other years. Again, this is probably attributable to a lack of spring sample data in 1989 (Table 4; Figure 6). Twelve year old fish were observed in each year, however the small sample size and great variability in size at older ages indicates these data are of little value. The one twelve year-old fish sampled in 1989 was the largest whitefish observed (765mm) in the three years of commercial catch assessment and compares to a Von Bertalannfy length at infinity parameter of 722mm calculated from a body-to-scale-radius regression of ages one through eleven.

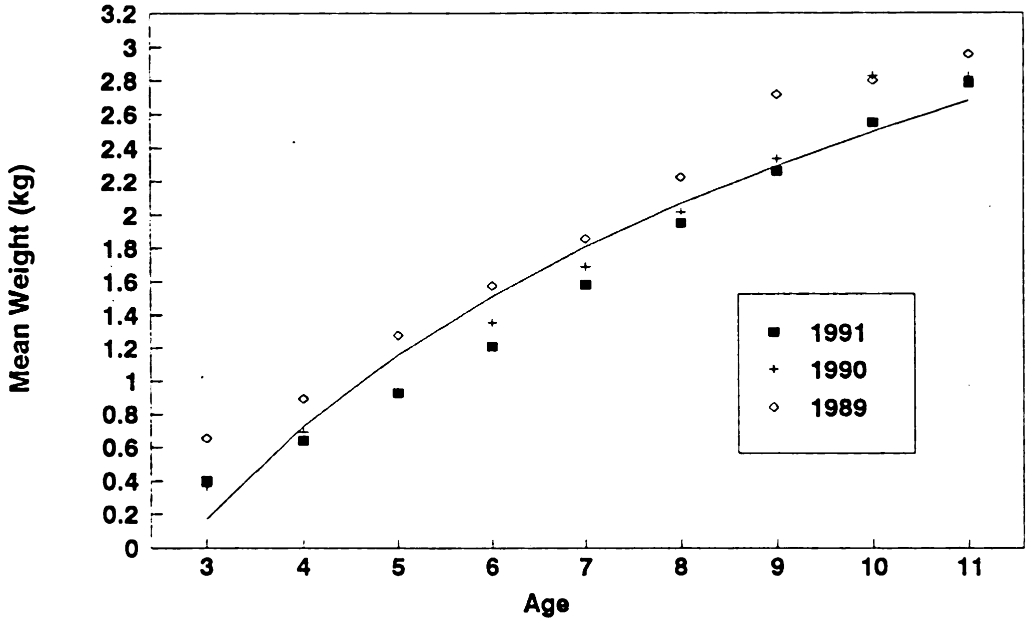


**Figure 5. Mean weights at age of lake whitefish sampled from trap nets throughout Saginaw Bay during 1989, 1990, and 1991. Line represents the regression of mean weight at age on ln age (weight = 1.95 - 1.93(ln age)).**

**Table 3. Mean weights at age of all lake whitefish sampled from large and small trap nets in Saginaw Bay, Lake Huron during 1989, 1990 and 1991.**

| | Mean Weight (kg) | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **1991** | **(n)** | **1990** | **(n)** | **1989** | **(n)** |
| **Age** | | | | | | |
| 1 | 0.062 | ( 1) | | | | |
| 2 | 0.171 | ( 7) | | | 0.275 | ( 2) |
| 3 | 0.399 | ( 79) | 0.368 | ( 7) | 0.653 | ( 22) |
| 4 | 0.642 | (132) | 0.690 | (157) | 0.892 | ( 97) |
| 5 | 0.924 | (307) | 0.928 | (148) | 1.275 | (129) |
| 6 | 1.209 | ( 72) | 1.352 | ( 90) | 1.573 | (241) |
| 7 | 1.578 | ( 70) | 1.689 | (101) | 1.857 | (162) |
| 8 | 1.950 | ( 44) | 2.013 | ( 56) | 2.226 | ( 77) |
| 9 | 2.260 | ( 33) | 2.336 | ( 23) | 2.718 | ( 25) |
| 10 | 2.549 | ( 21) | 2.827 | ( 12) | 2.803 | ( 19) |
| 11 | 2.785 | ( 9) | 2.824 | ( 1) | 2.957 | ( 11) |
| 12 | 2.897 | ( 2) | | | 4.950 | ( 1) |

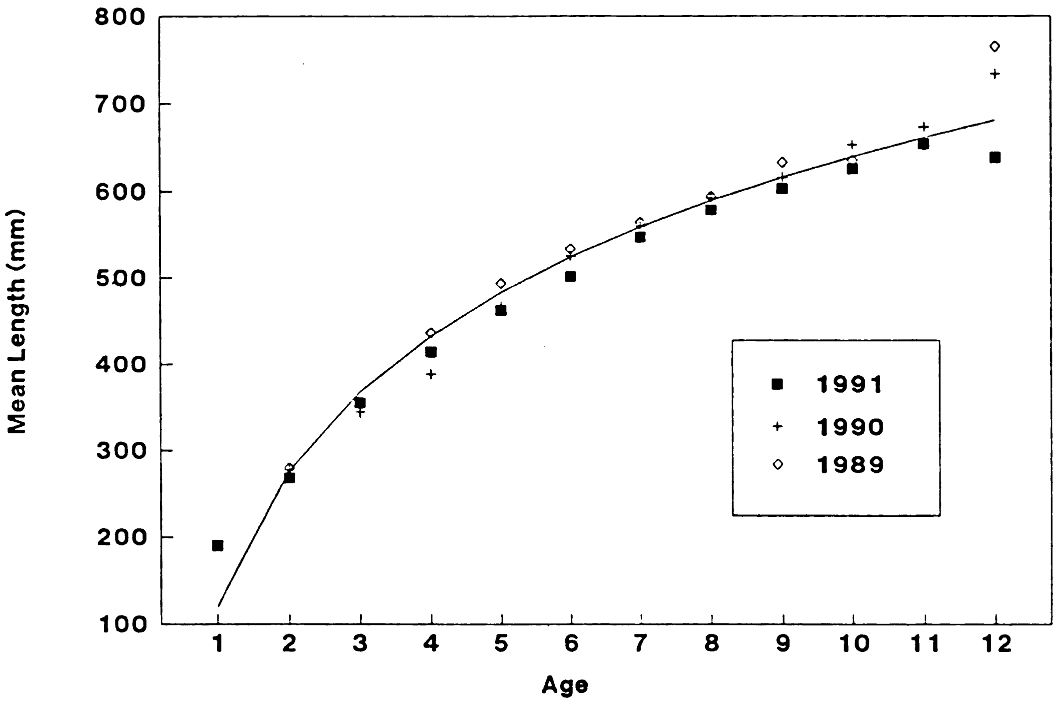


Figure 6. Mean lengths at age of lake whitefish sampled from trap nets throughout Saginaw Bay during 1989, 1990 and 1991. Line represents the regression of mean lengths at age on ln age (length = 119.83 + 225.82(ln age)).

Table 4. Mean lengths at age of all lake whitefish sampled from large and small trap nets in Saginaw Bay, Lake Huron during 1989, 1990 and 1991.

| | Mean Length (mm) | | | | | |
|---|---|---|---|---|---|---|
| Year | 1991 | (n) | 1990 | (n) | 1989 | (n) |
| Age | | | | | | |
| 1 | 190.00 | ( 1) | | | | |
| 2 | 268.43 | ( 7) | 277.00 | ( 4) | 280.00 | ( 2) |
| 3 | 355.25 | ( 79) | 344.29 | ( 28) | 357.91 | ( 22) |
| 4 | 414.36 | (132) | 388.00 | (278) | 436.35 | ( 98) |
| 5 | 462.61 | (307) | 467.31 | (268) | 493.24 | (129) |
| 6 | 501.18 | ( 72) | 525.37 | (145) | 533.19 | (242) |
| 7 | 547.06 | ( 70) | 559.52 | (161) | 563.90 | (162) |
| 8 | 578.36 | ( 44) | 592.13 | (104) | 594.22 | ( 77) |
| 9 | 603.33 | ( 33) | 615.94 | ( 35) | 633.20 | ( 25) |
| 10 | 625.48 | ( 21) | 653.18 | ( 17) | 635.89 | ( 19) |
| 11 | 654.33 | ( 9) | 673.60 | ( 5) | 652.18 | ( 11) |
| 12 | 638.50 | ( 2) | 734.00 | ( 1) | 765.00 | ( 1) |

To examine mean lengths at age of lake whitefish free from the possible biases associated with year-to-year variation, differences in gears, and differences in areas, I looked at mean lengths at age of fish sampled during spring, summer and fall of 1991 from large-mesh deepwater trap nets set in the whitefish permit area (Table 5; Figure 7). Although the mean lengths at age of fish at ages three and four years appear to be longer in summer than in spring, these differences are not significant (2-sample t-tests: age 3 =0.1581, d.f.=30, $P>0.05$; age 4 = 0.1720, d.f.=93, $P>0.05$). Lengths at age are nearly identical at ages six through eight, and small sample sizes and greater variability of lengths at older ages obscure any apparent differences in length by season at ages greater than eight.

**Sex and Maturation**

The sex ratios of whitefish sampled from the commercial catch varied strongly by season. Although the sex ratio of each year's combined samples were dominated by male fish ($Chi^2$=55.13, d.f.=2, $P<0.001$) (Figure 8), this was likely due to the high proportion of pre-spawning males sampled during the fall. Combined spring and summer samples from all years did not differ from a 50:50 sex ratio ($Chi^2$=0.7853 and 1.090 respectively, d.f.=1, $P>0.05$), although combined fall samples were composed predominantly of male fish ($Chi^2$=95.601, d.f.=1, $P<0.001$)(Appendix A).

Lake whitefish matured between the ages of three through seven years, with approximately 50% becoming sexually mature by age five (Figures 9 and 10).

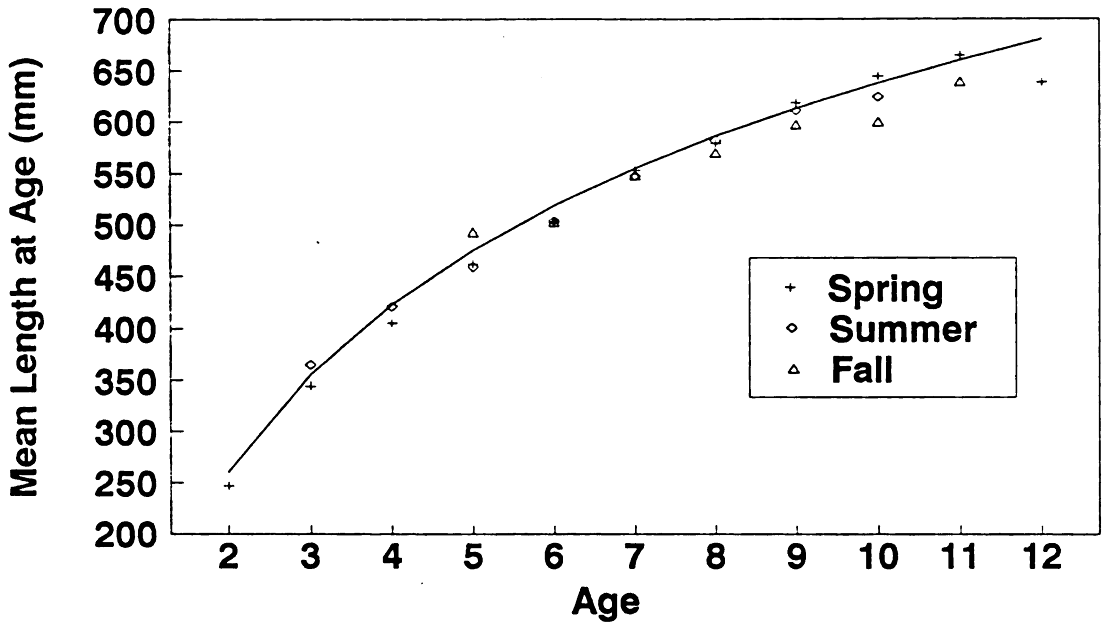


**Figure 7. Mean lengths at age of lake whitefish sampled from large-mesh trap nets in the whitefish permit area of Saginaw Bay during spring, summer and fall of 1991. Line represents the regression of mean lengths at age on ln age (length = 76.22 + 234.57(ln age)).**

**Table 5. Mean lengths at age of lake whitefish sampled during spring, summer and fall of 1991 from deepwater trap nets set in the whitefish permit area in outer Saginaw Bay, Lake Huron.**

| | Mean Length (mm) | | |
|---|---|---|---|
| **Season** | **Spring** (n) | **Summer** (n) | **Fall** (n) |
| **Age** | | | |
| 1 | | | |
| 2 | 247.00 ( 2) | | |
| 3 | 344.40 ( 15) | 365.00 ( 17) | |
| 4 | 405.27 ( 33) | 420.92 ( 63) | |
| 5 | 461.76 ( 71) | 458.93 (186) | 493.00 ( 1) |
| 6 | 502.00 ( 17) | 503.79 ( 29) | 502.29 ( 7) |
| 7 | 552.48 ( 21) | 546.85 ( 13) | 547.27 ( 11) |
| 8 | 578.53 ( 15) | 581.40 ( 5) | 569.09 ( 11) |
| 9 | 618.14 ( 14) | 610.50 ( 3) | 596.67 ( 12) |
| 10 | 644.40 ( 10) | 624.00 ( 2) | 599.33 ( 3) |
| 11 | 664.75 ( 4) | | 639.00 ( 3) |
| 12 | 638.50 ( 2) | | |
| Mean (Total) | 488.56 (202) | 457.39 (318) | 565.92 ( 48) |

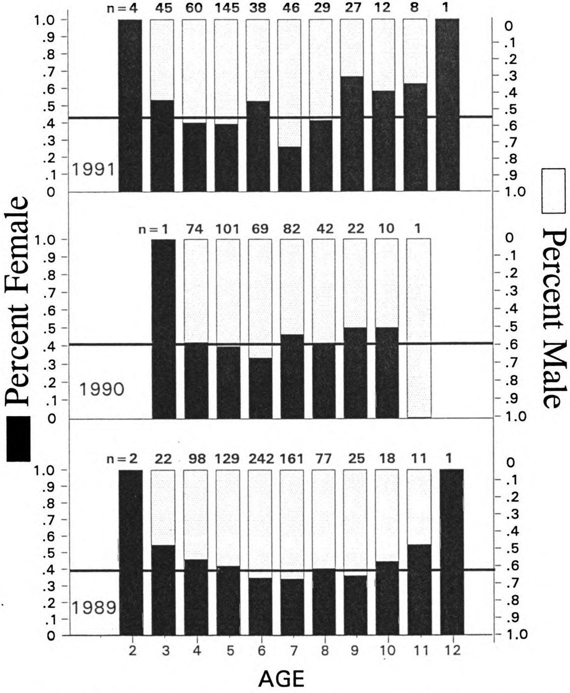


Figure 8. Sex composition of lake whitefish sampled from trap nets throughout Saginaw Bay, Lake Huron during 1989 (n=415), 1990 (n=402) and 1991 (n=786). Horizontal lines indicate annual overall sex composition.

