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Masters degree in Fisheries & Wildlife

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# POPULATION DYNAMICS AND STOCK DIFFERENTIATION OF LAKE WHITEFISH, *COREGONUS CLUPEAFORMIS*, IN GRAND TRAVERSE BAY, LAKE MICHIGAN

By

Mark William Prout

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# ABSTRACT

## POPULATION DYNAMICS AND STOCK DIFFERENTIATION OF LAKE WHITEFISH, COREGONUS CLUPEAFORMIS, IN GRAND TRAVERSE BAY, LAKE MICHIGAN

By

Mark William Prout

The population parameters and movement patterns of lake whitefish (Coregonus clupeaformis) in Grand Traverse Bay, Lake Michigan were investigated, in response to an expanding commercial fishery. Tagging data indicated that spawning stocks in East and West Bays were isolated, although each contributed to the Outer Bay fishery. The West Bay stock was characterized by a broad age distribution and low exploitation rates (5.4% - 12.7%). The East Bay stock exhibited a younger age distribution and higher exploitation rates (13.4% - 25.7%). West Bay whitefish had a slight growth advantage during the first two years of life (22 to 31 mm). The Outer Bay fishery harvested mainly fish of four to six years of age and exploitation rates averaged 19.9%. Growth of Outer Bay whitefish was intermediate to East and West stocks. An estimated 438,866 kilograms of adult whitefish was available to the Outer Bay fishery in 1986.

## ACKNOWLEDGMENTS

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# INTRODUCTION

Lake whitefish (Coregonus clupeaformis) have supported an intensive commercial fishery in Lake Michigan since the mid-1800's (Baldwin et. al. 1979). The fishery is one of largest freshwater commercial fisheries in North America and has produced annual yields of over two million kilograms several times during this century (Figure 1). The most productive areas of the fishery have been in Green Bay and along the north shore of the lake (Patriarche 1977), while marginal fishing areas are found further south along the coastlines (Scheerer 1982). Yield has fluctuated drastically over the century, creating sudden profitable large scale fisheries at times only to dimininsh within a few years as stock sizes declined.

Lake whitefish fisheries in Lake Michigan collapsed during the late 1950's after the sea lamprey had nearly exterminated the lake trout. This drastic decline in stock abundance was largely attributed to the invasion of the sea lamprey, yet over-harvesting, variable year class strength, and pollution of the spawning grounds have also been indicted (Wells and McClain 1973; Christie 1974). More recent studies suggest that climatic variation has played a major role in controlling year class strength (Freeberg 1985; Taylor et. al. 1987) and since the late 1950's year class sizes in northern Lake Michigan have differed by twelve-fold (Smale and Taylor 1988). These conclusions give further support to Christie's (1963) claims that early winters followed by early springs were conducive to the production of large year classes in Lake Ontario. The tremendous upsurge in commercial yield in the 1970's and 80's has undoubtly been, in part, a result of controlling lamprey populations, yet climatic conditions during this time frame have been optimal for the survival of young whitefish (Smale and Taylor 1988).

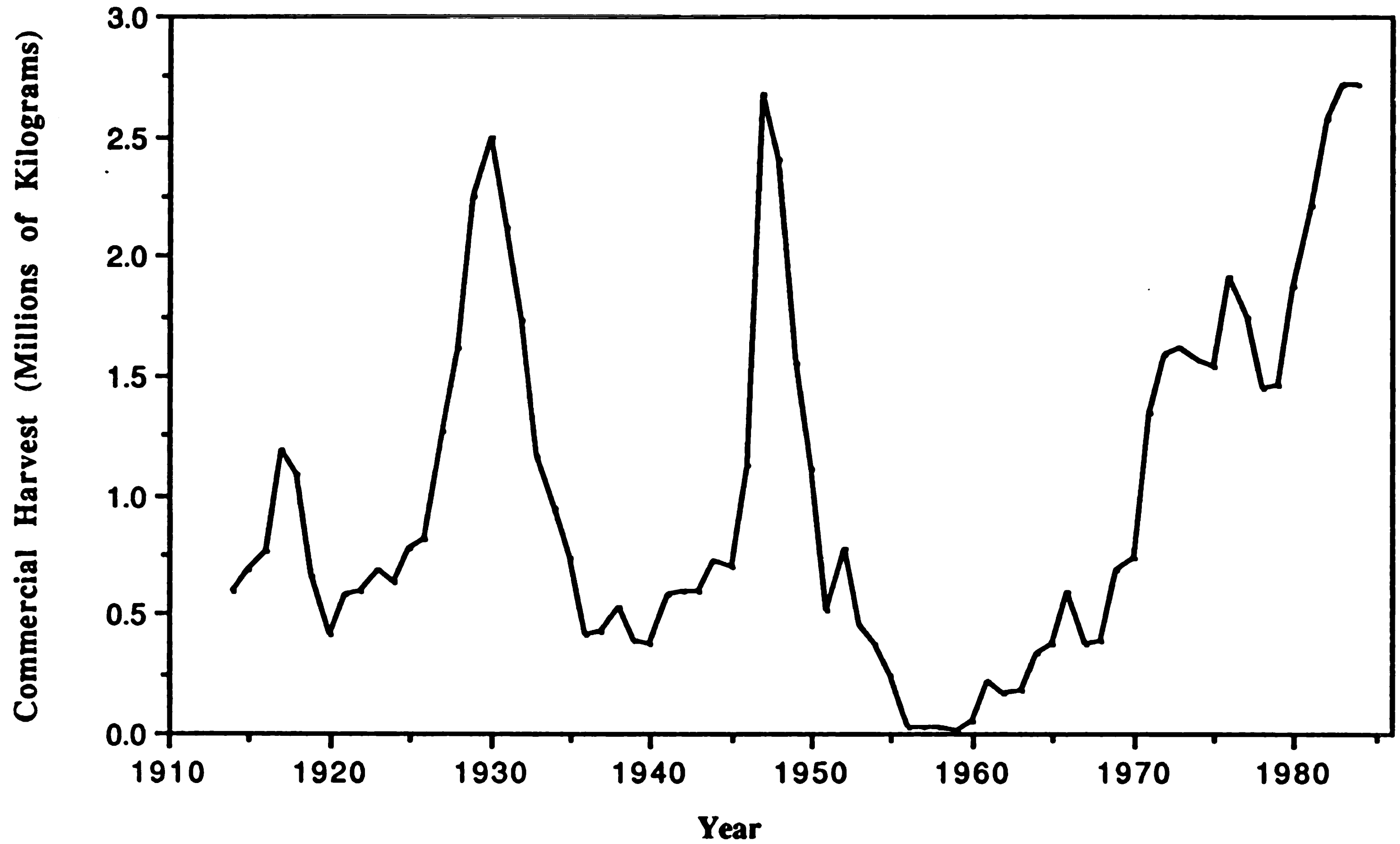


Figure 1: Commercial catch of lake whitefish in Lake Michigan from 1914 to 1984.

The recent high yields of whitefish in Lake Michigan are cause for concern over the future of the fishery given the inherent instability of the species production and an expanding fishery. Both state-licensed and Native American treaty fishermen have been economically dependent on the fishery with treaty fishermen taking 34% of the total harvest in Michigan waters during the period 1981-84 (Hatch 1986). The impact of an intensive fishery on whitefish production has been difficult to quantify because large year classes have often been produced by small stock sizes. However, Christie and Regier (1973) concluded that fisheries which reduce the average number of spawnings per female below one do not allow for replacement of the year class by its progeny. The apparent resiliency of the species lies in its ability to compensate for increased mortality with increased growth and reproductive rates (Healey 1975; 1980). Hence, the success of the fishery appears to be dependent upon an interaction between the intensity of fishing on the stock over time, the stock's scope of compensatory reserve, and the climatic conditions encountered during the periods of spawning and larval hatching.

Grand Traverse Bay of Lake Michigan has recently experienced an expanding treaty fishery. In 1979, a federal court decision, 471 F. Supp. 192 (W.D. Mich. 1979), declared that Native American tribes maintained fishing rights, free from state regulation, in waters ceded in the Treaty of 1836. This decision led to many controversies and disputes between state and tribal groups concerning the conservation measures necessary to protect fish stocks from over-harvesting. In 1985, a negotiated settlement was reached between the mentioned groups which re-allocated the fishery resources. Grand Traverse Bay was designated as strictly treaty waters for commercial fishing purposes, but opened to state-licensed sport fishing. In addtion, the commercial fishery expanded into the East and West basins of the bay which have not been commercially exploited in over twenty years.

Outer Grand Traverse Bay has supported a lake whitefish commercial fishery since 1977 (following a nine year closure initiated in 1968) where annual catch has averaged 210,000 kilograms and comprised 8-12% of the total annual yield of whitefish from Michigan waters during the years of 1981-85 (Hatch 1986). These figures do not include the catch from the existing whitefish sport fishery located in the southern basins of the bay. Creel census data in 1985 indicates sport catch to be approximately one-third of the commercial yield (G. Rakoczy, Michigan Department of Natural Resources, unpublished data). However, it is not certain whether both the sport and commercial fisheries are dependent upon the production of one stock of whitefish, or if three distinct populations inhabit each of the major basins as suggested by Rybicki and Keller (1977). Recent studies have identified discrete stocks of lake whitefish in other areas of Lake Michigan, based on differences in home range and vital statistics, each with a varying capacity for commercial production (Scheerer and Taylor 1985; Jacobson and Taylor 1985; Smale 1988). Other studies have shown that the Green Bay fishery is dependent upon two discrete stocks, differing in year class production and abundance (Gunderson 1978; Humphreys 1978; Hastreiter 1984; Ebner and Copes 1985). Failure to recognize the possibility of multiple stocks supporting the Grand Traverse Bay fisheries could result in the loss of local spawning stocks before catch statistics suggest any decline in lake whitefish abundance.

Given the inherent instability of lake whitefish stocks, the expanding commercial fishery in Grand Traverse Bay, and the potential for multiple stocks supporting commercial and sport fishing groups, the goal of this study is to provide a detailed description of lake whitefish population parameters within the three major areas of the bay. Specific objectives will be: 1) to determine home ranges of lake whitefish spawning aggregations in East, West, and Outer Bay; 2) to estimate exploitation and mortality rates of adult whitefish within the three areas of the bay; 3) to determine age and length distributions of whitefish in these areas; 4) to determine growth capabilities and maturation schedules of whitefish in these areas;

and lastly 5) to provide population estimates of adult whitefish in Grand Traverse Bay. The results of this study will provide baseline vital statistics of Grand Traverse Bay lake whitefish stock(s) during the initial years of the expanding commercial fishery.

# STUDY AREA

Grand Traverse Bay is located in the northeast region of Lake Michigan (Figure 2). The southern half of the bay is divided into the West and East arms which are separated by Old Mission Peninsula. The entire bay is approximately 48 km long and 19 km wide while the arms are approximately equal in length, 29 km, and both vary from 5 to 7 km in width. The average depth of the bay is 55 meters with maximum depths reaching 122.5 and 186.5 meters in West and East Bays respectively. The two major tributaries to the bay are the Elk and Boardman Rivers. The Elk discharges into East Bay at Elk Rapids while the Boardman discharges at the most southern end of West Bay.

Limnological characteristics were measured in the early 70's and indicated that the algal growth nutrient levels were very low and indicative of an oligotrophic environment (Auer et. al. 1976). West Bay primary productivity tended to be higher than the rest of the bay due to the phosphorus input from the Boardman River. Inputs of total phosphorus from West Bay tributaries accounted for 68% of all inputs for the entire bay. The zooplankton community of Grand Traverse Bay is dominated by copepods and cladocerans. Density estimates during 1971-73 were 22.0 per liter in West Bay, 17.0 per liter in Outer Bay, and 12.2 per liter in East Bay.

Grand Traverse Bay was closed to commercial fishing in 1968 due to the decline of many fish stocks. In 1977, Outer Bay (grids 715 and 716, Figure 2) was reopened to both gill net and trap net fishing. In 1985, a trap net fishery began operating in grid 815 in West Bay and grid 816 in East Bay as a result of the negotiated settlement. The most southern waters of the arms (grids 915 and 916)

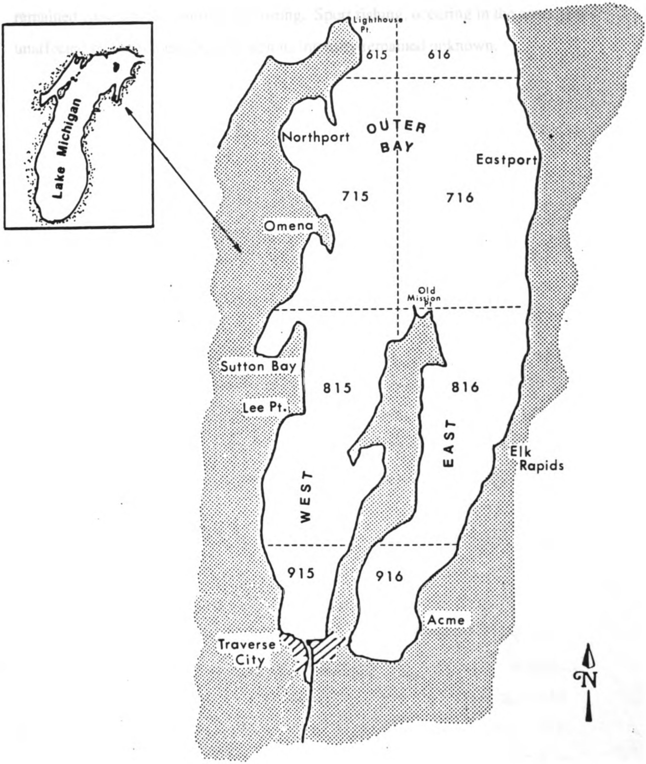


Figure 2: Grand Traverse Bay in northeastern Lake Michigan.

remained closed to all commercial fishing. Sport fishing, occuring in the arms, was unaffected by the settlement, although its intensity remained unknown.

# METHODS

Adult lake whitefish, caught in commercial trap nets, were tagged with Floy anchor tags in October and November of 1985 and 1986, at the onset of the spawning period. In 1985, whitefish were tagged at Lee Point in West Bay and at several locations in East Bay (Figure 3) with the cooperation of the tribal trap net operation. No tagging occurred in Outer Bay during the initial year of tagging because trap net fishing effort was concentrated in the arms of the bay during the tagging period. In the fall of 1986, tagging was repeated in East and West Bays and also expanded to several Outer Bay locations (Figure 3). During the spring of 1986, an abundance of sub-legal whitefish (< 432mm) in the catch allowed for additional tagging at five net locations in Outer Bay. The dates of tagging and the number tagged are shown in Table 1. All fishermen were notified of the tagging project by mail and were given a one dollar reward for each tag returned. Due to suspected non-reporting during the 1986 fishing season, a cash lottery was held at the end of the 1987 fishing season to encourage fishermen to return tags. Tags returned with the date and location of capture were used to document movement patterns of whitefish stocks within the study area.

Beginning in the fall of 1985 and continuing until the fall of 1987, trap net catch of lake whitefish was sampled for length, weight, age, sex ratio, and state of maturation (Table 2). An effort was made to sample from East, West, and Outer Bay during the same season, although regulations and relocation of fishing effort prevented this at times. Sampling in West Grand Traverse Bay was limited to one location just south of Lee Point, hereafter referred to as West Bay. In East Grand Traverse Bay, sampling occurred at several locations ranging from 2 kilometers

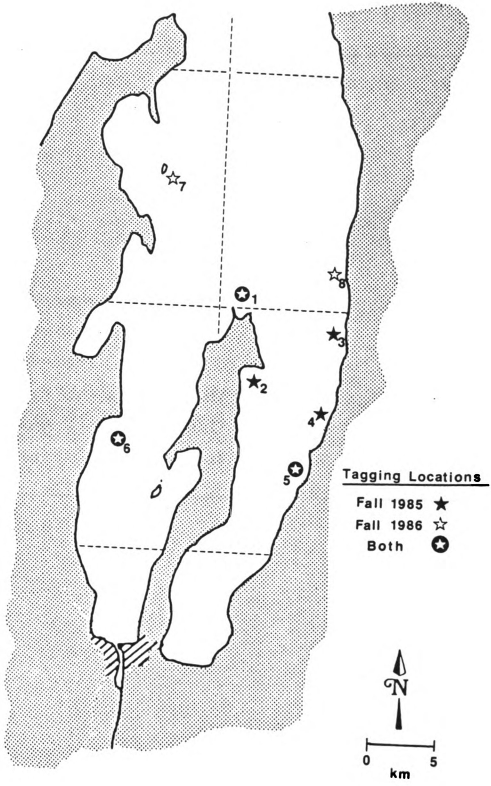


Figure 3: Tagging locations for lake whitefish in Grand Traverse Bay during 1985-1986.

Table 1: Tagging locations and dates of lake whitefish in Grand Traverse Bay during 1985 and 1986.

| Location | Date | Number |
|---|---|---|
| | 1985 | |
| West Bay | Nov. 7-27 | 661 |
| East Bay | Oct. 24 - Nov. 7 | 505 |
| | 1986 | |
| Outer Bay (Sub-legals) | Jun. 22 | 203 |
| Gull Island | Nov. 10-18 | 232 |
| Old Mission Pt. | Nov. 10 | 151 |
| SE Outer Bay | Nov. 11-17 | 65 |
| West Bay | Nov. 10-17 | 328 |
| East Bay | Nov. 7-18 | 261 |

Table 2: Sampling dates, locations, and numbers of lake whitefish sampled during the study period.

| Date | Location[1] | Gear[2] | Number |
|---|---|---|---|
| 10-10-85 | Gull Island | TN | 24 |
| 10-11-85 | Elk Rapids | TN | 58 |
| 10-24-85 | Elk Rapids | TN | 142 |
| 11-07-85 | Lee Point | TN | 57 |
| 11-25-85 | Lee Point | TN | 46 |
| 11-27-85 | Lee Point | TN | 46 |
| 12-03-85 | Lee Point | TN | 46 |
| 04-14-86 | Lee Point | TN | 43 |
| 04-25-86 | Elk Rapids | TN | 84 |
| 05-05-85 | Elk Rapids | TN | 46 |
| 05-27-86 | North Outer | TN | 85 |
| 05-27-86 | Old Mission Pt. | TN | 30 |
| 06-11-86 | East Bay | TR | 131 |
| 06-26-86 | Eastport | TN | 70 |
| 07-10-86 | Lee Point | SP | 40 |
| 07-11-86 | North Outer | TN | 27 |
| 07-17-86 | North Outer | TN | 103 |
| 07-17-86 | Old Mission Pt. | TN | 108 |
| 07-17-86 | Gull Island | TN | 68 |
| 07-23-86 | Acme | SP | 31 |
| 07-31-86 | North Outer | TN | 51 |
| 09-24-86 | Eastport | TN | 36 |
| 10-10-86 | Gull Island | TN | 41 |
| 10-20-86 | Lee Point | TN | 66 |
| 10-20-86 | Elk Rapids | TN | 30 |
| 10-24-86 | Lee Point | TN | 31 |
| 10-24-86 | Elk Rapids | TN | 69 |
| 04-27-87 | North Outer | TN | 100 |
| 05-19-87 | Lee Point | TN | 99 |
| 06-05-87 | East Bay | TR | 161 |
| 07-17-87 | Old Mission Pt. | TN | 71 |
| 07-17-87 | Gull Island | TN | 23 |
| 07-21-87 | Gull Island | TN | 69 |
| 07-30-87 | North Outer | TN | 40 |
| 08-03-87 | North Outer | TN | 38 |
| 10-23-87 | Lee Point | TN | 97 |
| 10-23-87 | Elk Rapids | TN | 82 |
| 11-06-87 | Gull Island | TN | 119 |

[1] Locations shown in Figure 2
[2] TN = trap net, TR = trawl, SP = sport

south to seven kilometers north of Elk Rapids, hereafter referred to as East Bay. The bulk of commercial harvest came from Outer Bay, and several locations were sampled. Spring sampling was done mainly in the northern waters from Lighthouse Point to Northport Point, referred to as North Outer Bay. Summer sampling occurred in North Outer Bay and also near Gull Island and Old Mission Point, which are referred to as South Outer Bay.

Catch on a given day was subsampled on the boat while traveling between net locations. Total length was measured to the nearest millimeter and weight was measured to the nearest 25 grams. Sex and state of maturation were determined when possible by fishermen consent by cutting open individual fish and examining gonadal tissues. Ages were determined from scales which were collected from the area between the lateral line and the anterioral portion of the dorsal fin of the fish.

