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POPULATION DYNAMICS AND STOCK DIFFERENTIATION
OF LAKE WHITEFISH, COREGONUS CLUPEAFORMIS,
IN NORTHEASTERN LAKE MICHIGAN

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Paul David Scheerer

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[signature]
Major professor

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POPULATION DYNAMICS AND STOCK DIFFERENTIATION OF LAKE WHITEFISH, COREGONUS CLUPEAFORMIS, IN NORTHEASTERN LAKE MICHIGAN

By

Paul David Scheerer

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ABSTRACT

POPULATION DYNAMICS AND STOCK DIFFERENTIATION
OF LAKE WHITEFISH, COREGONUS CLUPEAFORMIS,
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By

Paul David Scheerer

Lake whitefish, Coregonus clupeaformis, were tagged and the commercial trap net catch was sampled in the North Shore, Leland, Beaver Island (BI), and Grand Traverse Bay (GTB) areas of Lake Michigan, to determine vital statistics and differentiate discrete stocks.

Distribution of tag returns and statistical comparisons of certain population parameters indicate the existence of three stocks in these areas. The North Shore stock was considerably larger in numbers and biomass than the Leland stock.

Average exploitation rate was higher for the North Shore stock (49.6%) than the Leland stock (24.2%).

The Leland and GTB catch had broader age compositions, older fish, and larger fish than the North Shore and BI samples.

Instantaneous growth rates and mean back-calculated length were consistently higher for fish in the Leland stock.

North Shore whitefish mature at a younger age and smaller size and are recruited at an earlier age than the Leland fish.

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INTRODUCTION

Lake whitefish (*Coregonus clupeaformis*) have supported a major commercial fishery in Lake Michigan since the mid 1800's (Baldwin et al 1979). Historically, this species has exhibited wide fluctuations in abundance (Smith 1968, Wells and McLain 1973). Pollution of the spawning grounds, introduction of exotic species, variable year class strength, and overharvest have all been cited as probable causes of these fluctuations (Smith 1968, Wells and McLain 1973, Lawler 1965, Cucin and Regier 1966).

The whitefish is the last on a long list of commercially valuable coregonids in Lake Michigan (Baldwin et al 1979). Several species of large, commercially valuable ciscoes (*Coregonus* sp) were fished to extinction by the early fishery (Wells and McLain 1973). The whitefish has persisted as a result of its resilient conpensatory dynamics, and is presently managed under stringent regulatory authority. Healey (1975) characterizes the resilient nature of the whitefish by its early maturation and increased growth rates in response to increased exploitation.

A recent increasing trend in the annual production of lake whitefish has raised concern regarding the stability of the whitefish stocks in the northern portion of Lake

Michigan (Figures 1 and 2). This increase in harvest in statistical district MM-3 is due in part to an increase in effort by native American fishermen and to the presence of an abundant year class of whitefish in the fishery. The ecological stability of this species is of concern. Healey (1975) suggests that the scope of a whitefish population to compensate for increased mortality can be measured by the difference between the growth rate of the population and the maximum growth rate. Whether or not the whitefish can contiunue to maintain their abundance and support the commercial fishery depends upon their compensatory reserve for increasing their growth rate.

The commercial fishery for whitefish is regulated under a zone management plan implemented by the Michigan Department of Natural Resources in 1972. Licensing is limited to those fishermen who were licensed the previous season. Each license permits the fisherman to fish ten large-mesh deep water trap nets (4 1/2 inch stretched measure).

Current management plans include the implementation of a quota system by which to regulate fishing effort by geographical lake quadrants. Differentiation of discrete stocks and knowledge of their relative abundance and growth capabilities are essential to proper management of whitefish. A tagging study in combination with statistical comparisons of certain population parameters was implemented for this purpose.

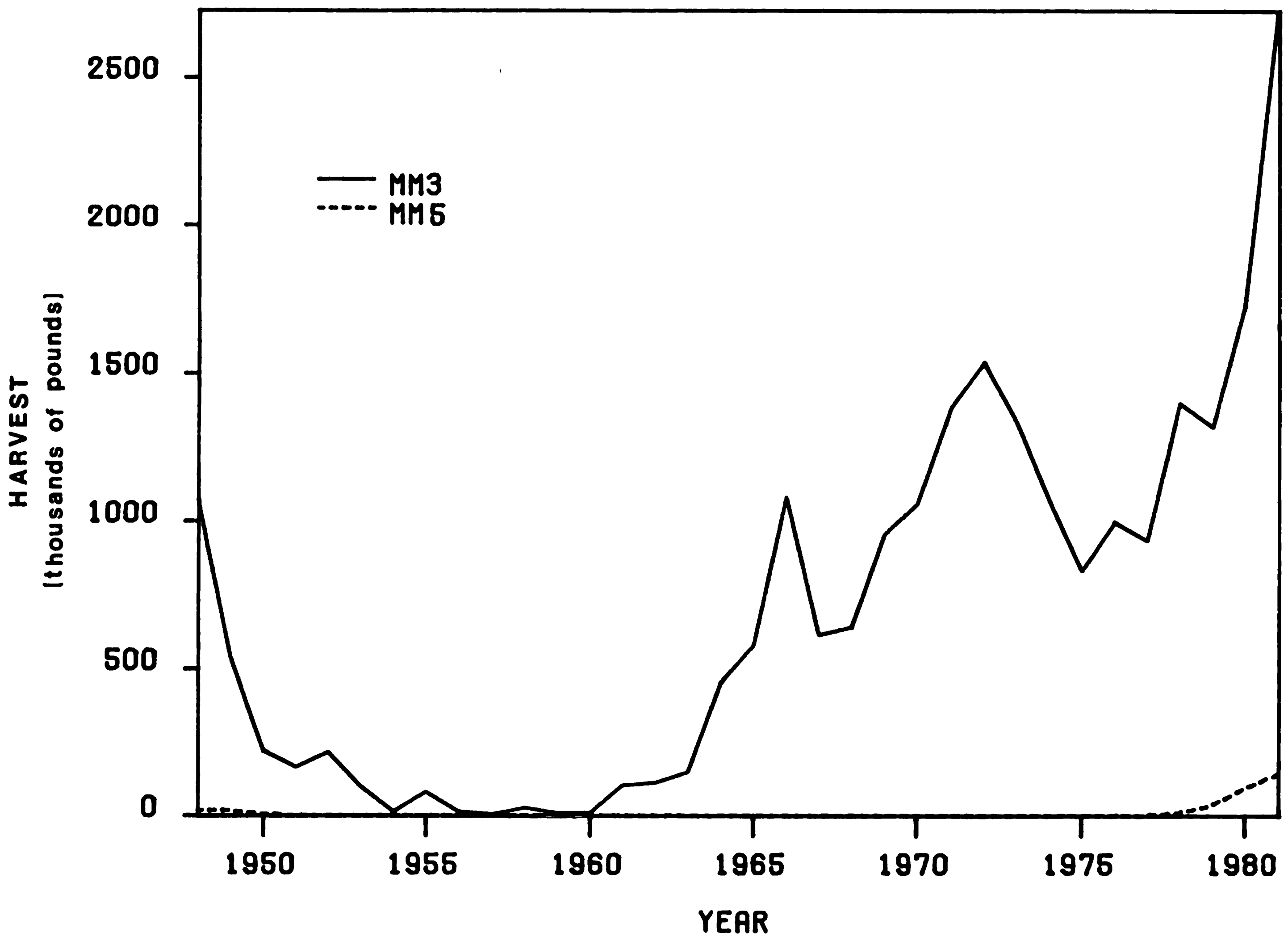

Figure 1. Commercial harvest of lake whitefish in statistical districts MM-3 and MM-5 of Lake Michigan from 1948 - 1981.

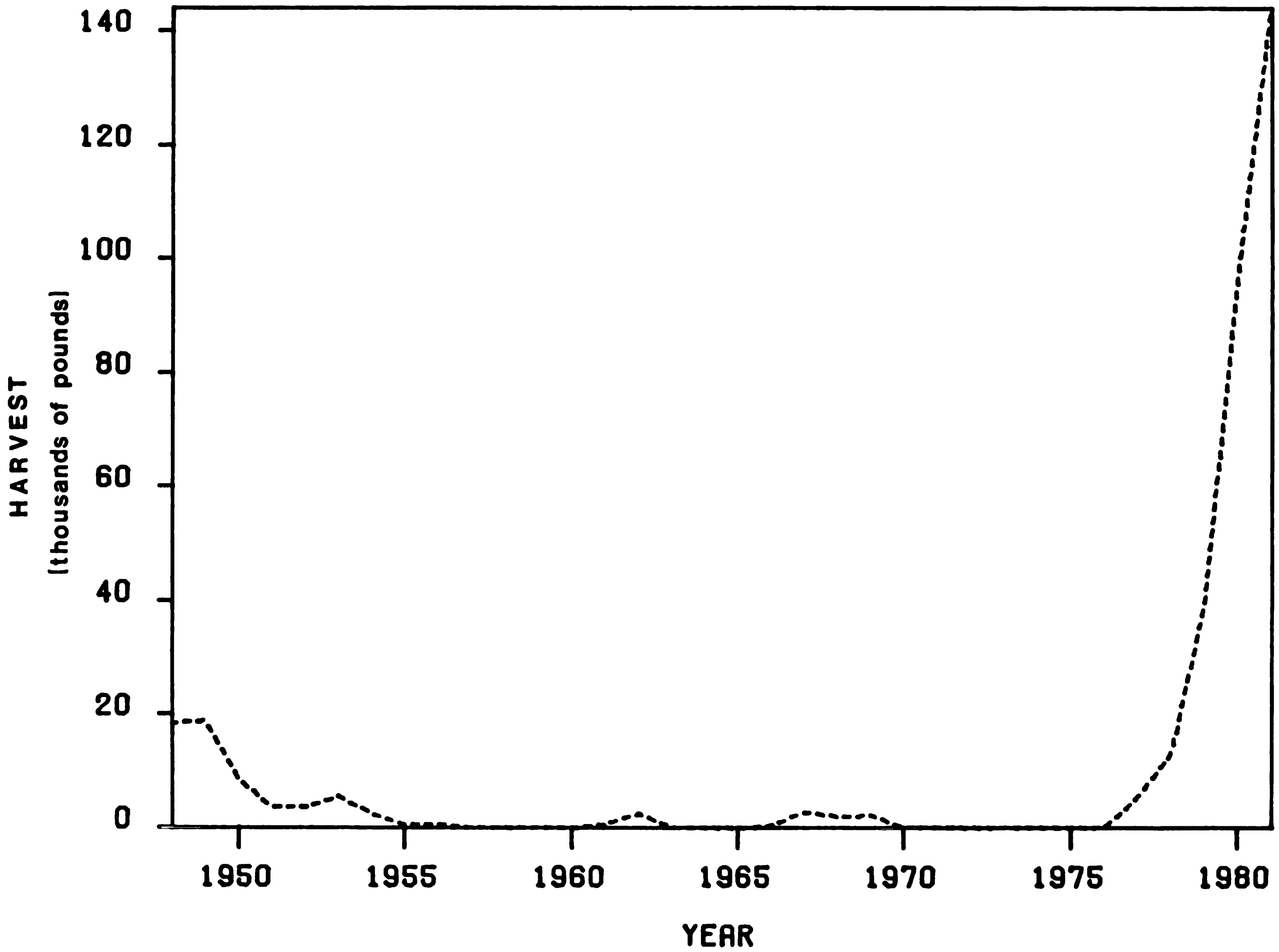

Figure 2. Commercial harvest of lake whitefish in statistical district MM-5 of Lake Michigan from 1948 - 1981.

The objectives of this study were to analyze the vital statistics of lake whitefish in the northeastern portion of Lake Michigan with special emphasis on mortality rates, growth rates, age structure, population numbers and biomass, and movements for the purpose of stock differentiation.

For the purpose of this investigation, a discrete stock has been defined as a manageable unit of reproductively isolated mature fish with homogenous characteristics of age composition, length composition, length at age, growth, and mortality.

METHODS

Sampling of the Commercial Catch

Commercial trap net catch was sampled for length, weight, and scale samples during the period from November 1980 through May 1982 (Table 1). The other primary fishing gear in the study area was the large mesh gill net. This gear is fished exclusively by the treaty fishermen and is prohibited for use by the state licensed commercial fishermen. The gill net catch was not sampled due to the inadequate narrow range of selectivity of this gear for obtaining length, weight, and age data. The selectivity curve of the large mesh gill net exhibits a peak of efficiency which diminishes as the mean length increses (McCombie and Fry 1960).

Sampling was concentrated around the southeast shore of the upper peninsula of Michigan , hereafter referred to as the North Shore area, and the western shore of the Leelanau peninsula from Leland south to Empire, hereafter referred to as the Leland area (Figure 3).

Additional sampling of the commercial catch was conducted in the Beaver Islands area and in the northeastern Grand Traverse Bay area. The Grand Traverse Bay samples were collected from the catch of an experimental purse seine funded by the Michigan Sea Grant and Carlson Fisheries in Leland. The purse seine is the only state licensed gear operating in that region of the Bay. The purse seine has a larger minimum size limit (19 inches) than that for the trap

Table 1. Sampling dates, locations, and numbers of lake whitefish, 1980-1982.

Port	Grids	Date	Sample Type	N
		North Shore Area		
Naubinway	115,116	10/23/80 10/29/80	SLW	513
Naubinway	116	11/4/80	Tagged	1683
Epoufette	117	6/29/81	SLWM	107
Epoufette	218	8/24/81	SLW	264
Epoufette	218	8/25/81	SLWF	36
Naubinway	116,117	10/17/81 10/24/81	SLW	331
Naubinway	117	11/3/81	Tagged	1024
Epoufette	216,218	5/17/82	SLW	263
Epoufette	216,218	5/17/82	GL	86
Epoufette	216,218	5/18/82	SLW*	63
		Leland Area		
Leland	714,814	10/29/80 10/30/80	SLW	114
Leland	714	11/7/80	Tagged	415
Leland	812,814,912	6/15/81	SLW	81
Leland	812,814,912	8/27/81	SLW	94
Leland	812	10/21/81	SLW	134
Leland	812	10/22/81	SLWM	110
Leland	812	11/2/81	Tagged	117
Leland	812,814,912	5/20/82	SLW	111
Leland	812,814,912	5/24/82	SLWG	14
Leland	812,814,912	5/24/82	SLW	107
Leland	812,814,912	5/24/82	LWSG*	11
Leland	812,814,912	5/24/82	LWS*	16
		Beaver Island Area		
Beaver Island	316	11/5/80	Tagged	19
Beaver Island	316	6/16/81	SLW	219
Charlevoix	317,418	5/18/82 5/19/82	SLW	169
		Grand Traverse Bay Area		
North Port	615	6/14/81	Tagged	163
North Port	615	6/14/81	SLW	140

S = scale sample, L = length, W = weight, G = girth,
F = fin rays, M = sex and maturity, * = nonrandom sample