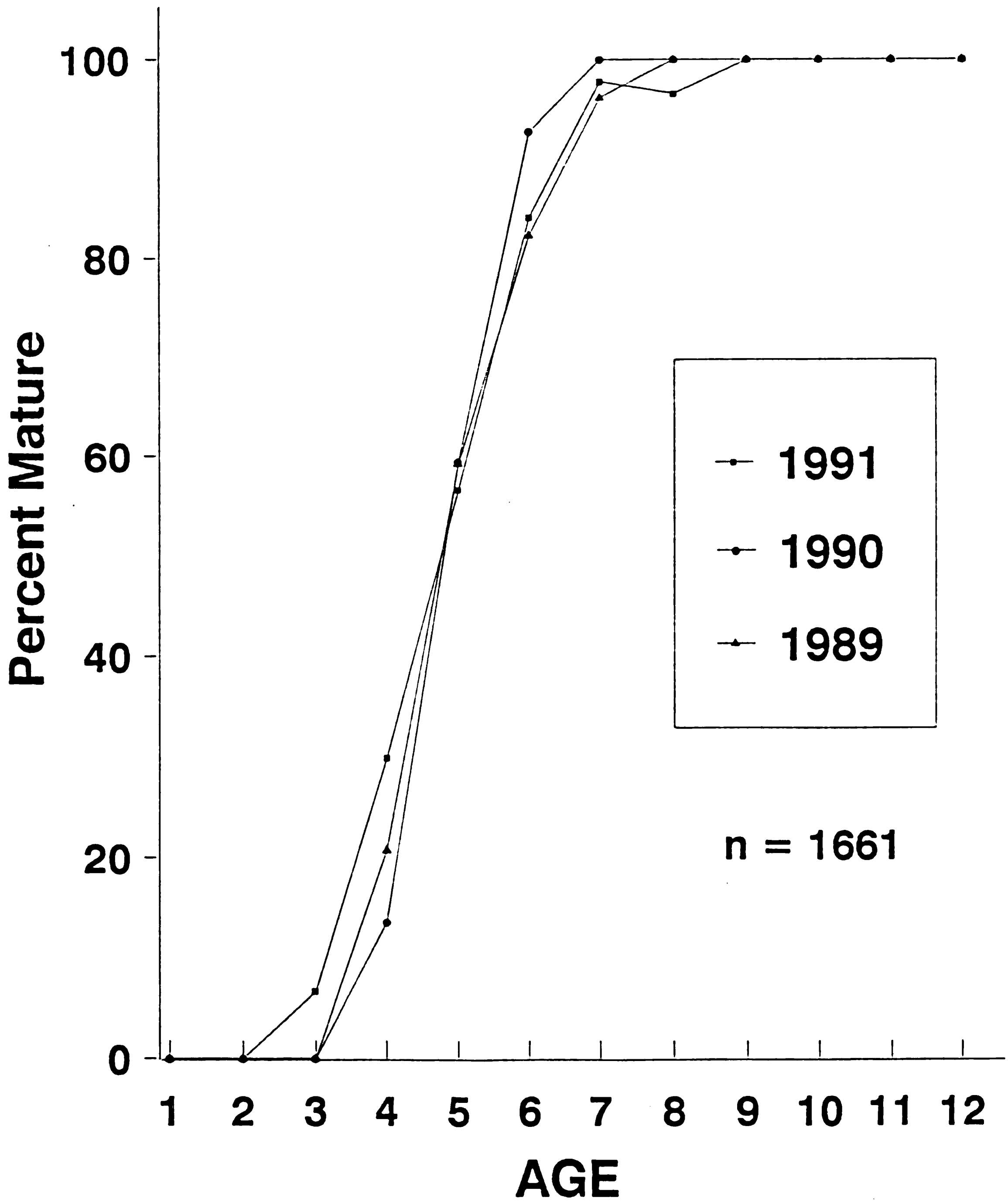


Figure 9. Percent of sexually mature lake whitefish at age from samples collected from the large and small-mesh trap net fisheries of Saginaw Bay, Lake Huron during 1989, 1990 and 1991.

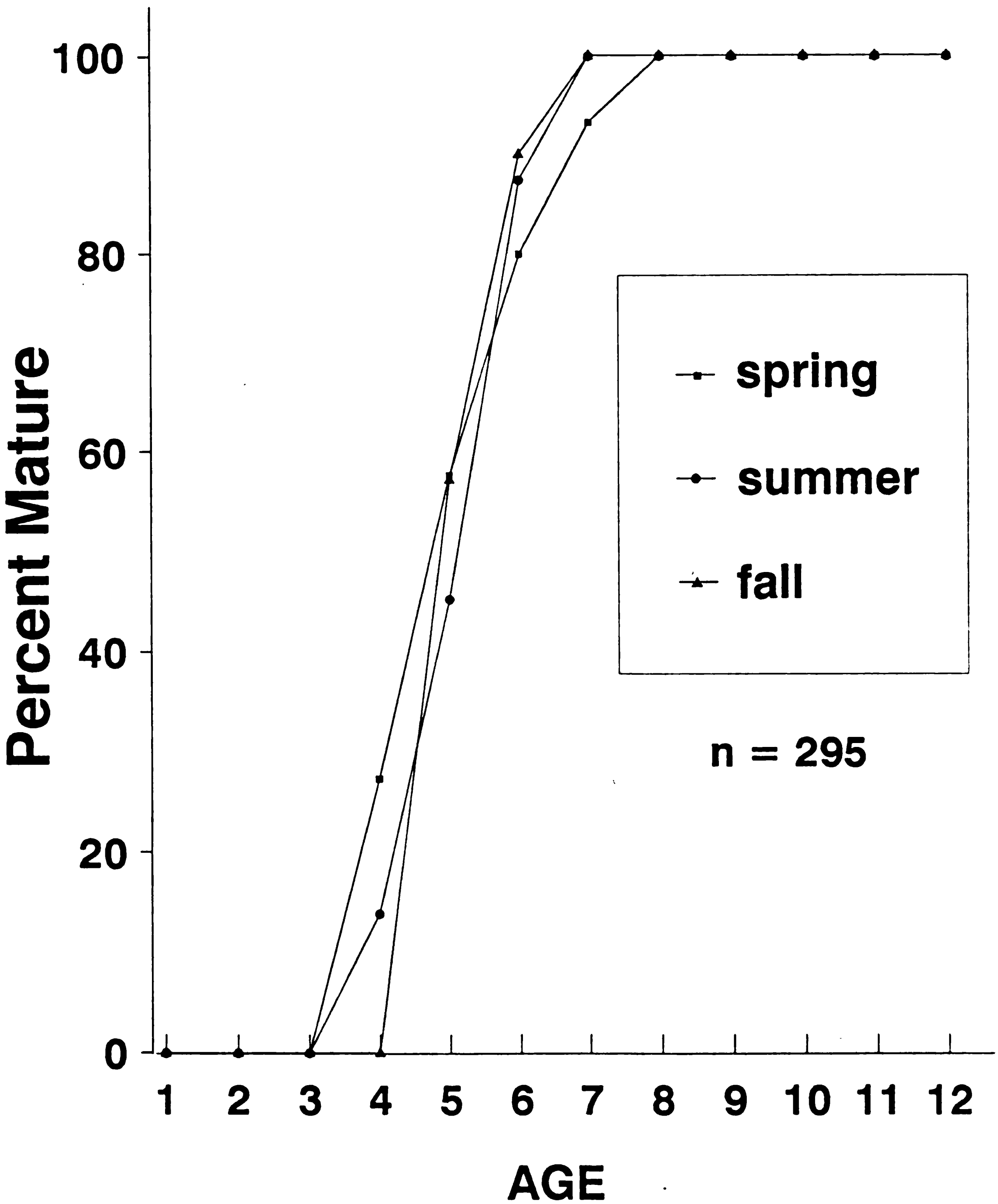


Figure 10. Percent of sexually mature lake whitefish at age from samples collected from the large-mesh trap net fishery in the whitefish permit area of outer Saginaw Bay, Lake Huron during 1991.

Small percentages of three year-old fish were sexually mature in 1991. In 1989 and 1990 the youngest mature fish were four years of age. By age six, approximately eighty percent of the year class had become mature, and nearly all (>90%) whitefish were mature at age seven.

Whitefish samples from the large-mesh trap net fishery in the permit area during spring, summer and fall of 1991 were assessed for sexual maturity. In spring, 26% of the four year-old whitefish sampled were sexually mature, in summer ten percent were mature, and in fall only one immature four year-old was encountered (Figure 10; Appendix B).

**Age and Growth**

Ninety-two percent of the age determinations of the primary and assistant scale-reader were in agreement. Of the 101 scale samples read independently by another experienced scale reader, 70.3% of the age determinations agreed with ours, 90% of the differences were of one year, and no determinations were different by more than two years.

Figure 11 illustrates the annual age composition of lake whitefish compiled from all trap net assessment data. Net run assessment of the 1989 catch revealed the broad age structure of the Saginaw Bay lake whitefish population. Six year-old fish dominated the catch, although eleven year-classes, from ages two through twelve, were represented. The age structure shifted in 1990 as four and five year-old fish dominated the catch. The 1990 age structure was also broad and composed of

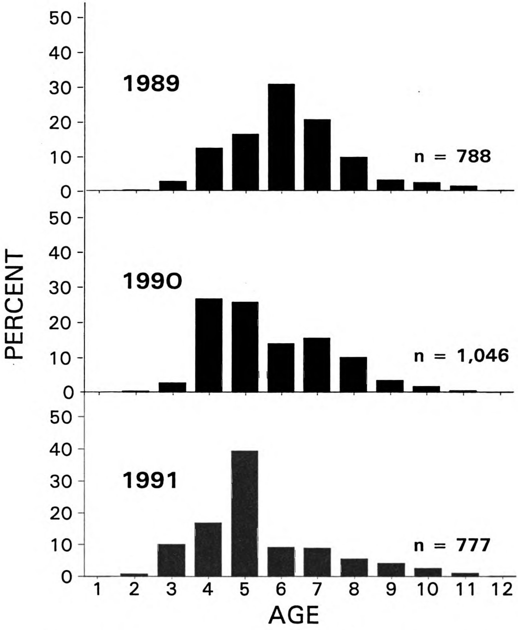


Figure 11. Percent at age composition of lake whitefish sampled from large and small-mesh trap net fisheries throughout Saginaw Bay during 1989, 1990 and 1991.

individuals from ages two through twelve years. In 1991, five year old fish dominated the catch, apparently due to continued recruitment of the strong 1986 year class. In 1991 the age structure was even broader than in the previous two years due to one year-old fish appearing in the catch.

To remove the possible effects of different seasonal and gear-induced effects on annual age composition, net run lake whitefish captured in large trap nets set in the permit area during the summers of 1989 through 1991 were examined (Figure 12). The resulting age compositions are similar to those of Figure 11, except fewer age classes are represented. In the summer of 1989, the permit area catch was dominated by five year-old fish, and fish from ages two through twelve were present in the catch. In 1990, four year-old fish are predominant, and only six age classes were present. In 1991, five year-old fish composed over 50% of the catch, and ages three through ten were present.

Annual differences in age distributions are also apparent in samples collected from small-mesh trap nets set near the Bayport Islands during fall (Figure 13). The 1983 year class dominated the small-mesh catch in 1989 as six year-olds. Six and seven year-old fish were the predominant ages in samples collected during 1990, and 1991 samples were of a very broad age distribution dominated by five year-old fish.