## Aging

Age and growth of whitefish were determined from the examination of scales. All scales were cleaned and observed on a microfiche projector using a magnification of 22x. Ages were determined by counting annular rings on a scale from each individual fish. Each annulus, designating one winter in the life of the fish, was distinguished by "cutting over" along the anterio-lateral ridges and crowding of circuli (van Oosten 1923). Annular measurements were made by measuring the distance from the focus of the scale to each annuli to be used for growth analysis. Aging of 160 whitefish was compared between the principal scale reader and a secondary experienced scale reader.

## Mortality

Mortality was determined by catch curve analysis and mark-recapture methods. Catch curves were constructed for each season and location by plotting the natural logarithm of frequency against age. Using least squares regression, the slope of the descending limb of the catch curve provided an estimate of total instantaneous mortality (Ricker 1975).

Survival was determined from tag returns, corrected for tag loss (Scheerer 1982), as follows

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

where:

$R_{12}$ = Recaptures in 1987 from tagging in fall of 1985

$R_{22}$ = Recaptures in 1987 from tagging in fall of 1986

$M_1$ = Number of fish tagged in the fall of 1985

$M_2$ = Number of fish tagged in the fall of 1986

Annual mortality was calculated from survival as follows:

$$A = 1 - S$$

Exploitation rates were calculated (Ricker 1975) for each tagging location as follows:

$$u = \# \text{ Recaptures} / \# \text{ Marked}$$

The number of recaptures was corrected for tag loss as discussed earlier (Scheerer 1982). From the above information, estimates of instantaneous total (Z), fishing (F), and natural (M) mortality were calculated (Ricker 1975) as follows:

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

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

$$M = Z - F$$

Growth

Length at age, estimated by back-calculation, was used to describe growth of whitefish stocks. The back-calculation method was used, in addition to comparisons of mean length at capture, to provide estimates for juvenile size ranges and recruiting year classes which are not fully vulnerable to the fishing gear. Size selectivity of trap nets (Eshenroder et. al. 1980) may bias mean length at age estimates because faster growing individuals are harvested initially, thus leading to overestimates of size of recruiting age classes.

Back-calculated lengths are estimated from an assumed linear relationship between fish scale radius and fish total length. However, often relationships are non-linear or exhibit non-homogenous variance over the range of observations. Smale and Taylor (1987), who discovered these problems for several Lake Michigan whitefish stocks (including East Grand Traverse Bay), derived a unbiased method of reducing the variance about the relationship. This method involves averaging scale radii at fixed fish length intervals while stratifying the sample, using Stein's two-stage sampling (Steel and Torrie 1980), across the range of lengths.

The average scale radius was determined from three scales from each fish, to reduce within fish variation, and then the average scale radius was estimated for ten millimeter fish length intervals. The number of observations needed per interval, to assure that each mean was estimated with equal precision, was calculated from Stein's test. Finally, a least squares regression was applied to the means. This method provides a relationship which best describes the "average" fish and reduces problems of Lee's phenomenon caused by the back-calculation process (Smale and Taylor 1987).

Lengths at age were estimated by using the corrected proportional back-calculation formula, as described by Carlander (1981), where mean annular measurements for each age group were used in the regression for back-calculation.

Calculated lengths were multiplied by a correction factor (f) of the form:

$$f = Lc / Lc^*$$

where Lc is the observed total fish length at capture and Lc* is the predicted length at capture using the length-scale regression for the observed total fish scale radius. This assumes that the proportional deviation of lengths from the regression is the same at each annulus as at the time of capture (Carlander 1981).

Length-Weight Relationships:

The relationship:

$$W = aL^{b}$$

where W equals weight in grams, L equals length in millimeters, and a and b are constants, was transformed by natural logarithms and fit by a least squares regression (Ricker 1975). Slope values were used as indicators of condition, or the amount of weight accumlated per unit of length. In addtion, the equations were used to predict weights from back-calculated lengths at age.

Population Size

Population abundance and biomass estimates were made for the Outer Bay fishery, where sufficient tag returns were available, using the Petersen mark-recapture method (Ricker 1975) where:

$$N = \frac{(\#\text{ of marked fish}) * (\text{trap net catch})}{(\#\text{ of trap net recaptures})}$$

For abundance estimates, the mean individual weight was estimated to allow catch to be converted from weight to numbers. For biomass estimates, weights of the marked and recaptured fish were used for these estimates. Confidence intervals were estimated using a Poisson estimator (Ricker 1975).

The number of recaptures was corrected for tag loss and the catch was corrected for recruitment during the fishing season. Instantaneous rates of tag loss have been estimated from previous lake whitefish studies (Scheerer 1982; Ebner and Copes 1985; Smale 1988). The tagging methods and the fishing gear used in this study are similar to those used in the above mentioned studies, therefore the instantaneous rate of 0.093 (annual rate of 9.0%) was used. The total catch was adjusted to account for the recruitment of fish which were sub-legal (<432 mm) at the time of tagging, yet grew into the catchable population during the fishing season.

## RESULTS AND DISCUSSION

DISTRIBUTION OF TAG RETURNS:

East Bay Returns: A total of 139 tags, or 18.1% of the 766 whitefish tagged, were returned over the two year study period. In 1985, whitefish were tagged at five locations in East Bay. Return rates for each site were similar with the exception of site #3 (Table 3). Combining all locations resulted in a 10.1% return rate for 1986. The return rate for 1987 more than doubled being 22.6%. Commercial harvest from the Outer Bay fishery nearly doubled in 1987 relative to 1986 and explains the increase in tag returns.

Tags were returned by both commercial and sport anglers throughout the study period (Appendix A). Return rates were highest from trap net harvest where 72.5% and 75.0% of total East Bay returns were taken in 1986 and 1987 respectively. Gill net returns increased from 3.9% in 1986 to 20.5% in 1987 while sport returns decreased from 23.5% to 4.5% of the total returns during this time.

Non-reporting by gill-net fishermen was considered to be high in 1986. On several occasions, tags were reported to be caught but were either lost or misplaced by the fisherman. Only two East Bay tags were returned by this group in 1986 while gill net harvest accounted for 69% of the total commercial catch in grids 715 and 716. Reporting appeared to increase in 1987 as more tags from the 1985 tagging were reported in the second year than in the first. Gill net fishermen return rates for tagged fish one year at large increased from 0.4% to 5.4% during the two years.

During the winter of 1985-86, Grand Traverse Bay froze over and provided anglers an opportunity to catch whitefish through the ice. The majority of East Bay

Table 3: Numbers of lake whitefish tagged and returned for the fall tagging locations of 1985 and 1986.

| Location[1] | # Tagged | # Returned 1986 N | 1986 % | 1987 N | 1987 % | Total N | Total % |
|---|---|---|---|---|---|---|---|
| | | | Fall 1985 | | | | |
| Outer Bay | | | | | | | |
| 1 | 57 | 5 | 8.7 | 0 | 0 | 5 | 8.7 |
| East Bay | | | | | | | |
| 2 | 76 | 9 | 11.8 | 4 | 5.3 | 13 | 17.1 |
| 3 | 75 | 4 | 5.3 | 3 | 4.0 | 7 | 9.3 |
| 4 | 218 | 23 | 10.5 | 16 | 7.1 | 39 | 17.7 |
| 5 | 135 | 15 | 11.1 | 6 | 4.4 | 21 | 15.5 |
| Total | 505 | 51 | 10.1 | 29 | 5.7 | 80 | 15.8 |
| West Bay | | | | | | | |
| 6 | 661 | 36 | 5.4 | 18 | 2.7 | 54 | 8.1 |
| | | | Fall 1986 | | | | |
| Outer Bay | | | | | | | |
| 1 | 151 | | | 16 | 10.6 | | |
| 7 | 232 | | | 48 | 20.7 | | |
| 8 | 65 | | | 17 | 26.2 | | |
| Total | 448 | | | 81 | 18.1 | | |
| East Bay | | | | | | | |
| 5 | 261 | | | 59 | 22.6 | | |
| West Bay | | | | | | | |
| 6 | 328 | | | 36 | 11.0 | | |

[1] Numbers correspond to those in Figure 3.

sport returns were caught during March of 1986 from the Elk Rapids area. Of the seven recaptures in March, five were tagged in this immediate area suggesting that a proportion of the fall tagged population remained in the local vicinity. No East Bay tags were returned during the 1986-87 winter where milder temperatures prevented the bay from freezing over completely. This does suggest that sport fishing effort may be higher during years when ice formation persists long enough to provide an ice fishery.

The first tags were returned during the first week of December of 1985, shortly after tagging, from Sault Ste Marie tribal gill-net fishermen. Seven tags were recaptured along the shoal in the southern area of grid 716 of which five were from East Bay, four to five weeks after tagging. Later that month, an additional five East Bay tags were recaptured in grid 716. Spawning ceased during the last week of November in 1985 so either portions of the tagged population moved north immediately after spawning or they spawned further north from the tagging location. Therefore the East Bay spawning stock, sampled near Elk Rapids, may not be isolated from whitefish spawning along the Outer Bay eastern shoal, if reproduction indeed occurs there.

West Bay Returns: A total of 90 tags, or 9.1% of the 989 whitefish tagged, were returned from the fall tagging at Lee Point in West Bay over the two year study period. Annual return rates for tagged fish one year at large were 5.4% and 11.0% for 1986 and 1987 respectively (Table 3). The increase in this rate was also due to a combination of increased exploitation and increased reporting from gill net fishermen.

Of the 90 tags returned from the West Bay tagging, 18.9% were from sport anglers, 40.0% from gill net fishermen, 35.6% from the sole trap net operation, and 5.6% from MDNR survey trawls in West Bay (Appendix B). Returns were lowest during the summer months while commercial catches in the Outer Bay were high. Only 22% of the total West Bay trap net returns were from the summer months while 36% of East Bay trap net returns came during this time.

Non-reporting was considered to be high from gill netters, but 50% of their returns during the 1986 and 1987 fishing seasons were of West Bay whitefish while only 16.2% of trap net returns were from West Bay. It appears that this disproportiate return rate is due to the different fishing locations of the two groups. Trap net effort did not occur in the southern half of grid 715 over the study period. However, the gill net fisherman who returned the most tags, per kilogram of whitefish caught, fished entirely in grid 715. In addition, trap net fishing occurred in all grids of the bay, so the lack of West Bay returns in the Outer Bay area suggests that either a smaller proportion of the West Bay stock moves into the Outer Bay fishery or that movements are predominantly restricted to the southern areas of grid 715.

West Bay sport fishing tag returns followed a seasonal trend similar to East Bay returns. A total of nine returns were from the Marion Island area in West Bay during February and March of 1986 when the ice fishery was available. No ice formed during the winter of 1986-87 and only one tag was returned.

Gull Island Returns: Whitefish were tagged at Gull Island in the fall of 1986 and 48 tags, or 20.7%, were returned during the 1987 fishing season (Table 3). Of these returns, 75% were from the trap net harvest while gill net harvest accounted for 25% (Appendix C). Sport anglers did not report any tags from the Gull Island stock. Most of the returns (58.3%) were during June and July when trap net effort and catch were high in grid 715.

Old Mission Point and Cresswell Road Returns: Numbers of whitefish tagged at these two locations were lower than other locations (Table 3). Return rates for Old Mission Point and Cresswell Road tagged whitefish were 10.6% and 26.2% respectively. Again, trap net returns were by far the highest than for any other gear, taking 75% of the returns from Old Mission Point and 82.4% from

Cresswell Road (Appendix 3). The number of returns were too few to suggest definite patterns of distribution, however, all returns from the Cresswell Road site on the southeast shoal of grid 715 were recaptured on the eastern side of the bay. Returns from Old Mission came from all grids in the fishery.

STOCK DIFFERENTIATION BY MOVEMENT PATTERNS:

Distributions of tag returns indicate a segregation of whitefish tagged at the three primary locations. Comparisons of the percentage of trap net catch versus the percentage of tag returns by grid were made to determine if the tagged populations were uniformly mixed throughout Grand Traverse Bay (Table 4). Tag returns and catch were combined for both 1986 and 1987 for each arm of the bay while only 1987 data was used for Gull Island. None of the tagged populations could be assumed to mix uniformly throughout the bay, given three to four months to disperse after tagging (Chi-Square Test, $P < 0.01$).

Whitefish from each tagged population were caught most frequently, relative to catch, within the grid in which they were tagged. The proportion of tags returned from the East Bay stock was higher than the proportion of catch taken in grids 615, 716, and 816. This suggests that a large portion of the stock moved north into the Outer Bay fishery. The majority of trap net tag returns from West Bay were from the spring and fall fishing in grid 815. However, catch from this grid comprised only four percent of the total catch from the entire bay which suggests that this stock is more sedentary than its East Bay counterpart. A higher return rate may have been realized with more fishing effort in grid 815. Gull Island returns were concentrated in grid 715 near the tagging location during the months of June and July when trap net harvest was highest in this grid. Trap net harvest in grid 716 was nearly double that from grid 715 in 1987, yet, five times as many Gull Island returns came from grid 715.

Table 4: Percentage of tag returns versus percentage of trap net catch for the primary tagging sites. East and West Bay percentages are from combined 1986 and 1987 data. Gull Island percentages are from 1987 data only. The number of tags returned with known capture site is in parentheses.

| | % of Trap Net Catch | | | % of Trap Net Returns | | |
|---|---|---|---|---|---|---|
| Grid | 1986 | 1987 | Total | East | West | Gull Isl. |
| 615 | 12.9 | 6.3 | 8.9 | 12.9<br>(13) | 7.7<br>(2) | 0.0<br>(0) |
| 715 | 38.3 | 25.6 | 30.6 | 13.9<br>(14) | 7.7<br>(2) | 83.9<br>(26) |
| 815 | 8.1 | 1.4 | 4.0 | 1.0<br>(1) | 69.2<br>(18) | 0.0<br>(0) |
| 616 | 2.2 | 1.9 | 2.0 | 1.0<br>(1) | 0.0<br>(0) | 0.0<br>(0) |
| 716 | 20.1 | 43.4 | 34.4 | 37.6<br>(38) | 15.4<br>(4) | 16.1<br>(5) |
| 816 | 18.3 | 21.3 | 20.1 | 33.7<br>(34) | 0.0<br>(0) | 0.0<br>(0) |

Analysis of tags returned per 1000 kilograms of catch indicated differential harvest rates of Outer Bay and southern arms tagged populations (Figure 4). Monthly ratios were determined by dividing the total number of trap net returns from each year's tagged population by the total trap net catch. The ratios were corrected for differences in the number of fish initially tagged. The results indicated higher harvest rates of Outer Bay tagged whitefish during the summer months when commercial harvesting occurred in Outer Bay. Differences diminished in the fall months as fishing occurred in the arms as well as Outer Bay. This suggests that whitefish which spawn in Outer Bay are harvested at higher rates in the Outer Bay fishery than those spawning in the arms.

The highest return per kilogram ratios occurred in November when effort was shifted to the original tagging sites in East and West Bays suggesting that fish were homing to the spawning grounds. Of the total trap net returns from the West Bay stock, 47% were caught during mid-October to mid-November near (within 1 km) the tagging location. In East Bay, 15% of the trap net returns from the East Bay stock were caught during October and early November in an area from three kilometers south to five kilometers north of Elk Rapids. There was no mixing of the primary tagged populations (East, West, and Gull Island) during the pre-spawning period, suggesting spatial reproductive isolation. The results of the tagging study agree with the findings of Ihssen et al. (1981) who found home spawning range of lake whitefish to be more geographically confined than the non-breeding period home range in five study lakes which included Lakes Huron and Ontario.

Home ranges, based on the location of at least 75% of the total tag returns, for the East, West, and Gull Island tagged populations are shown in Figure 5. An additional range, based only on trap net returns, is shown for West Bay. This small range is a reflection of the limited trap net effort in West Bay and also the

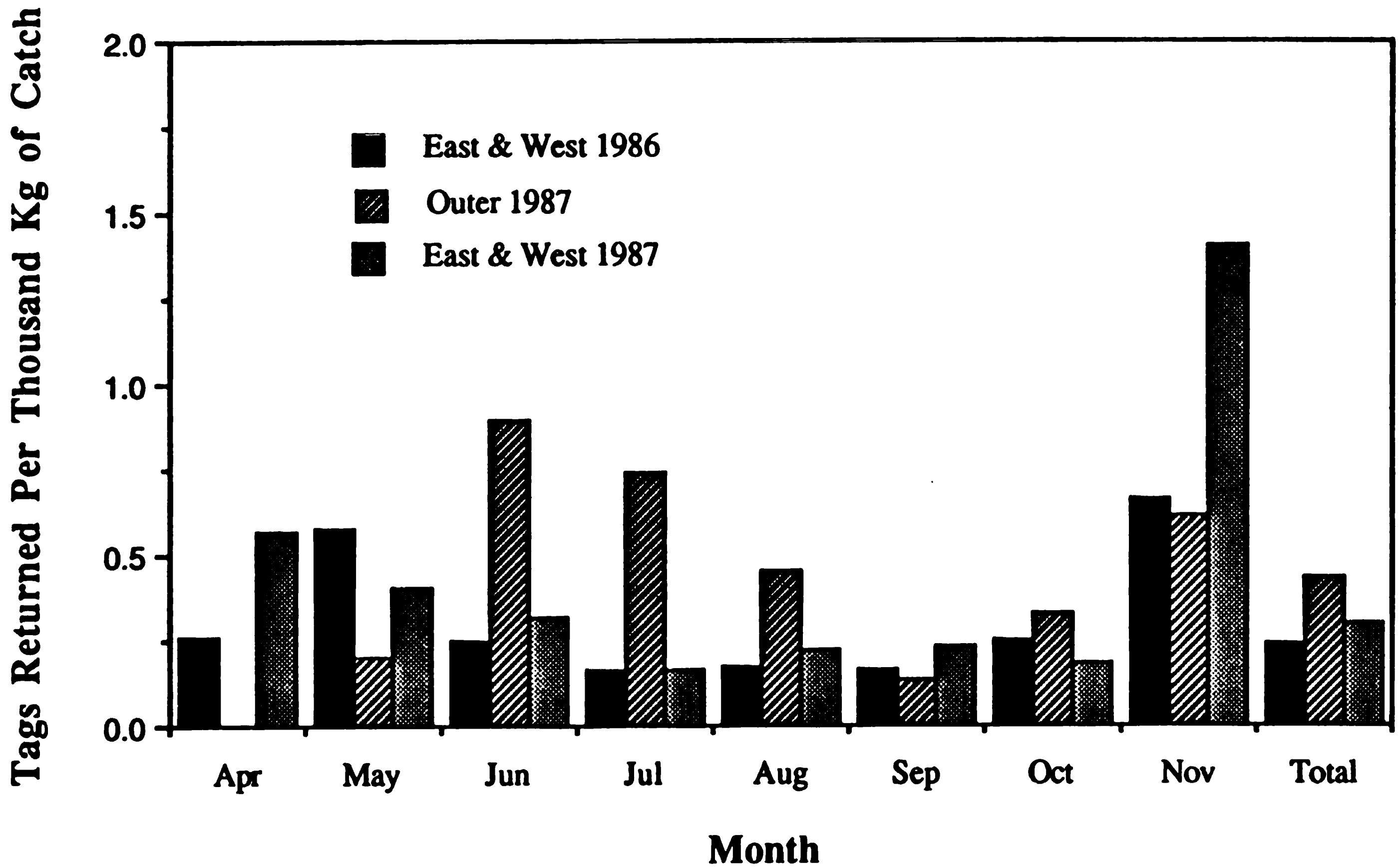


Figure 4: Tags returned per thousand kilograms of commercial catch during the 1986 and 1987 fishing seasons.

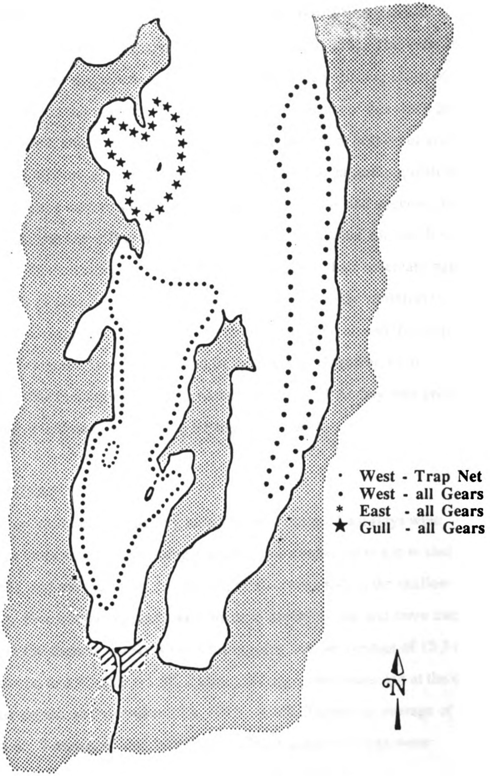


Figure 5: Home ranges of East Bay, West Bay, and Gull Island tagged populations for 1986 and 1987. Ranges are based on 75% of all returns. An additional West Bay range is shown based on 75% of trap net returns.

limited movements of the stock into the portions of Outer Bay where trap net fishing effort was high (grid 716 and the northern half of grid 715). The West Bay range based on all gears appears much larger, due to the patchy fishing effort of the three fishing groups on the western side of the bay. Movements of this stock into Outer Bay are limited, although gill net fishermen in the southern portion of grid 715 accounted for 40% of all West Bay returns. The East Bay tagged population moved along the entire eastern shoreline of Grand Traverse Bay and suggests that a delineation of East and Outer Bay stocks may not be worthy. MacLean and Evans (1981) suggested the isolation of whitefish stocks was due to their sedentary nature and the patchiness of their habitat. Isolation of East and West Bay whitefish is probably due to the pennisula which separates the two bays and also to the deep waters (100 to 300 meters) which are found in these arms. However, more homogeneous habitat conditions along the eastern shoreline of the bay may prevent any large degree of isolation of whitefish inhabiting this area.