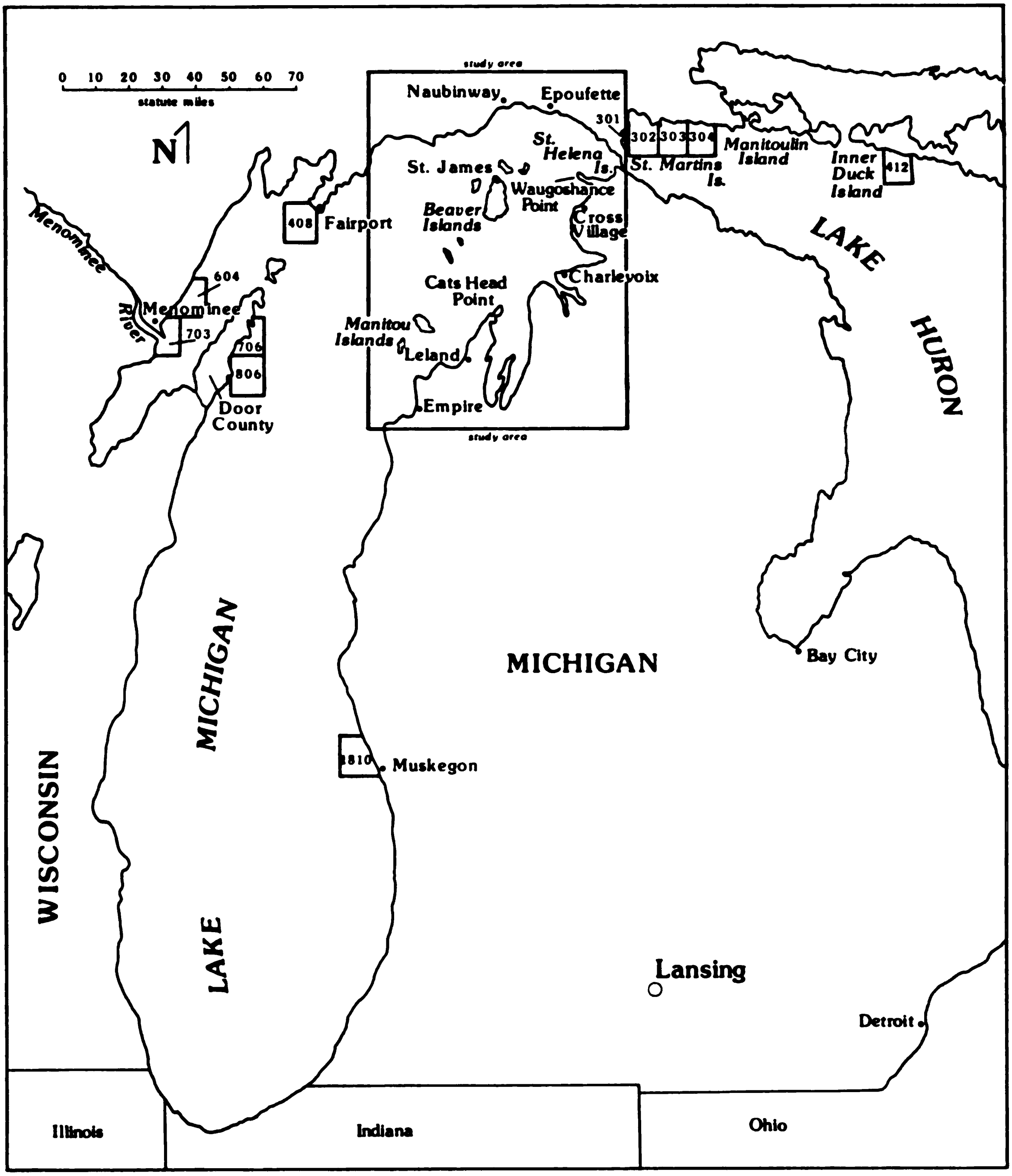

Figure 3. Map of the study area in northeastern Lake Michigan and adjacent waters of Lake Huron.

nets (17 inches), thus rendering these samples uncomparable for most purposes.

Certain locations were only sampled during certain seasons. This was a result of the relocation of commercial fishing effort in response to changes in whitefish abundance on the various fishing grounds. Whitefish have been noted to move into deeper water during the summer and return to shallower water in the fall to spawn (Lawler 1965).

A random sample of fish was selected from the unsorted catch at dockside. Total fish length was measured to the nearest 5 millimeters and weight was measured to the nearest 10 grams. Scales for age and growth analysis were removed from the lateral region of the fish directly below the dorsal fin.

Abundance and Movements

A total of 3239 fish were tagged during the closed fishing season (November 1-30), 2098 in 1980 and 1141 in 1981. In June 1981 an additional 163 sublegal fish (<483mm) were tagged from the purse seine operated in Grand Traverse Bay.

The fish tagged in November 1980 and June 1981 were tagged using Floy dart tags. In November 1981 a smaller diameter Floy anchor tag was used due to several complaints by the commercial fishermen regarding the unhealed sore apparent on the recaptured fish.

All fish were tagged directly below their dorsal fin so that the tag lodged under the interneural bones. Total length was recorded and the fish were returned immediately to the lake.

A reward system was implemented to encourage cooperation with the commercial fishermen. A $1 reward was paid for each returned tag. Additional information that was requested included the date and location of capture. Considerable personal contact and frequent mailings of newsletters were used to encourage cooperation and maintain interest of the whitefish fishermen. Double-tagging of 158 fish with one dart and one anchor tag was implemented in November 1981 to estimate tag loss.

Population numbers and biomass were estimated for all fish larger than 430 millimeters (17 inches) in November 1980 using a Petersen mark-recapture equation,

$$\hat{N} = MC/R$$

where, $\hat{N}$ is the population estimate,

M is the number of fish tagged in November 1980,

C is the total catch of whitefish during the 1981 season, and

R is the total number of recaptured tags during the 1981 season.

Chapman (1951) states that when the total numbers of recaptures are few, population size is overestimated, and an adjusted Petersen should be used. The adjustments amount to the addition of one to the values of M, C, and R in the above equation. Robson and Regier (1964) indicate that the bias will be less than two percent if the product of the marks and the recaptures is greater than the total population size. Since this product exceeded the estimated population sizes no adjustments were made.

Due to a presumed non-cooperation by certain fishermen in the study area, the values for C and R represent only those portions attributed to fishermen who were known to be cooperating.

The number of recaptured fish was adjusted for tag loss by a procedure described by Seber (1973). The total catch was adjusted to account for the recruitment of those fish which were sublegal (<430 millimeters) at the time of tagging, yet grew into the catchable population during the 1981 fishing season. To estimate recruitment the change in mean length, of the youngest age class present in the fall 1980 catch (age III), was followed through the sampling period. The seasonal increments of growth for this age class were used as the best available estimate of the seasonal growth of the fish that were sublegal in November 1980. That portion of the sampled legal dockside catch (weight) which was represented by the fish shorter than the mean length of an average November 1980 sublegal fish, at the time of each subsequent sample, was subtracted from the total catch. These fish were not part of the legal-sized tagged population at the time of tagging.

Examination of the distribution of tag returns, in conjunction with statistical comparisons of age compositions, length compositions, and mean length of several representative age classes, were used to differentiate discrete stocks of lake whitefish.

Aging

The ages of lake whitefish were determined by scale analysis. Scales were cleaned in the laboratory with a toothbrush and water then projected with a Bell and Howell ABR-1020 microfiche reader at a magnification of 22x. Scale ages were assigned by counting the number of annuli present. The primary criteria for distinguishing annuli was "cutting over" along the anterio-lateral ridges and spatial disruptions of the circuli (van Oosten 1923). One scale from each fish was selected at random and the distance from the focus of the scale to each annuli was measured along the center radius of the anterior field. The assigned ages were verified by comparisons with ages assigned by pectoral fin ray sections and a fifteen percent overlap by the principal scale readers. Pectoral fin rays were aged via examination of microtome sections immersed in oil under the low power of a compound microscope. Annuli were discerned according to procedures described by Ovchynnyk (1962).

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Weight-Length Relationships

The weight-length relationship,

$$W = aL^b,$$

where, W is the weight of the fish in grams,

L is the length of the fish in millimeters, and

a and b are constants,

was transformed to natural logarithms and fit by a least squares predictive regression. The underlying regression assumptions were statistically validated.

Growth

A least squares predictive regression of the form,

$$Lc = a + bS,$$

where, Lc is the total fish length at capture,

S is the anterior scale radius,

a is the y-intercept of the regression, and

b is the slope of the regression,

was used to predict the length of the fish at the time of formation of each annulus. A correction factor (f) of the form,

$$f = Lc/Lc^*,$$

where, Lc is the observed length at the time of capture, and

Lc* is the length at capture predicted from the body length-scale radius regression for the observed total scale radius,

was multiplied by the calculated lengths under the assumption that the proportional deviation of lengths from the regression is the same at each annulus as at the time of capture (Carlander 1981). The underlying regression assumptions of a normal distribution of residuals, linearity, and homogeneous variance of Lc over the range of S were tested. The mean back-calculated length at each annulus was computed for all fish in the samples, then averaged by age class.

The instantaneous true growth rate (G) for individual fish was estimated from the back-calculated lengths at annulus formation and the slope (b) of the transformed weight-length relationship,

$$G = b\,(\ln(L2) - \ln(L1)),$$

where, L2 is the length at formation of the most recent annulus,

L1 is the length at formation of the next to the last annulus, and

ln is the natural logarithm.

The instantaneous growth rate was calculated from the last two annuli on the scales, providing the best estimate for the most recent year of growth (Ricker 1975).

Mortality Estimates

The annual survival rate (S) was estimated from tag returns from the equation,

$$S = ((R12)(M2)/(M1)(R22)),$$

where, $R12$ is the total number of recaptures of November 1980 tags returned during the period from January 1982 - June 1982,

$R22$ is the total number of recaptures of November 1981 tags returned during the period from January 1982 - June 1982,

$M1$ is the number of fish tagged in November 1980,

$M2$ is the number of fish tagged in November 1981.

The annual mortality rate (A) was computed from the relationship,

$$A = 1 - S.$$

The annual exploitation rate (u) was calculated from tag returns from the relationship (Ricker 1975),

$$u = R11/M1,$$

where, $R11$ is the number of recaptured fish, adjusted for tag loss, that were caught during the 1981 fishing season.

The survival rates and the exploitation rates were calculated soley from those tags returned by cooperating fishermen. The exploitation rates were expanded to the entire fishery in each area by multiplying by the ratio of the total commercial catch to that of the cooperating fishermen in each area.

The instantaneous total mortality rate (Z) was estimated from the relationship,

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

where, ln is the natural logarithm.

The instantaneous total mortality (Z) was also estimated from catch curves (Robson and Chapman 1961) to serve as a check for the tagging estimates, and as the sole estimate where no tagging was conducted.

The instantaneous rate of fishing mortality (F) was estimated from the formula (Ricker 1975),

$$F = uZ/A.$$

The instantaneous rate of natural mortality (M), defined as that portion of the instantaneous total mortality attributable to non-fishing sources, was computed as the differerce Z - F.

Sex, Maturity, and Age at Recruitment

Length at maturity was estimated from one sample from the Leland area and one from the North Shore area. The North Shore sample was acquired on a day when the Michigan Department of Natural Resources was collecting samples for the same purpose. The other sample was obtained when fish were being filleted in Leland, Michigan. Sex ratios of these samples were estimated. Additional samples of this nature were not available because whitefish are marketed primarily in the round (not eviscerated).

Age at recruitment was estimated graphically from a plot of mean back-calculated length against age. The point on the abscissa (age) where the growth curve intersected the length at recruitment (432 millimeters) was the estimated age at recruitment.

RESULTS AND DISCUSSION

Distribution of Tag Returns

The distribution of tag returns indicates the existence of at least three discrete stocks of whitefish in the study area. One stock inhabits the waters south of Naubinway and north of the Beaver Islands. One is located along the eastern shore of the Leelanau peninsula from Cat Head Point south to Empire (Figure 3). The third is located southeast of the Beaver Islands. No mixing of the North Shore and the Leland tagged populations occurred. The shallow reef extending westward from Waugoshance Point through Hog and Garden Islands appears to act as a barrier to the movement of the North Shore stock (Figure 3). No tagged fish were recaptured in the vicinity of the Beaver Islands south of the reef and north of grids 615-616. In addition, the distribution of tag returns indicates that these three stocks are distinct from the stock(s) fished in Muskegon, the stock(s) in the southern arms of Grand Traverse Bay, and the stock(s) west of Seul Choix Point.

North Shore Tag Returns. A total of 505 tags, representing 18.7 percent of the tagged population, were returned from the North Shore area. This includes all recaptures from November 1980 through June 1982. During the 1981 fishing season 334 tags, representing 19.9 percent of the fish tagged in November 1980, were returned.

Eighty-six percent of the returns from the November 1980 tagging were returned during the 1981 fishing season (Table 2). Recaptures paralleled the peak fishing periods, with the largest number being reported in October 1981 (Appendix 1).

Tag returns from the North Shore taggings ranged from as far east as the the Duck Islands in Lake Huron, as far west as the mouth of the Menomonee River, Wisconsin, and as far south as Door County, Wisconsin (Figures 4 and 5). North Shore tags were primarily recaptured (94%) from grids 115-117 and 215-219 south of Naubinway, Michigan. The precise location of recapture of the 58 tags assigned to grid 116 for October 1981 is unknown. The fisherman failed to record the locations of recapture, yet stated that most of the tags came from grid 116 and the remainder were caught inshore, presumably from grids 115 and 117.

The first reported recapture from the North Shore taggings came from Lake Huron just east of the Mackinac bridge. This fish was caught less than three weeks after it was tagged. During the 1981 fishing season, three more recaptures were reported from Lake Huron. This indicates that there is some movement of the fish from the North Shore stock into Lake Huron. The few tag returns reported from northwestern Lake Huron, compared to the abundant returns from Lake Michigan grids 216-218, suggest that the stocks fished in these areas are distinct. No commercial catch in the waters of northwestern Lake Huron was sampled, thus

Table 2. Monthly tag returns of lake whitefish tagged during November 1980 and November 1981 in the Leland and North Shore areas. Percentages are based on the total number of returns from each tagging during the sampling period.

	North Shore				Leland			
	1980 Tags		1981 Tags		1980 Tags		1981 Tags	
Month	#	%	#	%	#	%	#	%
				1980				
November	1	0.3						
December					38	31.4		
				1981				
January					1	0.8		
February	5	1.7						
March					1	0.8		
April	27	9.0			23	19.0		
May	38	12.7			9	7.4		
June	40	13.3			10	8.3		
July	29	9.7			14	11.6		
August	9	3.0			3	2.5		
September	13	4.3			3	2.5		
October	96	32.0			5	4.1		
November	1	0.3			1	0.8		
December	1	0.3						
				1982				
January			1	0.9				
February			2	1.8				
March					1	0.8		
April	3	1.0	9	8.3			1	7.7
May	21	7.0	51	46.8			4	30.8
June	16	5.3	46	42.2	12	9.9	8	61.5
Subtotal	300		109		121		13	
Unknown	76		20		11		0	
Total	376		129		132		13	

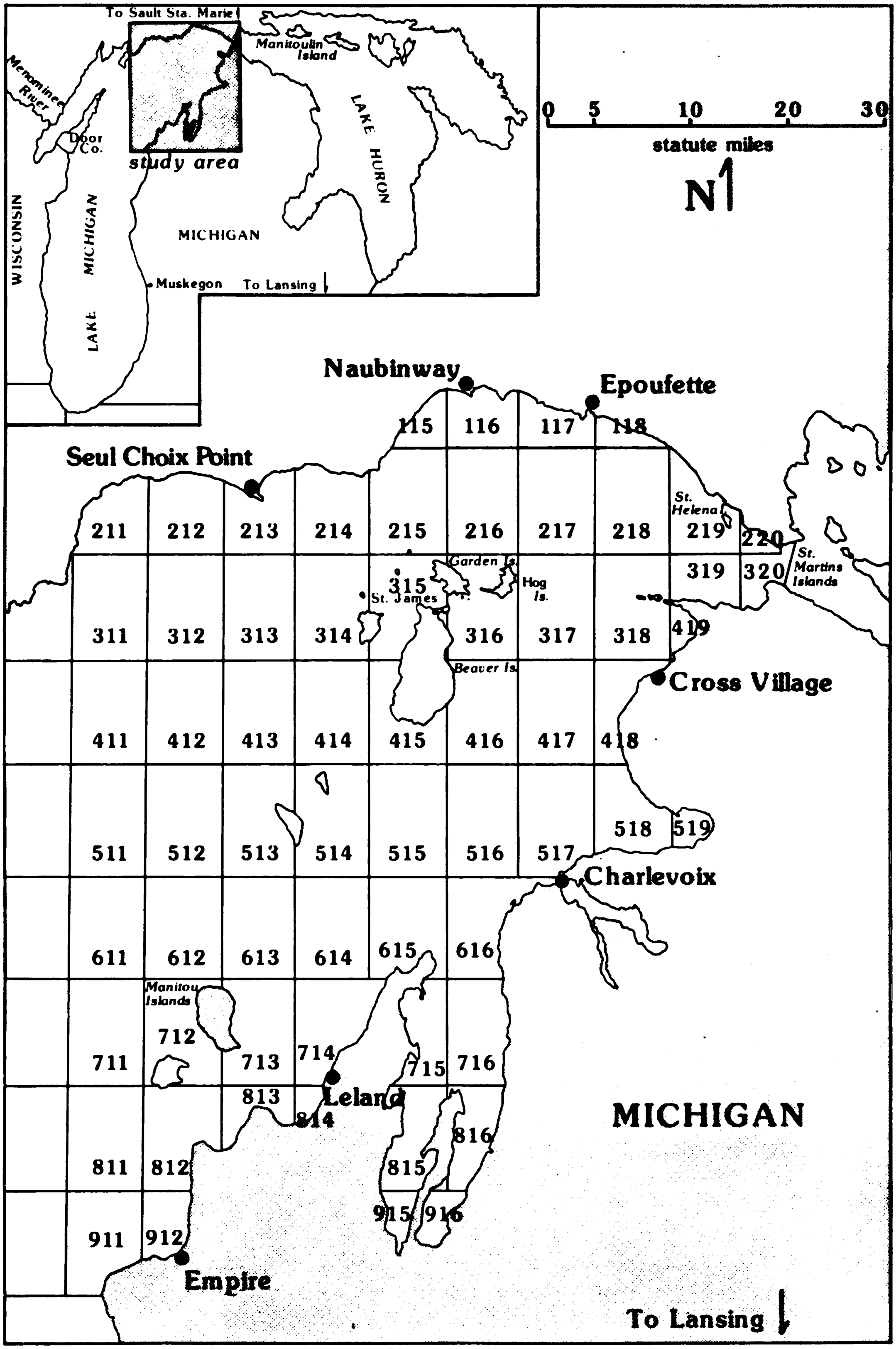


Figure 4. Map of the statistical grids within the study area in northeastern Lake Michigan.