To examine the data for seasonal differences in age composition, I compared the spring, summer and fall age compositions of lake whitefish captured in large trap nets set in the permit area during 1991 (Figure 14). The spring and summer age compositions are similar, with both dominated by five year-old fish. The increase in

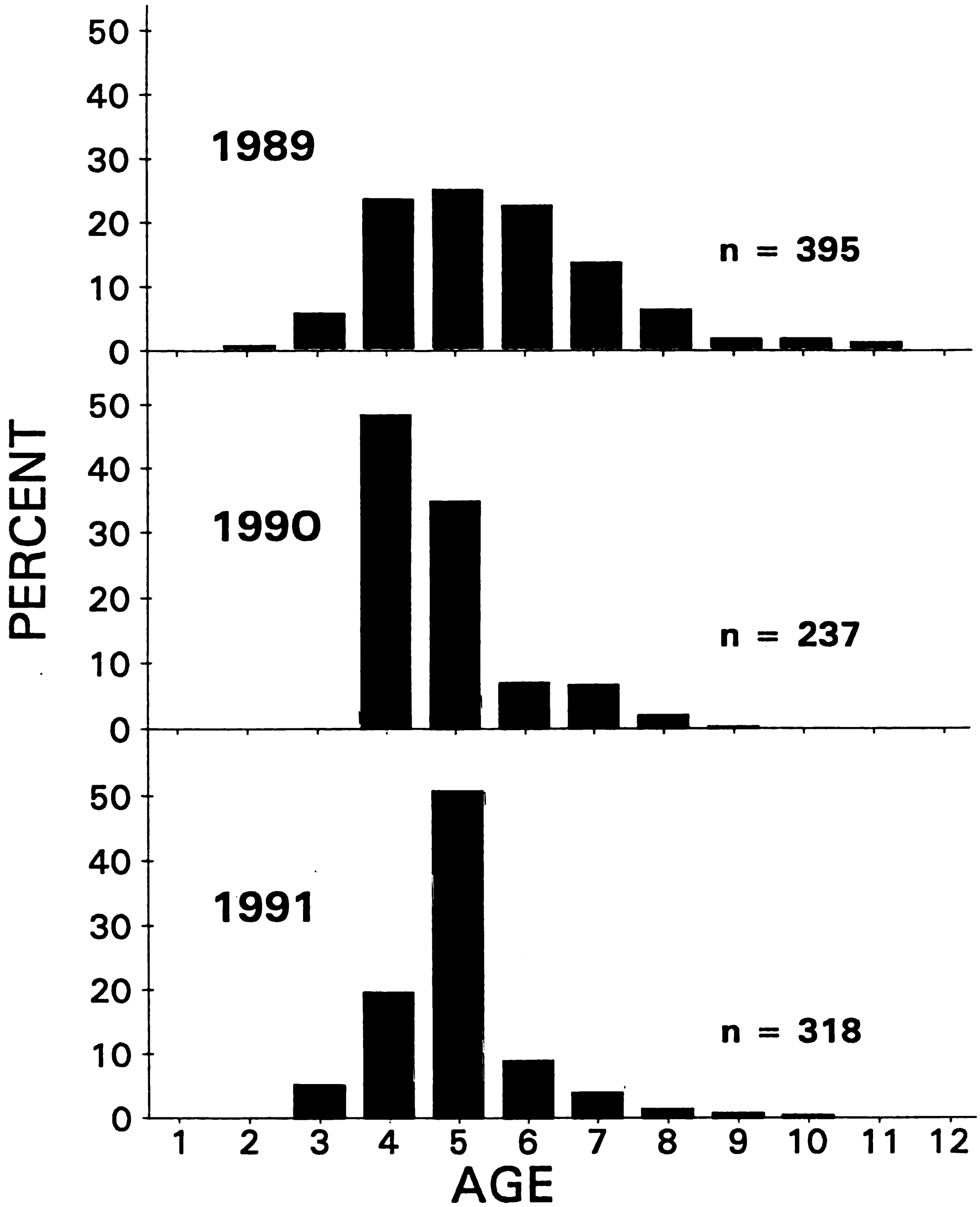


Figure 12. Age composition of lake whitefish sampled from large-mesh trap nets in the whitefish permit area in outer Saginaw Bay during summer in 1989, 1990 and 1991.

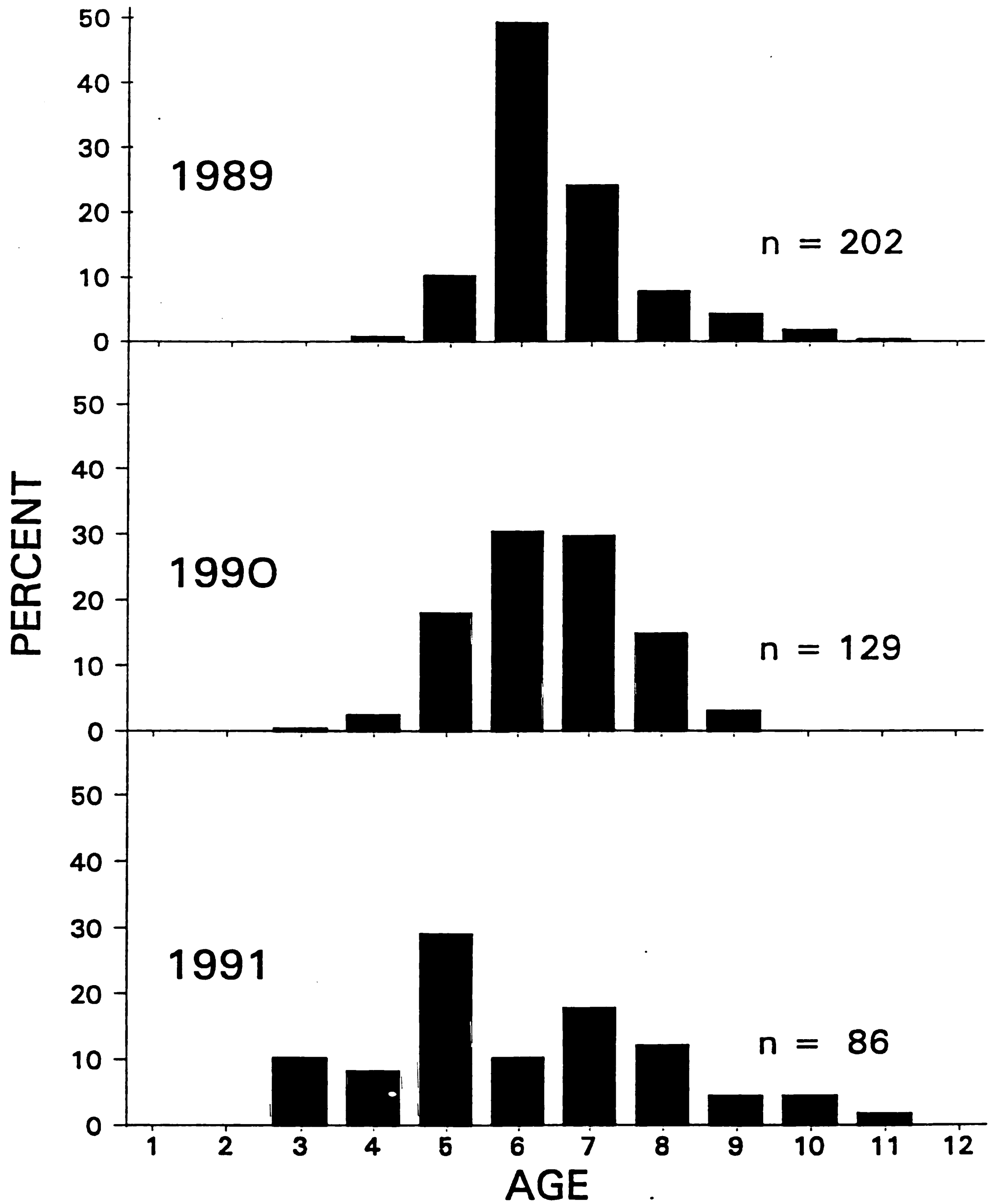


Figure 13. Age composition of lake whitefish sampled from small-mesh trap nets at Bayport Islands in inner Saginaw Bay during 1989, 1990 and 1991.

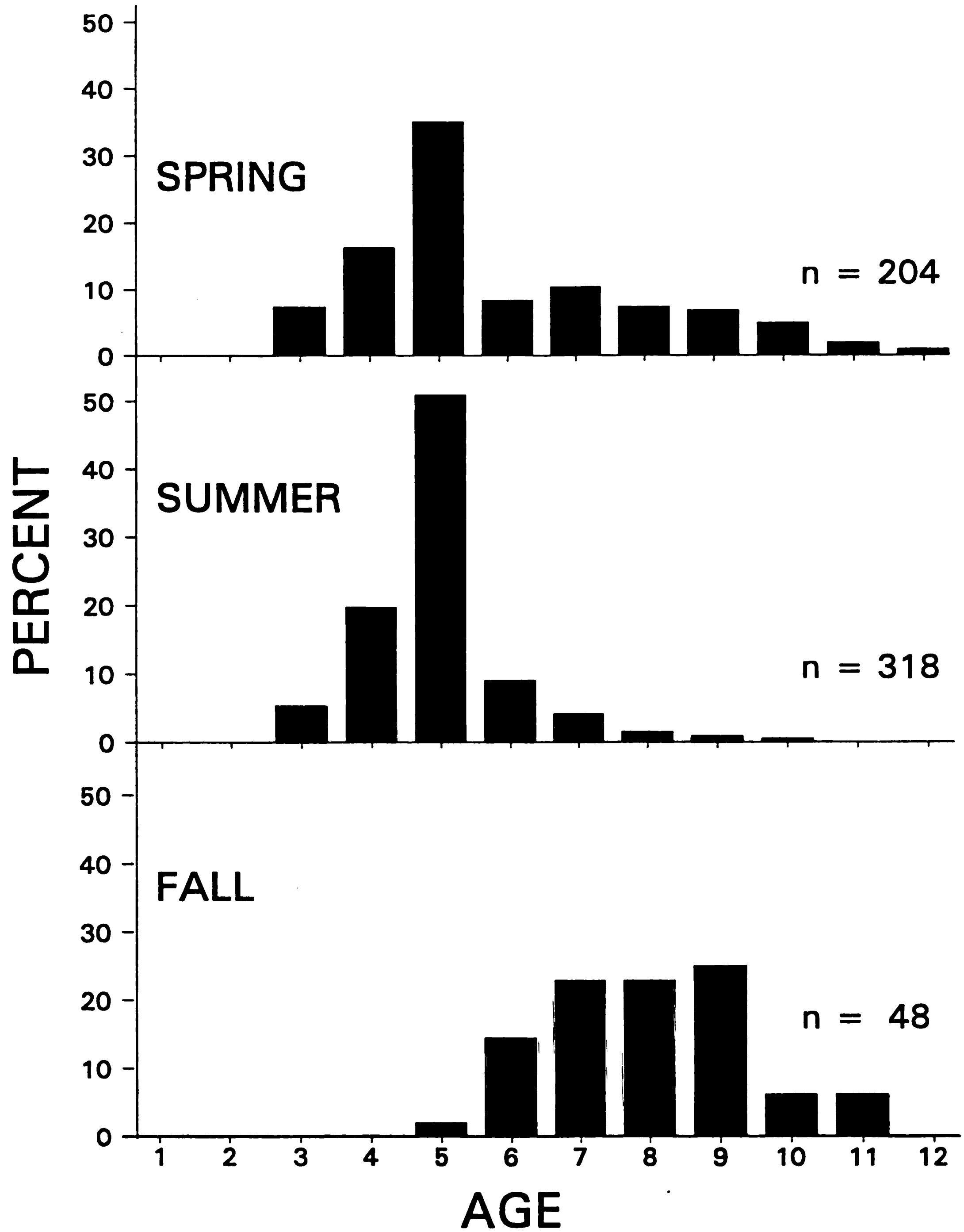


Figure 14. Age composition of lake whitefish sampled from large-mesh trap nets in the whitefish permit area in outer Saginaw Bay during spring, summer and fall of 1991.

the proportion of five year-old fish from spring to summer is most likely attributable to the continuing recruitment of five year-olds into the fishery. During spring, small percentages of eleven and twelve year-old fish were present in the catch. No fish older than ten were present in the catches assessed during the summer. In fall, few five year-olds were present and the predominate age class was nine years old. This seasonal change in age composition between summer and fall was also present in 1989, when the predominate age in the catch changed from age five in summer to age seven in fall (Figure 15). Both the 1989 and 1991 summer and fall age distributions were significantly different from one another Kolmogorov-Smirnoff two-sample test, $P<0.01$).

**Abundance and Biomass**

Abundance and biomass estimates were based upon tag return data, which were adjusted for both recruitment of younger fish into the fishery and for tag loss. To estimate the rate of tag loss, a total of 358 fish were double-tagged. Ten double-tagged fish were recovered, seven with both tags still attached and three with only one tag for a tag-loss rate of 30% over the course of the study. A daily Mayfield estimate of tag retention for the double-tagged sub-sample was extrapolated to yield an annual probability of retaining one tag over one year of 0.6906 (Bart and Robson 1982; White 1983). Based upon the binomial distribution of double-tagged returns, a 95% confidence interval of the tag loss rate ranges from 7 to 65% (Steele and Torrie 1980). Due to the wide confidence interval on the return of double-tagged

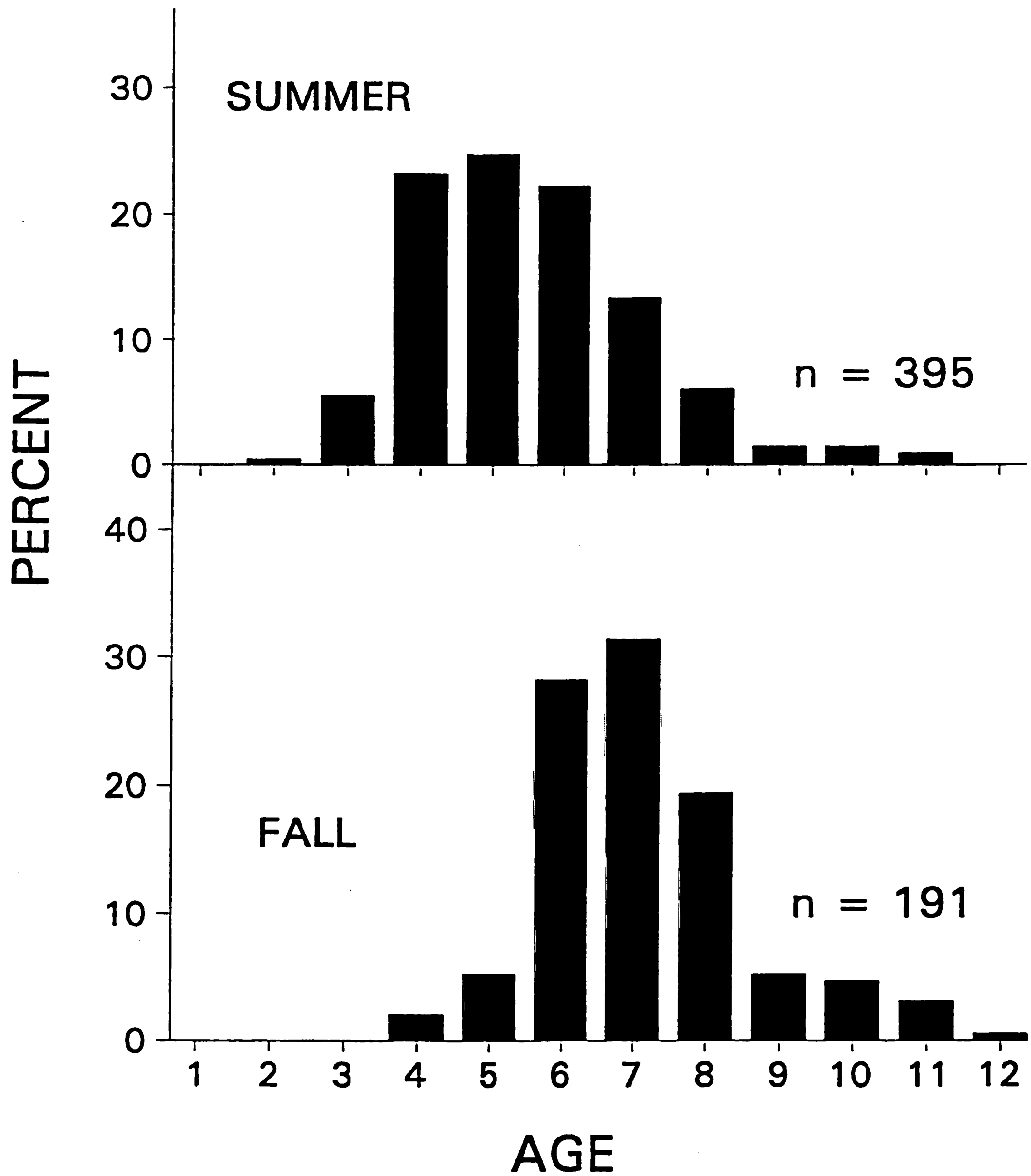


Figure 15. Age composition of lake whitefish sampled from large-mesh trap nets in the whitefish permit area in outer Saginaw Bay during summer and fall 1989.

fish, the 30.94% annual tag loss rate was used to adjust the total number of tagged fish (M) used to estimate abundance.