SPAWNING AREAS:

Spawning grounds near the tagging locations in West and East Bays were identified by the collection of eggs, using a water pump connected to a iron sled (Freeberg 1985), and the capturing, by gill net, of spawning fish in the shallow waters (1-5 m). Five minute transects were made at depths of one and three meters. At Lee Point, in the shallow waters west of the tagging site, an average of 15.3 (SE = 2.96, 3 transects) and 9.5 (SE = 5.50, 2 transects) eggs were collected at the one and three meter depths on November 29th, 1986. At Elk Rapids, an average of 63.0 (SE = 16.62, 3 transects) and 29.7 (SE = 1.76, 3 transects) eggs were collected at the one and three meter depths on November 30th, 1986. Collections during the following two weeks at both sites revealed declining egg numbers and suggested that the peak spawning period had been sampled. Gill net catches at both locations during the first week of December were dominated by ripe male lake whitefish. This provided further evidence that lake whitefish spawn in the areas adjacent to the tagging sites and the eggs collected were not those of closely related species such as the round whitefish (Prosopium cylindraceum).

The spawning ground substrate at Elk Rapids consisted of large boulders and cobble which were free of sand and silt. The Lee Point area consisted of patches of boulders surrounded by large patches of sand. Even the rocky areas, those prefered by whitefish, at Lee Point showed evidence of heavy siltation. Studies on sedimentation and current patterns in Grand Traverse Bay discussed by Auer et. al. (1976) showed that sediment of larger particle sizes (grain sizes less than 4$\phi$) was located in shallow shoal and inshore areas where wind-water energy levels are high (Figure 6A and B). The favorable spawning substrate found along the eastern shoreline in East Bay is probably due to currents driven by NW winds, which keeps the substrate free of sediment. The breadth of the West Bay spawning habitat is unknown, but Koelz (1929) observed spawning around Tucker Point, approximately 5 kilometers directly east of the West Bay sampling location. The quantity of suitable spawning habitat available in West Bay may be limited by the silt loading which was found in the Boardman River plume (Auer et. al. 1976).

EXPLOITATION RATES:

Exploitation rates were calculated for both 1986 and 1987 for each tagging location (Table 5). Total rates for each tagged population were divided into three separate rates for the primary zones; East, West, and Outer Bays. Returns from all gear types were combined and corrected for tag loss. Although non-reporting was known to occur, no corrections were made, therefore, these values represent minimum estimates and should be regarded with caution.

During the 1986 fishing season, exploitation of the East Bay stock was 2.4 times higher than that of the West Bay stock. This was due to a higher harvest rate

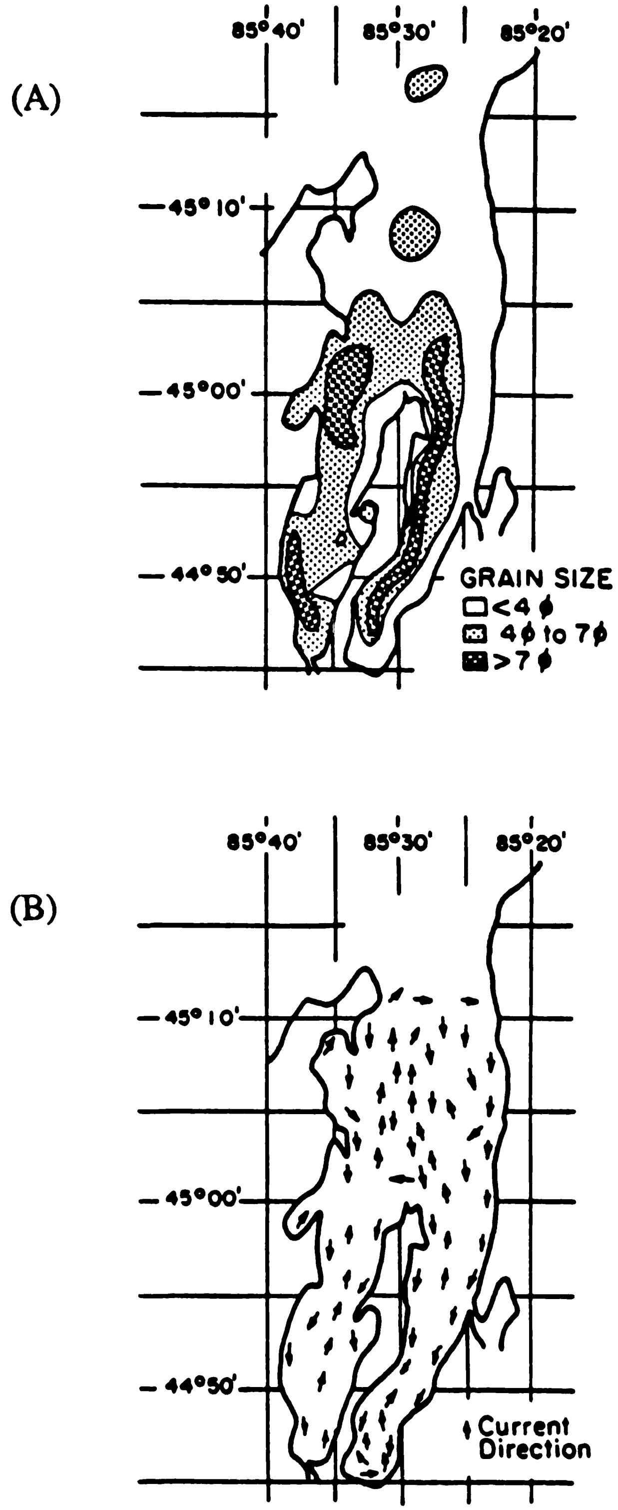


Figure 6: Areal distribution of sediment grain size (A) and generalized current patterns (NW wind) (B) for Grand Traverse Bay. (From Auer et.al. 1976).

Table 5: Annual exploitation rates in 1986 and 1987 for each tagging site, reported as percentages. Rates are partitioned by area of recapture and corrected for tag loss.

| | Recapture Location | | | |
|---|---|---|---|---|
| Population | Outer | West | East | Total |
| | | 1986 | | |
| West Bay | 1.8 | 3.9 | 0.0 | 5.7 |
| East Bay | 7.3 | 0.0 | 6.1 | 13.4 |
| | | 1987 | | |
| West Bay | 9.1 | 3.0 | 0.0 | 12.1 |
| East Bay | 18.0 | 0.4 | 7.3 | 25.7 |
| Outer Bay | | | | |
| Gull Island | 22.8 | 0.0 | 0.0 | 22.8 |
| SE Outer Bay | 27.7 | 0.0 | 1.5 | 29.2 |
| Old Mission Pt. | 7.9 | 0.7 | 2.6 | 11.2 |
| Average: | 16.7 | 0.2 | 1.1 | 19.9 |

in East Bay and also in Outer Bay. In 1987, exploitation of the West Bay stock increased by a factor of 2.1 and the East Bay stock by a factor of 1.9. Due to these similar increases, the East Bay stock was still harvested at a rate more than double its counterpart in 1987. Although these estimates represent minimum rates, a much larger proportion of the East Bay stock is harvested in the Outer Bay fishery.

Comparisons of all tagging locations indicates that the East Bay stock was harvested at a similar rate as whitefish tagged in Outer Bay during 1987. One exception was the tagged population at Old Mission Point where the calculated rate was similar to the West Bay rate. A portion of the returns from this group were caught in the southern arms suggesting the tagged population was less vulnerable to the Outer Bay fishery.

The high rates observed in 1987 for East and Outer Bay, although minimum estimates, ranging from approximately 23-29%, are similar to the rate, corrected for non-reporting, estimated for the Leland (29%) stock from 1980-84 (Smale 1988). If valid corrections for non-reporting could be made, the rates might be more similar to that reported for the North-Moonlight Bay stock (33%) during 1981-1982 (Hastreiter 1984). Higher rates were reported for the North Shore stock (45%) (Smale 1988) and the Big Bay de Noc stock (56%) (Ebner 1980). If it is assumed that only 20% of gill net recaptures were reported during 1987, Outer Bay exploitation rates would approach the North Shore estimate. Unfortunately, this cannot be tested, but should be addressed if tagging studies are to continue in Grand Traverse Bay.

## AGING

Comparisons of assigned ages from scales of 160 lake whitefish indicated a 63% (100/160) agreement between the principal scale reader and a secondary experienced reader. However, disagreement was not extreme with 93% being within +/- one year of age. There was a tendency of the principal scale reader to assign older ages. The secondary reader used impressions of the scales on acetate slides while the principal reader used the scale itself. After examining the impressions, I felt that the last annuli on older fish was difficult to see, compared to observing the scale itself, and therefore may lead to underaging.

Ricker (1975) suggested 80% agreement between readers as an acceptable level when using age structure for mortality estimates. Most Lake Michigan studies of lake whitefish have indicated agreement to be over 80%, unlike the results of this study. This is due to the dominance of 3-5 years olds in most heavily exploited whitefish fisheries, whereas a much older age structure was found in Grand Traverse Bay. Healey (1980) reported 60% agreement for whitefish in Canadian arctic lakes where fish are slow growing and longer lived. Casselman (1982) indicated that the scale method is increasingly unreliable from ages six to ten for most freshwater fishes, where true ages tend to be underestimated. If disagreement is an indicator of underaging then mortality estimates in this study would tend to be overestimated.

AGE COMPOSITIONS:

Age composition was examined on a seasonal basis for each of the four sampling areas: West Bay, East Bay, North Outer, and South Outer (Figures 7 and 8). Fall age structure data did indicate the presence of distinct spawning stocks in West and East Bays, while the sole Outer Bay sample in 1986 could not be statistically differentiated from these stocks (Table 6). The West Bay spawning stock was characterized by a much older age distribution over the three year period relative to the East Bay spawning stock. The percent of West Bay whitefish age eight and older was 61% in 1985, 62% in 1986, and 50% in 1987. In East Bay, the percentages were 22%, 21%, and 17% for the same years. In the South Outer Bay (Gull Island), individuals of age eight and older made up 37% of the 1986

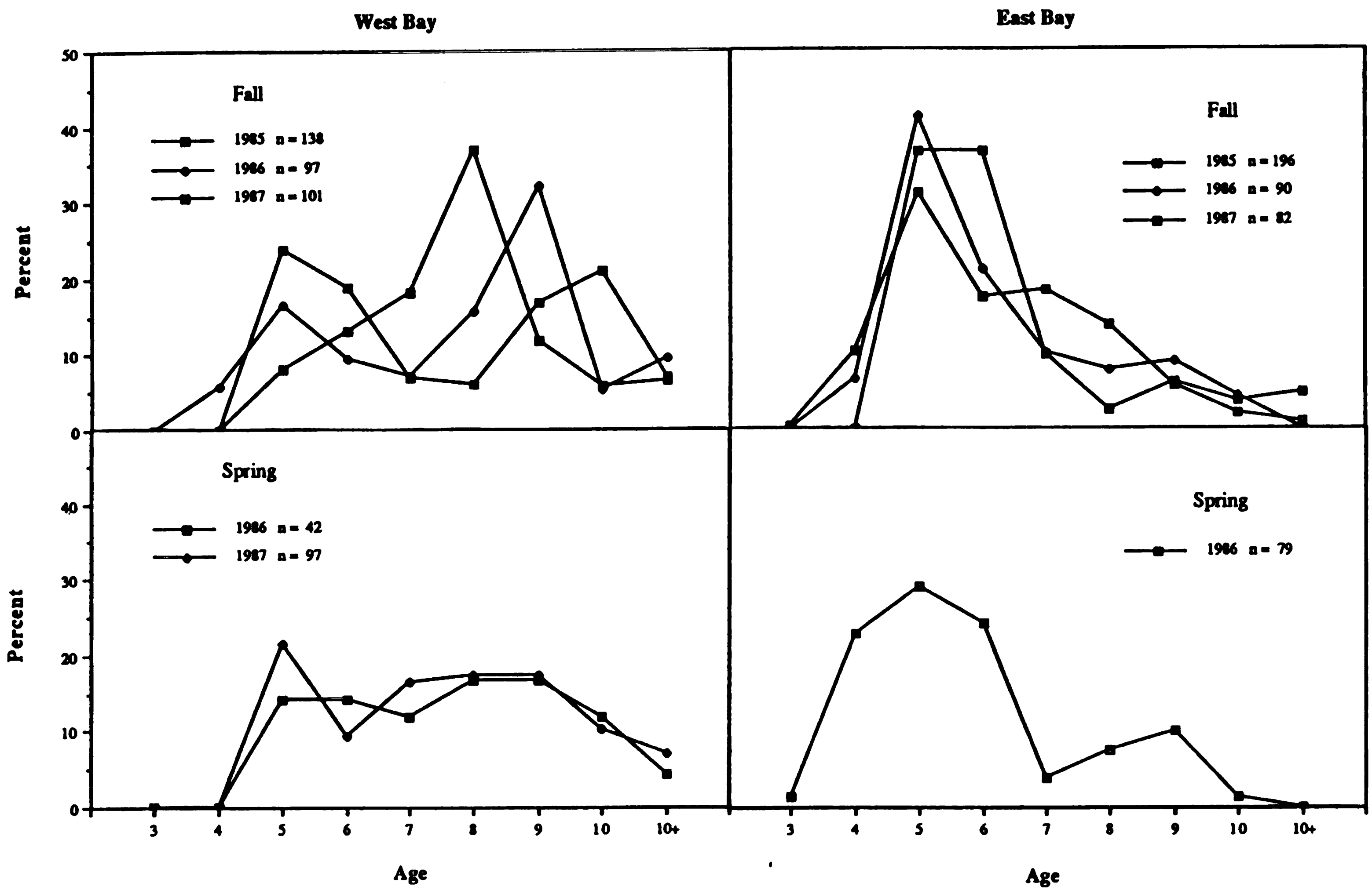


Figure 7: Percent age composition of lake whitefish from East and West Bay during 1985-87.

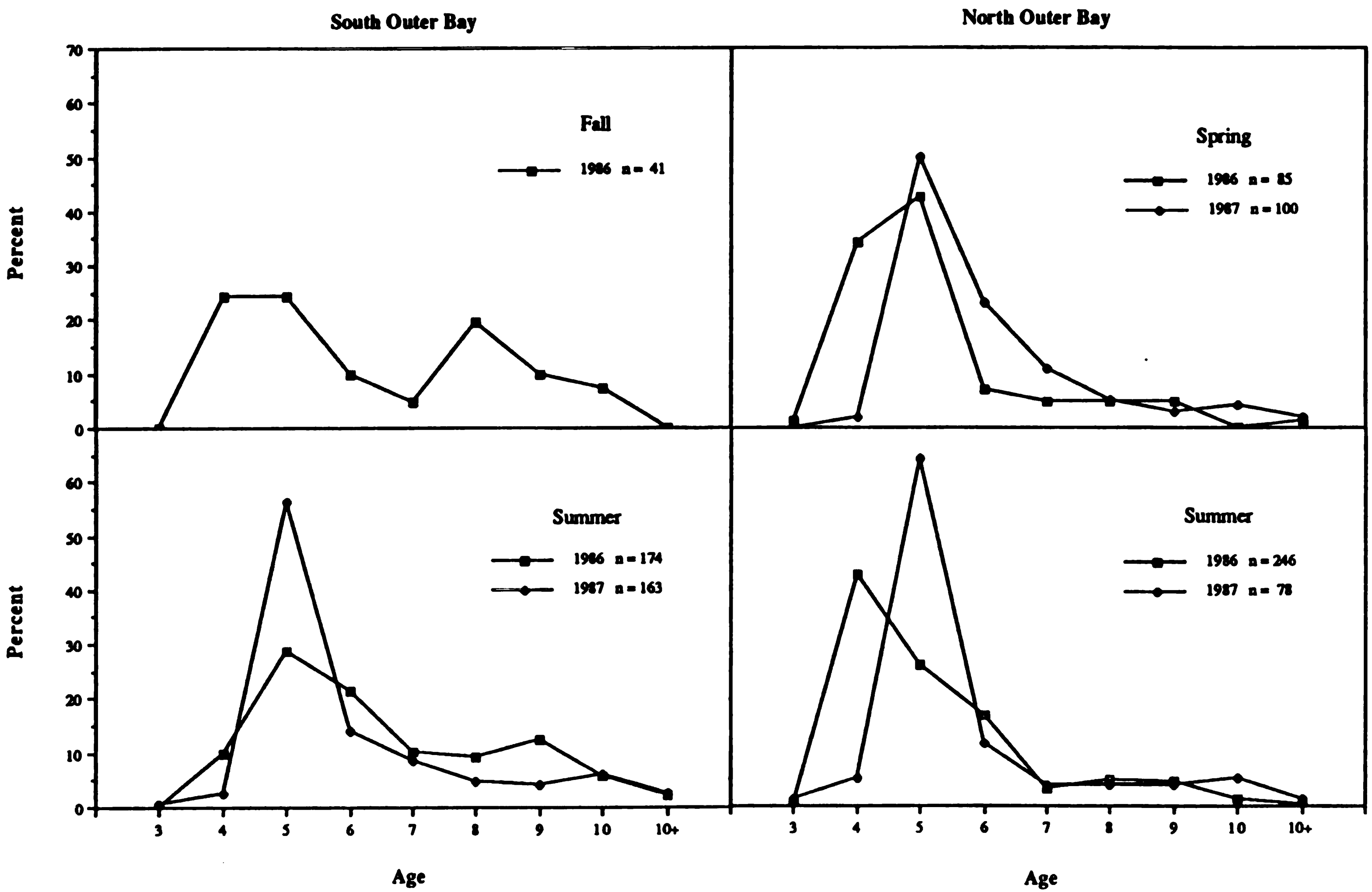


Figure 8: Percent age composition of lake whitefish from North and South Outer Bay during 1986-87.

Table 6: Comparisons of fall age frequencies using the Kolmogorov-Smirnov Two Group Test.

| Location | N | Date | Dmax | Prob |
|---|---|---|---|---|
| East | 195 | | | |
| vs | | Fall 1985 | 0.388 | p<0.001 |
| West | 138 | | | |
| East | 119 | | | |
| vs | | Fall 1986 | 0.394 | p<0.001 |
| West | 95 | | | |
| East | 119 | | | |
| vs | | Fall 1986 | 0.160 | p>0.200 |
| Gull Island | 41 | | | |
| West | 95 | | | |
| vs | | Fall 1986 | 0.269 | p>0.01 |
| Gull Island | 41 | | | |
| East | 82 | | | |
| vs | | Fall 1987 | 0.334 | p<0.001 |
| West | 101 | | | |

sample.

Spring sampling was more limited but results again indicated that West Bay was characterized by an older age structure compared to both East Bay and North Outer Bay (Table 7). The percent of whitefish age eight and older was 60% for West Bay, 19% for East Bay, and 11% for North Outer Bay in 1986. Similar results were found in 1987 where 52% and 14% of the fish were older than age seven for West Bay and North Outer Bay respectively. No fishing occurred in East Bay during the spring of 1987.

The commercial fishery is dependent solely upon Outer Bay during the summer months due to regulations prohibiting harvest in the southern arms. The age structure determined for North Outer Bay in July of 1986 was dominated by smaller, younger whitefish of four and five years old. The 1982 year class (four year-olds) comprised 41-48% of the samples, yet year classes in Grand Traverse Bay do not fully recruit to the gear until age six, as discussed in a later section, due to size selectivity of trap nets (Eschenroder et.al. 1980). In South Outer Bay, near Gull Island and Old Mission Point, the catch consisted of a much broader age structure while the 1982 year class was less abundant. In 1987, the discrepancy between these areas was no longer evident as the 1982 year class dominated the catch in all areas of Outer Bay. Differences in age structure between these localities could be due to either separate local populations experiencing differing rates of exploitation, size segregation, or variable recruitment (Healey 1980; Smale 1988).