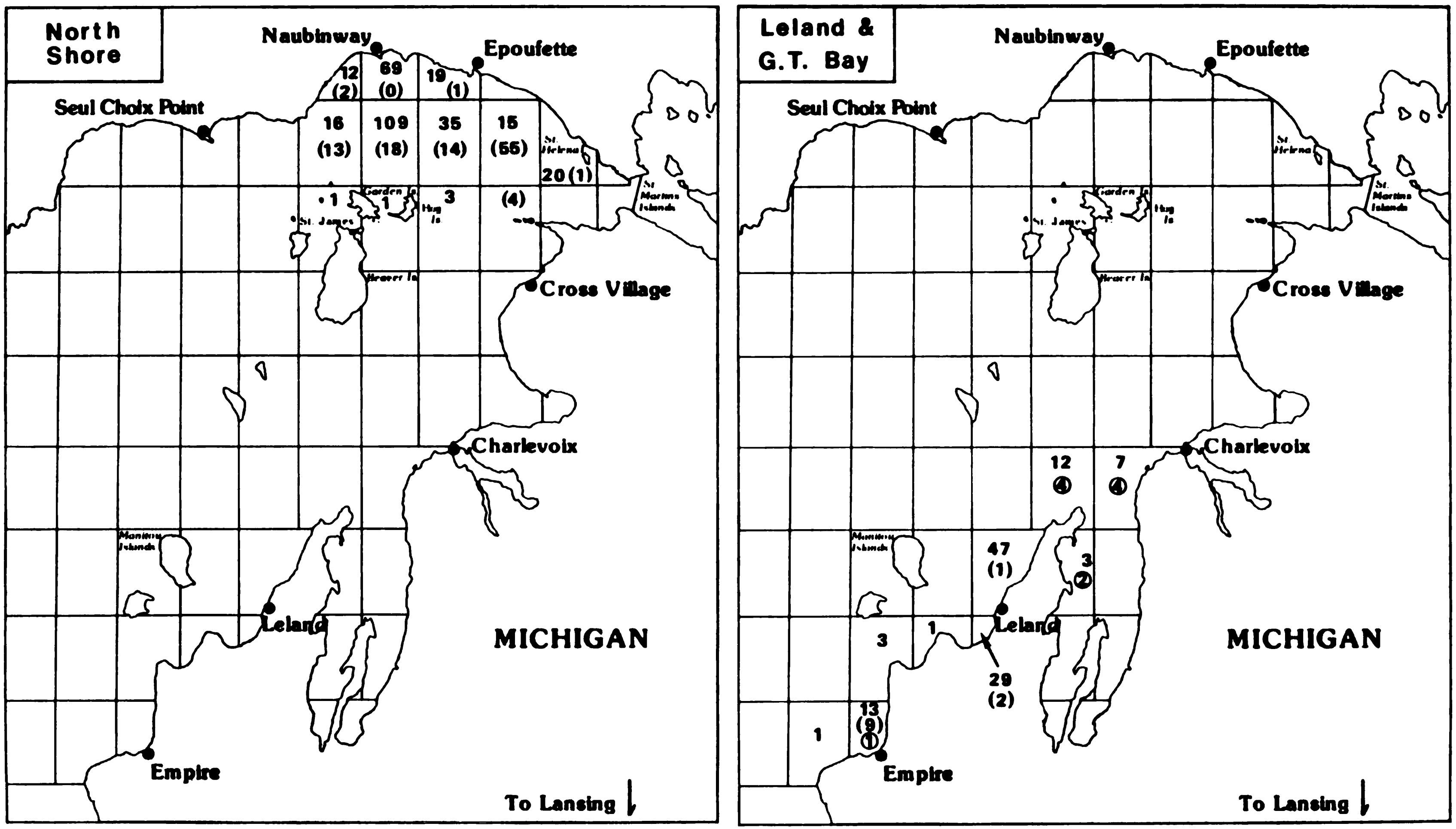


Figure 5. Distribution of tag returns from the 1980 and 1981 taggings in the North Shore, Leland and Grand Traverse Bay areas. Grand Traverse Bay returns are circled. Returns from the fall 1981 taggings are in parentheses.

examination of vital statistic parameters was not a possible avenue for discerning discrete stocks.

A few discrepancies between the reported recapture locations and the monthly catch locations were found in the data. For example, no catch was reported from grid 216 during February 1981 (Appendix 1), yet five recaptures were reported from grid 216 during that month. Further, a reported 300 thousand pounds of whitefish were harvested from grid 218 during 1981. No tags were reported from that grid, yet many were recorded in the nearby grids 217 and 219. During the first six months of 1982, 47 percent of the reported recaptures were from grid 218 (Table 3). It is suspected that the accuracy of the locations of the reported catch and tag returns is somewhat less than perfect.

In April 1981, after the winter ice cover had sufficiently melted, fishing was concentrated in the offshore grids 215-217 and those portions of grids 316-317 north of the Beaver Islands. Consequently, tag returns were primarily from these areas (Appendix 1). May 1981 recaptures were also concentrated in these grids. A few tagged fish had moved both east and west, as evidenced by recaptures near Seul Choix Point (grid 213) and Saint Helena Island (grid 219).

June and July returns were reported primarily from the offshore grids 216, 217 and 219. One tagged fish was recaptured in June from the Wisconsin waters of Lake Michigan near Door County. Another was caught near Saint

Table 3. Distribution of tag returns by statistical grid during 1980-1982 from the November 1980 and November 1981 taggings in the North Shore area. Percentages are based on total number of returns from each tagging date during each year.

	1980 Tagging								1981 Tagging			
	1980 Returns		1981 Returns		1982 Returns		1980 Total		1982 Returns		Grand Total	
Grid	#	%	#	%	#	%	#	%	#	%	#	%
						Lake Michigan						
115			10	3.7	2	5.0	12	3.8	2	1.8	14	3.3
116			68	24.9	1	2.5	69	22.0			69	16.3
117			19	7.0			19	6.1	1	0.9	20	4.7
213			6	2.2			6	1.9			6	1.4
215			10	3.7	6	15.0	16	5.1	13	11.9	29	6.9
216			101	37.0	8	20.0	109	34.7	18	16.5	127	30.0
217			29	10.6	7	17.5	36	11.5	14	12.8	50	11.8
218					15	37.5	15	4.8	55	50.5	70	16.6
219			19	7.0	1	0.3	20	6.4	1	0.9	21	5.0
315			1	0.4			1	0.3			1	0.2
316			1	0.4			1	0.3			1	0.2
317			2	0.7			2	0.6			2	0.5
318									4	3.7	4	1.0
408			2	0.7			2	0.6			2	0.5
604			1	0.4			1	0.3			1	0.2
806			1	0.4			1	0.3			1	0.2
						Lake Huron						
301	1	100					1	0.3			1	0.2
302			2	0.7			2	0.6			2	0.5
303			1	0.4			1	0.3			1	0.2
412									1	0.9	1	0.2
Total	1		273		40		314		109		423	

Martin Island, Lake Huron during July.

Harvest dropped off in August and September, thus fewer tags were returned durings these months. Recaptures were mostly from grid 216. Two tagged fish were caught in northwestern Lake Huron (grids 302 and 303).

During October 96 tags were returned. Fishing effort had shifted inshore, as the fish moved to the shallow areas to spawn. The recaptures were primarily from grids 115-117. The apparent inshore movement of spawning fish was evidenced by the presence of breeding tubercles and the emission of eggs and milt when the fish were handled during sampling. This indicates a homing of the stock tagged in November 1980 back to the same spawning grounds in November 1981.

The catch information for 1982 is not available at the present. Commercial catch is compiled by the Michigan Department of Natural Resources during the winter months and is not available until March of the following year.

The fishing season got a late start in 1982, as a result of extensive inshore ice in the early spring. Three tags were reported during the winter months near Waugoshance Point. These were returned by a treaty fisherman, presumably fishing through the ice. In April 1982, tags were all returned from the inshore grids 115-117. The April 1981 tags were caught primarily from the offshore grids 215-217 and 316-317. The colder winter of 1981-82 and the later melting of the ice cover may have delayed the offshore spring movements of the whitefish. When catch is available for 1982, it can be determined if the April 1982 catch was primarily from inshore or deep water areas.

The number of tag returns increased in May. For every 1980 tag returned, two 1981 tags were returned. There were nearly twice as many recaptures during May 1982 compared to May 1981. This would be expected since 1024 fish were added to the tagged population during November 1981. No difference between the distribution of the 1981 tags and the distribution of the 1982 tags was apparent in the spring months of 1982. This suggests that the same population was tagged during subsequent November taggings in this area.

For the first time during the study, tags were reported from grid 218. Fifty percent of the tags returned during the first six months of 1982 were from this grid. The June 1982 recaptures were abundant. Returns were mostly from the offshore grids 217 and 218.

Occasional long distance movements of whitefish are not uncommon in tagging studies of this species. An occasional fish tagged in the Green Bay and North-Moonlight Bay area by the University of Wisconsin was recaptured near Epoufette (Ebner 1980).

In summary, North Shore tag returns indicate that this stock inhabits a large portion of the lake and contributes to the catch of the fishery from the Mackinac Bridge area westward to Seul Choix. The reef extending eastward from Waugoshance Point appears to act as a barrier to whitefish movements southward, thus limiting the mixing of the North

Shore and Beaver Island stocks. For management purposes, these stocks can be considered independently in regard to limiting or redistributing fishing effort. Protection of the spawning population of the North Shore area can be insured by the regulation of the fall inshore fishery, since this stock appears to contribute heavily to the catch of that entire region.

Leland Tag Returns. A total of 145 tags, representing 27.3% of the tagged population, were returned from the Leland stock (Table 2). Thirty-nine tagged fish were returned between December 1, 1980 and January 5, 1981 from the same grid where they were tagged the preceeding November. During the 1981 fishing season 21.5 percent of the 376 remaining tags were recaptured. Very few tagged fish were returned during the first six months of 1982.

The eastern shoreline of Lake Michigan, south of Cat Head Point, is fished for whitefish by only three state licensed fishermen. Two of these fishermen are located at Muskegon and the other fishes between Leland and Empire.

Seasonal relocation of fishing effort in the Leland area complicates the interpretation of the true movements of the tagged fish. Tag returns from the North Shore area suggest that adult whitefish migrate seasonally as a unit. The patchy distribution of fishing effort in the Leland area does not permit the movements of the tagged population to be traced throughout the fishing season. Between January 1 and June 30, 1981, fifty-six percent of the catch of the Leland fisherman was reported from grids 615, 614, and 715. After July all of the catch from the Leland area was from grids 812, 814 and 912. Also, the tagging locations and the numbers of fish tagged were different between years. The November 1981 tagging was conducted on the spawning grounds in grid 714. The November 1982 tagging was conducted in grid 812. A total of 415 fish were tagged the first fall and 117 were tagged the following fall.

The Leland fisherman fished primarily in grids 812-814 and 911-912 during the spring of 1982. Nine out of ten of this fisherman's nets were set in these grids at the time of the May 1982 sample. The relocation of fishing effort, in combination with the smaller number of fish tagged in November 1981, can explain the smaller number of recaptures during the first six months of 1982, compared to those from the same period the previous year. Perhaps, when the Leland fisherman changed the location of his nets, different stocks, or subpopulation, were being harvested.

Proportionately more recaptures, per pound of catch, were reported from grids 714 and 814 during the 1981 fishing season (Appendix 2). Returns ranged from as far south as Muskegon, as far west as Door County in Wisconsin, and northeast into Grand Traverse Bay (Figure 5).

Ninety-two percent of all Leland area recaptures were reported from grids 615, 714, 812-814, and 911-912, which extend along the shoreline from Cat Head Point south to Empire (Table 4). Returns from Muskegon suggest a partial

Table 4. Distribution of tag returns by statistical grid during 1980-1982 from the November 1980 and November 1981 taggings in the Leland area and from the June 1981 tagging in the Grand Traverse Bay area. Percentages are based on the total number of returns from each tagging during each year.

	1980 Tagging								1981 Tagging			
	1980 Returns		1981 Returns		1982 Returns		1980 Total		1982 Returns		Grand Total	
Grid	#	%	#	%	#	%	#	%	#	%	#	%
					Leland							
615			8	11.3	4	33.3	12	9.8			12	8.8
616			7	9.9			1	0.8			7	5.2
703									1	7.7	1	0.7
706			1	1.4			1	0.8			1	0.7
714	38	100	9	12.7			47	38.5	1	7.7	48	35.6
715			3	4.2			3	2.5			3	2.2
812			2	2.8			2	1.6			2	1.5
813					1	8.3	1	0.8			1	0.7
814			27	38.0	2	16.7	29	23.8	2	15.4	31	23.0
911					1	8.3	1	0.8			1	0.7
912			9	12.7	4	33.3	13	10.7	9	69.2	22	16.3
1810			6	8.5			6	4.9			6	4.4
Total	38		70		12		122		13		135	
					Grand Traverse Bay							
615			2	40.0	2	33.3	4	36.4			4	36.4
616			1	20.0	3	50.0	4	36.4			4	36.4
715			2	40.0			2	18.2			2	18.2
912					1	16.7	1	9.1			1	9.1
Total	0		5		6		11		0		11	

mixing of the Leland stock with one or more stocks to the south. It is believed that the whitefish harvested near Muskegon (grid 1810) originate from a stock separate from those harvested in Leland. Only six tags were returned from over 250 thousand pounds of whitefish harvested in that area in 1981. If the Muskegon and Leland fish originated from the same stock, one would expect a higher number of recaptures from the Muskegon area.

Three tagged fish from the Leland area were recaptured in the Northport Bay area. The movement of fish from the Leland stock into northeastern Grand Traverse Bay indicates overlap of the ranges of the fish in these areas. Rybicki (1980) suggested the existence of three subpopulations of whitefish in Grand Traverse Bay, one of which resides in the northern portion of the Bay.

The results of this study do not allow the distinction of stocks between the Leland area and upper Grand Traverse Bay. Only one state licensed fishing vessel, the purse seine, operates in the Bay. The purse seine catch is restricted under a yearly quota of 50 thousand pounds. Treaty fishermen harvested 260 thousand pounds from the upper portion of the Bay (grids 715 and 716), although only one treaty fisherman is known to be cooperating. Suspected incomplete reporting of tags, and the patchy distribution of fishing effort in this area, limits the interpretation of the available data.