Because measures of abundance and biomass were based upon tag returns, it was essential to estimate the amount of cooperation by the fishermen involved in tag recapture and return. The major large-mesh trap net operators were fully cooperative, as it was due to their initiative and funding that the study was conducted. The other large-mesh trap net fisherman fished only seasonally in a northern area of the bay, and did not report any tag recoveries during several visits, phone and mail contacts. Therefore, it is assumed that all tags recovered by large-mesh trap net fishermen were reported. It was known that several small-mesh trap net fishermen were not returning the tags they recovered, but their tags were being returned by several wholesale fisheries. To determine whether most of the recovered tags were being received, the percentage of tags-to-catch of a small-mesh trap net fisherman who was known to be cooperative was compared with the percentage of other small-mesh trap net tags-to-catch (including tags returned by wholesale fisheries). This analysis demonstrated that the tags to catch ratios were independent of the method of tag return ($Chi^2$=1.035, d.f.=1, P>.05), thus it could be assumed that all recaptured tags were returned.

Abundance and biomass estimates were calculated for 1989 and 1990 (Table 6). A population estimated at 3,750,000 (95% Confidence Interval 2,946,076 - 4,759,047) whitefish existed in Saginaw Bay during 1989, decreasing to 2,690,000 (2,088,734 - 3,450,952) in 1990. Biomass, based on weighted mean individual

Table 6. 1989 and 1990 biomass and abundance estimates for Saginaw Bay (Lake Huron Management Zone MH4) calculated from the Petersen mark-recapture estimator.

| Year | M[a] | C[b] | R[c] | Estimated Population Size (N) | Mean Weight/ fish (kg)[d] | Estimated Total Biomass (kg) |
|---|---|---|---|---|---|---|
| 1989 | 2,111 | 117,229 | 66 | 3,749,552 | 1.79 | 6,711,698 |
| 1990 | 1,328 | 119,536 | 59 | 2,690,573 | 1.63 | 4,385,634 |
| 1989, 95% C.I. | | | 84 | 2,946,076 | | 5,273,477 |
| | | | 52 | 4,759,047 | | 8,518,693 |
| 1990, 95% C.I. | | | 76 | 2,088,734 | | 3,404,637 |
| | | | 46 | 3,450,952 | | 5,625,052 |

[a]Number of fish tagged, adjusted for recruitment
[b]Number of fish harvested annually
[c]Number of tagged fish which were recaptured, adjusted for tag loss
[d]Weighted mean weights of legal-sized individual fish in the large and small-mesh trap net fisheries

weights from samples of the large and small-mesh trap net fisheries, was estimated at 6,711,698 kg in 1989 and 4,385,634 in 1990.

**Movement Patterns**

Of 307 juvenile or sub-legal (< 483 mm) whitefish tagged during the spring of 1990, ten tags were returned with known recapture locations (Figure 16). All of these recaptures were made within the original tagging area, indicating little movement of juvenile whitefish during the study period. These recaptures were made throughout the year and do not indicate any seasonal trends (Appendix C).

The most distant recovery location of any of the tagged fish was from near South Bay, Manitoulin Island, Ontario, approximately 150 linear land miles from its tagging site (Figure 17). Nine additional tags were returned by Canadian commercial fishermen from gill netting operations in south eastern Lake Huron. These fisheries operate year-around and tags were recovered without any apparent seasonal pattern. Of interest is one fish which was tagged at the Bayport Islands during November of 1989 while in spawning condition and recaptured the following November in the Ontario waters of southern Lake Huron, near Kettle Point.

Due to the relatively exposed location of the large-mesh trap nets in the whitefish permit area, weather conditions limited our ability to tag fish from these nets. In November of 1989, 376 whitefish were tagged from these nets (Table 7). Three of these fish were returned during 1990 with known recapture locations, one from across the bay near Au Gres, one from the Bayport Islands to the south, and

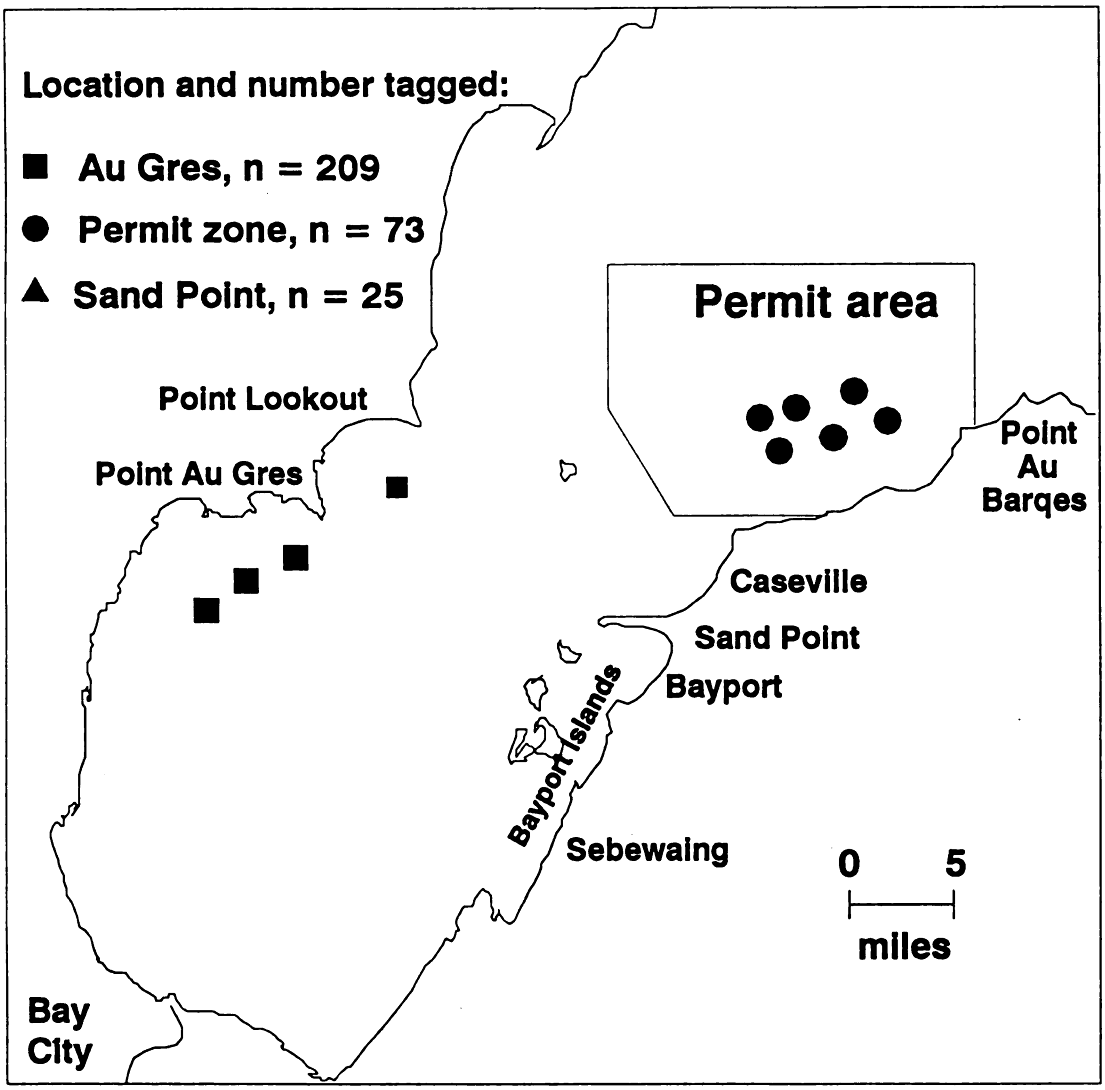


**Figure 16. Tags returned in 1990 and 1991 with known recapture locations from tagging conducted during spring 1990 near Au Gres, Sand Point, and the whitefish permit area of sub-legal sized lake whitefish.**

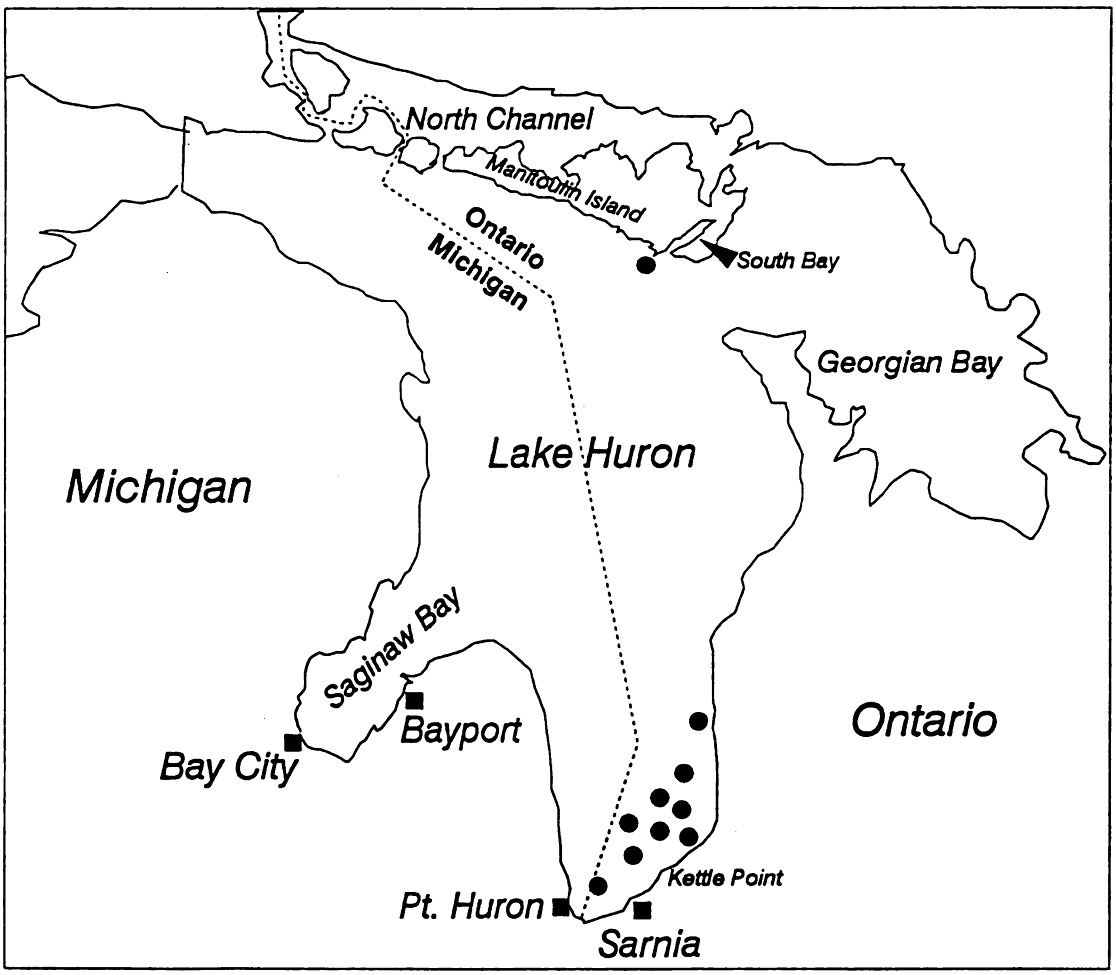


**Figure 17. Tags returned in 1990 and 1991 with known recapture locations by Canadian commercial fishermen.**

Table 7. Numbers of lake whitefish tagged, double-tagged, and returned from all fall tagging locations during 1989 through 1991.

| Location | Date | Number tagged | 1990 N | 1991 N | Total N |
|---|---|---|---|---|---|
| Fall 1989 | | | | | |
| North Island | 11-04 | 168 | 7 | 13 | 20 |
| Heisterman Island | 11-13 | 518 | 16 | 17 | 33 |
| | 11-14 | 733 | 15 | 12 | 27 |
| Sand Point | 11-09 | 374 | 5 | 3 | 9 |
| | 11-12 | 263 | 4 | 5 | 10 |
| | 11-13 | 68 | 1 | 1 | 2 |
| Permit Zone | 11-07 | 204 | 2 | 7 | 9 |
| | 11-13 | 172 | 1 | 1 | 2 |
| Total | | 2500 | 51 | 60 | 110 |
| Fall 1990 | | | | | |
| Heisterman Island | 11-03 | 262 | | 6 | |
| | 11-09 | 804 | | 15 | |
| | 11-14 | 203 | | 4 | |
| Sand Point | 11-03 | 216 | | 6 | |
| | 11-10 | 419 | | 4 | |
| Permit Zone | 11-02 | 74 | | 1 | |
| AuGres | 11-08 | 373 | | 10 | |
| Total | | 2351 | | 46 | |

one from the permit area (Figure 18). In 1991 eight tags were returned, seven of these from the permit area and one from the Canadian gill net fishery in southern Lake Huron. In November of 1990, 74 fish were tagged in the permit area (Table 7). Only one of these tags was recaptured from a known location, near Au Gres.