Comparisons of mean age of the trap net catch (Table 8) did not indicate a major shift in age structure for either East or West Bay in response to the expanding fishery. Healey (1980) demonstrated that shifts in age structure of whitefish populations in northern Canadian lakes were related to the intensity of exploitation. A shift in age structure occurs when the abundance of vulnerable stock is small in relation to the recruiting year classes. There was no definite trend

Table 7: Comparisons of spring and summer age frequencies using the Kolmogorov-Smirnov Two Group Test.

| Location | N | Date | Dmax | Prob |
|---|---|---|---|---|
| East | 78 | | | |
| vs | | Spring 1986 | 0.484 | p<0.001 |
| West | 42 | | | |
| East | 78 | | | |
| vs | | Spring 1986 | 0.251 | p>0.010 |
| North Outer | 83 | | | |
| West | 42 | | | |
| vs | | Spring 1986 | 0.631 | p<0.001 |
| North Outer | 83 | | | |
| North Outer | 173 | | | |
| vs | | Summer 1986 | 0.313 | p<0.001 |
| South Outer | 174 | | | |
| West | 97 | | | |
| vs | | Spring 1987 | 0.441 | p<0.001 |
| North Outer | 100 | | | |
| North Outer | 77 | | | |
| vs | | Summer 1987 | 0.109 | p>.0.200 |
| South Outer | 162 | | | |

Table 8: Mean age of lake whitefish captured in commercial trap nets reported for each sampling area by season and year.

| Location | Date | Mean Age | SE |
|---|---|---|---|
| West Bay | Fall 1985 | 7.74 | 0.132 |
| | Spring 1986 | 8.12 | 0.336 |
| | Fall 1986 | 7.21 | 0.218 |
| | Spring 1987 | 7.67 | 0.208 |
| | Fall 1987 | 7.38 | 0.196 |
| East Bay | Fall 1985 | 6.18 | 0.111 |
| | Spring 1986 | 5.76 | 0.184 |
| | Fall 1986 | 6.21 | 0.184 |
| | Fall 1987 | 6.37 | 0.189 |
| South Outer Bay | Summer 1986 | 6.45 | 0.137 |
| | Fall 1986 | 6.29 | 0.312 |
| | Summer 1987 | 6.07 | 0.142 |
| North Outer Bay | Spring 1986 | 5.72 | 0.195 |
| | Summer 1986 | 5.28 | 0.116 |
| | Spring 1987 | 6.07 | 0.172 |
| | Summer 1987 | 5.85 | 0.231 |

in mean age for the West Bay stock over the study period but the mean was always higher than age seven. East Bay mean age increased slightly during the falls of the three year period but ranged from 1.0 to 2.4 years lower than West Bay.

The West Bay whitefish stock was dominated by the 1977 year class in the falls of 1985 and 1986 as eight and nine year-olds. In 1987, this year class was still abundant as ten year-olds and contributed nearly twenty-one percent to the commercial catch. All year classes following the 1977 appear to be smaller, and therefore production of the West Bay stock is on the decline. Smale (1988) reported a similar trend for the Leland stock which declined drastically after the 1977 year class was fished out. In East Bay, the 1977 year class contributed a smaller proportion to the stock, but was still present throughout the study period. This may be the result of relatively stronger year classes, such as the 1981 and 1982, recruiting to the fishery.

Mean age of whitefish in the Outer Bay fishery was lowest in the northern portion and slightly higher in the southern area. Mean age in North Outer Bay increased from 1986 to 1987 within the same season as the 1982 year class recruited to the fishery. South Outer Bay mean age declined over the study period but remained higher than North Outer. Again, this suggests that larger, older whitefish are absent in the northern waters of Outer Bay. This may be a function of a localized population experiencing, on the average, higher fishing mortality, relative to South Outer Bay, since the fishery re-opened in 1977.

The 1977 year class has been reported as one of the strongest of the century in other whitefish stocks inhabiting the North Shore, Leland, Beaver Island, and Cross Village areas in northeastern Lake Michigan, where catches peaked in 1981 and 1982 (Scheerer 1982; Smale 1988). The sustenance of this year class through ten years of life in Lake Michigan is evidence for a low exploitation rate on the West Bay spawning stock. There is no published account of a Great Lakes whitefish population where ten year-olds comprised over 20% of the catch. Given the low tag return rate for the West Bay stock, in addition to its broad age distribution, it is clear that its contribution to the Outer Bay fishery is much lower than the East Bay stock.

Historical age structure data from Grand Traverse Bay was available from assessment work, some which is reported by Patriarche (1977) and Scheerer (1982), and some is unpublished. The Michigan Department of Natural Resources (Great Lakes Station) has collected this data, using experimental gill nets, from several locations in the bay. In 1968, the Outer Bay population was dominated by three year-old fish which led to the closure of the fishery (Figure 9). The stock showed some recovery in the years following, and by 1981 the age structure was dominated by four and five year-olds, very similar to the structure found in this study. Data from the lower arms of Grand Traverse Bay, during the late 60's and early 70's, showed drastic differences from Outer Bay (Figure 10). Over this time period, the percentage of fish age six and older in the arms ranged from 25% to 63%, while Outer Bay ranged from 1% to 11%. The lower arms of the bay had been closed to commercial fishing since the lamprey invasion had caused the near collapse of Lake Michigan whitefish stocks. Therefore, the historic data suggests first that fishing did play a role in the decline of whitefish populations, if it is assumed that lamprey predation was homogenous throughout GrandTraverse Bay. Secondly, whitefish stocks in Grand Traverse Bay appeared to be localized in the 1960's and 70's, reflected by the differential fishing pressure exerted throughout regions of the bay.

More recent data (1977 to 1985) from East and West Bays shows even broader age structures than from the earlier years, where now mature age groups dominate the stocks, with the exception of 1981 (Figure 11). This shift to older ages in Grand Traverse accompanied a trend of increasing yield in all areas of Lake Michigan (Figure 1). Smale (1988) reported that this increase in yield was

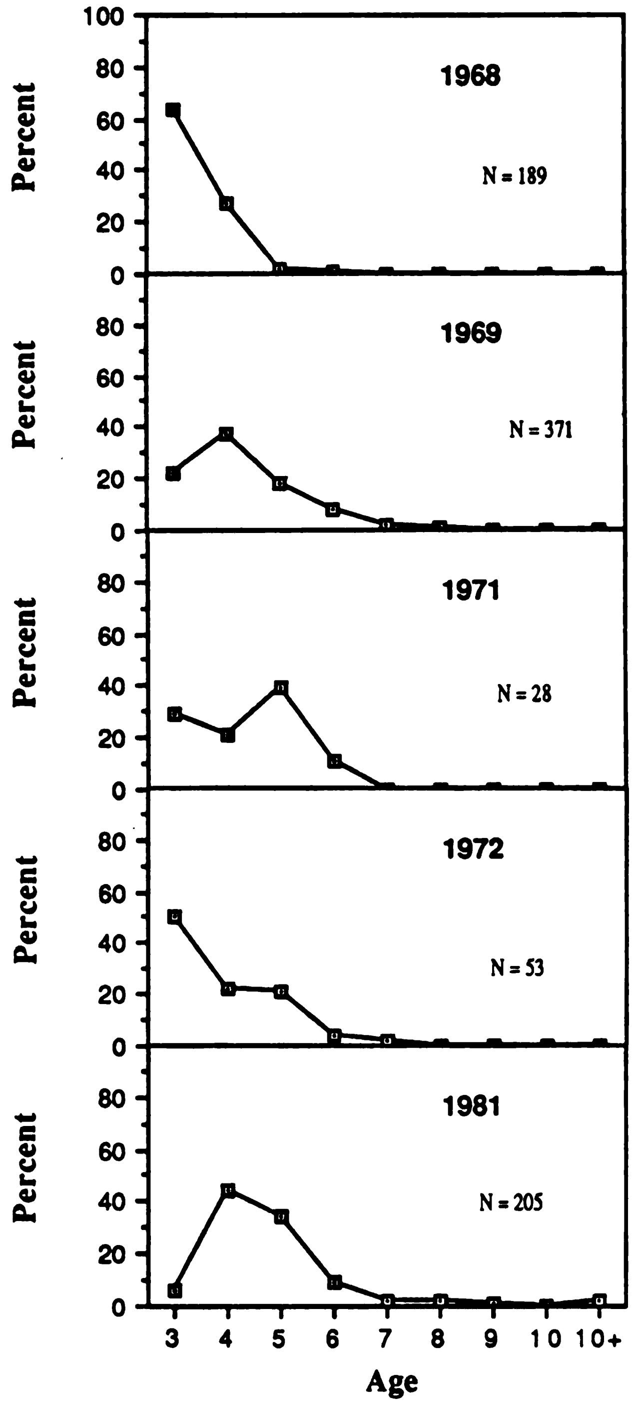


Figure 9: Percent age composition of lake whitefish from North Outer Bay determined by gill net assessment for the years 1968-69, 1971-72, and 1981.

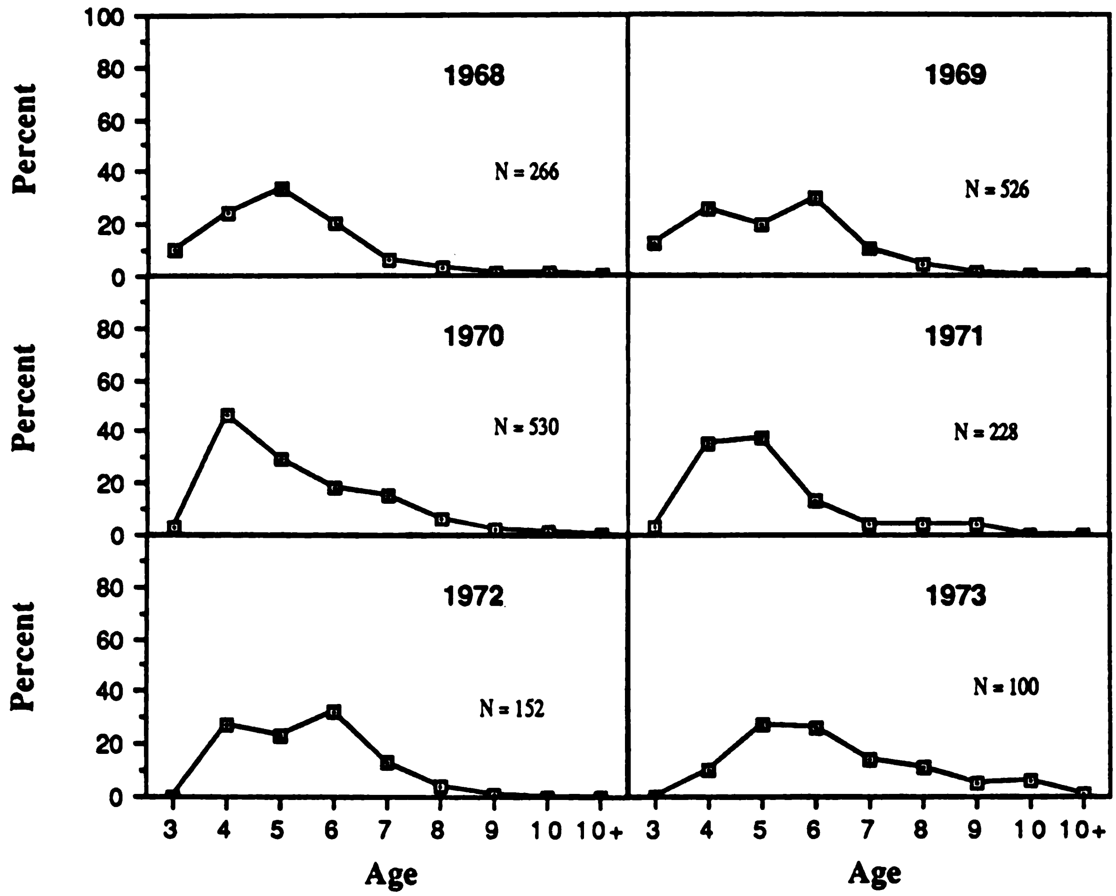


Figure 10: Percent age composition of lake whitefish from the southern arms of Grand Traverse Bay determined by gill net assessment for the years 1968-73.

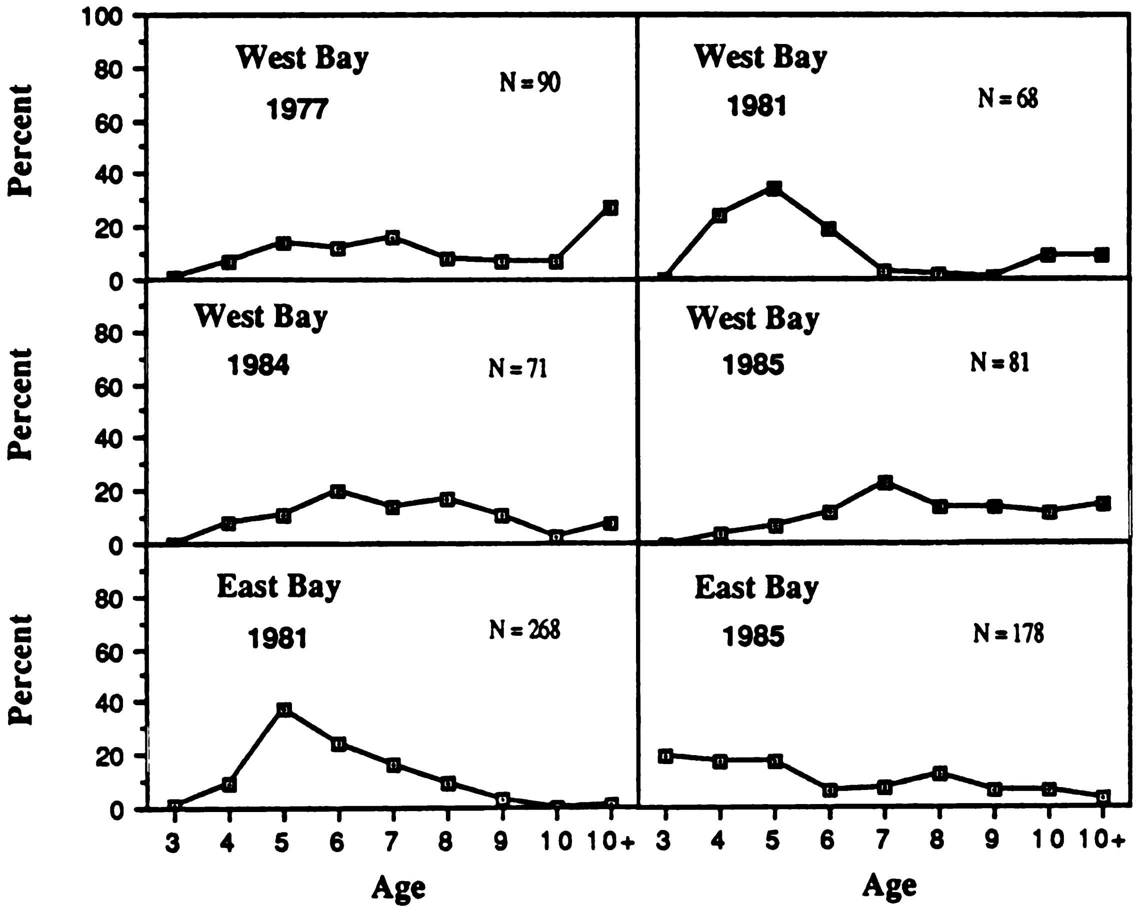


Figure 11: Percent age composition of lake whitefish from West Bay for the years 1977, 1981, and 1984-85, and from East Bay for the years 1981 and 1985.

accompanied by an steady increase in mean age in the whitefish fishery of the north shore of Lake Michigan from the late 60's to early 80's which was attributed to a reduction of sea lamprey predation, and a trend of climatic conditions optimal for producing increasingly stronger year classes (Taylor et al. 1987).

Further examination of the 1981 data for East and West Bays in Figure 11, and Outer Grand Traverse Bay in Figure 9 reveals a large degree of similarity in age structure, unlike other years. This suggests that the recruiting age classes, which would include the 1977 year class, were unusually large and offset the variability in abundance, due to differential fishing pressure, among these stocks. This is supported by the fact that lake-wide whitefish yield nearly doubled from 1977 to 1983. These observations of the historical data demonstrate the need for developing an index of year class strength if the impacts of fishing mortality are to be accurately assessed over time.

MORTALITY:

Separate catch curves were constructed by combining fall data from the East and West Bay spawning stocks for 1985-87, and by combining data from 1986-1987 for the Outer Bay spring and summer samples (Figure 12). The East Bay curve was characterized by a rather straight descending slope from ages five to nine while the West Bay data displayed a bimodal curve. Concave curves were observed for the Outer Bay samples.

Mortality estimates from catch curves are biased by three factors (Ricker 1975; Healey 1975): 1) unrepresentative sampling of age groups; 2) aging error; 3) and variable recruitment of year classes. Only the first two can be directly controlled by the researcher while the effects of the latter can only be minimized by either indexing year class size or averaging several years data together to smooth the curve (Chapman and Robson 1960; Ricker 1975). The evidence of variable year

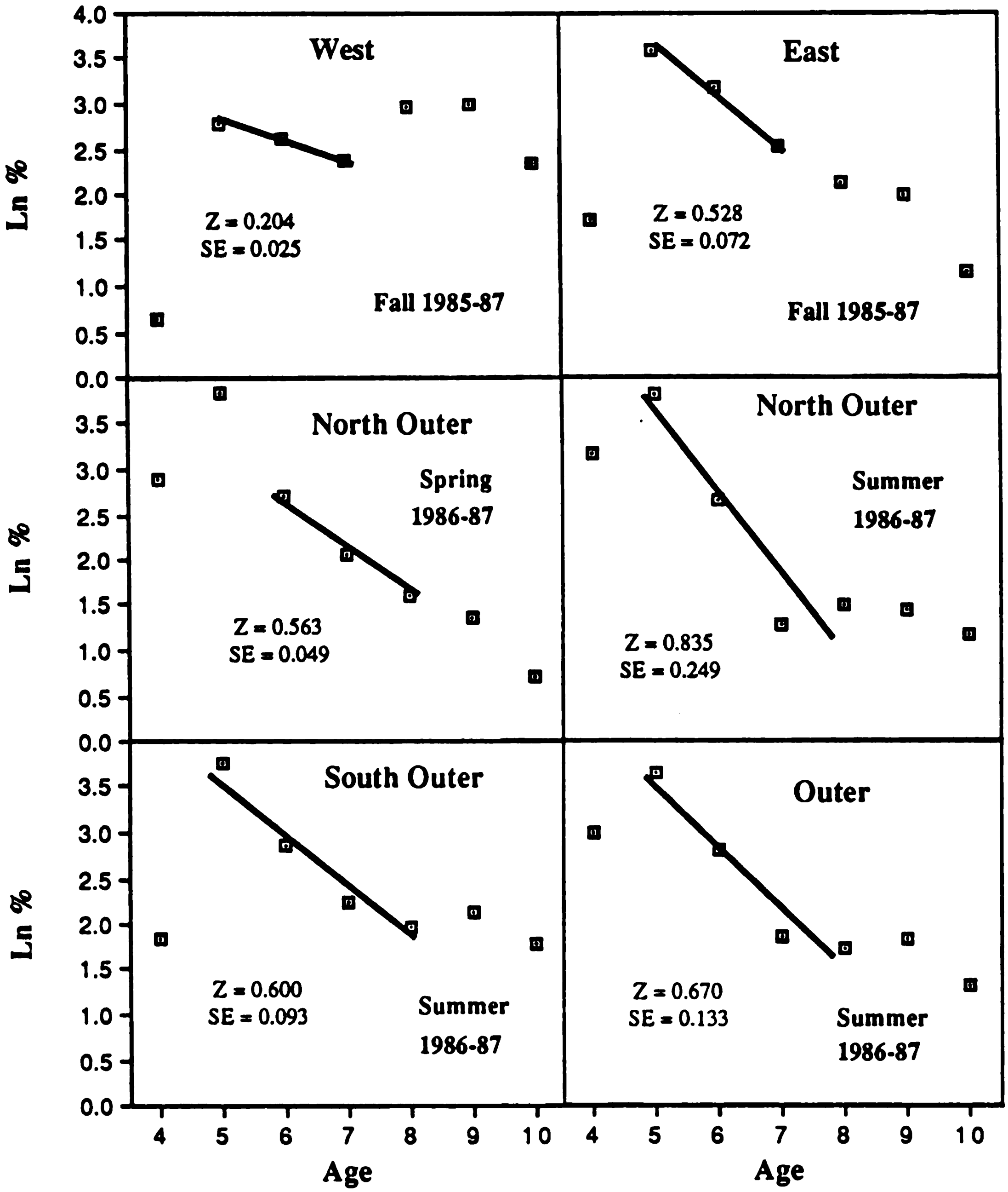


Figure 12: Catch curves and mortality estimates for East and West Bays from the fall catch during 1985-87, for North Outer Bay from the spring and summer catch of 1986-87, for South Outer Bay from the summer catch of 1986-87, and for all of Outer Bay from the summer catch of 1986-87.

class strength is strongly depicted in the West Bay catch curve even after averaging the three years data. Recruitment to the fishery occurs between ages five and six and yet these ages are no more abundant than eight and nine year-olds. Therefore, catch curve mortality estimates may be biased, when large differences in year class strength are evident.