April marked the beginning of the 1981 fishing season, after the winter ice cover on the lake had melted. Twenty three tagged fish were recaptured during April. Ninety-one percent of these were reported from grid 814. Two tags were returned from the Muskegon area. In May, only a few tagged fish were recaptured and these were from grids 714 and 814 near Leland. During June, the recaptures were distributed evenly along the shoreline in the Leland study area. Another tag was returned from Muskegon. July tag returns were reported primarily from grids 615, 616, and 714. One fish was recaptured on the purse seine in Northport Bay (grid 715) and another in Muskegon.

Few tags were returned during the remainder of the 1981 fishing season. Fishing effort was concentrated in grids 615, 616, and 715 near the mouth of Grand Traverse Bay and in grids 812 and 912 near Empire. The relatively few recaptures suggests that the tagged stock may have moved back to their spawning grounds in grid 714. Homing of whitefish was noted in the North Shore stock and, although no harvest nor recaptures were reported from grid 714 after July, a homing tendency of the Leland tagged stock is suggested.

Recaptures during the first six months of 1982 were scarce. The returns were concentrated in grid 615 near Cat Head Point and grid 912 near Empire.

The patchy distribution of the fishing effort, both geographically and seasonally, limits the utility of tagging operations in the Leland area. The tag returns indicate a broad geographical distribution of this stock, and suggest a homing tendency of the tagged fish. These findings are consistent with those from the North Shore area.

Grand Traverse Bay Tag Returns. Only eleven of the 140 tagged fish from the June 1981 tagging in Grand Traverse Bay were returned (Table 4, Appendix 2). The small number of returns is, in part, due to the later tagging date in this region (Table 4). These fish were only available for harvest from the June 1981 until the end of the study. The tagged fish in the other areas were available for harvest from November 1980 until the end of the study. Also, the fish tagged on the purse seine were all shorter than the 19 inch minimum size limit for this gear, thus many of them were not of legal size for harvest by either trap nets or the purse seine. Several sublegal tagged fish were reported to have been caught by the purse seine during July 1981. These were all returned to the water with no record made of their numbers. It has been mentioned previously that incomplete reporting of tagged fish is suspect in this area. No tags were reported from grid 716 where a substantial portion of the catch of lake whitefish in the Bay was reported.

The tags that were returned from the Grand Traverse Bay tagging suggest an overlap of the fish from the Leland and upper Grand Traverse Bay areas. Continued investigation is required to discern the discreteness of the Leland, Grand

Traverse Bay, and Muskegon stocks, if it exists. Index trawling by the Michigan Department of Natural Resources, in the waters from Leland south to Pentwater, showed few residual populations of whitefish (Rybicki 1980). The non-sedentary nature of these whitefish in this area complicates stock differentiation.

Tag Loss

A total of 158 fish were tagged in November 1980 with two tags each. This double-tagging procedure was conducted to estimate the frequency of tag loss in the population (Seber 1973). The double-tagged fish had one green dart tag, identical to those used in November 1980, and one yellow anchor tag, identical to those used in November 1981. One of the double tagged fish was returned with only the green tag remaining. Another of the double tagged fish was returned with only the yellow tag remaining. The former was recaptured on June 21, 1982. The latter was recaptured on June 19, 1982. Assuming that the tags were lost at the midpoint of the interval between the date of tagging and the date of recapture, an instantaneous rate of tag loss was calculated (Appendix 3). The value estimated for the instantaneous rate of tag loss (T) for the November 1980 tags was 0.2184.

In order to adjust the population estimates for tag loss, the reported tag returns were separated into intervals, such that the dates of recapture were known precisely. These intervals spanned several months during the fishing season since the only information concerning the date of recapture of several tags was that they were caught after the last sampling date and prior to the next sampling date. The midpoint of each interval was used as the time (t), expressed in years, to estimate the percentage of tags lost during that interval from the relationship, R = exp

(-T)(t), where R is the percent of the returned double-tagged fish which retained both tags. The number of recaptures during each interval was divided by the percent tag loss estimated for that interval. The adjusted recaptures were summed over all intervals.

An instantaneous rate of tag loss of 0.2184 is the same as an annual tag loss of 19.6 percent. This value is larger than the 11.1 percent reported by Ebner and Copes (1982), but is approximately the same as the 19.3 percent estimated by Humphreys (1978).

My estimate is crude, at best, because it is based on the return of a single incomplete double-tag, for each tag type. Continued return of double-tagged lake whitefish in the remainder of the 1982 season, and in future seasons, will put more strength in this estimate.

Aging

Scale aging was considered to be a reliable technique for the purposes of this study. A ninety-four percent agreement was found between ages assigned by scales and those assigned by fin rays (Appendix 5). Mills and Beamish (1980) noted similar agreement (93%) between ages assigned by scales and fin rays of experimentally reared whitefish.

A fifteen percent overlap by the two principal scale readers for the first two samples showed an overall 82.3 percent agreement. The difference between ages assigned by the investigators only varied by one year for any fish (Appendix 4). This is better agreement than the 78 percent reported by Christie (1963) and the 60 percent reported by Healey (1980). Ricker (1975) states that 80-90 percent agreement is good, and is only attainable in fast growing populations.

Beamish et al (1976) found scales to underestimate the true ages of the older whitefish in northern Canada. Humphreys (1978) did not find this to be the case in northwestern Lake Michigan. Perhaps more distinct seasonal temperature variation, which is a major factor influencing the formation of annular marks on scales (Hoagman 1968), results in the more reliable aging of whitefish in the relatively warmer waters of Lake Michigan compared to northern Canada.

A method of comparing the precision of a set of age determinations (Beamish and Fournier 1981) was used to estimate the "index" or average of the mean percent error of the overlap by the two principal scale readers. This method was also applied to the scale and fin ray overlap. Since there was no disagreement in the assignment of ages to whitefish by move than one year the index was the same for both scale readers and for both aging techniques. The index of average percent error was 2.4 percent for the overlap by the principal scale readers, and 0.8 percent for the scale-fin ray overlap (Appendices 3 and 4). These measures imply that the assignment of ages tc lake whitefish in this study was consistent, i.e. precise.

Age Compositions

The percent age composition of the sampled catch from the North Shore, Leland, and Beaver Island areas indicates the existence of at least one distinct stock in each area. The presence of the strong 1977 year-class, which first appeared as age III fish in the November 1980 catch, is noted throughout the study area (Table 5). This age class dominated the catch during all seasons (Table 6). Statistical analysis of the age compositions between the sampling locations showed that they were all significantly different ($p<.01$)(Table 7).

The apparent absence of fish older than age V in the June 1981 North Shore sample contrasts sharply with the 30.8 percent and the 10.6 percent of older fish present in the Leland and Beaver Island areas, respectively. The increasing representation of the 1977 and 1978 year classes in the catch, as the seasons progress, suggests that these fish were not fully vulnerable to the gear until the end of the 1981 season, or later.

Eschenroder et al (1980) conducted an investigation concerning the selectivity of large mesh trap nets for whitefish in Hammond Bay, Lake Huron. They noted that whitefish are not fully vulnerable to the gear until the reach a length of 489 millimeters in total length. The girth-length regression for the North Shore stock is nearly identical to that from Hammond Bay (Appendix 6). This indicates that only a small proportion of the whitefish in

Table 5. Percent age composition of commercial trap net (TN) and gill net (GN) catch in northeastern Lake Michigan in 1965 through 1982.

Area Date	Gear	N	Age 1	2	3	4	5	6	7	8	9	10	11	12	≥13	Ref.
Leland																(a)
May 1982	TN	232			1.7	12.9	53.0	7.8	11.6	0.4	3.9	3.9	2.2	1.7	0.9	
Oct. 1981	TN	244		0.4	6.6	67.2	11.1	7.4	1.2	0.8	0.8	2.0	1.6	0.4	0.4	
Aug. 1981	TN	94			6.4	67.0	5.3	7.4	5.3	1.1	1.1	4.3		2.1		
June 1981	TN	81			2.5	44.4	22.2	12.3	6.2	2.5		1.2	2.5	4.9	1.2	
Oct. 1980	TN	114			57.0	28.9	7.0		2.6	1.8	1.8			0.9		
Grand Traverse Bay																(a)
June 1981	TN	140				4.3	57.1	29.3	3.6	2.1		1.4	0.7		1.4	
Grand Traverse Bay (Grid 715)																(b)
Fall 1981	TN	223				11.2	45.3	20.6	1.8	4.9	3.1	4.5	1.3	4.9	2.2	
Grand Traverse Bay - North end																(d)
1973	GN	53			51	22	21	4	2							
1971	GN	28			29	21	39	11								
1969	GN	371		1	22	37	18	8	2	1						
1968	GN	189		6	64	27	2	1								
North Shore																(a)
May 1982	TN	263			0.4	17.1	79.5	3.0								
Oct. 1981	TN	331			7.9	85.8	6.0	0.3								
Aug. 1981	TN	300			13.0	83.7	3.0	0.3								
June 1981	TN	107		0.9	14.0	79.4	5.6									
Oct. 1980	TN	513		0.2	77.6	20.9	1.0		0.2			0.2				
North Shore (Grids 214,215,216)																(b)
Summer 1980	GN	371			36.7	56.3	6.5	0.3	0.3							
North Shore																(c)
July 1978	TN	407			31.9	36.6	16.5	10.3	2.5	0.7	1.0	0.5				
May 1979	TN	198			4.5	59.6	24.2	5.6	5.1	0.5	0.5					
Epoufette																(d)
Oct. 1976	TN	184		1.6	83.2	14.1	1.1									
North Shore																(d)
1973	TN	141	1	1	65	30	1	1	1							
1972	TN	141	1	28	68	2	1									
1971	TN	296		8	81	10	1									
1970	TN	169		44	54	2										
North Shore																(e)
Oct. 1966	TN	346	0.9	16.5	77.5	5.2										
Beaver Island																(a)
May 1982	TN	169			31.4	63.9	4.1									
June 1981	TN	219		2.7	68.0	18.7	5.5	2.3	2.3	0.5						
Cross Village (Grid 418)																(b)
Fall 1981	GN	46			10.9	54.3	17.4	6.5	2.2	4.3	2.2				2.2	
Hog Island/Ile aux Galets																(c)
June 1979	TN	122			12.3	30.3	16.4	6.6	14.8	2.5	6.6	4.9	4.1	1.6		
Oct. 1978	TN	242		1.1	21.8	50.7	15.2	14.7	2.4	3.2	1.9	2.4				
July 1978	TN	211		0.5	12.8	38.4	15.2	22.3	3.3	2.4	2.4	2.8				
Oct. 1977	TN	124		4.0	36.3	36.3	20.2	0.8	1.6		0.8					
Hog Island																(e)
Oct. 1965	GN	59		6.8	81.3	8.5	1.7	1.7								

(a) this study
(b) unpublished data from the Sault Ste. Marie tribe of Chippewa Indians
(c) Rybicki (1980)
(d) unpublished data from the Michigan Department of Natural Resources
(e) Piehler (1967)

Table 6. Percent of the sampled catch (pounds) in each age class from northeastern Lake Michigan in 1980 through 1982.

Area		Age											
Date	N	2	3	4	5	6	7	8	9	10	11	12	>13
NORTH SHORE													
Oct. 1980	513	0.1	73.6	23.6	1.6	0.3				0.8			
June 1981	117	0.3	11.2	80.8	7.7								
Aug. 1981	300		11.3	84.0	4.2	0.5							
Oct. 1981	331		5.9	85.7	8.0	0.4							
May 1982	263		0.3	14.5	81.1	4.1							
LELAND													
Oct. 1980	114		45.4	24.1	11.4		5.6	5.0	5.5			3.0	
June 1981	81		3.5	32.4	16.8	14.0	6.8	3.4		2.9	6.0	9.8	4.4
Aug. 1981	94		4.2	50.6	6.0	9.0	10.4	1.7	2.8	10.7		4.6	
Oct. 1981	244	0.1	3.6	56.0	11.6	10.1	1.9	1.9	1.7	5.8	4.7	1.4	1.2
May 1982	232		0.9	8.2	41.1	7.9	13.8	0.7	7.4	8.5	4.6	4.3	2.6
BEAVER ISLAND													
June 1981	219		1.5	62.8	21.2	9.1	3.3	3.7	0.8				
May 1982	169			27.7	63.9	5.9				2.5			
GRAND TRAVERSE BAY													
June 1981	140			3.3	50.1	29.5	4.6	2.9		3.4	1.6		4.4

Table 7. Age composition comparisons among sampling locations using a Chi square goodness of fit test.

Samples Compared	Age Categories	X^2	df	α
	Fall 1980			
North Shore (115,116) vs. Leland (714,814)	<4,4,5,6+	50.13	3	<.001
	Spring 1981			
North Shore (117) vs. Leland (812,814,912)	<4,4,5,6,7+	58.49	4	<.001
North Shore (117) vs. Beaver Island (316)	3,4,5,6,7+	35.42	4	<.001
Leland (812,814,912) vs. Beaver Island (316)	3,4,5,6,7+	21.95	4	<.001
	Summer 1981			
North Shore (218) vs. Leland (812,814,912)	3,4,5,6,7+	65.64	4	<.001
	Fall 1981			
North Shore (116,117) vs. Leland (812)	3,4,5,6,7+	57.94	4	<.001
	Spring 1982			
North Shore (216,218) vs. Leland (812,814,912)	3,4,5,6,7+	86.32	4	<.001
North Shore (216,218) vs. Beaver Island (317,418)	4,5,6+	13.39	2	<.01
Leland (812,814,912) vs.	3,4,5,6,7+	61.89	4	<.001

the North Shore catch are fully vulnerable to the trap nets, thus skewing the age composition of the sampled catch to the right, i.e. older age classes.

A slightly higher percentage of fish aged IV and V in the October 1981 sample, compared to those in the August 1981 sample, indicates a possible movement of older fish onto the spawning grounds in the fall. Seasonal inshore movements of older whitefish have been observed in Green Bay (Ebner 1980, Humphreys 1978, Gunderson 1978). If the tagged fish are indeed homing to the same spawning grounds in subsequent years, this magnifies the importance of the protection of the North Shore spawning stock to the entire fishery in that area. A depletion or failure of this spawning stock could mark the collapse of the fishery between Seul Choix Point and the Mackinac bridge.

The apparent absence of fish older than age VI in the May 1982 sample from the Beaver Islands area (grids 317 and 418), compared to the June 1981 sample from that vicinity (grid 316), suggests the existence of either a second stock or a segregation of the population by age classes in the region southeast of the Islands (Figure 6). The absence of tag returns from this area does not permit a distinction between these possible explanations.