From nets set off the north shore of Sand Point, 1,340 whitefish were tagged and released during November of 1989 and 1990 (Table 7). Twenty-nine of these fish were recaptured at locations throughout the bay, one in southern Lake Huron, and one was returned from a commercial fish wholesale business in Racine, Wisconsin (Figure 19). Only two fish were recaptured near the original tagging site, most (17) were recaptured in the permit area, eight were recaptured in nets set near the Bayport Islands, and one was recaptured near Point Au Gres. Fall recaptures do not indicate homing to the tagging site (Appendix C).

The Bayport Islands are located close to the commercial fish docks at Bayport and are protected from hazardous storms arising from the northeast. These factors allowed us to tag a large number (2,678) of whitefish from nets set off the northwestern shores of the islands during November in 1989 and 1990. Consequently, the largest number (105) of tag recoveries are of fish tagged in these nets (Figure 20). These tags were recovered from all areas of the bay (99), and seven were recaptured in the Canadian waters of southern Lake Huron. There do not appear to be seasonal or annual patterns of movement which are discernable from these tag return data.

Fall tagging was conducted near Au Gres only during 1990 when 373

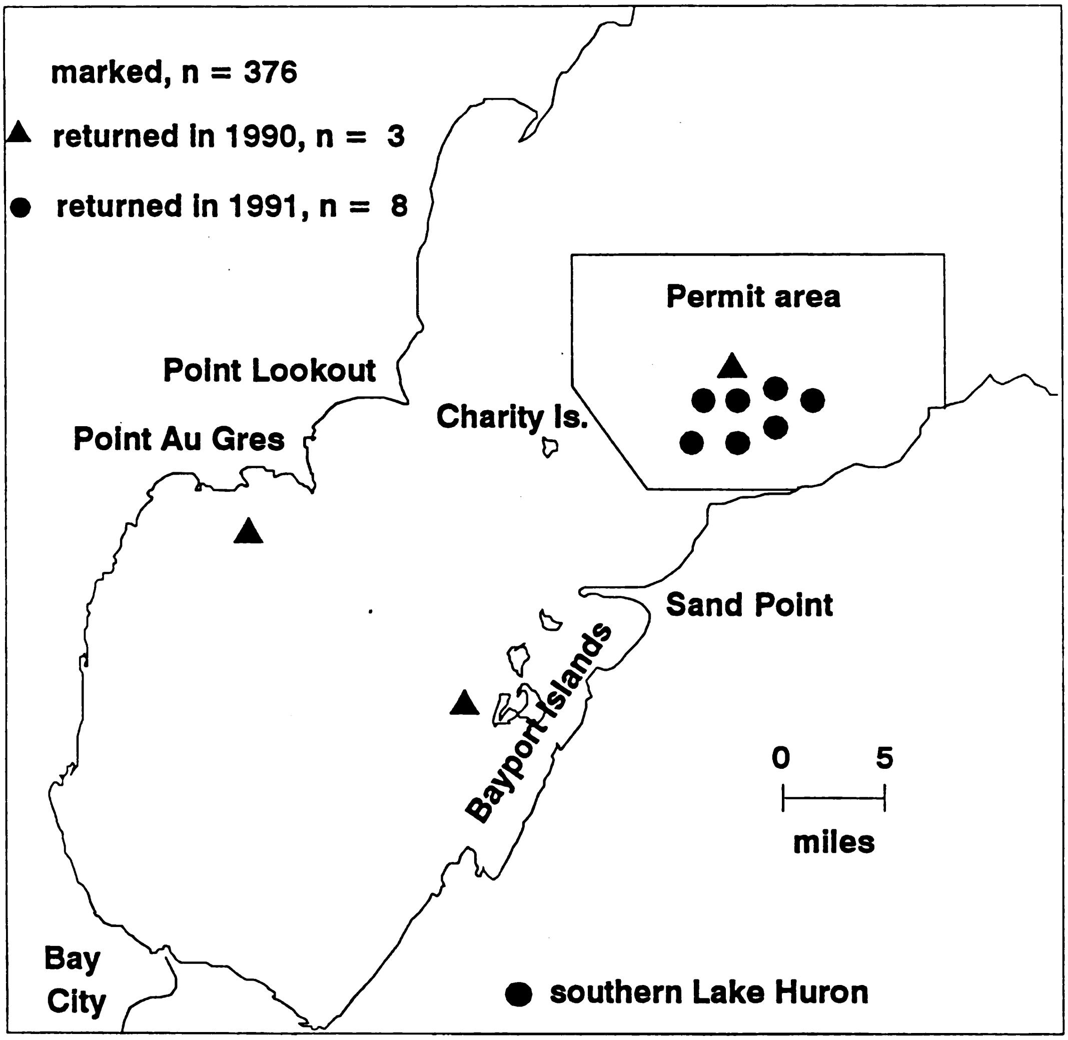


Figure 18. Tags returned in 1990 and 1991 with known recapture locations from tagging conducted during the fall of 1989 in the whitefish permit area.

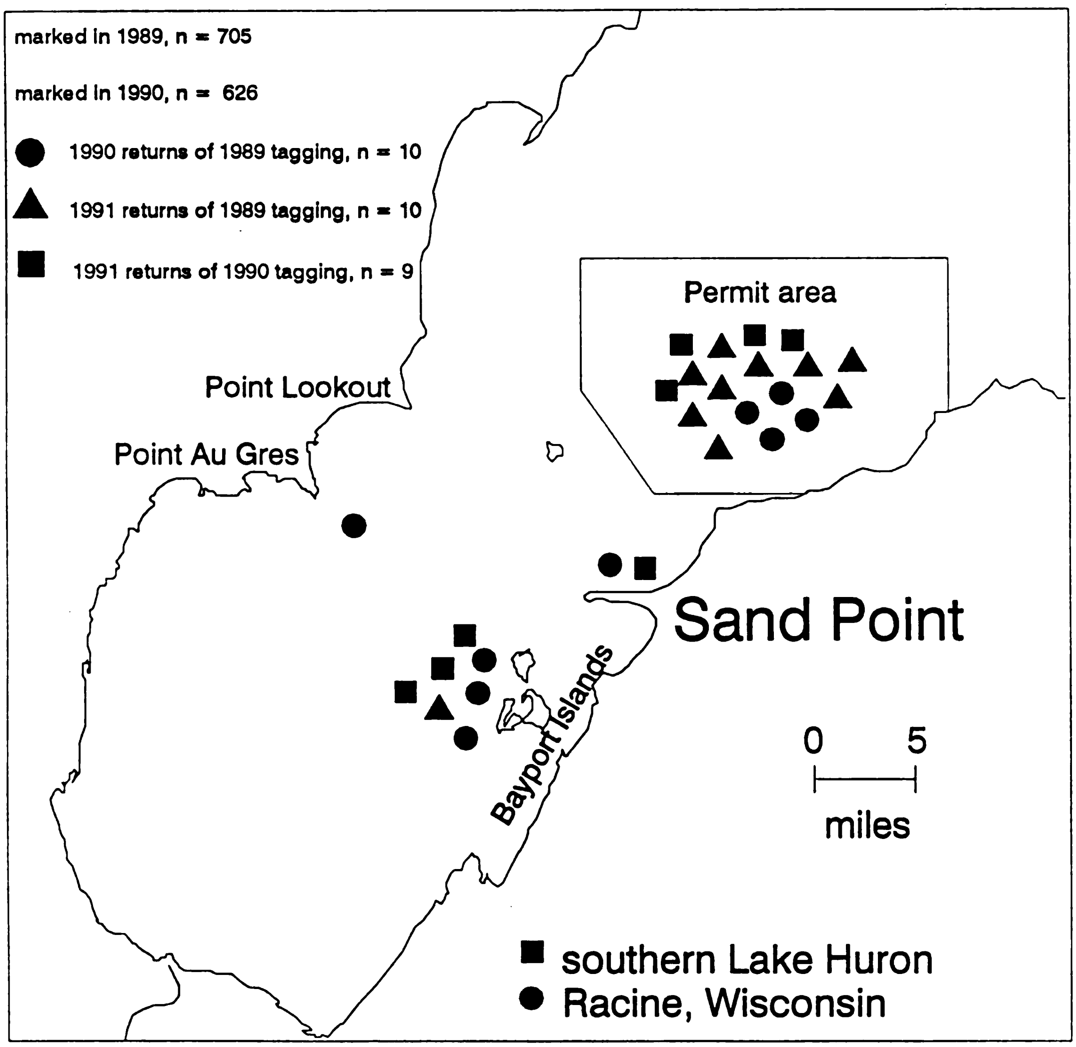


Figure 19. Tags returned in 1990 and 1991 with known recapture locations from tagging conducted during fall 1989 and fall 1990 at Sand Point.

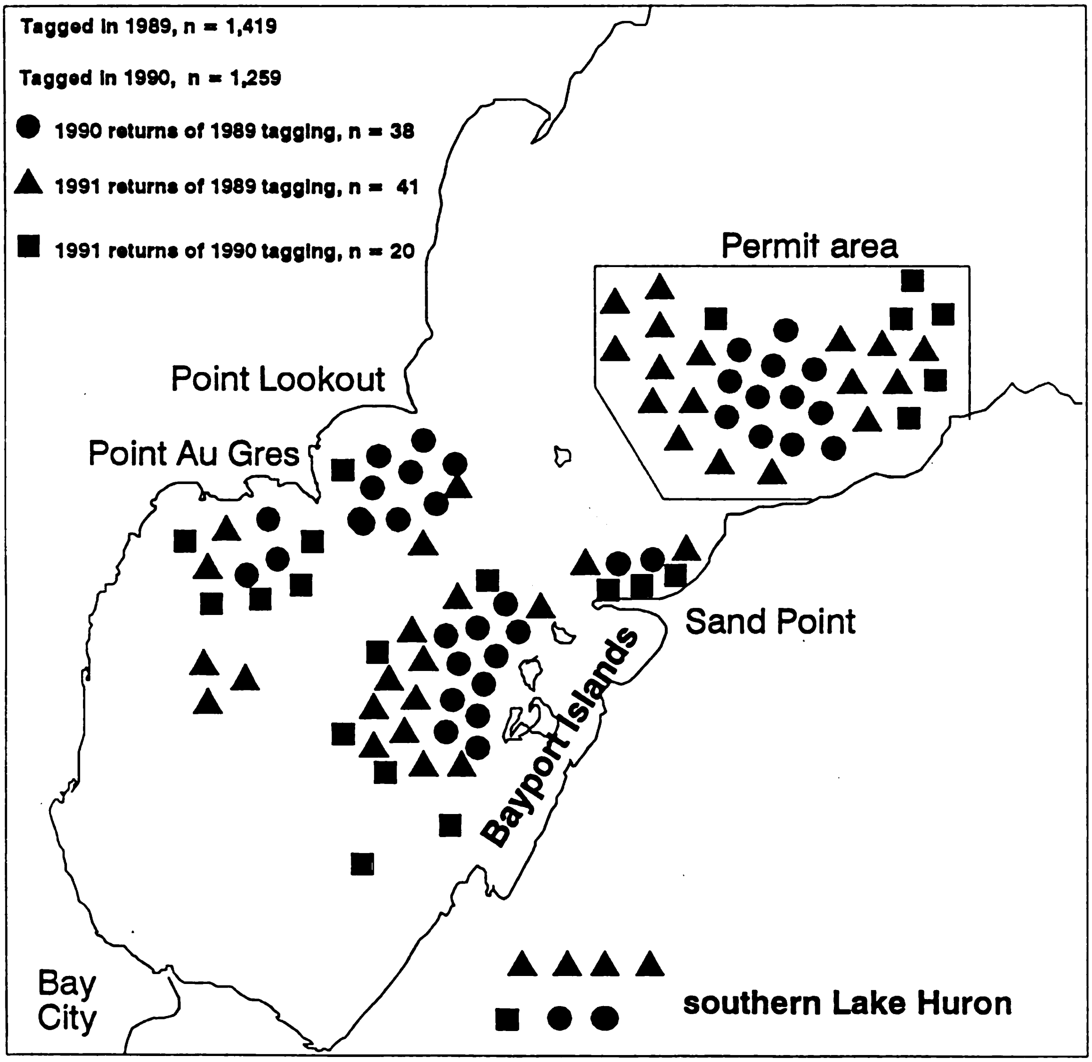


Figure 20. Tags returned in 1990 and 1991 with known recapture locations from tagging conducted during fall 1989 and fall 1990 at Bayport Islands.

whitefish were tagged and released. Ten of these fish were recaptured, eight from near the original tagging site and two from the permit area (Figure 21).

**Yield**

Using population estimates, age distributions, and growth characteristics determined in this study, allowable yield was estimated from a target optimal total annual mortality rate of 60%. This mortality rate was reported to be the median mortality limit which lake whitefish populations can endure over time without collapsing (Clark 1985).

Yields for 1990 and 1991 were calculated using population estimates from the fall of 1989 and 1990. For each year the average biomass of each age class was calculated using the following equation (Ricker 1975):

$$\bar{B} = \int_{t=0}^{1} B_0 e^{(G-Z)t} dt$$

where $B_o$ equals the fall biomass estimate; instantaneous growth rate (G) was determined from summer age data of whitefish permit area, Bayport Islands and Sand Point fish; instantaneous total mortality rate (Z) was estimated from cohort analysis to be 0.85, exploitation (u) = 0.0363, instantaneous fishing mortality was set at (F) = 0.6, and instantaneous natural mortality (M) = 0.313. All parameters except the instantaneous growth rates were constant for all ages.