A instantaneous total mortality (Z) estimate of 0.204 was calculated from the first descending arm of the bimodal curve, ages five to seven. The second dome includes the strong 1977 year class as it moved through the fishery during the study period, from which an estimate of Z = 0.381 was made. Survey sampling with experimental gill nets near Marion Island by the Michigan Department of Natural Resources provided additional age composition data in which a spring mortality estimate of Z = 0.284 for seven to ten year-olds was calculated for the combined samples of 1984-85. This suggests that fall data is characteristic of the population in general and not solely the result of old members of the spawning stock becoming more catchable.

Instantaneous mortality rates for five to seven year-olds of the East Bay stock (Z = 0.528) was lower than expected from the high tag returns relative to Outer Bay. However, this mortality rate is an average over a five or six year period which includes the time period (pre-1985) before commercial fishing was allowed in the arms. It was slightly higher than the rate Smale (1988) calculated (Z = 0.460) for East Traverse whitefish, 6-12 years-old, caught in trawls over the summers of 1983-84. Survey sampling in 1981 with experimental gill nets provided an estimate of Z = 0.447 for 5-8 year olds (MDNR unpublished data). Other studies in the mid-1970's reported lower rates; 0.344 for 3-9 year olds (Patriarche 1977) and 0.416 for 5-13 year olds (Rybicki and Keller 1977). These rates were estimated during the years when the entire bay was closed to fishing, therefore, the migration of East Traverse whitefish into the Outer Bay fishery may explain the increase. Mortality estimates from individual years did indicate an increase in mortality from 1985 to 1987 although biases due to variable year class strength are problematic.

Estimates of mortality for the 1986 fishing season were also calculated for West and East Bays using tag returns from the 1985 fall tagging (Table 9). These estimates provide total annual mortality estimates which are approximately double the catch curve estimates. Partitioning total instantaneous mortality into components of fishing and natural causes indicates a very large natural mortality for both stocks relative to other Great Lakes studies on whitefish. Other estimates are more commonly one half this value with the exception of a Lake Huron population (Spangler 1970) which experienced high mortality due to sea lamprey predation. The incidence of lamprey wounding scars, although not recorded, was not observed often enough to suggest this as an explanation for high natural mortality in Grand Traverse Bay.

There are several assumptions which are made when calculating mortality rates from tagging results. Ricker (1975) discussed potential errors in estimating mortality rates when these assumptions are broken. He referred to type A errors as those which affect the estimate of rate of fishing (F) but not the estimates of total mortality (Z) or survival (S). The two errors in this group are: 1) the death of any considerable number of fish, or the loss of their tags, shortly after tagging; and 2) incomplete reporting of tags taken by fishermen. Notice that incomplete reporting, which was known to occur, does not effect the Z estimate, but only the partitioning of total mortality into its fishing and natural causes. Therefore it is certain that non-reporting resulted in over-estimated natural mortality rates, but the magnitude of error is unknown.

Tagging estimates of total mortality are higher than expected, based on age distributions of Grand Traverse stocks and other Lake Michigan stocks which have experienced heavy fishing pressure for many years. One possible explanation for

Table 9: Mortality and exploitation rates of lake whitefish stocks in Grand Traverse Bay and other Great Lakes areas. A = annual mortality, Z = instantaneous total mortality, u = annual exploitation, F = instantaneous fishing mortality, and M = instantaneous natural mortality.

| Location | Ages | A | Z | u | F | M |
|---|---|---|---|---|---|---|
| West Bay | | | | | | |
| Tag returns (1986) | | 0.746 | 1.370 | 0.057 | 0.105 | 1.265 |
| Catch curve (1985-87) | 5-7 | 0.184 | 0.204 | | | |
| East Bay | | | | | | |
| Tag returns (1986) | | 0.733 | 1.320 | 0.134 | 0.241 | 1.079 |
| Catch curve (1985-87) | 5-10 | 0.410 | 0.528 | | | |
| North Shore, Lake Michigan (Scheerer and Taylor 1985) | | | | | | |
| Tag returns (1981) | | 0.772 | 1.478 | 0.436 | 0.835 | 0.543 |
| Catch curve (1980-81) | 4-6 | 0.939 | 2.794 | | | |
| Leland, Lake Michigan (Scheerer and Taylor 1985) | | | | | | |
| Tag returns (1981) | | 0.586 | 0.881 | 0.221 | 0.363 | 0.518 |
| Catch curve (1980-81) | 4-8 | 0.587 | 0.884 | | | |
| North Moonlight Bay, Lake Michigan (Ebner 1980) | | | | | | |
| Catch curve (1977-79) | 4-8 | 0.610 | 0.941 | | 0.326 | 0.600 |
| Big Bay de Noc, Lake Michigan (Ebner 1980) | | | | | | |
| Catch curve (1977-79) | 4-8 | 0.772 | 1.478 | | 1.064 | 0.414 |
| South Bay, Lake Huron (Spangler, 1970) | | | | | | |
| Catch curve | 2-3 | 0.764 | 1.444 | | 0.069 | 1.375 |
| | 3-4 | 0.923 | 2.567 | | 0.632 | 1.935 |
| | 4-5 | 0.993 | 4.197 | | 0.925 | 3.992 |

this discrepancy is that the rates are accurate, but age distributions have yet to reflect increases in mortality, due to variations in year class sizes. If accurate estimates were made one would expect shifts towards a younger age structure in future years in both East and West Bays. However, inaccurate rates may have been made due to Type B errors (Ricker 1975) which affect the estimate of total mortality but not the rate of fishing. These errors are due to: 1) the loss of tags from fish at a constant rate over the study period; 2) higher mortality of tagged fish similarly distributed through time; and 3) emigration of tagged fish from the fishing grounds similarly distributed through time. An attempt was made to correct for tag loss but there was no method of testing the second two potential errors. Future tagging studies in Grand Traverse Bay will have to address these problems if more conclusive results are desired.

Catch curve mortality estimates were higher in all areas of Outer Grand Traverse Bay than those from either East or West Bay. Separate estimates were calculated for North and South Outer Bay due to differences in length compositions of the catch taken in these areas. Age data was combined for 1986-87 but separated by spring and summer sampling. The spring estimate for North Outer Bay was $Z = 0.563$ ($r^2 = 0.969$) for ages six to eight and the summer estimate was $Z = 0.835$ ($r^2 = 0.797$) for ages of five to eight. No spring estimate was available for South Outer Bay (Gull Island area) but the summer estimate was $Z = 0.600$ ($r^2 = 0.956$) for five to eight year-olds. An average estimate for the entire Outer Bay fishery was estimated to be $Z = 0.670$ ($r^2 = .927$) from the summer data. This estimate was much lower than the value Scheerer (1982) reported for this area in the spring of 1981 ($Z = 1.195$) for the same range of ages. However, his estimate is probably biased by the recuitment of large year classes during that time .

A common characteristic of whitefish catch curves in Outer Bay is the concave shape of the descending limb. This phenomenon was also found by Scheerer

(1982) for North Outer Bay in June of 1981. Ricker (1975) suggests that concavity of the catch curve can be caused by either a decrease in natural mortality with increasing age or a recent increase in fishing mortality. Hastreiter (1984) and Ebner (1983) both reported concave catch curves for Green Bay whitefish stocks which they indicated were results of increasing fishing effort. Scheerer (1982) reported similar results for the Leland whitefish stock, which inhabits waters of the western side of the Leelanau pennisula. This stock experienced an increase in fishing mortality from 1977 to 1981 after a seven year closure.

An argument of increased mortality causing concavity during the 1986-87 fishing seasons in Outer Grand Traverse Bay is not entirely justified. The fishery was reopened in 1977 which would explain Scheerer's results in 1981 but not the persistence of concavity into 1986. A more probable explanation is that the year classes of 1977 and 1978 were significantly stronger than the following year classes of 1979 and 1980. This would cause plots of numbers at age to be non-linear and skewed towards older ages during the study period. Smale (1988) estimated the 1977 year class to be six times as large as the 1979 year class in the North Shore stock and attributed this to the exceptionally cold winter and warm spring of 1976-77 which provided ideal conditions for egg and larval survival.

Concavity of catch curves has a definite effect on estimation of mortality. All Outer Bay mortality estimates decreased with an increase in the number of ages included in the analysis. Depending on the location of sampling, and the range of ages used, total annual mortality rates ranged from 30% to 60% for the Outer Bay fishery.

LENGTH COMPOSITIONS:

Trap Net Harvest: Analysis of whitefish length compositions from West Bay, East Bay, and Gull Island in Outer Bay during the fall seasons from 1985 to 1987 indicated minor annual fluctuations within locations while differences between sites were large (Figure 13). Spawning aggregations from all three locations were found to differ significantly ($P < 0.001$) during each of the three years with the exception of the 1987 East Bay-Outer Bay comparison ($P > 0.01$) (Table 10). The East Bay stock consisted of smaller adults with 53-55% below 505 mm, while theWest Bay stock consisted of much larger adults with only 8-21% below 505 mm. The Gull Island stock was intermediate to its neighboring counterparts with 28-40% of the adults below 505 mm. Both the Lee Point and Gull Island spawning aggregations experienced small shifts towards smaller size distributions, while the East Bay stock maintained its distribution over the study period. These shifts were due to the recruitment of the 1982 year class to the fishery during 1986 and 1987.

Length distributions during seasons other than fall for these locations shifted towards smaller fish. Examining the mean length of catch at these locations over the study period indicates a trend of smaller means for spring or summer samples (Figure 14). This could either be due to changes in catchability throughout the fishing season where larger fish become more vulnerable during the pre-spawning period as reported for other whitefish populations (Ebner 1980; Scheerer 1982), or higher mortality rates due to spawning stress of older individuals (Smale 1988).

There appeared to be two distinct fishing grounds in Outer Bay where length distributions differed (Figure 15). North Outer Bay catch was characterized by very small fish in 1986 with sub-legal sized fish (below 430 mm) comprising nearly 25% of the catch. In South Outer Bay, near Gull Island and the Old Mission shoal, distributions were skewed towards larger fish with fewer sub-legal fish caught. In 1987, the presence of sub-legal fish was reduced in North Outer Bay, and length distributions shifted towards larger sizes. Whitefish smaller than 460 mm decreased from 57% to 20% in the spring and from 44% to 24% in the summer in North Outer Bay over the two year period. The converse occurred in South Outer Bay, where length frequencies shifted to the 450 to 510 mm range. The

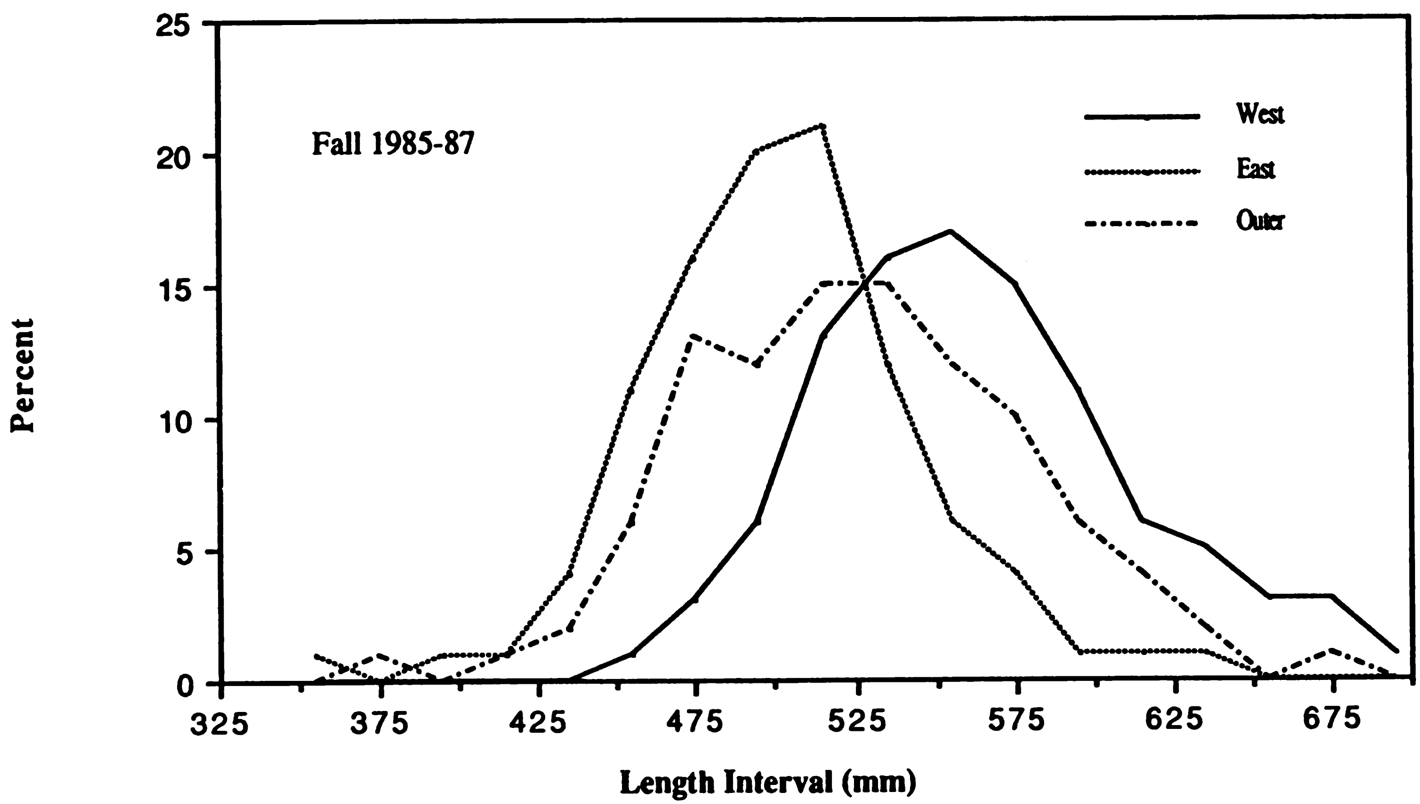


Figure 13: Percent length composition of lake whitefish from West, East, and South Outer Bays from the fall catch of 1985-87.

Table 10: Comparisons of cumulative length frequencies of the fall trap net catch in West, East, and Outer Bay from 1985 to 1987 using the Kolmogorov-Smirnov Two Group Test.

| Location | N | $D_{max}$ | Probability |
|---|---|---|---|
| **1985** | | | |
| West vs East | 661 / 504 | 0.545 | $p < 0.001$ |
| West vs Outer | 661 / 65 | 0.321 | $p < 0.001$ |
| East vs Outer | 504 / 65 | 0.292 | $p < 0.001$ |
| **1986** | | | |
| West vs East | 257 / 260 | 0.543 | $p < 0.001$ |
| West vs East | 257 / 234 | 0.253 | $p < 0.001$ |
| East vs Outer | 260 / 234 | 0.320 | $p < 0.001$ |
| **1987** | | | |
| West vs East | 192 / 81 | 0.407 | $p < 0.001$ |
| West vs Outer | 192 / 119 | 0.237 | $p < 0.001$ |
| East vs Outer | 81 / 119 | 0.225 | $p > 0.010$ |

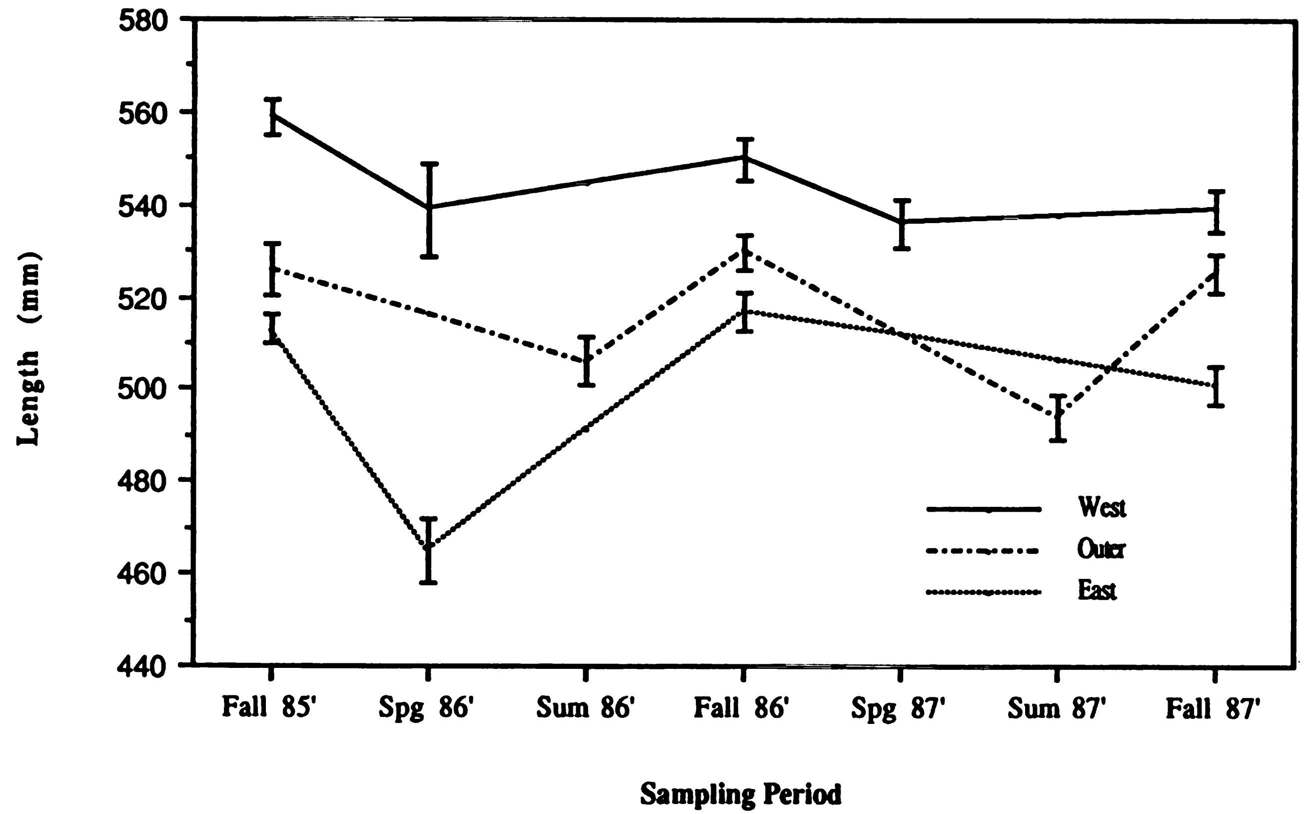


Figure 14: Seasonal mean lengths and standard errors of lake whitefish from trap net catch during the study period.