Comparisons of the 1980-1982 age compositions from the North Shore area, with those reported by the Michigan Department of Natural Resources, show strong similarities (Table 5). The 1970-1973 catch sampled in the North Shore

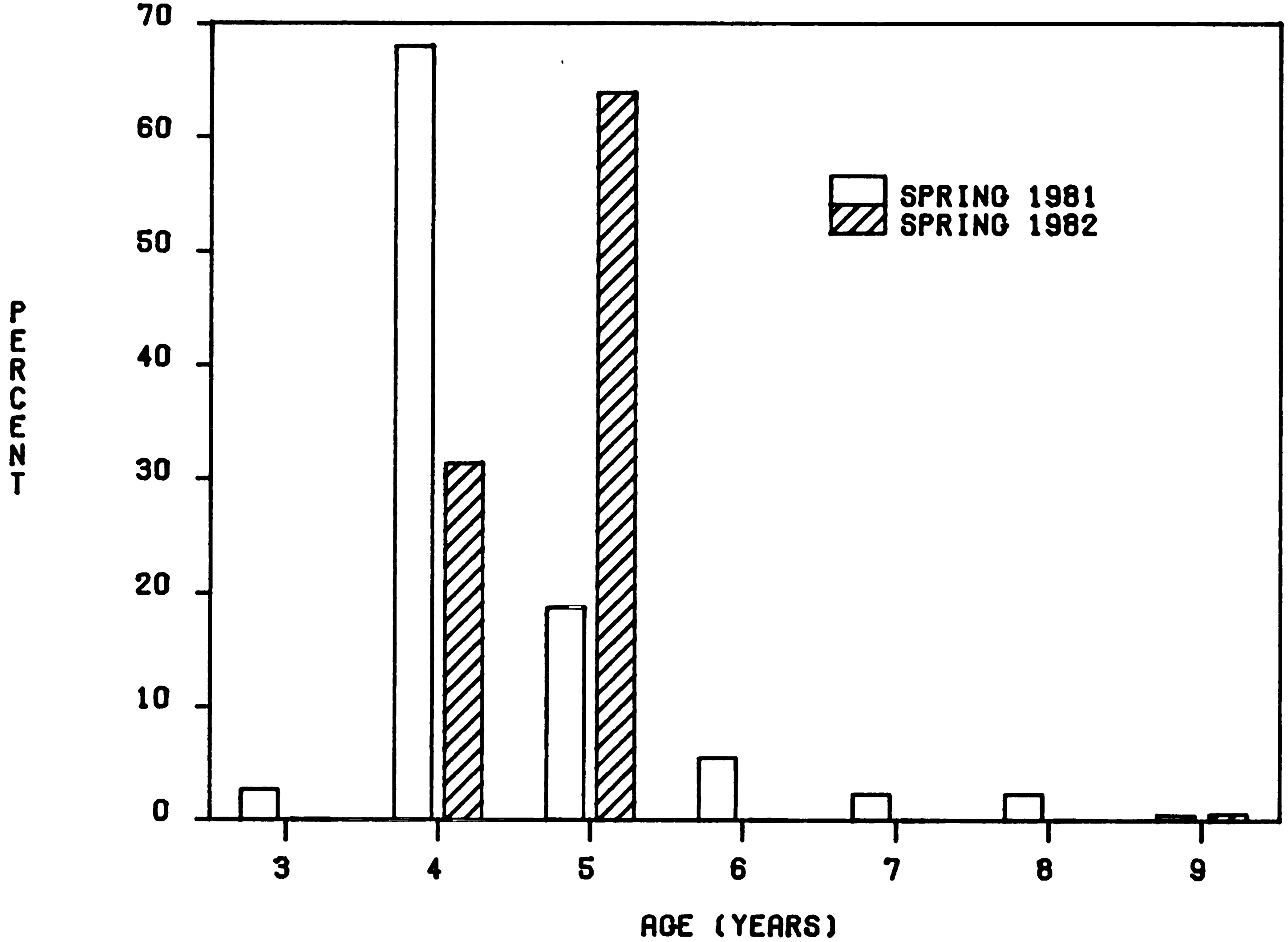


Figure 6. Age compositions of the sampled catch of lake whitefish, in springs 1981 and 1982, from the Beaver Island area of Lake Michigan.

area was dominated by ages III and IV. The harvest during that period was dominated by the 1965 and the 1969 year-classes. The narrow age distribution and the dependence of the fishery on one or two age classes, is a characteristic of this fishery.

The presence of numerous age classes in the samples from Grand Traverse Bay is also consistent with the values reported by the Michigan Department of Natural Resources. Minor differences between their results and this study are probably a reflection of the different selectivity characteristics and minimum size limit of the purse seine. Gill net catch was sampled for the Michigan DNR's estimates.

Any differences in the age composition between two areas may be a reflection of differential fishing pressure exerted on the stocks, segregation of the population by age class or by sex, variable recruitment (Christie 1963, Lawler 1965), predation (Wells and McLain 1973), or food availability during the life stages, from egg to adult. The presence of the strong 1977 year-class in the catch, throughout the study area, leads me to believe that the factors affecting recruitment are rather homogenous between areas.

Cucin and Regier (1966) and Roelofs (1958) showed that the strong 1943 year classes of whitefish in Lake Huron and the lake herring _Coregonus artedi_ Leseur in Lake Michigan corresponded with the strong 1943 year class of whitefish in Lake Michigan. This indicates that the factors favoring the abundance of the whitefish and similar species are indeed somewhat homogenous within the northern Great Lakes.

A pattern in the annual variation of year class strength has been observed in Lake Michigan in past investigations, whereby a strong year class is followed the next year by a weaker year class (Roelofs 1958, Humphreys 1978). The 1978 year class in the present study follows this trend, in that it is relatively less abundant than the 1977 year class. This succession of an abundant cohort by a less abundant cohort is probably due to competitive intraspecific interactions among the prerecruited whitefish.

Lawler (1965) suggested the existence of some relationship between the temperature during spawning, embryonic development, and hatching and the abundance of year classes of whitefish. The effect of cold winter temperature on the earlier formation and longer duration of the ice cover on the lake was discussed as a possible mechanism by which the effects of the strong November winds, upon the turbidity of the water on the spawning grounds, may be reduced. This, in turn, would enhance survival of the eggs.

In order to determine the true factors limiting year class success, detailed investigation of egg, larval, and juvenile mortality are necessary. This information would aid tremendously by enabling the prediction of the strength of prerecruited age classes prior to their entry into the fishery. Ultimately, catch quotas could be tailored to each stock, by incorporating knowledge of the relative abundance of the prerecruited stock with that of the recruited stock.

The 1977 year-class had a strong influence on the mean age of the North Shore samples during the study period (Table 8). The steadily increasing mean age from sample to sample throughout the sampling period indicates that the same stock was being sampled at all times.

In Leland this pattern is not as prevalent. The higher mean ages for this area reflect the presence of numerous fish aged V and older in the catch. The mean age in the spring samples are higher than those for the summer and fall samples. This may be a result of a change in the location of the gear, small sample sizes, or a seasonal segregation by age classes.

Healey (1980) noted a complete removal of the older ages of lake whitefish and subsequent increases in the younger ages associated with increased exploitation. In this study, the North Shore and Beaver Island stocks are characteristic of heavily exploited stocks while the Leland stock is characteristic of a lightly exploited stock.

Table 8. Mean age of lake whitefish from the sampled catch in the North Shore, Leland, Beaver Island, and Grand Traverse Bay areas of Lake Michigan.

Location	Grids	Date	Sample Size	Age Mean	S.Dev.
North Shore	115,116	10/29/80	513	3.24	0.56
	117	6/29/81	107	3.90	0.48
	218	8/24/81 8/25/81	300	3.91	0.41
	116,117	10/17/81 10/24/81	331	3.99	0.39
	216,218	5/17/82	261	4.85	0.44
Leland	714,814	10/30/80	114	3.81	1.46
	812,814,912	6/15/81	81	5.53	2.52
	812,814,912	8/27/81	94	4.82	1.90
	812	10/21/81 10/22/81	244	4.60	1.65
	812,814,912	5/20/82 5/24/82	232	5.83	1.97
Beaver Island	316	6/16/81	219	4.45	0.96
	317,418	5/18/82 5/19/82	169	4.76	0.67
Grand Traverse Bay	615	6/14/81	140	5.63	1.44

Population and Biomass Estimates

Population estimates using Petersen mark-recapture techniques indicate that the North Shore stock is considerably larger than the Leland stock. There were an estimated 1.7 million legal sized fish in the North Shore stock in November 1980 (Appendix 7). The stock boundaries have been delineated to include statistical grids 115-118 and 213-220 (Figure 3). The biomass estimate for this stock was 1.4 million kilograms. Ninety-five percent confidence intervals using a poisson approximation (Ricker 1975) were 1.5-1.8 million individuals and 1.3-1.6 million kilograms. In Leland there were an estimated 264 thousand whitefish weighing 329 thousand kilograms in November 1980. Ninety-five percent confidence intervals are 206-337 thousand individuals and 257-420 thousand kilograms. Leland stock boundaries include grids 615, 714, 812-814, and 911-912.

The population estimates were based soley upon the reported catch in pounds, converted to kilograms, and the number of recaptures from the fishermen known to be cooperating. These fishermen are the ones who reported all tags that were recaptured, allowed their catch to be sampled, and/or donated their time and equipment during the tagging operations. The catch was adjusted for the recruitment of those fish that were sublegal in November 1980, yet grew into the catchable portion of the population during the 1981 fishing season (Appendix 8).

In the Leland area thirty-nine tagged fish were captured during the five weeks immediately following the closed fishing season (November 1-30). These fish were returned from the same location where they were tagged. It is believed that these fish did not get a chance to thoroughly mix with the remainder of the Leland stock. These recaptures provided an estimate of 7.6 thousand fish on the spawning grounds. The estimate of the spawning population represents 2.9 percent of the total estimated numerical size of the Leland stock. This suggests that this particular spawning population was a minor portion of the entire Leland area spawning stock. These fish were not included in the total population estimate, since it was believed that they were captured before they could disperse and mix with the entire untagged portion of the population.

Population numbers and biomass were dominated by the 1977 year class in all areas (Table 9). The percent representation of each age class in the North Shore area differs little between the numbers and biomass columns, where as in the Leland area, the older fish make up a larger percentage of the total biomass than the total numbers. For example, fish aged V and older represent 30.5 percent of the total harvestable biomass, yet only 14.5 percent of the total numbers. The closing of the Leland area to commercial fishing from 1970-1976 has allowed the survival of a larger percentage of older fish in this population, compared to the North Shore area. Historically, the North Shore area has

Table 9. Population numbers and biomass (kg) of lake whitefish by age class for November 1980 in the North Shore, Leland, and Leland spawning areas. All figures were derived from the October 1980 percent age compositions in the respective areas.

Age	North Shore Number	North Shore Biomass	Leland Number	Leland Biomass	Leland Spawners Number	Leland Spawners Biomass
3	1,272,535	1,058,329	148,945	149,558	4,295	4,313
4	365,906	338,895	76,849	79,391	2,216	2,290
5	16,632	22,976	19,278	37,544	556	1,083
6	0	0	0	0	0	0
7	3,326	4,308	7,130	18,448	206	532
8	0	0	4,754	16,471	137	475
9	0	0	4,754	18,118	137	523
10	3,326	11,488	0	0	0	0
11	0	0	0	0	0	0
12			2,377	9,883	69	285
Total	1,663,207	1,435,996	264,087	329,422	7616	9501

supported a larger number of fishermen and has produced considerably larger yields than the Leland area (Figure 1). The larger size of the North Shore population is the reason that this is so. Why this area is more productive requires detailed examination of the spawning habitats, food availability, and fecundity characteristics of the whitefish in these areas.

Mortality Estimates

The estimated annual exploitation rate (u) of the North Shore tagged fish (49.6%) was more than double that of the Leland tagged fish (24.2%). The rates of exploitation were estimated from those tags returned by the cooperating fishermen in each area. These rates were expanded by the ratio of the total catch to that of the cooperating fishermen in each area to obtain values of the total exploitation rates for each stock (Appendix 9).

An estimate was not possible for the Grand Traverse Bay tagged fish. Too few tags were returned to adequately define the stock boundaries. In addition, since the fish tagged in this region were all shorter than the minimum size limit (19 inches), several of the recaptures were returned to the lake.

The annual survival rate (S), estimated from tag returns, was 29.3 percent for the North Shore stock and 41.4 percent for the Leland stock. The corresponding instantaneous total mortality rates (Z) were 1.229 and 0.881, respectively (Table 10).

The instantaneous total mortality rate (1.229) estimated for the North Shore stock was approximately that estimated for ages III and IV (1.240) by Patriarche (1974) for whitefish in northern Lake Michigan (Table 11). Healey (1975) reported a value of 1.022 as the mean of 14 exploited populations of whitefish and a value of 0.673 as the mean of 13 unexploited whitefish populations. The North Shore

Table 10. Annual (A), instantaneous total (Z), instantaneous fishing (F), and instantaneous natural (M) mortality rates of lake whitefish in northeastern Lake Michigan.

Location	Method of Estimation	Ages	A	Z	F	M
North Shore	tag returns		0.708	1.229	0.861	0.368
	catch curve (springs)	(4-6)	0.824	1.736 (r^2=.777)		
	catch curve (falls)	(4-6)	0.939	2.794 (r^2=1.000)		
Leland	tag returns		0.586	0.881	0.363	0.518
	catch curve (springs)	(5-8)	0.624	0.979 (r^2=.913)		
	catch curve (falls)	(4-8)	0.587	0.884 (r^2=.928)		
Beaver Island	catch curve (springs)	(4-9)	0.658	1.073 (r^2=.940)		
Grand Traverse Bay	catch curve (spring 1981)	(5-8)	0.697	1.195 (r^2=.939)		

Table 11. Annual (A), instantaneous total (Z), instantaneous fishing (F), and instantaneous natural (M) mortality rates for lake whitefish from Lake Michigan and other lakes.

Location (Method of Estimation)	Ages	A	Z	F	M	Reference
Northshore						
tag returns		0.708	1.229	0.861	0.368	This study
catch curve (springs)	4-6	0.824	1.736			This study
catch curve (falls)	4-6	0.939	2.794			This study
catch curve	3-4	0.711	1.240	0.820	0.420	Patriarche, 1974
Leland						
tag returns		0.586	0.881	0.363	0.518	This study
catch curve (springs)	5-8	0.624	0.979			This study
catch curve (falls)	4-8	0.587	0.884			This study
Beaver Island						
catch curve (spring 1981)	4-9	0.602	0.920			This study
catch curve (spring 1982)	5-6	0.935	2.736			This study
catch curve (springs)	4-9	0.658	1.073			This study
Grand Traverse Bay						
catch curve (spring 1981)	5-8	0.697	1.195			This study
catch curve	5-13	0.340	0.416		0.416	Rybicki and Keller, 1977
Big Bay de Noc						
catch curve (springs)	4-8	0.772	1.478	1.064	0.414	Ebner, 1980
catch curve	3-4	0.936	2.789			Roelofs, 1958
North-Moonlight Bays						
catch curve (springs)	4-8	0.610	0.941	0.464	0.477	Ebner, 1980
catch curve	4-10	0.668	1.102	0.634	0.468	Humphreys, 1978
Lesser Slave Lake Canada (age composition)		0.529	0.753	0.124	0.629	Bell et al., 1977
Average of 14 exploited populations		0.640	1.022			Healey, 1975
Average of 13 unexploited populations		0.490	0.673	0	0.673	Healey, 1975

estimate is larger than both of these estimates. The Leland estimate (0.881) is intermediate between the two. Both the Leland and North Shore estimates are considerably less than the value of 2.813 calculated by Roelofs (1958) for the fish in Big Bay de Noc. A large proportion of his total was attributed to sea lamprey, *Petromyzon marinus* Linnaeus, predation.