Yield estimates for 1990 and 1991 differred by 1/3, yet their 95% confidence intervals overlapped indicating that the difference was not significant. In

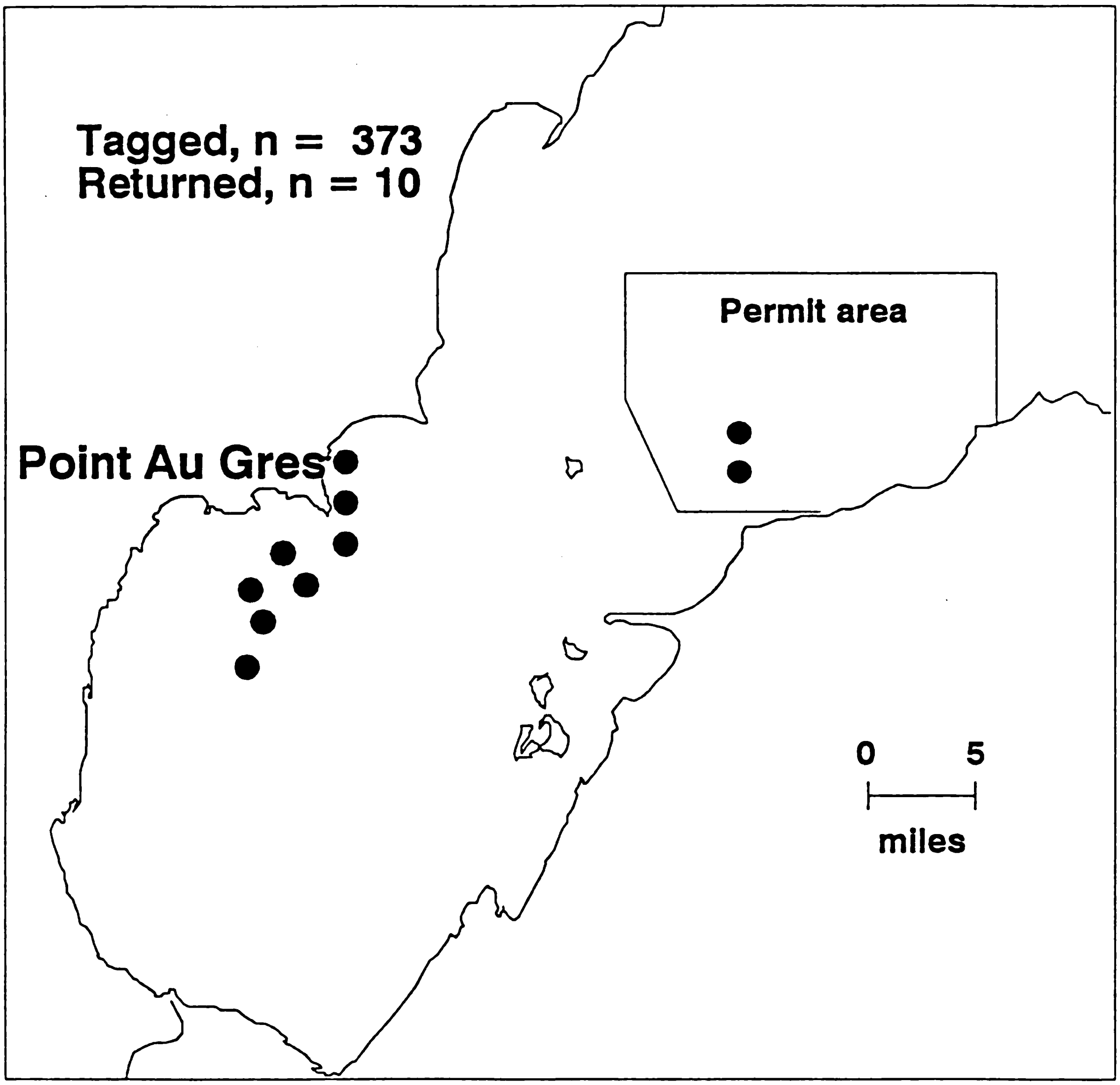


Figure 21. Tags returned in 1991 with known locations from tagging conducted during fall 1990 near Au Gres.

1990, yield at instantaneous fishing mortality (F) = 0.6 was estimated to be 3,002,685 kg (95% Confidence Interval = 2,359,221 - 3,811,049) (Table 8), decreasing to 1,962,022 kg (95% Confidence Interval = 1,523,149 - 2,516,506) (Table 9). Actual harvests in these two years were 208,967 kg in 1990 and 193,332 kg in 1991. F was estimated from analysis of the 1983 year-class at 0.0371. Using this value of F in the yield equation, yield in 1991 closely approximates actual harvest at 185,659 kg.

## DISCUSSION

This study provided new, baseline information about the lake whitefish population of Saginaw Bay which will be useful for future management of the stock. The broad age and size structure of the population indicates that the stock is not experiencing heavy mortality due to fishing or natural causes. The observed differences in size and age structure of whitefish sampled from different areas and at different seasons are probably attributable to seasonal distributions due to behavior. For example, juvenile lake whitefish are known to inhabit shoal waters (Reckahn 1970; Scott and Crossman 1975) and thus are found more frequently in the shoal areas of inner Saginaw Bay. During fall, an abundance of larger, older fish congregate to spawn on the shoals, and younger, immature fish do not mix with the spawners. Thus the fall age compositions are very different from those during other seasons.

In heavily exploited lake whitefish populations, such as Lake Michigan's

Table 8. 1990 yield estimates for Saginaw Bay lake whitefish at F = 0.60.

| Age in 1989 | % of catch at age | Biomass in 1989 (kg) | 95% Confidence Intervals (Lower limit) (kg) | (Upper limit) (kg) | a G | b Z | c F |
|---|---|---|---|---|---|---|---|
| 4 | 7.0 | 469819 | 369143 | 596309 | 0.330 | 0.85 | 0.6 |
| 5 | 16.5 | 1107430 | 870124 | 1405584 | 0.240 | 0.85 | 0.6 |
| 6 | 34.5 | 2315536 | 1819350 | 2938949 | 0.263 | 0.85 | 0.6 |
| 7 | 23.1 | 1550402 | 1218173 | 1967818 | 0.167 | 0.85 | 0.6 |
| 8 | 11.0 | 738287 | 580082 | 937056 | 0.127 | 0.85 | 0.6 |
| 9 | 3.6 | 241621 | 189845 | 306673 | 0.108 | 0.85 | 0.6 |
| 10 | 2.7 | 181216 | 142384 | 230005 | 0.135 | 0.85 | 0.6 |
| >10 | 1.6 | 107387 | 84376 | 136299 | 0.074 | 0.85 | 0.6 |
| | Total | 6711698 | 5273477 | 8518693 | | | |

| Age in 1990 | Biomass in 1990 (kg) | 95% Confidence Intervals (Lower limit) (kg) | (Upper limit) (kg) | Harvest at F = .60 (kg) | 95% Confidence Intervals (Lower limit) (kg) | (Upper limit) (kg) |
|---|---|---|---|---|---|---|
| 4 | 366350 | 287846 | 464982 | 219810 | 172708 | 278989 |
| 5 | 829028 | 651379 | 1052227 | 497417 | 390827 | 631336 |
| 6 | 1751472 | 1376157 | 2223022 | 1050883 | 825694 | 1333813 |
| 7 | 1123418 | 882686 | 1425877 | 674051 | 529611 | 855526 |
| 8 | 525588 | 412962 | 667093 | 315353 | 247777 | 400256 |
| 9 | 170580 | 134027 | 216506 | 102348 | 80416 | 129903 |
| 10 | 129464 | 101721 | 164319 | 77678 | 61033 | 98591 |
| >10 | 74694 | 58689 | 94805 | 44817 | 35213 | 56883 |
| Total | 4970594 | 3905466.8 | 6308830.5 | 2982356.4 | 2343280.1 | |

a
instantaneous growth rate
b
instantaneous total annual mortality rate
c
instantaneous fishing mortality rate

Table 9. 1991 yield estimates for Saginaw Bay lake whitefish at F = 0.60.

| Age in 1990 | % of Catch at age | Biomass in 1990 (kg) | 95% Confidence intervals (Lower limit) (kg) | (Upper limit) (kg) | a G | b Z | c F |
|---|---|---|---|---|---|---|---|
| 4 | 16.4 | 719244 | 558360 | 924149 | 0.330 | 0.85 | 0.6 |
| 5 | 28.4 | 1245520 | 966917 | 1600355 | 0.240 | 0.85 | 0.6 |
| 6 | 17.1 | 749943 | 582193 | 963594 | 0.263 | 0.85 | 0.6 |
| 7 | 19.0 | 833270 | 646881 | 1070660 | 0.167 | 0.85 | 0.6 |
| 8 | 12.3 | 539433 | 418770 | 693111 | 0.127 | 0.85 | 0.6 |
| 9 | 4.1 | 179811 | 139590 | 231037 | 0.108 | 0.85 | 0.6 |
| 10 | 2.0 | 87713 | 68093 | 112701 | 0.135 | 0.85 | 0.6 |
| >10 | 0.7 | 30699 | 23832 | 39445 | 0.074 | 0.85 | 0.6 |
| | Total | 4385634 | 3404637 | 5635052 | | | |

| Age in 1991 | Biomass in 1991 (kg) | 95% Confidence interval (Lower limit (kg) | (Upper limit) (kg) | Harvest at F = .60 (kg) | 95% Confidence intervals (Lower lim (kg) | (Upper limit) (kg) |
|---|---|---|---|---|---|---|
| 4 | 239384 | 185838 | 307582 | 143631 | 111503 | 184549 |
| 5 | 558128 | 433284 | 717133 | 334877 | 259970 | 430280 |
| 6 | 1161053 | 901344 | 1491824 | 696632 | 540806 | 895095 |
| 7 | 730899 | 567408 | 939124 | 438539 | 340445 | 563474 |
| 8 | 343436 | 266615 | 441277 | 206062 | 159969 | 264766 |
| 9 | 123847 | 96145 | 159130 | 74308 | 57687 | 95478 |
| 10 | 93995 | 72970 | 120773 | 56397 | 43782 | 72464 |
| >10 | 61010 | 47363 | 78391 | 36606 | 28418 | 47034 |
| Total | 3311752 | 2570966 | 4255234 | 1987051 | 1542579 | 2553140 |

a
instantaneous growth rate
b
instantaneous total annual mortality rate
c
instantaneous fishing mortality rate

North Shore population no fish older than age five are present (Scheerer 1982). Age at maturity is another indication of fishing pressure, as age at maturity decreases with sustained heavy fishing pressure. Saginaw Bay lake whitefish did not begin to mature until reaching the age of four years and were not 100% mature until reaching seven years of age, similar to the lightly exploited Alpena whitefish population (Freeberg et al. 1990).

These basic observations on the relative amount of exploitation were supported by estimates of mortality and exploitation calculated from catch curve and cohort analysis. Catch curve analysis is the least reliable of the two estimates however, due to variations in year class strength which obscure true trends in year-to-year numbers at age. The third method of estimating mortality and exploitation, from tag return data, is probably the most flawed. For the mark-recapture based population parameters to be reliable, the following conditions must apply: the marked fish (M) become randomly distributed in the population before the second sample (C) is taken and (C) must be selected at random from the population (Robson and Regier 1964). It is also assumed that the population is closed. By tagging fish during the fall spawning closure and waiting over-winter to recapture tags, the first condition is probably met. However, the second condition has clearly not been met by virtue of the fact that the fishery occurs within Saginaw Bay, and many tagged fish ventured beyond the bay into Lake Huron proper. Although the Canadian fishery did return a substantial number of tags, the Canadian catch far exceeds the Saginaw Bay harvest, and the ratios of tags-to-catch are grossly different between the two areas. This indicates that either the Saginaw Bay whitefish partially mix with the population(s) inhabiting the eastern shore of southern Lake Huron, or one homogenous stock exists and tag reporting was (very) incomplete from the Canadian fishery. Canadian fishermen were notified of the study by mail, and tag returns were received from both the fishermen themselves and from governmental on-board fishery observers, indicating that tag recovery reporting was good.

Because M is functionally over-estimated, the resulting annual survival rate is over-estimated. Hence, total annual mortality is over-estimated, and exploitation, instantaneous total annual mortality, instantaneous total mortality, instantaneous total fishing mortality, and instantaneous total natural mortality rates are all under-estimated.

One hypothesis which has been put forth to explain the apparent mixing of whitefish in southern Lake Huron with those inhabiting Saginaw Bay is a that a lack of suitable spawning habitat exists in the southern Lake with the exception of the Bay which contains vast areas of suitable spawning substrate, causing fish to migrate into the Bay to spawn. Perusal of the Atlas of the Spawning and Nursery Areas of Great Lakes Fishes (Goodyear et al. 1982) indicates that this may be the case. The atlas states that most of the shoreline, island and reef areas of Saginaw Bay were used for whitefish spawning, and other than two small reef areas in the southern basin at Harbor Beach and Port Huron, no other whitefish spawning areas were known to exist in southern Lake Huron. The literature does not address whitefish spawning grounds in the Ontario waters of southern Lake Huron, but communication with Ontario fisheries managers and fishermen indicates that a possible spawning location exists near Kettle Point and no other grounds are known (N. Robert Payne, Ontario Ministry of Natural Resources, personal communication; John Little, commercial fisherman, personal communication).

Other support for this hypothesis includes the favorable ice cover which forms early (mid-November) annually on the Bay, followed by rapid spring break-up and fast warming of the highly productive enriched waters of the Bay. Freeberg et al. (1990) discovered that whitefish year-class strength is determined during the first few weeks post-hatching and that early ice-cover followed by an early, warm spring lead to greater survival and eventual recruitment of whitefish. Saginaw Bay consistently provides these conditions.

The problems which plagued the mark-recapture based exploitation and mortality estimates also effected estimates of stock abundance and biomass, which were based upon tagging data. Because M was effectually over-estimated, estimates of abundance and biomass were also over-estimated. This is obvious when comparing the 1989 and 1990 biomass estimates with historical harvest, biomass is estimated at approximately two to three times the all-time record harvest. Because tagging occurred during the fall when the fishery was presumably composed of mixed stocks, I was unable to estimate that portion of the marked fish which resided primarily within the Bay in order to estimate the fishable population of Saginaw Bay.

Yield estimates are based upon the above described flawed biomass estimates and were likewise unreliable, however, using the estimated total annual fishing mortality value the actual harvest was closely approximated.