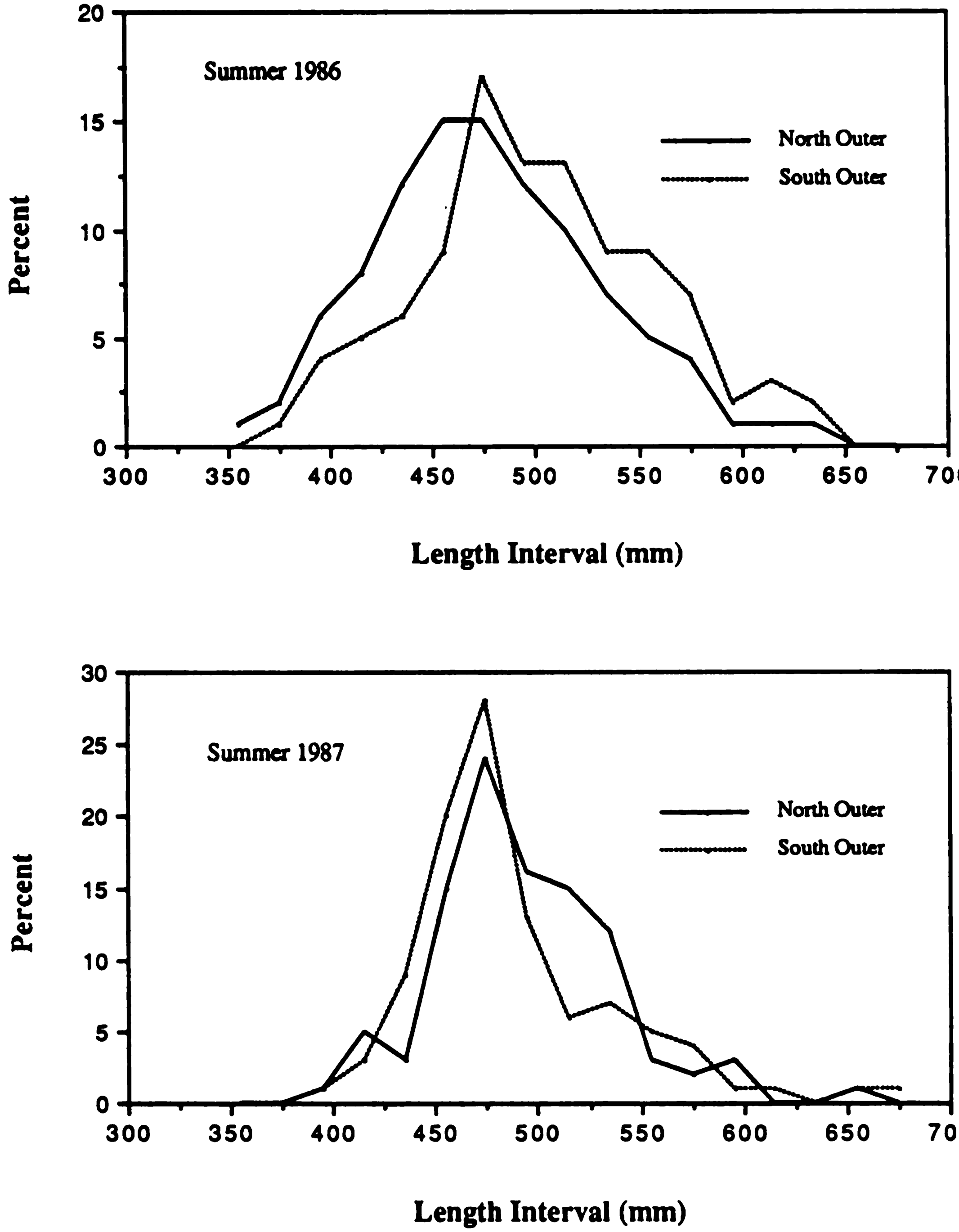


Figure 15: Percent length composition of lake whitefish from North and South Outer Bays from the summer trap net catch of 1986 and 1987.

presence of large numbers of sub-legal fish in 1986 was due to the recruitment of the large 1982 year class as four year-olds. The delay in appearance of this year class further south until 1987 may be due to differences in habitat between these areas. Whitefish are known to segregate by size with smaller fish inhabiting shallower waters (Smale 1988). Northern Outer Bay is, on the average, much shallower than waters further south where in some areas depths approach the maximum depth of Lake Michigan. The absence of sub-legals in 1987 does not neccessarily negate this argument. Recent studies regarding factors controlling year class strength of whitefish populations suggests that the 1983 year class was weak. Freeberg (1985) concluded this year class was of one-third the size of the 1984 cohort in East Traverse Bay.

Mean lengths and weights of whitefish age classes from West Bay were consistently higher than from East Bay during the fall seasons of the study period. The West Bay stock was larger than the East Bay stock in eighteen of nineteen age class comparisons of mean length, of which fourteen were significant (t-test, $P < 0.05$) (Table 11). Similar results in mean weight were found (Table 12) where West Bay whitefish were heavier in sixteen (twelve were significant, ($P < 0.05$) of nineteen comparisons. Although this would suggest the West Bay stock maintains a growth advantage over the East Bay stock, there was no definite trend of increasing difference in length with older age between the stocks. This divergence in growth must occur in the juvenile stage and may be a result of either density dependent growth, differences in egg hatching dates, or diet differences (Bidgood 1973).

Comparisons of size at capture of whitefish in Outer Bay and the two southern arms were available from spring sampling only. During May of 1986, East Bay whitefish of four to six years of age were considerably smaller than those of North Outer Bay (Table 13). In April-May of 1987, no consistent length difference was

Table 11: Mean lengths (mm) and standard errors for each age class in the fall catch from West and East Bays from 1985 to 1987. Significant differences between age classes are indicated by * (t-test, $p < 0.05$).

| Age | | West Bay N | West Bay Mean Length | West Bay SE | East Bay N | East Bay Mean Length | East Bay SE |
|---|---|---|---|---|---|---|---|
| **1985** | | | | | | | |
| 5 | * | 11 | 505 | 5.64 | 60 | 491 | 3.25 |
| 6 | | 18 | 517 | 5.30 | 33 | 516 | 4.72 |
| 7 | * | 25 | 545 | 6.02 | 36 | 535 | 4.90 |
| 8 | * | 51 | 561 | 4.05 | 25 | 541 | 5.52 |
| 9 | * | 16 | 591 | 10.50 | 11 | 566 | 9.44 |
| 10 | | 8 | 615 | 12.98 | 4 | 591 | 3.65 |
| **1986** | | | | | | | |
| 4 | * | 8 | 483 | 9.55 | 10 | 468 | 6.89 |
| 5 | * | 27 | 505 | 4.29 | 49 | 497 | 3.97 |
| 6 | * | 20 | 525 | 4.94 | 23 | 513 | 5.48 |
| 7 | * | 7 | 551 | 8.28 | 10 | 526 | 5.98 |
| 8 | * | 18 | 553 | 6.43 | 11 | 531 | 8.86 |
| 9 | * | 31 | 578 | 5.33 | 12 | 586 | 10.42 |
| 10 | * | 6 | 607 | 9.88 | 4 | 581 | 18.75 |
| **1987** | | | | | | | |
| 5 | * | 24 | 497 | 3.96 | 30 | 480 | 3.76 |
| 6 | * | 17 | 516 | 6.06 | 30 | 498 | 4.97 |
| 7 | | 7 | 544 | 13.27 | 8 | 534 | 5.66 |
| 8 | | 6 | 551 | 6.90 | 2 | 537 | 23.97 |
| 9 | * | 17 | 568 | 6.14 | 5 | 553 | 13.82 |
| 10 | * | 20 | 581 | 6.31 | 3 | 553 | 13.22 |

Table 12: Mean weights (gms) and standard errors for each age class in the fall catch from West and East Bays from 1985 to 1987. Significant differences between age classes are indicated by a * (t-test, $p < 0.05$).

| | | West Bay | | | East Bay | | |
|---|---|---|---|---|---|---|---|
| Age | | N | Mean Weight | SE | N | Mean Weight | SE |
| **1985** | | | | | | | |
| 4 | | 0 | - | - | 21 | 949 | 50.5 |
| 5 | * | 11 | 1231 | 62.4 | 60 | 1171 | 31.0 |
| 6 | * | 18 | 1305 | 47.8 | 33 | 1356 | 47.0 |
| 7 | * | 25 | 1576 | 74.7 | 36 | 1519 | 57.4 |
| 8 | * | 51 | 1719 | 47.5 | 25 | 1609 | 48.0 |
| 9 | | 16 | 2064 | 106.9 | 11 | 1975 | 128.0 |
| 10 | | 8 | 2481 | 167.8 | 4 | 2181 | 54.0 |
| **1986** | | | | | | | |
| 4 | * | 8 | 1088 | 75.9 | 10 | 880 | 63.8 |
| 5 | * | 27 | 1164 | 39.4 | 49 | 1091 | 36.2 |
| 6 | | 20 | 1290 | 44.8 | 23 | 1272 | 66.0 |
| 7 | * | 7 | 1618 | 91.8 | 10 | 1258 | 56.9 |
| 8 | * | 18 | 1529 | 52.1 | 11 | 1357 | 80.6 |
| 9 | * | 31 | 1907 | 73.8 | 12 | 2090 | 170.0 |
| 10 | | 6 | 2308 | 141.0 | 4 | 1994 | 250.4 |
| **1987** | | | | | | | |
| 5 | * | 24 | 1094 | 36.1 | 30 | 1000 | 27.9 |
| 6 | * | 17 | 1240 | 59.7 | 30 | 1143 | 50.5 |
| 7 | | 7 | 1418 | 95.4 | 8 | 1463 | 66.0 |
| 8 | | 6 | 1542 | 29.8 | 2 | 1400 | 200.0 |
| 9 | * | 17 | 1819 | 111.4 | 5 | 1680 | 148.1 |
| 10 | * | 20 | 2076 | 72.4 | 3 | 1633 | 120.2 |

Table 13: Mean lengths (mm) and weights (gms) for all ages in the spring catch from East Bay and Outer Bay in 1986. Significant differences between locations for each age class are indicated by a * (t-test, $p < 0.05$).

| | East Bay | | Outer Bay | |
|---|---|---|---|---|
| Age | N | Mean Length (SE) | N | Mean Length (SE) |
| 4 * | 18 | 397 ( 8.30) | 32 | 435 ( 5.36) |
| 5 * | 23 | 438 ( 4.00) | 43 | 463 ( 4.03) |
| 6 * | 19 | 488 ( 7.09) | 14 | 504 ( 8.34) |
| 7 | 3 | 545 ( 4.50) | 4 | 535 ( 9.70) |
| 8 | 6 | 525 (19.15) | 7 | 532 (17.31) |
| 9 * | 8 | 567 ( 7.39) | 9 | 553 (10.57) |
| 10 | 1 | 583 ( - ) | 3 | 550 (13.22) |
| Age | N | Mean Weight (SE) | N | Mean Weight (SE) |
| 4 * | 18 | 731 ( 49.0) | 32 | 980 ( 40.5) |
| 5 * | 23 | 936 ( 33.8) | 43 | 1148 ( 36.0) |
| 6 * | 19 | 1274 ( 64.0) | 14 | 1391 ( 83.9) |
| 7 | 3 | 1475 ( 51.4) | 4 | 1656 ( 97.0) |
| 8 | 6 | 1458 (148.6) | 7 | 1768 (169.3) |
| 9 * | 8 | 1806 (106.4) | 9 | 1850 (145.3) |
| 10 | 1 | 2000 ( - ) | 3 | 1725 (162.8) |

found between West and North Outer Bay, although weights tended to be larger for Outer Bay whitefish (Table 14).

Sport Harvest: Sport harvest from East and West Bay during the summer of 1986 consisted of smaller and younger whitefish relative to the commercial catch (Figure 16). The sample from East Bay was taken in grid 916, the very southern area of the bay. Ninety percent of the catch from this location was below the commercial minimum size limit (432 mm). This agreed with winter harvest data collected by the Grand Traverse Band of Chippewa and Ottawa Indian Biological Services in March of 1986 at the same location. Eighty-three percent of this sample was below commercial size limit. This suggests that sport-fishing mortality of whitefish in East Bay occurs during the commercial gear pre-recruit stages and will not be detected from mortality estimates made from the commercial harvest. West Bay sport catch was sampled at Lee Point and the difference between the sizes harvested from sport and trap net gears was not as drastic. Only 20% of the sample was below the commercial minimum size limit.

BACK-CALCULATED LENGTHS:

Plots of individual observations indicated that variance in scale radius increased with increasing fish length just as Smale andTaylor (1986) described for Lake Michigan whitefish stocks. The relationship between fish length and scale radius was found to be linear ($P < 0.001$; $F = 19{,}275$; $N = 663$ fish, 29 means) using mean scale radii at 10 mm length intervals (Figure 17). The equation used to back-calculate lengths from annular measurements was:

$$\text{Length} = 84.1 + 3.58\ (\text{Scale Radius})$$

To provide equal precision of the means, Stein's two-stage sampling formula (Steel

Table 14: Mean lengths (mm) and weights (gm) for each age class in the spring 1987 catch from West and North Outer Bays. Significant differences between locations for each age class are indicated by * (t-test, $p < 0.05$).

| | West Bay | | North Outer Bay | |
|---|---|---|---|---|
| Age | N | Mean Length (SE) | N | Mean Length (SE) |
| 5 | 21 | 473 ( 5.02) | 50 | 474 ( 3.21) |
| 6 | 9 | 498 (10.77) | 23 | 503 ( 4.94) |
| 7 * | 16 | 529 ( 5.40) | 11 | 538 ( 8.26) |
| 8 * | 17 | 546 ( 6.06) | 5 | 524 (15.79) |
| 9 | 17 | 560 ( 7.52) | 3 | 570 (15.88) |
| 10 | 10 | 594 (10.91) | 4 | 584 (13.00) |
| Age | N | Mean Weight (SE) | N | Mean Weight (SE) |
| 5 * | 21 | 1107 ( 50.0) | 50 | 1200 ( 31.0) |
| 6 * | 9 | 1158 ( 68.3) | 23 | 1326 ( 43.4) |
| 7 * | 16 | 1450 ( 67.0) | 11 | 1650 ( 84.7) |
| 8 * | 17 | 1594 ( 52.1) | 5 | 1480 (183.4) |
| 9 * | 17 | 1693 ( 81.2) | 3 | 2050 (204.4) |
| 10 | 10 | 2048 (167.6) | 4 | 2163 (160.0) |

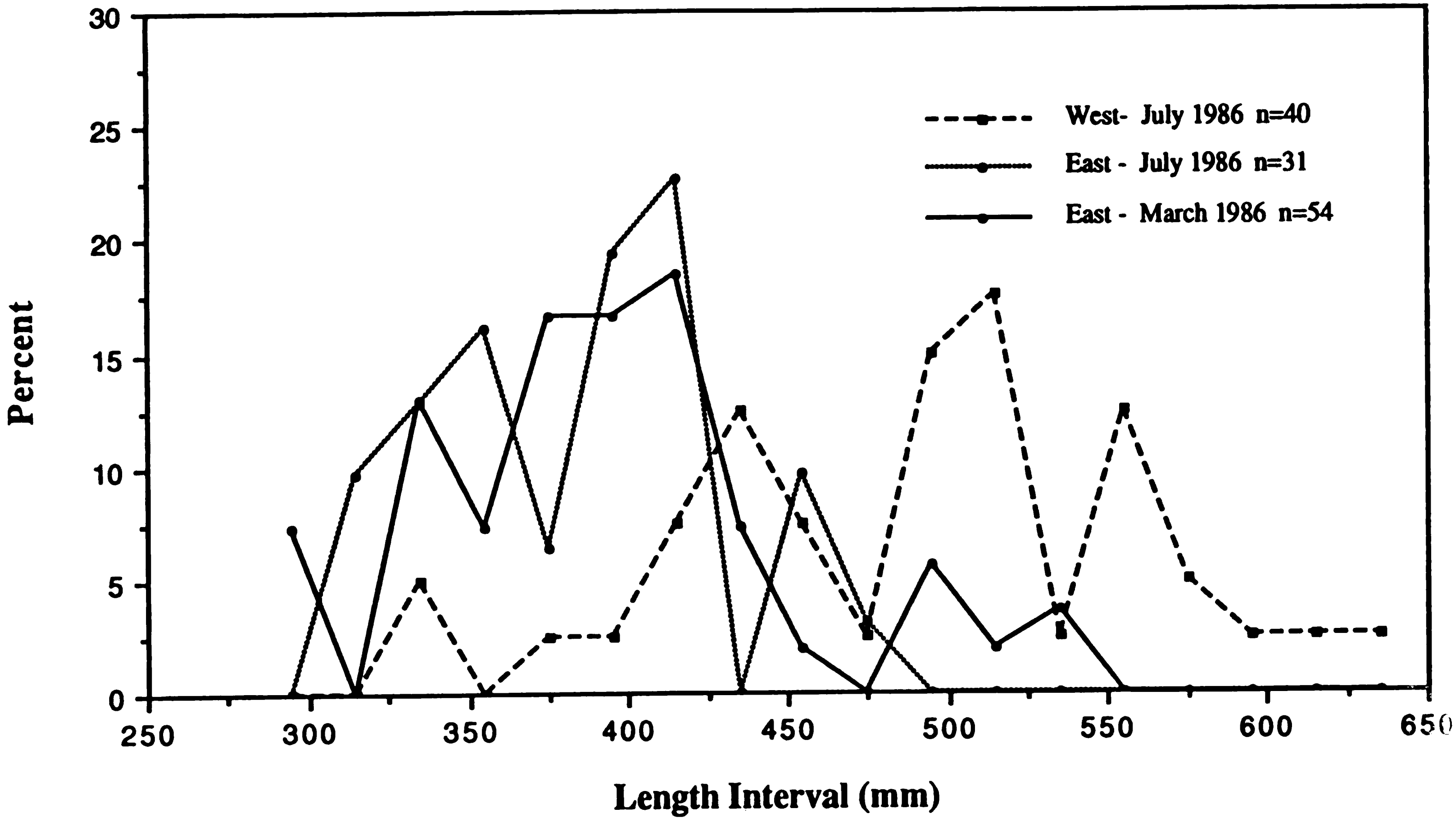


Figure 16: Percent length composition of lake whitefish from East and West Bays from sport catch during 1986.

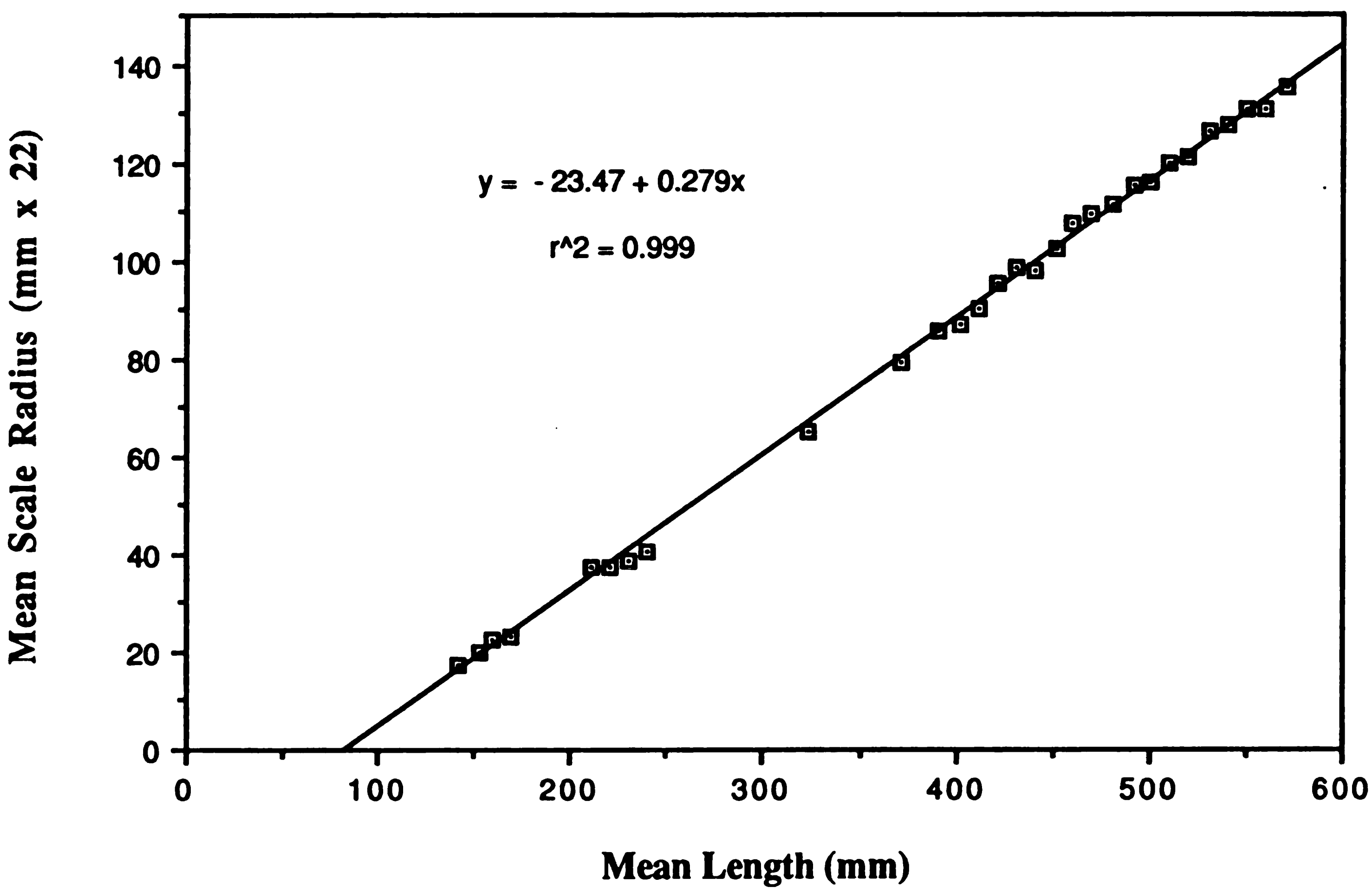


Figure 17: Plot of mean scale radius versus mean fish length (10 mm intervals) of lake whitefish from Grand Traverse Bay.

and Torrie 1980) was used to determine the number of observations needed for each length interval. The range of lengths used in the regression was 140 to 570 mm, although some intervals were excluded because sufficient sample sizes could not be attained to equate precision accross the entire range. Sample sizes steadily increased with increasing length and ranged from six to fifty-eight.