The instantaneous rates of total mortality for the Beaver Islands and Grand Traverse Bay stocks, estimated from age compositions, were 1.073 and 1.195 respectively. These estimates were derived from catch curves (Robson and Chapman 1961), as are most reported values of Z in the literature. A catch curve is a plot of the natural log of frequency against age. Total instantaneous mortality is estimated from a linear regression of the points in the descending limb of this plot. The slope of this regression is the total instantaneous mortality rate (Z). An estimate of this type assumes that the rate of recruitment is constant for all ages present in the fishery. This assumption is obviously not valid when strong year classes, such as the 1977 year class, are present in the catch. Robson and Chapman (1961) suggest averaging the percentages of the fish in each age class over several years to offset the effects of unequal recruitment. The relative frequencies of ages were averaged over the two years of the study, when data was available (Table 11, Figure 7). The range of ages used for each estimate is indicated by the horizontal range of the

Figure 7. Catch curves for stocks of lake whitefish from the North Shore, Leland, Beaver Island, and Grand Traverse Bay areas of Lake Michigan, in spring and fall.

a - North Shore, springs of 1981 and 1982 combined
b - North Shore, falls of 1980 and 1981 combined
c - Leland, springs of 1981 and 1982 combined
d - Leland, falls of 1980 and 1981 combined
e - Beaver Island, spring 1981
f - Beaver Island, spring 1982
g - Beaver Island, springs of 1981 and 1982 combined
h - Grand Traverse Bay, spring 1981

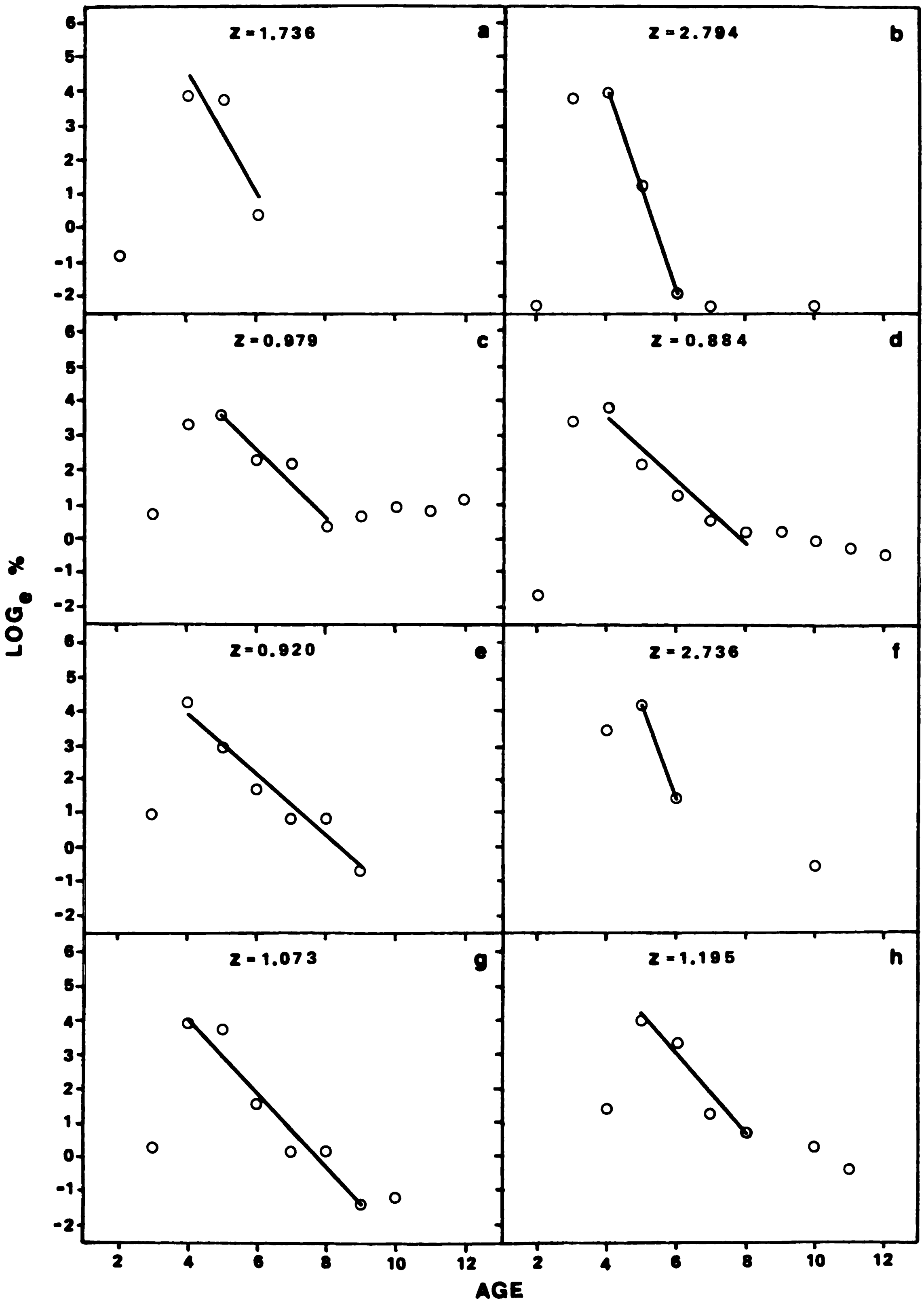

Z=1.736
a
Z=2.794
b
Z=0.979
c
Z=0.884
d
Z=0.920
e
Z=2.736
f
Z=1.073
g
Z=1.195
h
LOGe %
AGE

Figure 7.

regression line in each plot. Estimates were calculated for the Beaver Island samples independently, and combined. Separate estimates were determined for spring and fall samples.

Although the relative age frequencies were averaged over the two years of the study, the effects of the 1977 year class were still prominent. Therefore, the estimates for the North Shore area and for the spring 1982 Beaver Island sample are considered to be overestimates. The estimates for the Leland area are quite similar to the tag return estimates for that area. This indicates that the catch curve estimates are reasonably accurate when a broad age composition is present in the catch.

Examination of the descending limb of the fall catch curve for the Leland stock reveals an obvious concavity. This area was closed to commercial fishing in 1970 and was reopened in 1977 (Figure 2). Consequently, the older fish in the population had higher survival rates during their early life and were still present in the catch. The younger ages have lower survival rates, as a result of fishing mortality in addition to natural mortality. This is indicated by the steeper slope in that portion of the curve representing these ages. In order to obtain the best estimate of the mortality rate of the Leland fish from catch curves, ages IX and older were omitted from regressions.

The first age class considered to be fully vulnerable to the gear was that age class which was the most abundant in the catch. Considering the results of the trapnet selectivity study conducted on whitefish in Hammond Bay, Lake Huron (Eschenroder et al 1980), there are probably no age classes which are fully vulnerable to the gear in the North Shore and the spring 1982 Beaver Island samples.

Catch curve estimates are generally not suitable for comparison between studies, due to the somewhat arbitrary manner by which the first age class that is fully vulnerable to the gear is selected. Commonly the most abundant age class is considered to be the youngest age used in the construction of catch curves, however these fish may not be captured with 100 percent efficiency by the gear. Cucin and Regier (1965) found that the narrow range of ages present in single mesh gill net catch overestimates whitefish total and natural mortality rates. This is due to the sharp decrease in efficiency of gill nets beyond a certain size of maximum efficiency of capture.

The instantaneous rate of fishing mortality (F) was higher for the North Shore stock (0.861) that for the Leland stock (0.364) (Table 10). The instantaneous fishing mortality represents 70.1 percent of the total instantaneous mortality in the North Shore area and 41.3 percent in the Leland area.

Ebner (1980) reported F values of 1.064 for the whitefish from Big Bay de Noc and 0.464 for whitefish from North-Moonlight Bays (Table 11). These values represented 72 percent and 49 percent of the total instantaneous mortality for each area, respectively. The Z values for this study were estimated from catch curves that exhibited concavity of the lower portion of the descending limb, as was illustrated in the Leland sample. The concavity of the descending limb of a catch curve tends to underestimate the total instantaneous mortality rates, thus overestimating the contribution of fishing mortality as a relative frequency of Z. This in turn causes the instantaneous natural mortality rate (M), which is the difference Z-F, to be underestimated.

The instantaneous rates of natural mortality were estimated to be 0.368 in the North Shore area and 0.518 in the Leland area. These represent annual natural mortality rates of 29.9 percent in the North Shore area and 58.7 percent in the Leland area. The lower rate of natural mortality in the North Shore area may be a result of the larger removal of individuals by the fishery. This may act to reduce the mortality from non-fishing sources. Healey (1975) reported an instantaneous natural mortality rate of 0.629 as an average for 13 unexploited whitefish populations. Rybicki and Keller (1977) reported a value of 0.416 for M in an unexploited portion of Grand Traverse Bay. Additional values of Z, F, and M from the literature are presented for comparison in Table 11.

Length and Weight

The mean length and weight of the average fish in the sampled catch was larger in the Leland stock than the North Shore and Beaver Island stocks at the time of each sample (Table 12). This is a consequence of the older age structure of the Leland catch. The increase in the mean size of the average fish in the Leland and North shore areas during the sampling period reflects the dominance of the 1977 year class in the catch. The 1977 year class comprised 73-86 percent of the North Shore catch. This year class also dominated the Beaver Island and Leland samples, representing 63-64 percent and 32-56 percent of the catch in these areas respectively. The presence of this strong year class overshadows the effect of the recruitment of sublegal fish, thus the mean size increased from sample to sample.

The deviation of the June 1981 North Shore sample, from this trend of increasing mean size, is probably due to the nature of this particular sample. The June 1981 sample is not truly representative of the dockside commercial catch. It was obtained on a day when the Michigan Department of Natural Resources fisheries biologists were obtaining a sample of lake run catch, i.e. sublegals were included, for sex and maturity estimates. Consequently, fish that were smaller than those that would ordinarily be kept by the commercial fishery, were present in disproportionate numbers.

Table 12. Mean length (mm) and weight (g) of lake whitefish from the sampled catch in the North Shore, Leland, Beaver Island, and Grand Traverse Bay areas of Lake Michigan.

Grids	Sampling Date	N	Length Mean	Length S.D.	Weight Mean	Weight S.D.
			North Shore			
115,116	10/29/80	513	459.9	25.9	848.3	202.5
117	6/29/81	107	441.4	35.3	855.8	243.2
218	8/24/81 8/25/81	300	460.5	21.6	934.4	167.7
116,117	10/17/81 10/24/81	331	473.3	23.6	950.8	184.0
216,218	5/17/81 5/18/81	263	473.6	24.4	969.7	179.6
			Leland			
714,814	10/30/80	114	486.0	58.9	1231.3	728.2
812,814,912	6/15/81	81	501.4	68.9	1457.8	817.4
812,814,912	8/27/81	94	501.3	63.8	1549.0	899.2
812	10/21/81 10/22/81	244	511.8	62.9	1526.2	838.4
812,814,912	5/20/82 5/24/82	232	525.3	68.5	1695.9	899.7
			Beaver Island			
316	6/16/81	219	479.0	35.6	1099.6	275.7
317,418	5/18/82 5/19/82	169	475.5	31.1	1049.1	331.5
			Grand Traverse Bay			
615	6/14/81	140	499.4	42.8	1329.2	494.9

Gear selectivity may have had some effect on the June 1981 sample means. If the faster growing members of the 1977 year class were vulnerable to the fishing gear as age III fish in the fall of 1980, then the four year olds in June 1981 would represent the slower growing members of this year class. This could also explain the decrease in the mean size between these sampling dates. Since no decrease in the mean size was noted between fall 1981 and spring 1982 samples, the decrease in mean size is believed to be a result of the nature of the spring 1981 sample.

The presence of proportionately more older fish in the spring 1981 sample compared to the spring 1982 Beaver Island sample is reflected in the higher mean size of the whitefish in 1981. Either two distinct stocks exist in the region southeast of Beaver Island, or the samples represent segregation by age class.

The spring 1981 catch sampled from the Beaver Island area resembled that from the Leland area. These samples were characterized by the presence of numerous fish age VI and older in the catch. The older fish, which are also the larger fish, result in higher mean length and weight values in Leland than those for the North Shore sample. In the spring of 1982, the sample from the Beaver Island area contained few old fish. The mean length and weight of this sample resembled those from North Shore in May 1982.

The length composition of the sampled catch from the Leland area was significantly different ($p<.001$) than that from the North Shore and Beaver Island areas (Table 13). The larger representation of old fish in the Leland catch resulted from more fish being in the larger length categories (Table 14).

Less than one percent of the fish sampled in the North Shore area were longer than 540 millimeters in total length. Thirteen to twenty precent of the Leland catch was longer than 540 millimeters. Five and a half percent of the Beaver Island spring 1981 sample and 1.2 percent of the 1982 sample was longer than 540 millimeters. The closure of the Leland fishery between 1970-1976, and the lighter exploitation rate in this area, account for the presence of numerous large fish.

The North Shore and Beaver Island (grid 316) spring 1981 length compositions were significantly different ($p<.001$), yet the spring 1982 contrasts were not ($p>.10$). Despite the lack of statistical differences, these samples are believed to have originated from separate genetic stocks based on the distribution of tag returns.

Plots of the spring Beaver Island samples, with the North Shore samples included as a reference, illustrate the differences between the stock structure of the catch sampled from grid 316 in 1981 and that sampled from grids 317 and 418 in 1982 (Figure 8). The 1982 samples are quite similar, but the 1981 samples are not. The presence of older fish in the 1981 Beaver Island sample distinguishes it from the North Shore sample and the 1982 Beaver Island samples.

Table 13. Length composition comparisons among sampling locations using a Chi square goodness of fit test.

Sampled Compared (grids)	Length Range (20mm intervals)	X^2	df	α
	Fall 1980			
North Shore (115,116) vs. Leland (714,814)	<440 - >559	72.15	7	<.001
	Spring 1981			
North Shore (117) vs. Leland (812,814,912)	<440 - >559	66.87	7	<.001
North Shore (117) vs. Beaver Island (316)	<440 - >539	81.23	6	<.001
Leland (812,814,912) vs. Beaver Island (316)	<440 - >559	23.82	7	<.001
	Summer 1981			
North Shore (218) vs. Leland (812,814,912)	<440 - >559	95.19	7	<.001
	Fall 1981			
North Shore (116,117) vs. Leland (812)	<440 - >559	141.77	7	<.001
	Spring 1982			
North Shore (216,218) vs. Leland (812,814,912)	<440 - >559	121.84	7	<.001
North Shore (216,218) vs. Beaver Island (317,418)	<440 - >539	3.63	6	>.250
Leland (812,814,912) vs. Beaver Island (317,418)	<440 - >559	85.95	7	<.001

Table 14. Length compositions of the sampled catch from northeastern lake Michigan in 1980-1982.

	Leland					North Shore					Beaver Island		G. T. Bay	
Length Category (mm)	Fall 1980	Spring 1981	Summer 1981	Fall 1981	Spring 1982	Fall 1980	Spring 1981	Summer 1981	Fall 1981	Spring 1982	Spring 1981	Spring 1982	Spring 1981	Length Category (mm)
320							.9							320
340														340
360				.4			.9							360
380							8.4				2.3		.7	380
400	.9	2.5	1.1	2.0	.4	2.3	13.1	.3		1.5	1.8			400
420	3.5	6.2	3.2	4.5	2.6	17.9	20.6	12.3	6.9	4.6	4.6	4.1		420
440	25.4	12.3	10.6	9.4	6.5	35.1	26.2	33.3	16.0	19.0	14.2	24.3	4.3	440
460	35.1	29.6	30.9	9.4	13.8	27.3	14.0	32.3	32.0	30.8	25.1	29.0	21.4	460
480	19.3	8.6	18.1	20.1	15.5	10.9	13.1	15.7	31.4	25.5	26.0	21.9	35.0	480
500	1.8	13.6	8.5	17.2	23.3	4.5	.9	5.3	10.0	15.2	14.6	15.4	20.0	500
520	.9	6.2	8.5	12.3	9.5	1.0	1.9		3.0	2.7	5.9	4.1	9.3	520
540	2.6	6.2	5.3	8.6	3.4	.6		.7	.6	.4	1.4	.6	2.9	540
560	1.8	6.2	2.1	4.9	5.2	.2				.4	2.3		2.1	560
580	.9			2.9	3.4						1.8		.7	580
600	.9		2.1	.8	3.9									600
620			2.1	.8	.9								.7	620
640	2.6	1.2	2.1	1.6	4.3								1.4	640
660	2.6	1.2	3.2	2.0	3.9	.2							.7	660
680	1.8	4.9	1.1	1.2	1.3									680
700			1.1		.9									700
720				.4	.9									720
740		1.2		1.2	.4								.7	740