Saginaw Bay lake whitefish are forced by seasonal thermal conditions to be migratory. With the exception of spring and fall, during turn-over, lake whitefish are usually found just off the lake bottom, under the thermocline in water between 6 and 8°C. The relatively shallow waters of Saginaw warm rapidly during the summer months, and by early August temperatures at 30m are near 10°C (Beeton et al. 1967). Water temperatures remain above 10°C until mid-September and lake whitefish apparently leave the Bay's waters for the open lake where more favorable temperatures can be found.

When this study was being planned, it was expected that the Saginaw Bay whitefish would prove to be an isolated, closed population composed of multiple reproductively isolated stocks, similar to most other Great Lakes whitefish populations studied (eg. Budd 1957; Cucin and Regier 1966; Ebner and Copes 1985; Casselman et al. 1981; Scheerer and Taylor 1985; Smale 1988; Prout 1989; Walker et al. in press; etc.). Perhaps the most significant finding of this study is that Saginaw Bay lake whitefish are not discrete from the population inhabiting southern Lake Huron waters. Fall tag returns did not indicate homing to specific spawning grounds, or even to Saginaw Bay. Over five percent of the tags recovered were returned from the Ontario waters of southern Lake Huron, presumably these fish also range south along the Michigan shore where no fishery operates to intercept and report them. The recovery of one tag to the far north at the mouth of South Bay, Manitoulin Island, Ontario indicates that this population is very migratory, and perhaps mixes with other Lake Huron whitefish populations. These findings support those of Hill (1982) who found no evidence for discrete stocks of whitefish in outer Saginaw Bay from four locations, based on the results of electrophoretic studies. The implications of this finding leads to a new view of the Saginaw Bay whitefish population as being part of a larger southern Lake Huron stock, based on the movements of tagged fish.

The findings of this study are important for the continued management of the Saginaw Bay lake whitefish fishery. Rather than assuming that the stock is discrete and exists within the geographical boundaries of Lake Huron's Whitefish Management Zone 4, tag returns have indicated the far-ranging migratory nature of these fish. Saginaw Bay's importance as a spawning and nursery ground for lake whitefish will place more importance on continued clean-up of it's industrial pollutants and the identification and preservation of critical spawning areas. One research need emphasized by this study is to identify lake whitefish spawning and nursery grounds within the southern portion of Lake Huron, in both U. S. and Canadian waters.

Realization that the fall fishery is targeting an international, mixed-stock concentration of spawners may lead to increased United States - Canadian management of this important fishery. Another research need identified by this study is to determine the number of lake whitefish stocks and the degree of stock mixing which occurs in the southern Lake Huron basin.

Even though estimates of exploitation from this study are not reliable, the small catch-to-tag return ratios and the size and age structure observed indicate that the population is experiencing low levels of exploitation. Thus, it is probable that fishing effort could increase without harmful effect to the population. Finally, it is apparent that both the large and small-mesh trap net fisheries are harvesting fish from the same population, thus the current different minimum size limits for each fishery lack a logical purpose and pose both enforcement and management complications.

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Appendix A. Sex composition by season, location, gear, and age of lake whitefish assessed from commercial trap net catches of Saginaw Bay, Lake Huron during 1989 through 1991.

| Season | Location | Gear | Age | % F | % M | N |
|---|---|---|---|---|---|---|
| 1991 | Saginaw Bay | All | 2 | 1.00 | 0.00 | 4 |
| | | | 3 | 0.53 | 0.47 | 45 |
| | | | 4 | 0.40 | 0.60 | 60 |
| | | | 5 | 0.39 | 0.61 | 145 |
| | | | 6 | 0.53 | 0.47 | 38 |
| | | | 7 | 0.26 | 0.74 | 46 |
| | | | 8 | 0.41 | 0.59 | 29 |
| | | | 9 | 0.67 | 0.33 | 27 |
| | | | 10 | 0.58 | 0.42 | 12 |
| | | | 11 | 0.63 | 0.38 | 8 |
| | | | 12 | 1.00 | 0.00 | 1 |
| | | MEAN (TOTAL) | | 0.44 | 0.56 | (415) |
| Spring | Permit Zone | TN-L | 2 | 1.00 | 0.00 | 1 |
| | | | 3 | 0.88 | 0.13 | 8 |
| | | | 4 | 0.36 | 0.64 | 11 |
| | | | 5 | 0.58 | 0.42 | 26 |
| | | | 6 | 0.60 | 0.40 | 5 |
| | | | 7 | 0.13 | 0.87 | 15 |
| | | | 8 | 0.44 | 0.56 | 9 |
| | | | 9 | 0.70 | 0.30 | 10 |
| | | | 10 | 0.57 | 0.43 | 7 |
| | | | 11 | 0.25 | 0.75 | 4 |
| | | | 12 | 0.00 | 1.00 | 1 |
| | | MEAN (TOTAL) | | 0.49 | 0.51 | (97) |
| Spring | Bay City | TN-S | 2 | 0.00 | 1.00 | 3 |
| | | | 3 | 0.40 | 0.60 | 20 |
| | | | 4 | 0.17 | 0.83 | 12 |
| | | | 5 | 0.29 | 0.71 | 7 |
| | | | 6 | 0.20 | 0.80 | 5 |
| | | | 7 | 0.00 | 1.00 | 3 |
| | | MEAN (TOTAL) | | 0.26 | 0.74 | (50) |

Appendix A. Cont.

| Season | Location | Gear | Age | % F | % M | N |
|---|---|---|---|---|---|---|
| Summer | Permit Zone | TN-L | 3 | 0.44 | 0.56 | 9 |
| | | | 4 | 0.52 | 0.48 | 29 |
| | | | 5 | 0.44 | 0.56 | 84 |
| | | | 6 | 0.63 | 0.38 | 16 |
| | | | 7 | 0.63 | 0.38 | 8 |
| | | | 8 | 0.00 | 1.00 | 1 |
| | | | 9 | 1.00 | 0.00 | 2 |
| | | | 10 | 1.00 | 0.00 | 1 |
| | | MEAN (TOTAL) | | 0.49 | 0.51 | (150) |
| Fall | Permit Zone | TN-L | 5 | 0.00 | 1.00 | 1 |
| | | | 6 | 0.71 | 0.29 | 7 |
| | | | 7 | 0.27 | 0.73 | 11 |
| | | | 8 | 0.55 | 0.45 | 11 |
| | | | 9 | 0.67 | 0.33 | 12 |
| | | | 10 | 0.33 | 0.67 | 3 |
| | | | 11 | 1.00 | 0.00 | 3 |
| | | MEAN (TOTAL) | | 0.54 | 0.46 | (48) |
| Fall | Bayport Islands | TN-S | 3 | 0.63 | 0.38 | 8 |
| | | | 4 | 0.38 | 0.63 | 8 |
| | | | 5 | 0.12 | 0.88 | 26 |
| | | | 6 | 0.17 | 0.83 | 6 |
| | | | 7 | 0.22 | 0.78 | 9 |
| | | | 8 | 0.25 | 0.75 | 8 |
| | | | 9 | 0.33 | 0.67 | 3 |
| | | | 10 | 1.00 | 0.00 | 1 |
| | | | 11 | 1.00 | 0.00 | 1 |
| | | MEAN (TOTAL) | | 0.27 | 0.73 | (70) |
| <u>1990</u> | Saginaw Bay | All | 3 | 1.00 | 0.00 | 1 |
| | | | 4 | 0.42 | 0.58 | 74 |
| | | | 5 | 0.40 | 0.60 | 101 |
| | | | 6 | 0.33 | 0.67 | 69 |
| | | | 7 | 0.46 | 0.54 | 82 |
| | | | 8 | 0.40 | 0.60 | 42 |
| | | | 9 | 0.50 | 0.50 | 22 |
| | | | 10 | 0.50 | 0.50 | 10 |
| | | | 11 | 0.00 | 1.00 | 1 |
| | | MEAN (TOTAL) | | 0.41 | 0.59 | (402) |

Appendix A. Cont.

| Season | Location | Gear | Age | % F | % M | N |
|---|---|---|---|---|---|---|
| Spring | Permit Zone | TN-L | 4 | 0.46 | 0.54 | 35 |
| | | | 5 | 0.48 | 0.52 | 42 |
| | | | 6 | 0.40 | 0.60 | 20 |
| | | | 7 | 0.52 | 0.48 | 33 |
| | | | 8 | 0.67 | 0.33 | 21 |
| | | | 9 | 0.59 | 0.41 | 17 |
| | | | 10 | 0.50 | 0.50 | 10 |
| | | | 11 | 0.00 | 1.00 | 1 |
| | | MEAN (TOTAL) | | 0.50 | 0.50 | (179) |
| Summer | Permit Zone | TN-L | 4 | 0.37 | 0.63 | 35 |
| | | | 5 | 0.47 | 0.53 | 32 |
| | | | 6 | 1.00 | 0.00 | 2 |
| | | | 7 | 0.20 | 0.80 | 5 |
| | | | 8 | 1.00 | 0.00 | 1 |
| | | MEAN (TOTAL) | | 0.43 | 0.57 | (75) |
| Fall | Bayport Islands | TN-S | 3 | 1.00 | 0.00 | 1 |
| | | | 4 | 0.50 | 0.50 | 4 |
| | | | 5 | 0.19 | 0.81 | 27 |
| | | | 6 | 0.28 | 0.72 | 47 |
| | | | 7 | 0.45 | 0.55 | 44 |
| | | | 8 | 0.10 | 0.90 | 20 |
| | | | 9 | 0.20 | 0.80 | 5 |
| | | MEAN (TOTAL) | | 0.30 | 0.70 | (148) |
| <u>1989</u> | Saginaw Bay | All | 2 | 1.00 | 0.00 | 2 |
| | | | 3 | 0.55 | 0.45 | 22 |
| | | | 4 | 0.46 | 0.54 | 98 |
| | | | 5 | 0.42 | 0.58 | 129 |
| | | | 6 | 0.35 | 0.65 | 242 |
| | | | 7 | 0.34 | 0.66 | 161 |
| | | | 8 | 0.40 | 0.60 | 77 |
| | | | 9 | 0.36 | 0.64 | 25 |
| | | | 10 | 0.44 | 0.56 | 18 |
| | | | 11 | 0.55 | 0.45 | 11 |
| | | | 12 | 1.00 | 0.00 | 1 |
| | | MEAN (TOTAL) | | 0.39 | 0.61 | (786) |

Appendix A. Cont.

| Season | Location | Gear | Age | % F | % M | N |
|---|---|---|---|---|---|---|
| Summer | Permit Zone | TN-L | 2 | 1.00 | 0.00 | 2 |
| | | | 3 | 0.55 | 0.45 | 22 |
| | | | 4 | 0.48 | 0.52 | 92 |
| | | | 5 | 0.50 | 0.50 | 98 |
| | | | 6 | 0.50 | 0.50 | 88 |
| | | | 7 | 0.40 | 0.60 | 52 |
| | | | 8 | 0.42 | 0.58 | 24 |
| | | | 9 | 0.67 | 0.33 | 6 |
| | | | 10 | 0.50 | 0.50 | 6 |
| | | | 11 | 0.50 | 0.50 | 4 |
| | | MEAN (TOTAL) | | 0.48 | 0.52 | (394) |
| Fall | Permit Zone | TN-L | 4 | 0.25 | 0.75 | 4 |
| | | | 5 | 0.10 | 0.90 | 10 |
| | | | 6 | 0.30 | 0.70 | 54 |
| | | | 7 | 0.38 | 0.62 | 60 |
| | | | 8 | 0.41 | 0.59 | 37 |
| | | | 9 | 0.30 | 0.70 | 10 |
| | | | 10 | 0.56 | 0.44 | 9 |
| | | | 11 | 0.67 | 0.33 | 6 |
| | | | 12 | 0.00 | 1.00 | 1 |
| | | MEAN (TOTAL) | | 0.36 | 0.64 | (191) |
| Fall | Bayport Islands | TN-S | 4 | 0.00 | 1.00 | 2 |
| | | | 5 | 0.19 | 0.81 | 21 |
| | | | 6 | 0.24 | 0.76 | 100 |
| | | | 7 | 0.22 | 0.78 | 49 |
| | | | 8 | 0.38 | 0.63 | 16 |
| | | | 9 | 0.22 | 0.78 | 9 |
| | | | 10 | 0.00 | 1.00 | 4 |
| | | | 11 | 0.00 | 1.00 | 1 |
| | | MEAN (TOTAL) | | 0.23 | 0.77 | (202) |

Appendix B. Age compositions of all commercial trap net catch samples collected from 1989 through 1991 from Saginaw Bay, Lake Huron.

| Date | Location | Gear[a] | Age | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1989 | | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| 07/18 | Permit | TN-L | 0 | 2 | 41 | 38 | 45 | 14 | 14 | 9 | 1 | 0 | 0 | 151 |
| 08/01 | Permit | TN-L | 1 | 11 | 37 | 41 | 22 | 19 | 7 | 3 | 0 | 0 | 0 | 144 |
| 08/09 | Permit | TN-L | 1 | 9 | 14 | 19 | 22 | 19 | 8 | 2 | 6 | 4 | 0 | 104 |
| 10/20 | Permit | TN-L | 0 | 0 | 1 | 6 | 33 | 38 | 17 | 4 | 3 | 3 | 0 | 106 |
| 10/20 | Islands | TN-S | 0 | 0 | 1 | 10 | 50 | 25 | 8 | 5 | 1 | 1 | 0 | 101 |
| 10/30 | Permit | TN-L | 0 | 0 | 3 | 4 | 21 | 22 | 20 | 6 | 6 | 3 | 1 | 86 |
| 10/30 | Islands | TN-S | 0 | 0 | 1 | 11 | 50 | 24 | 8 | 4 | 3 | 0 | 0 | 101 |
| 1990 | | | | | | | | | | | | | | |
| 05/03 | Permit | TN-L | 0 | 0 | 2 | 14 | 8 | 14 | 18 | 7 | 3 | 5 | 1 | 72 |
| 05/03 | Permit | TN-L | 0 | 0 | 4 | 6 | 10 | 17 | 6 | 7 | 4 | 0 | 0 | 54 |
| 05/31 | Permit | TN-L | 1 | 10 | 41 | 22 | 4 | 4 | 5 | 0 | 3 | 0 | 0 | 90 |
| 05/31 | Permit | TN-L | 0 | 0 | 31 | 30 | 11 | 9 | 12 | 14 | 1 | 2 | 0 | 110 |
| 05/31 | Permit | TN-L | 0 | 2 | 14 | 15 | 7 | 4 | 4 | 1 | 1 | 0 | 0 | 48 |
| 06/11 | Permit | TN-L | 0 | 0 | 11 | 10 | 4 | 12 | 13 | 7 | 6 | 1 | 0 | 64 |
| 07/10 | Permit | TN-L | 0 | 0 | 29 | 29 | 11 | 7 | 1 | 1 | 0 | 0 | 0 | 70 |
| 07/24 | Permit | TN-L | 0 | 4 | 66 | 50 | 5 | 7 | 2 | 0 | 0 | 0 | 0 | 135 |
| 08/16 | Permit | TN-L | 0 | 0 | 20 | 4 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 29 |
| 10/16 | Islands | TN-S | 0 | 1 | 2 | 6 | 11 | 22 | 15 | 2 | 0 | 0 | 0 | 59 |
| 10/30 | Islands | TN-S | 0 | 0 | 2 | 19 | 29 | 13 | 7 | 0 | 0 | 0 | 0 | 70 |

Appendix B.
(cont.)