Rather than deriving separate equations for each bay, one relationship was estimated for all areas because differences in mean scale radii at length over similar size ranges were not determined. However, given the small available size range for comparison over all locations and the large variance in scale radius in this study, differences would be difficult to determine. Smale (1988) reported no difference in this relationship between several whitefish stocks of northeastern Lake Michigan. Using separate equations would also present problems because almost all whitefish of small sizes (130-300 mm) were caught in south East Traverse Bay, therefore, equations for West and Outer Bay would be based on only adult size ranges. Smale and Taylor (1986) and Ricker (1973) both described the potential for artificial results for regressions over small ranges of the dependent variable. This phenomenon was found in Scheerer's (1982) back-calculations for lake whitefish which resulted in severe over-estimates of length at juvenile ages.

Reliability of the regression for back-calculation was tested by comparing lengths of yearlings caught in East and West Traverse Bay (Table 15). Assuming growth resumes in mid-May for juvenile whitefish then back-calculations proved to be reliable for both bays.

Growth was examined for the spawning stocks in East and West Bays separately by combining fall data from 1985-87 (Table 16) while spring and summer data from the Outer Bay was divided into the northern and southern areas for analysis (Table 17). Comparisons of the East and West Bay spawning stocks sampled from the trap net catch indicate that West Bay whitefish maintain a growth

Table 15: Comparison of mean length (mm) at capture of yearling lake whitefish caught in survey trawls in East and West Bays with back-calculated lengths at age one. Back-calculated lengths are averages from all ages in the trap net catch.

| Date | N | Mean Length (mm) | SE |
|---|---|---|---|
| | | **East Bay** | |
| | | Length at Capture | |
| 6-07-83 | 65 | 158.8 | 2.06 |
| 6-03-84 | 6 | 180.7 | 4.41 |
| 6-21-85 | 35 | 157.3 | 2.24 |
| 6-11-86 | 7 | 152.9 | 4.25 |
| 6-05-87 | 84 | 154.1 | 0.71 |
| Weighted Mean | 197 | 157.0 | 1.67 |
| | | Back-calculated Length | |
| 1985-87 | 391 | 151.0 | - |
| | | **West Bay** | |
| | | Length at Capture | |
| 5-28-87 | 11 | 169.9 | 2.38 |
| | | Back-calculated Length | |
| 1985-87 | 336 | 173.0 | - |

Table 16: Average backcalculated total lengths (mm) for age classes of lake whitefish from West and East Bays, combined from the fall seasons of 1985-87.

West Bay

| | Age at Capture | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Age | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Mean |
| 1 | | 170 | 172 | 167 | 172 | 174 | 177 | 178 | 173 |
| 2 | | 268 | 248 | 232 | 238 | 246 | 250 | 248 | 245 |
| 3 | | 353 | 328 | 304 | 305 | 311 | 318 | 316 | 315 |
| 4 | | 440 | 407 | 378 | 369 | 369 | 381 | 378 | 382 |
| 5 | | | 468 | 446 | 437 | 428 | 437 | 436 | 442 |
| 6 | | | | 493 | 490 | 480 | 487 | 485 | 486 |
| 7 | | | | | 523 | 517 | 522 | 521 | 520 |
| 8 | | | | | | 540 | 548 | 546 | 544 |
| 9 | | | | | | | 566 | 567 | 566 |
| 10 | | | | | | | | 583 | 583 |
| N = | 0 | 8 | 62 | 55 | 39 | 75 | 63 | 34 | 336 |

East Bay

| | Age at Capture | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Age | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Mean |
| 1 | 148 | 160 | 151 | 151 | 149 | 147 | 146 | 155 | 151 |
| 2 | 226 | 243 | 222 | 209 | 202 | 197 | 201 | 214 | 214 |
| 3 | 284 | 333 | 302 | 279 | 267 | 254 | 260 | 281 | 286 |
| 4 | | 414 | 386 | 355 | 340 | 315 | 324 | 344 | 362 |
| 5 | | | 456 | 429 | 409 | 380 | 392 | 408 | 428 |
| 6 | | | | 480 | 468 | 440 | 450 | 454 | 465 |
| 7 | | | | | 506 | 485 | 499 | 496 | 497 |
| 8 | | | | | | 519 | 530 | 527 | 524 |
| 9 | | | | | | | 554 | 548 | 552 |
| 10 | | | | | | | | 566 | 566 |
| N = | 1 | 31 | 140 | 87 | 54 | 39 | 28 | 11 | 391 |

Table 17: Average back-calculated total lengths (mm) for age classes of lake whitefish from North and South Outer Bays, combined from spring and summer seasons of 1986-87.

North Outer Bay

| | Age at Capture | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Age | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Mean |
| 1 | 166 | 172 | 162 | 158 | 162 | 164 | 171 | 156 | 164 |
| 2 | 249 | 257 | 238 | 228 | 232 | 232 | 241 | 221 | 240 |
| 3 | 336 | 339 | 315 | 308 | 311 | 297 | 304 | 282 | 317 |
| 4 | | 421 | 393 | 385 | 390 | 359 | 367 | 342 | 392 |
| 5 | | | 459 | 450 | 458 | 422 | 428 | 397 | 448 |
| 6 | | | | 491 | 502 | 476 | 483 | 455 | 486 |
| 7 | | | | | 523 | 508 | 521 | 493 | 513 |
| 8 | | | | | | 532 | 545 | 521 | 536 |
| 9 | | | | | | | 564 | 545 | 557 |
| 10 | | | | | | | | 543 | 543 |
| N = | 3 | 106 | 179 | 67 | 25 | 23 | 21 | 9 | 433 |

South Outer Bay

| | Age at Capture | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Age | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Mean |
| 1 | 165 | 171 | 163 | 151 | 159 | 159 | 161 | 157 | 160 |
| 2 | 243 | 258 | 240 | 217 | 221 | 215 | 224 | 222 | 231 |
| 3 | 360 | 338 | 313 | 295 | 289 | 278 | 283 | 286 | 302 |
| 4 | | 418 | 386 | 371 | 364 | 337 | 342 | 345 | 372 |
| 5 | | | 452 | 436 | 427 | 403 | 402 | 404 | 434 |
| 6 | | | | 484 | 476 | 458 | 458 | 460 | 470 |
| 7 | | | | | 507 | 494 | 499 | 500 | 500 |
| 8 | | | | | | 526 | 523 | 530 | 526 |
| 9 | | | | | | | 545 | 552 | 548 |
| 10 | | | | | | | | 575 | 575 |
| N = | 1 | 23 | 145 | 66 | 32 | 27 | 34 | 23 | 361 |

advantage over their life period relative to East Bay whitefish. This advantage begins in the first year of life, increases further in the second year, then declines but is still apparent by age ten. Differences in length at age were nevertheless small, where West Bay whitefish recruited to the fishery at a mean age of 4.8 while East Bay whitefish recruited at a mean age of 5.1.

Length at age one determined separately for each year suggests that East and West Bay spawning stocks are discrete. Average lengths ranged from 174-177 mm and from 151-157 mm for West and East Bay yearlings repectively. To further substantiate this difference, spawning male whitefish captured directly on the spawning shoals revealed similar results. Back-calculation from males caught on West Bay spawning grounds averaged 173 mm (n = 24) while those from East Bay spawning grounds averaged 146 mm (n = 39). To maintain this difference over the study period, it would appear that any mixing between these stocks at spawning time is minimal.

Whitefish growth in Outer Grand Traverse Bay was comparable to the East and West stocks. Sizes at age one were intermediate to those in the arms of the bay. North Outer Bay whitefish grew faster from ages two to five but this was due to the samples being dominated by faster growing four and five year-olds which probably were not fully recruited to the gear. It is evident that higher mortality rates in the Outer Bay fishery have not resulted in a faster growing population when compared to the East and West Bay stocks. The slight growth advantage of juvenile whitefish in North Outer is most likely a result of Lee's phenomenon, where samples were dominated by young whitefish not fully vulnerable to the gear.

Lee's phenomenon results from either size selective mortality, gear selectivity, or back-calculation error (Ricker 1975). Plots of mean annular distance by age and age of capture for each of the four locations indicates Lee's phenomenon is present and is not due to the back-calculation method (Figure 18). Given the selectivity

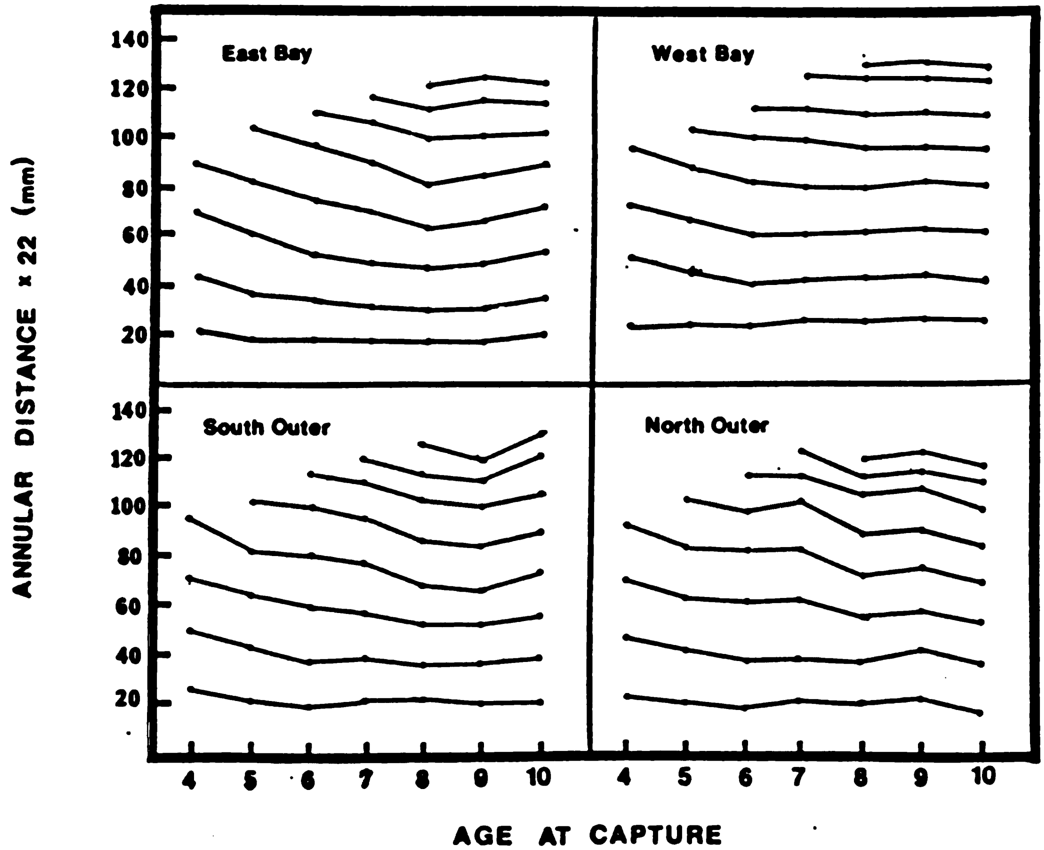


Figure 18: Plots of mean annular distance versus age at capture of lake whitefish from East, West, North, and South Outer Bays.

curves for trap nets and gill nets (Eschenroder et al. 1980; McCombie and Fry 1960), the larger, faster growing fish of a year class are the first to recruit to the fishery. Both Outer Bay locations and also East Bay indicate a decrease in mean annulus distance from age four to age eight. The West Bay stock displayed a less severe Lee's phenomenon where mean annulus distance decreased from only age four to six. This suggests that the rate of fishing influences the degree of Lee's phenomenon. A lighter fishing intensity with a size selective gear would catch the faster growing members of a year class as they reach recruitment size but would not remove a large enough proportion to cause a reduction in the average growth of the year class at older ages. Estimates of growth from the less exploited West Bay stock are less variable over the ages which are fully recruited whereas in the other areas of the bay whitefish growth estimates will be biased if calculated from one age group. Reverse Lee's phenomenon was observed at age 10, however, sample sizes in this study were small for the oldest ages and variance in annular distance was found to increase with increasing age. The observed rising curve may be an artifact of sample size. This phenomenon was absent in the West Bay stock where natural mortality has been the dominating force.

Growth in length was compared to other Lake Michigan whitefish stocks which have been subject to detailed study. Lengths at age were adjusted for differences in the scale to body length regression intercept. Figure 19 shows growth for East and West Traverse stocks in addition to the North shore and Leland stocks studied by Scheerer (1982) and Smale (1988) from 1980-1984. Grand Traverse stocks experience much slower growth than the more heavily exploited stocks, however mortality rate alone does not determine growth rate. It appears that differences in stock densities occur in Lake Michigan, regardless of the rate of fishing, and have a major influence on growth rate. Catch per effort of West Bay whitefish has been consistently lower than for East Bay whitefish during the fall seasons for trap net

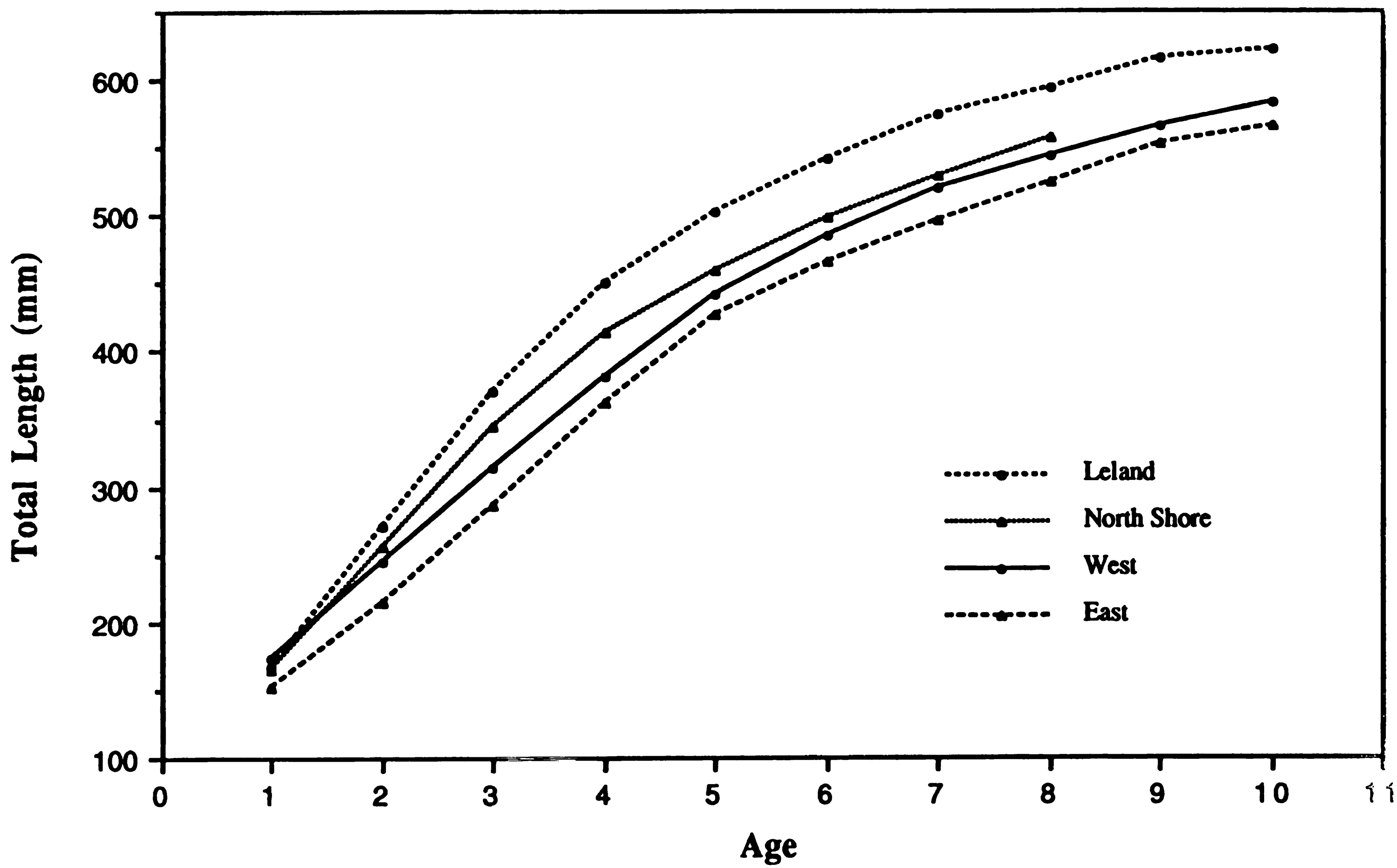


Figure 19: Back-calculated lengths at age for whitefish stocks from Leland, North Shore, West Bay, and East Bay of Lake Michigan.

fishing, and during the summers for sport fishing, suggesting a less dense stock.

LENGTH-WEIGHT RELATIONSHIP:

Predictive regressions were used to determine the relationship between length and weight of lake whitefish within each season of the year and each area of the bay (Table 18). Both length and weight were transformed by natural logarithms and a least squares regression was fit to the data. These equations can be used to describe the relationship between the two variables, and also to predict weight from length, assumed to be the dependent variable (Ricker 1975).

Slope values were consistently higher from fall samples than from spring or summer samples regardless of location. Differences between locations were slight when sexes were combined, with East Bay whitefish found to be heaviest at a given size while West and Outer Bay whitefish were more similar. Positive allometric growth, or slope values greater than three, was common to all areas during the fall, while below or nearly isometric growth was observed during spring and summer seasons.

An examination of mean weight at size intervals revealed only small differences between the three locations from fall samples (Figure 20). Weight gain per unit length is very similar among the areas but when examined by age,West Bay whitefish are both longer and heavier than the other two aggregations. Using back-calculated lengths and length-weight regression equations, weight was calculated for each age (Table 19). The differences observed agreed with those found in size at capture between East and West Bay adult stocks.