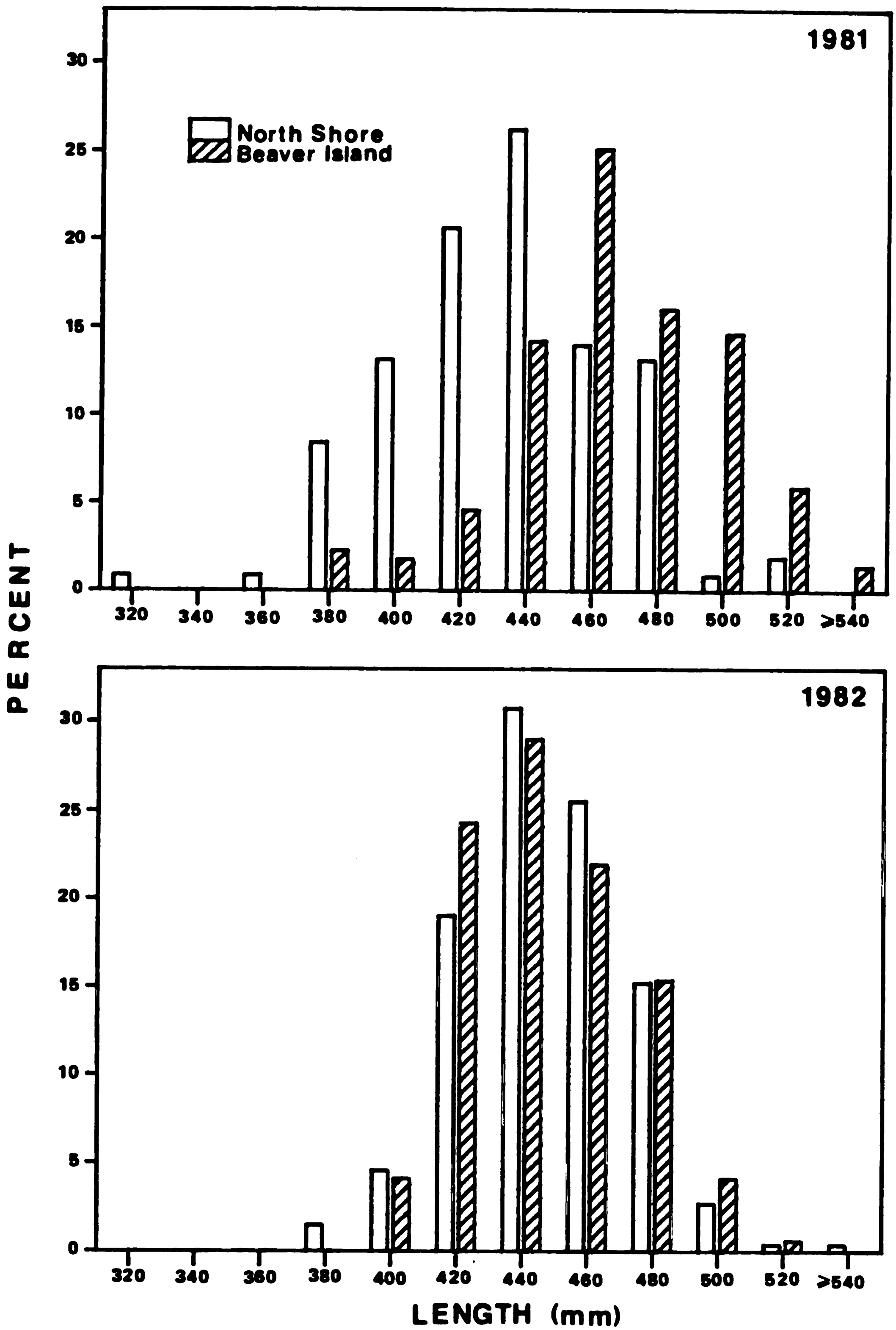


Figure 8. Length compositions of the spring 1981 and spring 1982 sampled catch of lake whitefish from the North Shore and Beaver Island areas of Lake Michigan.

The mean length of the whitefish comprising the 1977 year class from the Leland samples (Figure 9) were larger at each age than those from corresponding samples for the North Shore area ($p<.05$)(Table 15) (Appendix 10). The June 1981 whitefish in the North Shore area from the 1977 year class were shorter than the corresponding fish in the Beaver Island area ($p<.05$). The May 1982 comparison of the mean length of the fish in this year class, between these two areas, was not significant ($p>.10$). The opposite was found for the comparisons of the mean length of the fish from the 1977 year class between the Leland and Beaver Island spring samples. The 1981 contrast was not significant ($p>.10$), yet the 1982 contrast was ($p<.05$). This further exemplifies the idea that the Beaver Island samples were obtained from different stocks, or subpopulations of the same stock, in subsequent years.

The plots of the mean length at age for the representatives of the 1976 year class exhibit trends similar to those observed for the 1977 year class (Figure 9), especially for those fish sampled in August 1981, October 1981, and May 1982. The November 1980 means were not significantly different ($p>.10$) between the North Shore and Leland stocks, however the August 1981 samples exhibited differences in mean length ($P<.01$), with the Leland fish being larger. These are the only samples where the 1976 year class was present in sufficient numbers to justify statistical comparison ($n>19$).

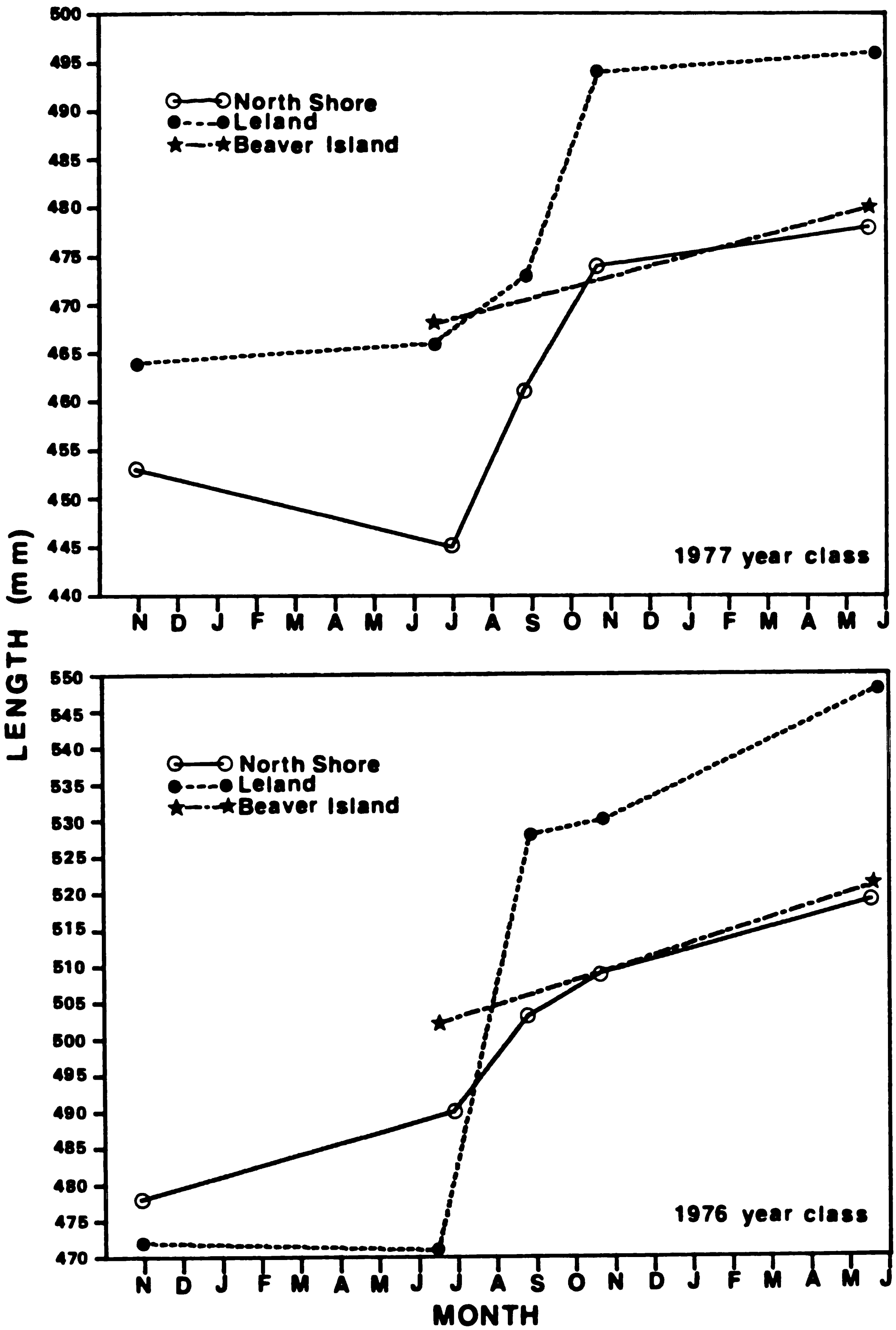


Figure 9. Mean length of the 1977 and 1976 year classes in the sampled catch from northeastern Lake Michigan in October 1980 through May 1982.

Table 15. Results of comparisons of mean length (mm) at age for lake whitefish from northeastern Lake Michigan using Scheffé tests. The hypothesis of equality of means was rejected if the interval $\bar{q}_k$ ± 95% MSD did not include zero.

Samples Compared	Year Class (Age)	Mean Length (mm)	Scheffé Test: Contrast $\bar{q}_k$	Scheffé Test: 95% MSD	Scheffé Test: 90% MSD	Decision
November 1980						
North Shore vs.	1977	453.4	10.35	4.97		reject
Leland	(III)	463.7				
North Shore vs.	1976	478.4	6.05	12.31	10.82	accept
Leland	(IV)	472.3				
June 1981						
North Shore vs.	1977	444.8	21.32	9.31		reject
Leland	(IV)	466.1				
North Shore vs.	1977	444.8	23.26	6.36		reject
Beaver Island	(IV)	468.1				
Leland vs.	1977	466.1	1.93	8.69	7.61	accept
Beaver Island	(IV)	468.1				
August 1981						
North Shore vs.	1977	461.3	12.05	5.45		reject
Leland	(IV)	473.2				
October 1981						
North Shore vs.	1977	474.1	19.76	6.02		reject
Leland	(IV)	493.8				
North Shore vs.	1976	508.8	21.62	16.49		reject
Leland	(V)	530.4				
May 1982						
North Shore vs.	1978	445.2	17.11	10.20		reject
Leland	(IV)	462.3				
North Shore vs.	1977	478.3	17.47	4.41		reject
Leland	(V)	595.8				
North Shore vs.	1978	445.2	11.29	8.77		reject
Beaver Island	(IV)	456.5				
North Shore vs.	1977	478.3	1.33	4.59	3.98	accept
Beaver Island	(V)	479.6				
Leland vs.	1978	462.3	5.82	9.89	7.03	accept
Beaver Island	(IV)	456.5				
Leland vs.	1977	595.8	16.14	5.12		reject
Beaver Island	(V)	479.6				

The mean length of those fish in the October 1980 and the June 1981 samples which comprise the 1976 year class, deviated from the pattern observed for the 1977 year class in the Leland area (Table 16). The Leland fish in these samples were shorter than those fish from the other two areas. The Leland fish were much larger in the later samples. The first two samples from Leland may not have been truly representative, due to their small total sample sizes (n=33, n=18).

The assumption of normality, which is essential for valid probability statements concerning means using an analysis of variance, was tested and the hypothesis accepted for 17 of the 18 distributions ($p<.05$) (Appendix 11). A five percent probability of type I error implies that the hypothesis of normality will be rejected one time out of twenty, when the hypothesis is indeed correct. Hence, all contrasts were tested as though the hypothesis was valid. Adjustments of the degrees of freedom of the test statistics for the Scheffe interval were made, prior to testing differences between means, when the assumption of homogeneous variance was rejected (Box 1954). Results of the tests for homogeneous variance are in Appendix 11.

The mean length of the fish in the study area from the 1978 year class was compared between the May 1982 samples. This is the first sample where this age class was present in the catch in any appreciable numbers. The mean length of the fish in the 1978 year class from the Leland area were

Table 16. Mean length (L), mean weight (W) and number (N) of lake whitefish at various ages at each sampling date in northeastern Lake Michigan. Length is in millimeters. Weight is in grams.

Area	October 1980			June 1981			August 1981			October 1981			May 1982		
Age	L	W	N	L	W	N	L	W	N	L	W	N	L	W	N
North Shore															
2	416	600	1	322	317	1									
3	453	804	398	411	684	15	444	813	39	436	716	26	415	650	1
4	478	959	107	445	870	85	461	938	251	474	950	284	445	822	45
5	543	1390	5	490	1173	6	503	1294	9	509	1255	20	478	990	209
6							540	1530	1	520	1320	1	519	1308	8
7	518	1400	1												
10	673	3520	1												
Beaver Island															
3				405	598	6									
4				468	1015	149							457	926	53
5				502	1248	41							480	1048	108
6				512	1347	12							521	1506	7
7				524	1566	5									
8				562	1772	5									
9				580	1970	1									
10				718	4450	1									

Table 16. (continued)

Area	October 1980			June 1981			August 1981			October 1981			May 1982		
Age	L	W	N	L	W	N	L	W	N	L	W	N	L	W	N
Leland															
2										365	430	1			
3	464	981	65	443	985	2	439	1013	6	431	829	16	436	853	4
4	472	1026	33	466	1083	36	473	1171	63	494	1271	164	462	1072	30
5	567	1999	8	471	1123	18	528	1758	5	530	1596	27	496	1314	123
6				537	1685	10	547	1866	7	571	2089	18	548	1737	18
7	601	2611	3	540	1645	5	612	3022	5	603	2380	3	573	2011	27
8	677	3500	2	560	2035	2	605	2460	1	675	3625	2	615	2820	1
9	663	2875	2				670	4080	1	642	3140	2	652	3232	9
10				690	3435	1	655	3903	4	684	4348	5	658	3699	9
11				663	3620	2				678	4348	4	674	3652	5
12	659	4150	1	630	2942	4	630	3335	2	740	5310	1	675	4270	4
13													734	5055	2
Grand Traverse Bay															
4				458	1035	6									
5				482	1170	80									
6				510	1338	41									
7				538	1692	5									
8				558	1820	3									
10				648	3165	2									
11				660	2970	1									

larger than those from the North Shore area ($p<.05$). The Beaver Island fish from the 1978 year class were larger than the North Shore fish ($p<.05$), but were not significantly different ($p>.10$) from the Leland fish.

The available sex data indicates that the mean length at age for females is larger than for males in the Leland and North Shore areas (Table 17). The females are also heavier than males at any given age. This would be expected since many were in their prereproductive condition.

Table 17. Mean length at age in millimeters (L) and numbers (N) of male and female lake whitefish from the Leland and North Shore areas of Lake Michigan.

Age	Leland[1]				North Shore[2]			
	Males		Females		Males		Females	
	L	N	L	N	L	N	L	N
2			365.0	1			322.0	1
3	425.0	7	431.0	5	402.3	4	413.6	11
4	494.3	40	498.5	24	436.9	33	450.2	50
5	525.0	1			462.0	2	503.5	4
6	558.0	5	596.3	4				
9			630.0	1				
11			630.0	1				
13	720.0	1						
Total		54		36		39		66

1 sampled October 1981

2 sampled June 1981

Weight-Length Relationships

The transformed least squares predictive regressions of weight on length varied considerably between areas and among sampling dates (Table 18). Ricker (1973) suggests that a functional regression be fit to weight-length data because the dependent variable, length, is not fixed. A functional regression fits a line by minimizing the squared distances of the points from the regression line with respect to both variables simultaneously. A better predictive relationship would result from using a predictive least squares regression where the distances of the points from the regression line are minimized with respect to the dependent variable. If the joint distribution of the dependent and the independent variables is bivariate normal, least squares estimators are valid for testing hypotheses (Brownlee 1960).

A quadrant test (Cramer 1946) was implemented to test the joint distributions of weight and length for bivariate normality (Appendix 12). Dr. John Gill (personal communication) indicated that tests of the hypothesis of equality of regression slopes, using analyses of covariance techniques (Snedecor and Cochran 1967), result in valid conclusions when the probability of type I error is very small, even if the hypothesis of bivariate normality is rejected.

Since all contrasts of slopes were either highly significant ($p<.001$) or the variables were jointly distributed as bivariate normal, least squares regressions

Table 18. Predictive weight-length relationships for lake whitefish from the North Shore, Leland, Beaver Island, and Grand Traverse Bay areas of Lake Michigan. Total length was measured in millimeters and weight was measured in grams.