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10/30 | Sand Pt. | TN-S | 0 | 0 | 0 | 3 | 7 | 11 | 1 | 3 | 0 | 0 | 0 | 25 |
| 11/08 | Au Gres | TN-S | 1 | 5 | 16 | 36 | 35 | 33 | 20 | 2 | 1 | 0 | 0 | 149 |
| 1991 | | | | | | | | | | | | | | |
| 04/25 | Permit | TN-L | 0 | 7 | 20 | 43 | 13 | 6 | 6 | 4 | 3 | 0 | 1 | 103 |
| 05/16 | Permit | TN-L | 2 | 8 | 12 | 26 | 9 | 14 | 9 | 9 | 7 | 4 | 1 | 101 |
| 05/20 | Bay City | TN-S | 4 | 36 | 27 | 17 | 9 | 6 | 0 | 0 | 1 | 0 | 0 | 101 |
| 06/20 | Permit | TN-L | 0 | 9 | 20 | 60 | 15 | 5 | 2 | 2 | 1 | 0 | 0 | 114 |
| 07/02 | Permit | TN-L | 0 | 1 | 21 | 67 | 10 | 3 | 1 | 0 | 1 | 0 | 0 | 104 |
| 07/03 | Permit | TN-L | 1 | 7 | 24 | 57 | 5 | 4 | 2 | 2 | 0 | 0 | 0 | 100 |
| 10/11 | Permit | TN-L | 0 | 0 | 0 | 1 | 7 | 11 | 11 | 12 | 3 | 3 | 0 | 48 |
| 10/11 | Sand Pt. | TN-S | 0 | 0 | 0 | 2 | 4 | 6 | 6 | 1 | 1 | 0 | 0 | 20 |
| 10/11 | Islands | TN-S | 0 | 11 | 9 | 29 | 7 | 13 | 7 | 4 | 4 | 2 | 0 | 86 |

[a]TN-L = large-mesh trap net, TN-S = small-mesh trap net

Appendix C. Tagging and tag return data for all tags recovered during 1990 and 1991.

| Tagging date | Tagging location | Tag number | Date returned | Return location |
|---|---|---|---|---|
| 11-04-89 | Heisterman Is. | 02158 | 04-90 | Grid 1508 |
| | | 02263 | 04-15-90 | Permit Zone |
| | | 02155 | 07-02-90 | Permit Zone |
| | | 02211 | 11-14-90 | Sand Point |
| | | 02259 | 10-20-91 | Permit Zone |
| | | 00018 | 06-91 | Permit Zone |
| | | 00076 | 06-91 | Permit Zone |
| | | 00004 | 10-90 | Heisterman Is. |
| | | 00154 | 07-11-90 | Permit Zone |
| | | 00129 | 10-22-90 | Permit Zone |
| | | 00066 | 04-01-91 | Grid 1507 |
| | | 00111 | 05-20-91 | Permit Zone |
| | | 00081 | 10-11-911 | Sand Point |
| | | 00149 | 10-20-91 | Permit Zone |
| | | 00107 | 10-28-91 | Maisou Island |
| | | 00147 | 10-30-91 | Permit Zone |
| | | 00116 | 11-20-91 | Maisou Island |
| | | 00031 | 03-15-91 | Grid 1608 |
| | | 00008 | 10-12-91 | Grid 1608 |
| 11-07-89 | Permit Zone | 00212 | 06-91 | Permit Zone |
| | | 00309 | 06-91 | Permit Zone |
| | | 00177 | 06-91 | Permit Zone |
| | | 00373 | 05-22-90 | Permit Zone |
| | | 00189 | 10-31-90 | Permit Zone |
| | | 00215 | 05-20-91 | Permit Zone |
| | | 00214 | 10-09-91 | Sand Point |
| | | 00235 | 10-30-91 | Permit Zone |
| | | 00231 | 05-28-91 | Heisterman Is. |
| 11-09-89 | Sand Point | 00567 | 06-91 | Permit Zone |
| | | 00429 | 10-90 | Racine, Wisconsin |
| | | 00580 | 07-02-90 | Permit Zone |
| | | 00441 | 10-22-90 | Permit Zone |
| | | 00561 | 10-31-90 | AuGres (Rifle B) |
| | | 00572 | 11-01-90 | Heisterman Is. |
| | | 00683 | 05-21-91 | Permit Zone |
| | | 00500 | 10-20-91 | Permit Zone |
| 11-12-89 | Sand Point | 07907 | 06-91 | Permit Zone |
| | | 00841 | 06-91 | Permit Zone |
| | | 00838 | 04-90 | Grid 1507 |
| | | 00796 | 04-90 | Grid 1507 |
| | | 00870 | 10-24-90 | Permit Zone |
| | | 00851 | 10-31-91 | Permit Zone |
| | | 00946 | 10-11-91 | Permit Zone |
| | | 00847 | 10-30-91 | Heisterman Is. |
| | | 00939 | 10-30-91 | Permit Zone |
| | | 01381 | 06-91 | Permit Zone |

| Tagging date | Tagging location | Tag number | Date returned | Return location |
|---|---|---|---|---|
| | | 01342 | 06-91 | Permit Zone |
| | | 01229 | 04-91 | Permit Zone |
| | | 01257 | 04-91 | Permit Zone |
| | | 01520 | 04-91 | Permit Zone |
| | | 01117 | 04-91 | Permit Zone |
| | | 01293 | 04-04-90 | Permit Zone |
| | | 01183 | 04-12-90 | Grid 1507 |
| | | 01077 | 04-20-90 | Grid 1408 |
| | | 01024 | 05-03-90 | Grid 1408 |
| | | 01283 | 05-15-90 | Grid 1507 |
| | | 01213 | 05-22-90 | Permit Zone |
| | | 01525 | 05-24-90 | Permit Zone |
| | | 01251 | 05-28-90 | Permit Zone |
| | | 01191 | 06-05-90 | Permit Zone |
| | | 01350 | 10-16-90 | Grid 1608 |
| | | 01502 | 10-25-90 | Heisterman Is. |
| | | 01495 | 10-26-90 | Heisterman Is. |
| | | 01130 | 10-29-90 | Heisterman Is. |
| | | 01112 | 11-01-90 | Heisterman Is. |
| | | 01338 | 11-10-90 | Sand Point |
| | | 01055 | 11-14-90 | Sand Point |
| | | 01347 | 05-08-91 | Permit Area |
| | | 01500 | 11-14-91 | Maisou Island |
| | | 01041 | 10-20-91 | Permit Zone |
| | | 01029 | 10-22-91 | Heisterman Is. |
| | | 01501 | 10-28-91 | Heisterman Is. |
| | | 01220 | 10-30-91 | Grid 1507 |
| | | 01289 | 10-31-91 | Maisou Island |
| | | 01486 | 11-01-91 | Grid 1507 |
| | | 01084 | 10-23-91 | Saginaw Bay |
| | | 01115 | 10-23-91 | Saginaw Bay |
| 11-13-89 | Permit Zone | 07407 | 10-90 | Heisterman Is. |
| | | 07267 | 04-25-90 | Permit Zone |
| 11-13-89 | Sand Point | 07347 | 06-91 | Permit Zone |
| | | 07328 | 10-20-90 | Heisterman Is. |
| 11-14-89 | Heisterman Is. | 02112 | NA | NA |
| | | 01905 | Fall 91 | NA |
| | | 02356 | 11-90 | s. Lake Huron |
| | | 02310 | 10-90 | Heisterman Is. |
| | | 02127 | 04-19-90 | Grid 1507 |
| | | 01648 | 04-22-90 | Grid 1408 |
| | | 01819 | 05-03-90 | Grid 1408 |
| | | 01758 | 05-04-90 | Permit Zone |
| | | 02011 | 06-04-90 | Permit Zone |
| | | 01953 | 06-27-90 | Permit Zone |
| | | 01680 | 06-27-90 | Permit Zone |
| | | 02319 | 08-24-90 | s. Lake Huron |
| | | 02348 | 10-22-90 | AuGres, Rifle Bar |
| | | 02164 | 10-23-90 | Heisterman Is. |
| | | 00036 | 10-31-90 | Heisterman Is. |
| | | 02362 | 11-01-90 | Heisterman Is. |
| | | 01582 | 03-19-91 | s. Lake Huron |
| | | 01909 | 04-17-91 | Grid 1507 |

| Tagging date | Tagging location | Tag number | Date returned | Return location |
|---|---|---|---|---|
| | | 01754 | 10-20-91 | Permit Zone |
| | | 02181 | 10-25-91 | Maisou Island |
| | | 02064 | 10-28-91 | Heisterman Is. |
| | | 01564 | 10-29-91 | Sand Point |
| | | 01719 | 10-30-91 | Permit (Oak Pt.) |
| | | 01670 | 10-31-91 | Maisou Island |
| | | 02194 | 11-01-91 | Heisterman Is. |
| | | 01607 | 06-12-91 | Grid 1608 |
| | | 01677 | 10-28-91 | Saginaw Bay |
| 04-12-90 | Au Gres | 08624 | 06-90 | Au Gres |
| | | 08225 | 06-20-90 | Grid 1408 |
| | | 08709 | 04-15-91 | Grid 1508 |
| | | 08992 | 04-17-91 | Grid 1507 |
| 04-16-90 | Permit | 08504 | 04-91 | Permit Zone |
| | | 08815 | 04-20-90 | Permit Zone |
| | | 08517 | 05-24-90 | Permit Zone |
| | | 08514 | 06-20-90 | Permit Zone |
| | | 08511 | 05-20-91 | Permit Zone |
| 05-04-90 | Permit | 08548 | 06-20-90 | Permit Zone |
| 11-02-90 | Permit | 10516 | 03-91 | s. Lake Huron |
| 11-03-90 | Heisterman Is. | 10156 | 04-91 | Grid 1609 |
| | | 10073 | 03-25-91 | Grid 1508 |
| | | 10077 | 04-24-91 | Saginaw Bay |
| | | 10074 | 06-02-91 | Permit Zone |
| | | 10174 | 10-11-91 | Permit Zone |
| | | 10297 | 04-18-91 | Grid 1707 |
| 11-03-90 | Sand Point | 10635 | 06-91 | Permit Zone |
| | | 10716 | 05-20-91 | Permit Zone |
| | | 10627 | 06-18-91 | Permit Zone |
| | | 10180 | 10-10-91 | Sand Point |
| | | 10796 | 10-31-91 | Maisou Island |
| | | 10721 | 11-15-91 | Maisou Island |
| | | 10242 | 04-91 | Permit Zone |
| | | 10226 | 04-18-91 | Permit Zone |
| | | 10995 | 07-14-91 | Grid 1407A |
| | | 10902 | 11-08-91 | Grid 1507 |
| | | 09048 | 11-08-91 | Grid 1507 |
| | | 10985 | 11-10-91 | Grid 1507 |
| | | 08019 | 07-14-91 | Grid 1407A |
| | | 08016 | 10-18-91 | Grid 1507 |
| 11-09-90 | Heisterman Is. | 09979 | NA | NA |
| | | 09779 | 06-91 | Permit Zone |
| | | 09778 | 06-91 | Permit Zone |
| | | 09774 | 04-91 | Permit Zone |
| | | 09529 | Fall 91 | NA |
| | | 09337 | 03-29-91 | Grid 1508 |
| | | 09486 | 04-01-91 | Grid 1408 |
| | | 09995 | 04-05-91 | Grid 1507 |
| | | 09019 | 04-18-91 | Grid 1508 |
| | | 09986 | 05-10-91 | Bay City (1707) |
| | | 09673 | 06-06-91 | Permit Zone |
| | | 09881 | 10-10-91 | Sand Point |
| | | 09651 | 10-23-91 | Sand Point |

| Tagging date | Tagging location | Tag number | Date returned | Return location |
|---|---|---|---|---|
| | | 09357 | 10-29-91 | Sand Point |
| | | 09912 | 10-31-91 | Maisou Island |
| 11-10-90 | Sand Point | 08766 | 07-15-91 | Grid 1608 |
| | | 08364 | 06-91 | Permit Zone |
| | | 02473 | 04-25-91 | Permit Zone |
| | | 08876 | 11-01-91 | NA |
| 11-14-90 | Heisterman Is. | 8848 | 04-25-91 | Grid 1507 |
| | | 7632 | 06-91 | Heisterman Is. |
| | | 7130 | Fall 91 | Heisterman Is. |
| | | 7191 | 04-23-91 | Heisterman Is. |
| | | 7032 | 10-22-91 | Heisterman Is. |
| Unknown | Unknown | Unknown | 04-91 | Permit Zone |
| | | | 06-91 | Grid 1508 |
| | | | 06-91 | Grid 1508 |
| | | | 06-91 | Grid 1508 |
| | | | 06-91 | Grid 1508 |
| | | | 03-90 | Grid 1507 |
| | | | 03-90 | Grid 1507 |
| | | | 05-90 | Grid 1410 |
| | | | 05-90 | Grid 1410 |
| | | | 04-05-90 | Grid 1507 |
| | | | 04-05-90 | Grid 1507 |
| | | | 05-24-91 | Grid 1507 |