SEX RATIO:

Whitefish examined from both East and West Bays during the falls of 1985 to 1987 did not reveal any divergence from the expected 50-50 sex ratio (using Chi-

Table 18: Parameters for length-weight regressions (transformed by natural logarithms) for Grand Traverse Bay lake whitefish caught during the study period. Samples were from trap net catch unless noted to be from juvenile survey trawls or sport catch.

| Date | N | Sex | Intercept | Slope | $r^2$ |
|---|---|---|---|---|---|
| | | East Bay | | | |
| Fall 1985-87 | 397 | Both | -14.644 | 3.492 | 0.881 |
| " | 169 | Male | -14.588 | 3.477 | 0.906 |
| " | 228 | Female | -13.853 | 3.370 | 0.866 |
| Spring 1986 | 80 | Both | - 9.111 | 2.620 | 0.912 |
| Sum 1985-87 (Trawl) | 131 | Both | -11.755 | 2.993 | 0.938 |
| | | West Bay | | | |
| Fall 1985-87 | 368 | Both | -14.069 | 3.396 | 0.885 |
| " | 191 | Male | -13.026 | 3.225 | 0.907 |
| " | 177 | Female | -15.154 | 3.575 | 0.898 |
| Sum 1986 (Sport) | 40 | Both | -12.067 | 3.073 | 0.968 |
| Spg 1987 | 97 | Both | -10.290 | 2.801 | 0.866 |
| | | Outer Bay | | | |
| Fall 1985-87 | 179 | Both | -13.997 | 3.389 | 0.884 |
| " | 116 | Male | -12.663 | 3.166 | 0.894 |
| " | 63 | Female | -15.829 | 3.691 | 0.923 |
| Spg 1986 | 113 | Both | -10.588 | 2.869 | 0.903 |
| Sum 1986 | 317 | Both | -11.030 | 2.925 | 0.879 |
| Spg 1987 | 100 | Both | -11.061 | 2.940 | 0.870 |
| Sum 1987 | 241 | Both | -12.328 | 3.128 | 0.897 |
| Sum 1986-87 | 123 | Male | -11.343 | 2.969 | 0.868 |
| " | 122 | Female | -11.264 | 2.961 | 0.838 |

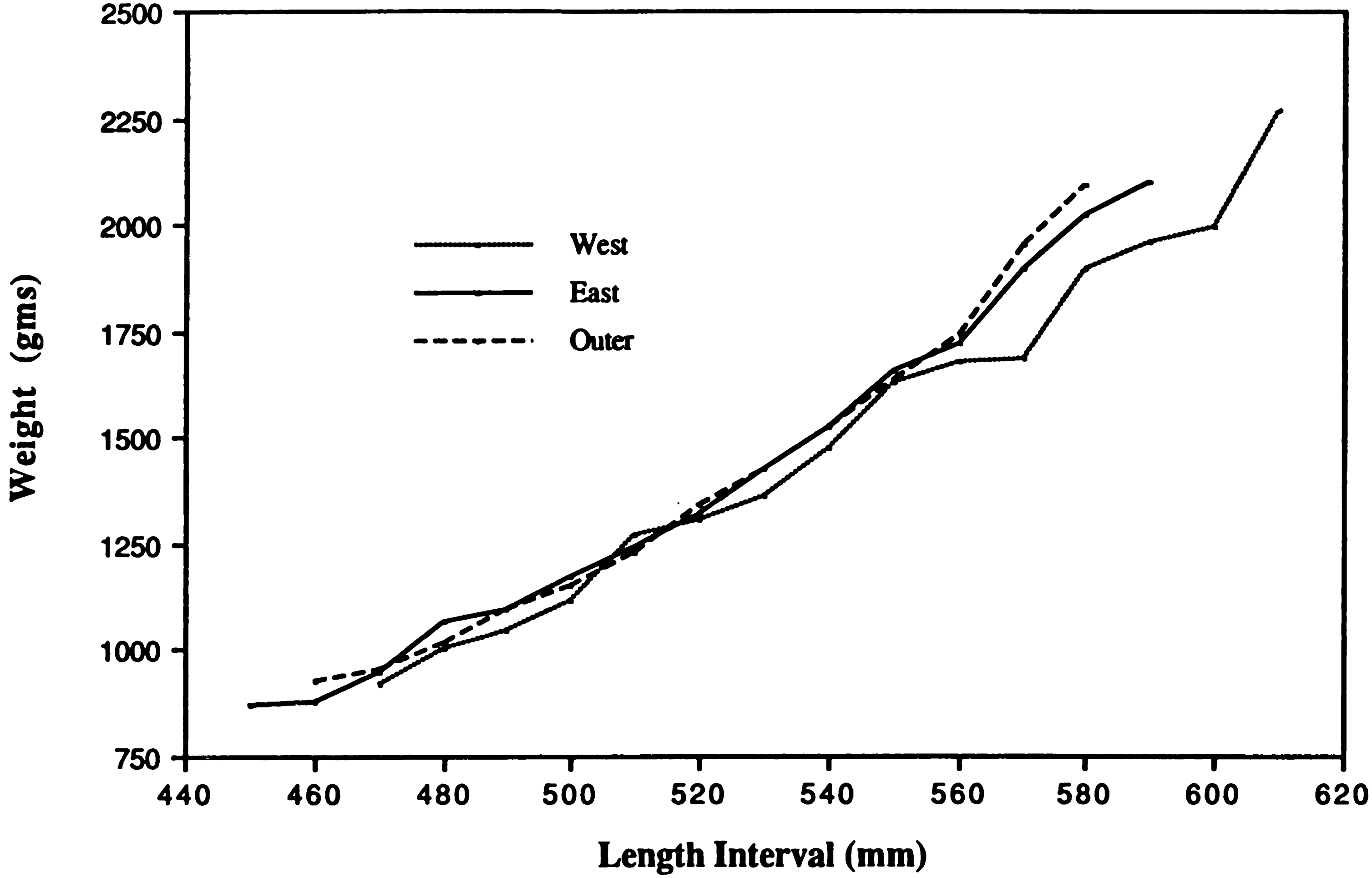


Figure 20: Plots of mean fish weight versus mean fish length (10 mm intervals) of lake whitefish from the fall catch in West, East, and South Outer Bays.

Table 19: Back-calculated weights from average length at age using fall length-weight regressions for the West and East Bay whitefish stocks.

| Age | Length (mm) | Weight (gm) | Increment (gm) |
|---|---|---|---|
| | | West Bay | |
| 1 | 173 | 31 | 31 |
| 2 | 245 | 101 | 70 |
| 3 | 315 | 237 | 136 |
| 4 | 382 | 456 | 219 |
| 5 | 442 | 748 | 292 |
| 6 | 486 | 1032 | 284 |
| 7 | 520 | 1299 | 267 |
| 8 | 544 | 1514 | 215 |
| 9 | 566 | 1732 | 218 |
| 10 | 583 | 1915 | 183 |
| | | East Bay | |
| 1 | 151 | 18 | 18 |
| 2 | 214 | 60 | 42 |
| 3 | 286 | 165 | 105 |
| 4 | 362 | 376 | 211 |
| 5 | 428 | 675 | 299 |
| 6 | 465 | 901 | 226 |
| 7 | 497 | 1137 | 236 |
| 8 | 524 | 1368 | 231 |
| 9 | 552 | 1640 | 272 |
| 10 | 566 | 1791 | 151 |

Square test). Over the three year period males represented 49.6% (205/413; P > 0.20) of the West Bay catch. East Bay whitefish were comprised of 47.6% (171/359; P > 0.20) males during the same period. Spring samples in 1986 from East Bay found 51.6% (64/124; P > 0.20) of the catch to be males. These findings were in agreement with MDNR experimental gill net survey samples which found 51.3% (78/152; P > 0.20) males from West Bay in June of 1984 and 1985 and 51.1% (91/178; P > 0.20) males from East Bay in June of 1985.

In Outer Bay, there was a slight difference in sex ratio between the spring and summer seasons. Combined spring samples from 1986 and 1987 found males to represent 42.8% (110/257; P < 0.05) of the catch while combined summer samples were comprised of 49.3% (132/268; P > 0.20) males.

Fall samples from South Outer Bay were comprised of 51.2% (21/41; P > 0.20) males in October of 1986, whereas during the first week of November of 1987 males represented 73.1% (87/119; P < 0.001) of the catch. This discrepancy is most likely due to segregation of the sexes during some short time period preceding spawning. Smale (1988) found males to comprise a larger portion of the catch during the fall season than during the spring and summer months in the North Shore area of Lake Michigan. Since lake whitefish were found to spawn in East Grand Traverse Bay during mid-November to the first week of December (Freeberg 1985), most accurate descriptions of sex ratio would be determined in early to mid-October before the spawning sex segregation occurs.

MATURATION:

An examination of whitefish caught during the fall seasons in both East and West Bays did not provide an accurate description of maturation. Combining all three years of fall data, only three immature fish were found from West Bay samples and only six from East Bay samples. This would indicate that mature whitefish segregate from immature whitefish about a month before spawning actually occurs.

Size at maturation for Outer Bay whitefish caught during the summer months indicated differences between males and females (Table 20). Nearly all males are mature by 455 mm while all females are mature by approximately 500 mm.

POPULATION SIZE:

Estimates of population size could not be calculated individually for East and West Bay due to several reasons. Firstly, Ricker (1975) explained how either the marking or the total fishing effort must be randomly distributed in the study area to obtain unbiased Petersen estimates of population size. In the fall of 1985, tagging was done solely in the arms, whereas, during the 1986 fishing season 88% of the total catch was taken in the Outer Bay grids. Secondly, there was no way of distinguishing the catch from one stock or another during the fishing season. Given the low return rate for the West Bay stock, a population estimate would suggest a large stock size while all other evidence argues for a smaller size relative to the East Bay stock. An analysis of tags returned per kilogram of catch from within grids 815 and 816 indicated that return rates were nearly twice as large in West Bay as in East Bay when fishing was concentrated in these areas during the spring and fall seasons. Catch per effort over the study period has consistently been higher in East Bay also.

In 1986, tagging was done in Outer Bay as well as in both arms. This either reduced or eliminated the problems of non-random marking or fishing for the Petersen estimate. However, only tagging and catch from the cooperating trap net operation from grids 615, 715, and 716 of Outer Bay, and grid 816 of East Bay were used in the calculation. West Bay was not included because of the low return rate from this stock in the Outer Bay trap net fishery. It was assumed that this stock did not mix with fish which were vulnerable to the trap net fishery in Outer Bay.

Table 20: Percentage of mature male and female lake whitefish for 20 mm size classes from Outer Bay in 1986 and 1987.

| Size Class | Females | | Males | |
|---|---|---|---|---|
| | N | % Mature | N | % Mature |
| | | **Summer 1986** | | |
| 355 | 0 | - | 1 | 0 |
| 375 | 0 | - | 4 | 25 |
| 395 | 7 | 0 | 8 | 25 |
| 415 | 6 | 17 | 14 | 50 |
| 435 | 20 | 30 | 27 | 67 |
| 455 | 16 | 75 | 20 | 95 |
| 475 | 17 | 82 | 17 | 100 |
| 495 | 9 | 78 | 12 | 100 |
| 515 | 15 | 100 | 11 | 100 |
| 535 | 14 | 100 | 10 | 100 |
| 555 | 6 | 100 | 9 | 100 |
| | | **Summer 1987** | | |
| 375 | 0 | - | 1 | 0 |
| 395 | 1 | 0 | 1 | 100 |
| 415 | 5 | 20 | 1 | 100 |
| 435 | 4 | 50 | 9 | 78 |
| 455 | 26 | 58 | 24 | 79 |
| 475 | 33 | 61 | 34 | 97 |
| 495 | 23 | 100 | 18 | 94 |
| 515 | 14 | 93 | 11 | 100 |
| 535 | 17 | 94 | 8 | 100 |
| 555 | 10 | 100 | 5 | 100 |

Estimates of biomass and number of whitefish, corrected for tag loss and recruitment (Scheerer 1982), available to the Outer Bay fishery in the fall of 1986 along with 95% confidence intervals are 438,866 kg (369,774 - 539,709) and 345,564 fish (291,161 - 424,968). Compared to other Lake Michigan whitefish stocks, the Grand Traverse Bay fishery is less productive than the more highly exploited stock in the North Shore area, but more dense than the moderately exploited Leland stock. The Leland stock biomass peaked in 1980 at 290,000 kg when the strong year class of 1977 entered the fishery and declined to 130,000 kg by 1982 (Scheerer 1982; Smale 1988). The sole trap net fishermen a Leland discontinued fishing for whitefish by 1985 suggesting that the population declined further yet. The Traverse estimate is from the time period when the 1977 year class was nine years of age, and before the time when the strong 1982 year class had been recruited, which indicates the population size is below average production over the five year period. North Shore biomass estimates ranged from 1.6 million kg to 0.77 million kg from 1980 to 1982 (Scheerer 1982; Smale 1988).

The contribution of each age class to the total population is shown in Table 21. In the fall of 1986, the majority of the population was comprised of five year olds, or the 1981 year class. The 1977 year class was still abundant, comprising 13.7% of the adult population biomass as nine year-olds. Approximately 56% of the biomass is comprised of age six and older whitefish. The distribution of spawning adults over several age classes prevents the population from depending on one year class for egg deposition.

In the early summer of 1986, 206 sub-legal whitefish were tagged at several locations in Outer Bay. All of these fish were assumed to belong to the 1982 year class beginning to recruit to the fishery as four year-olds. The abundance of this year class was estimated by allowing these fish to mix during the summer months and using a Petersen estimate calculated over the period of November 1986 to

Table 21: Estimated population size and biomass (kg) for each age class in the fall of 1986 for East and Outer Bay combined.

| Age | Numbers | Biomass |
|---|---|---|
| 4 | 49,070 | 43,490 |
| 5 | 135,461 | 147,888 |
| 6 | 58,400 | 73,374 |
| 7 | 21,771 | 28,812 |
| 8 | 37,902 | 49,421 |
| 9 | 29,373 | 60,327 |
| 10 | 12,786 | 26,087 |
| >10 | 3,801 | 9,467 |

November 1987. The number marked was corrected for mortality over the summer months, the returns corrected for tag loss, and the catch of only this year class determined. The size of the 1982 year class in November of 1986 in numbers and biomass with 95% confidence intervals was 174,272 kg (128,577 - 270,367) and 203,354 fish (150,031 - 315,480). This estimate was considerably higher (four times) than the estimated abundance of this year class in the total adult population. This is due to two reasons; first the year class had not fully recruited to the fishery by the fall of 1986, and secondly because there is a tendency for catchability of small legal sized whitefish to be lower during the fall months probably due to fishing effort being targeted at mature adult aggregations moving in shoal to spawn.

The population estimate of the 1982 year class has potential for being developed into an index of recruitment. Correlating population estimates of sub-legal whitefish with catch per unit effort of sub-legal whitefish during the early summer of their fourth year would allow for a prediction of recruitment one year in advance. This would also allow for catch curves to be corrected for variable year class sizes, which account for the majority of variance in mortality estimates from this method. To accomplish this goal, continued tagging of sub-legal whitefish would be necessary to develop the relationship between abundance and catch per unit effort.

## SUMMARY

The distribution of tag returns during the study period indicated that spawning stocks in East and West Bays were distinct. Although both stocks contributed to the Outer Bay fishery, a much higher proportion of the East Bay stock was observed to move into Outer Bay. West Bay whitefish were more commonly observed near the original tagging location. There was no harvest of the West Bay stock in East Bay over the study period, while only one East Bay tagged fish was caught in West Bay. The Gull Island stock in Outer Bay, tagged only in 1986, was also observed more commonly near the tagging location, and there were no returns from this stock in the southern arms.

Annual exploitation rates for the West and East Bay stocks increased from 1986 to 1987 when catch and effort in the bay nearly doubled. Minimum estimates for 1986 and 1987 were 5.7% and 12.7% for West Bay and 13.4% and 25.7% for East Bay. An average rate of 19.9% was estimated for three tagging locations in Outer Bay during 1987. Minimum exploitation rates by sport anglers in East Bay declined from 2.4% in 1986 to 0.4% in 1987, while in West Bay, rates were 1.5% for the two years. There was no correction made for non-reporting by anglers.

Estimates of mortality by both catch curve and mark-recapture procedures were in strong disagreement for both East and West Bay stocks. Catch curve estimates of total annual mortality were 18.4% and 41% for the West and East Bay stocks respectively, and represent average mortality rates over the last five or six year period. Estimates for the 1986 fishing season based on tag returns were much higher being 75% for West Bay and 73% for East Bay. Fishing mortality

accounted for 8% of West Bay and 18% of East Bay total mortality, determined by tag returns. These values suggest extremely high natural mortality rates compared to other recent lake whitefish studies, therefore may be suspect. If these estimates reflect accurate total mortality rates, major shifts in the age structure will be observed in the next one to two years, especially in the West Bay stock.

Total annual mortality, estimated by catch curve analysis for the combined years of 1986 and 1987, averaged 49% for Outer Bay. Estimates for North Outer Bay (57%) were higher than South Outer Bay (45%).

The West Bay spawning stock consisted of large fish with an average of 10% being below 505 mm in length from 1985 to 1987. The 1977 year class dominated this stock as it contributed 37%, 32%, and 21% to the spawning stock from 1985 to 1987. None of the recruiting year classes appeared to be as large as the 1977. The 1979 and 1980 year classes contributed only 8.7% and 8.1% to the spawning stock over the study period, suggesting stock abundance is declining.

An average of 54% of the East Bay spawning stock was below 505 mm. The 1977 year class contributed 14%, 9%, and 4% to this stock during the three year period. The recruiting 1981 and 1982 year classes dominated the stock in 1987, contributing 73% to the fall commercial catch from East Bay which peaked at 16,300 kg.

Length compositions near Gull Island in Outer Bay consisted of 35% below 505 mm during the fall of the years 1985-87. Length compositions during the spring and summer months in Outer Bay consisted of smaller whitefish. In North Outer Bay, 23% of the 1986 catch was below the legal size limit, while in South Outer, 14% was sub-legal. During 1987, these proportions declined to 10% and 7% for North and South Outer Bay respectively, as the 1982 year class recruited to the fishery. The absence of sub-legals in 1987 suggests the 1983 year class is weak, giving strong evidence to Freeberg's (1985) claims that climatic conditions control year class strength. The 1982 year class dominated catch from North Outer

Bay where it contributed 41% and 64% during the summers of 1986 and 1987. This year class did not appear in significant numbers in South Outer Bay until 1987 when it contributed 55% to the harvest.

There appeared to be very little growth variation within Grand Traverse Bay compared to the faster growth observed in other exploited Lake Michigan whitefish populations. Recruitment to the fishery ranged from a mean age of 4.8 in West Bay to 5.1 in East Bay. The slight growth advantage of the West Bay stock occurs during the first and second year of life where average length exceeds the East Bay stock by 22 to 31 mm. Growth of whitefish in the Outer Bay fishery was intermediate to the East and West Bay stocks.

Lee's phenomenon was apparent in all areas of Grand Traverse Bay, a function of fishing gear selectivity. Its effect was not as severe in the West Bay stock providing further evidence that fishing mortality has been lower in past years.

Differences in length to weight relationships were small between East, West, and Outer Bay fall samples during 1985-87. Slope values were 3.49, 3.40, and 3.39 for the three areas respectively. Values were consistently smaller during the spring and summer seasons ranging from 2.87 to 3.13 in Outer Bay.

Population sizes could not be estimated for individual spawning stocks. However, an adult estimate of 438,866 kilograms, of which 56% was of ages six and older, was available to the Outer Bay fishery in the fall of 1986. Whitefish abundance in Grand Traverse Bay was higher than that of the Leland stock in 1980-82, but much lower than those from the productive Green Bay and North Shore stocks in northern Lake Michigan. The 1982 year class appears to be a large year class in Outer Grand Traverse Bay. An estimate of 174,272 kilograms, for this year class as four year-olds, was made in the fall of 1986. Further recruitment of this year class in future years will provide stability to the fishery.

# APPENDICES

Appendix A: Monthly tag returns by gear type of lake whitefish tagged during the falls of 1985 and 1986 in East Grand Traverse Bay.

| Gear | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1985 Tagging - 1986 Fishing Season | | | | | | | |
| Sport | 0 | 0 | 7 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 12 |
| Gill | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 2 |
| Trap | 0 | 0 | 0 | 2 | 4 | 3 | 6 | 5 | 8 | 7 | 2 | 37 |
| | | | | | 1985 Tagging - 1987 Fishing Season | | | | | | | |
| Sport | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 |
| Gill | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 4 |
| Trap | 0 | 0 | 0 | 3 | 6 | 0 | 4 | 2 | 3 | 4 | 0 | 22 |
| | | | | | 1986 Tagging - 1987 Fishing Season | | | | | | | |
| Sport | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Gill | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 10 | 0 | 14 |
| Trap | 0 | 0 | 0 | 3 | 8 | 8 | 4 | 3 | 8 | 4 | 6 | 44 |

Appendix B: Monthly tag returns by gear type for lake whitefish tagged during the falls of 1985 and 1986 in West Grand Traverse Bay.

| Gear | Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sep | Oct | Nov | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1985 Tagging - 1986 Fishing Season** | | | | | | | | | | | | |
| Sport | 0 | 6 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 10 |
| Gill | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 6 |
| Trap | 0 | 0 | 0 | 0 | 7 | 2 | 0 | 0 | 1 | 3 | 4 | 17 |
| **1985 Tagging - 1987 Fishing Season** | | | | | | | | | | | | |
| Sport | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Gill | 4 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 9 |
| Trap | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 3 | 5 |
| **1986 Tagging - 1987 Fishing Season** | | | | | | | | | | | | |
| Sport | 1 | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 0 | 0 | 0 | 5 |
| Gill | 4 | 4 | 3 | 3 | 1 | 0 | 1 | 0 | 0 | 4 | 1 | 21 |
| Trap | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 2 | 1 | 1 | 3 | 10 |

Appendix C: Monthly tag returns by gear type for lake whitefish tagged at three Outer Grand Traverse Bay locations.

| Gear | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Old Mission Point 1986 Tagging - 1987 Fishing Season | | | | | | | |
| Sport | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 2 |
| Gill | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 |
| Trap | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 1 | 2 | 0 | 12 |
| | | | | | SE Outer Bay 1986 Tagging - 1987 Fishing Season | | | | | | | |
| Sport | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Gill | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 |
| Trap | 0 | 0 | 0 | 0 | 3 | 1 | 2 | 1 | 3 | 2 | 2 | 14 |
| | | | | | Gull Island 1986 Tagging - 1987 Fishing Season | | | | | | | |
| Sport | 0 | 0 | 0 | 0 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gill | 2 | 1 | 2 | 1 | 1 | 0 | 2 | 0 | 0 | 2 | 1 | 12 |
| Trap | 0 | 0 | 0 | 0 | 0 | 15 | 13 | 4 | 0 | 3 | 1 | 36 |

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