Sampling Location	Date	Predictive Regression	r^2
North Shore			
115,116	10/29/80	Log W = -13.15 + 3.24(Log L)	.80
117	6/29/81	Log W = -13.49 + 3.32(Log L)	.90
117(>400mm)	6/29/81	Log W = -12.83 + 3.20(Log L)	.76
117(males)	6/29/81	Log W = -12.12 + 3.09(Log L)	.84
117(females)	6/29/81	Log W = -13.89 + 3.39(Log L)	.92
218	8/24/81 8/25/81	Log W = -13.11 + 3.25(Log L)	.78
116,117	10/17/81 10/24/81	Log W = -13.35 + 3.28(Log L)	.78
216,218	5/17/82 5/18/82	Log W = -11.72 + 3.02(Log L)	.76
all samples		Log W = -12.37 + 3.12(Log L)	.78
Leland			
714,814	10/30/80	Log W = -14.79 + 3.53(Log L)	.96
812,814,912	6/15/81	Log W = -12.72 + 3.21(Log L)	.96
812,814,912	8/27/81	Log W = -13.89 + 3.40(Log L)	.94
812	10/21/81	Log W = -14.03 + 3.41(Log L)	.94
812(males)	10/21/81	Log W = -12.53 + 3.17(Log L)	.95
812(females)	10/21/81 10/22/81	Log W = -13.78 + 3.38(Log L)	.95
812,814,912	5/20/82	Log W = -13.61 + 3.35(Log L)	.96
all samples		Log W = -13.93 + 3.40(Log L)	.95
Beaver Island			
316	6/16/81	Log W = -12.60 + 3.17(Log L)	.88
317,418	5/18/82	Log W = -13.08 + 3.25(Log L)	.85
all samples		Log W = -12.82 + 3.21(Log L)	.87
Grand Traverse Bay			
615	6/14/81	Log W = -12.16 + 3.11(Log L)	.88

were chosen over geometric mean regressions due to their better predictive abilities. Examination of residual plots indicated the validity of the assumption of homogeneous variance of the predicted weights around the regression line, over the range of observed lengths for each area (Anscombe and Tukey 1963, Behnken and Draper 1972).

The increase in weight (W) of lake whitefish can be described as a function of length (L) to the power b from the relationship, $W=al^b$, where a is a constant. A natural log transformation of this equation results in a linear relationship with the slope b. Comparison of slope values of the transformed relationships is one manner of determining differences between fish stocks. A higher slope value for one population compared to another indicates that that the fish from the former population are heavier at a given length than the fish from the poplulation with the lower slope value. The same is true for comparisons of the same stock at different times of the year.

The slopes of the weight-length regressions were significantly different ($p<.001$) between the North Shore and Leland areas at all sampling dates (Table 19). The same was true for all contrasts between the Leland and Beaver Island areas. The fish from the Leland stock are heavier at a given length than the fish from the Beaver Island and North Shore area, with one exception (Table 20). The June 1981 sample from the North Shore had a higher slope value (3.32) for the weight-length regression than the Leland sample

Table 19. Tests of equality of slopes of the weight-length regressions between sampling areas using an analysis of covariance (Snedecor and Cochran, 1967).

Location	Sample Size	Slope	Residuals df	Residuals SS	Residuals MS	F ratio	α
October 1980							
North Shore	513	3.24	511	3.877	0.0076		
Leland	114	3.53	112	0.787	0.0070		
Sum			623	4.664	0.0075		
Pooled	627	3.57	624	6.042			
Difference			1	1.378	1.3776	183.91	< .001
June 1981							
North Shore	107	3.32	105	0.818	0.0078		
Leland	81	3.21	79	0.592	0.0075		
Sum			184	1.410	0.0077		
Pooled	188	3.40	185	1.603			
Difference			1	0.193	0.1927	25.16	< .001
North Shore	107	3.32	105	0.818	0.0078		
Beaver Island	219	3.17	217	1.587	0.0073		
Sum			322	2.405	0.0075		
Pooled	326	3.21	323	2.417			
Difference			1	0.011	0.0118	1.58	> .10
Beaver Island	219	3.17	217	1.587	0.0073		
Leland	81	3.21	79	0.592	0.0075		
Sum			296	2.179	0.0074		
Pooled	300	3.27	297	2.584			
Difference			1	0.406	0.4056	55.10	< .001
August 1981							
North Shore	300	3.25	298	1.874	0.0063		
Leland	94	3.40	92	0.909	0.0099		
Sum			390	2.784	0.0071		
Pooled	394	3.71	391	4.139			
Difference			1	1.355	1.3550	189.77	< .001
October 1981							
North Shore	331	3.28	329	2.484	0.0076		
Leland	244	3.41	242	2.639	0.0109		
Sum			571	5.123	0.0090		
Pooled	575	3.69	572	7.717			
Difference			1	2.594	2.5943	289.22	< .001
May 1982							
Beaver Island	169	3.25	167	1.198	0.0072		
North Shore	263	3.02	261	1.963	0.0075		
Sum			428	3.161	0.0074		
Pooled	432	3.14	429	3.505	0.0082		
Difference			1	0.344	0.3437	46.51	< .001
Leland	251	3.35	249	2.384	0.0096		
Beaver Island	269	3.25	167	1.198	0.0072		
Sum			416	3.582	0.0086		
Pooled	420	3.51	417	4.385	0.0105		
Difference			1	0.803	0.8029	93.25	< .001
North Shore	263	3.02	261	1.963	0.0075		
Leland	251	3.35	249	2.384	0.0096		
Sum			510	4.347	0.0085		
Pooled	514	3.64	511	6.848	0.0134		
Difference			1	2.501	2.5010	293.55	< .001

Table 20. Slopes (b) of the predictive weight-length regression for lake whitefish from northern Lake Michigan.

Location	Month and Year of sample	Sample Size	b	Reference
Leland	May-June, 1981-1982	313	3.27	This study
Leland	August 1981	94	3.40	This study
Leland	October, 1981-1982	358	3.48	This study
North Shore	May-June, 1981-1982	370	2.92	This study
North Shore	August, 1981	300	3.25	This study
North Shore	October, 1981-1982	844	3.31	This study
Beaver Island	May-June, 1981-1982	388	3.21	This study
Grand Traverse Bay	May-June, 1981	140	3.11	This study
North and Moonlight Bays	June-July, 1977-1979	1,832	3.36	Ebner, 1980
North and Moonlight Bays	Sept.-Oct., 1975-1979	1,623	3.51	Ebner, 1980
Big Bay de Noc	May, 1977-1979	1,462	2.95	Ebner, 1980
Big Bay de Noc	Sept.-Oct., 1976-1979	1,668	3.23	Ebner, 1980
Grand Traverse Bay (outer)	June, 1978-1979	97	3.03	Rybicki, 1980
Ile aux Galets	June, 1978	125	3.21	Rybicki, 1980
Northern Green Bay	May, 1979	63	2.95	Rybicki, 1980
Peshtigo Reef	June, 1977	269	2.96	Gunderson, 1978
Chambers Island	June, 1977	298	3.14	Gunderson, 1978
Grand Traverse Bay (lower)	unknown, 1971-1973	486	3.46	Patriarche, 1977
North Shore	unknown, 1971-1973	unknown	3.28	Patriarche, 1977
North Shore	May, June, Oct., 1966	683	2.91	Piehler, 1967
East of Seul Choix	October, 1966	328	3.12	Piehler, 1967
Gull Island	Aug.-Sept., 1950	254	2.99	Caraway, 1951
High Island	Aug.-Sept., 1950	174	2.82	Caraway, 1951.

(3.21). This sample from the North Shore area contained a disproportionate number of sublegal fish, as mentioned previously. These smaller fish influenced the slope of the regression line considerably. When the June 1981 sample (b=3.32) was combined with the May 1982 sample (b=3.02) from the North Shore area, the resultant regression slope (2.92) was lower than either of the separate regression slopes. Also, if only those fish larger than 400 millimeters are used in the regression, the slope was 3.20. The influence of the presence of the sublegal fish on the slope value for the June 1981 North Shore sample is almost as large as the differences in slope being tested. Therefore, tests involving comparisons of slopes from this sampling date should be interpreted with caution.

The North Shore and Beaver Island comparisons of slope were not consistent with previous results involving these samples. The June 1981 slopes were not significantly different ($p>.10$). The May 1982 slope from the Beaver Island sample was larger than that for the North Shore sample ($p<.001$). Previous comparisons of vital statistic parameters between these areas showed similarities for the May 1982 samples and differences for the June 1981 samples. The nonrepresentative nature of the spring 1981 North Shore sample most likely biased this sample, as noted previously. Significant differences between May 1982 samples are not surprising since the stocks in these areas are believed to be distinct.

Slope values can be used as an index of the relative condition of a poplulation of fish. They may be influenced by factors such as the relative abundance of food, genetic characteristics of the stocks, optimality of local temperature regimes, and reproductive conditions of the fish.

Seasonal variability of the values of the slopes from the weight-length regressions was obvious within each sampling area (Table 20). The higher slope values for the fall samples suggest the presence of whitefish, which are heavier at a given length, onto the spawning grounds. Presumably this heaviness is a result of the developement of reproductive products. It appears from the available sex data that the females are largely responsible for the higher fall slope values. The slope value for the weight-length relationship of the females in the North Shore June 1981 sample was 3.39 compared to the slope value of 3.09 for the males in that sample (Table 18). The corresponding slope values for the Leland October 1981 sample were 3.38 for the females and 3.17 for the males.

Since the market preference for whitefish is in the round (not eviscerated), only two samples containing sex and maturity information were available. Because samples earlier in the year were not available, it was not possible to discern the true magnitude of the differences between male and female weight-length regressions, that is solely a result of ovarian egg developement.

Values of the slope of the predictive weight-length relationships from other investigations of lake whitefish in northern Lake Michigan are provided for comparison in Table 20. The wide range of reported values further illustrates the variability of this parameter both seasonally and between locations. The spring 1981 Grand Traverse Bay sample has a small slope (3.11), similar to that reported for the outer portion of the Bay (3.03) (Rybicki 1980), yet is quite different from the slope (3.46) reported for the lower Bay (Patriarche 1977). The North Shore slope values closely resemble those reported from this area by Piehler (1967) and Patriarche (1977) and are similar to those values reported for the heavily exploited Big Bay de Noc stock (Ebner 1980).

Mean Back-Calculated Growth

The legal-sized lake whitefish from the Leland stock tend to be larger at the time of annulus formation than those from the North Shore, Beaver Island, and Grand Traverse Bay areas (Figure 10, Table 21). It appears that the fish from the North Shore and Beaver Island stocks are larger at the prerecruited ages than those fish from Leland. The mean back-calculated lengths at the earlier ages represent an extrapolation beyond the values of the dependent variable (total scale radius) used in the regression, and should be regarded with caution.

The growth curves are nearly identical for the North Shore, Beaver Island, and Grand Traverse Bay areas for ages I-VI. Only two fish, out of the 1514 sampled in the North Shore area, exceeded six years of age, thus no comparisons were made beyond this age. The Beaver Island and Grand Traverse Bay samples exhibit similar mean back-calculated lengths for ages VI-VIII. Insufficient sample sizes ($n<5$) for fish aged IX or older do not allow for meaningful comparisons in these areas.

The scale radius-body length equations calculated from the combined samples for each area are given in Table 22. Regressions were computed for the Beaver Island samples separately to determine if obvious differences in back-calculated lengths resulted. The strong similarity between the separate regressions and associated mean back-calculated lengths for the Beaver Island samples

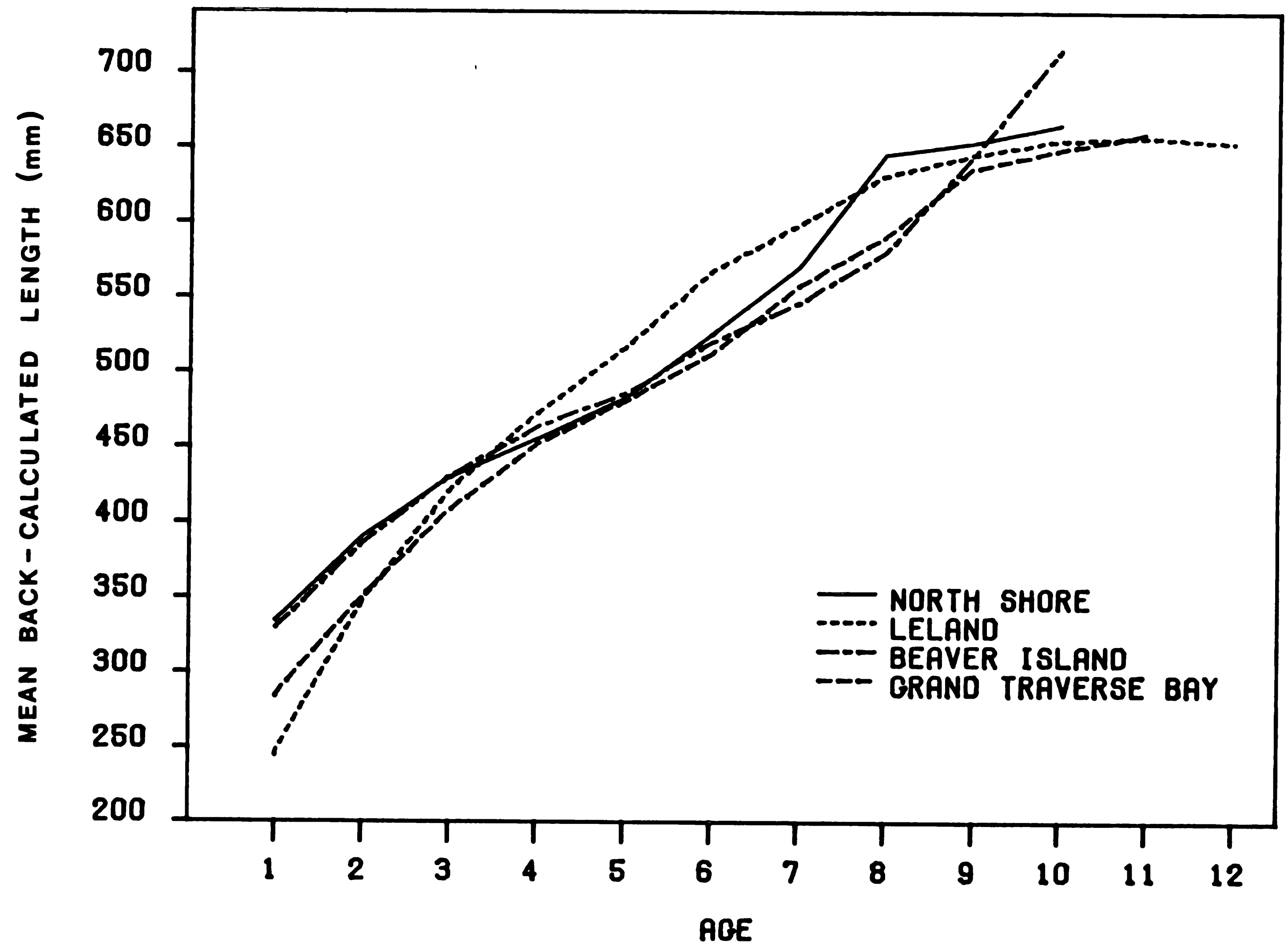


Figure 10. Mean back-calculated length (mm) at age of lake whitefish sampled in northeastern Lake Michigan.

Table 21. Comparisons of mean back-calculated lengths (mm) at annulus formation for lake whitefish from northeastern Lake Michigan.

Location	Dates	N	Age											
			1	2	3	4	5	6	7	8	9	10	11	12
North Shore[1]	1980-82	1514	334	390	430	455	482	525	570	646	653	666		
Leland[1]	1980-82	761	245	348	421	472	516	567	599	631	646	655	657	654
Beaver Island[1]	1980-82	407	329	386	430	463	486	520	546	580	645	715		
Grand Traverse Bay[1]	1980-82	138	284	350	408	452	480	512	558	591	637	649	660	
Epoufette[2]	1968-73	183	160	305	411									
Naubinway and Brevort[3]	1967	496	223	310	424	500	561							
Naubinway[4]	1966	238	185	320	424	490								
Epoufette[4]	1966	124	183	316	424	478								

References

[1]this study

[2]unpublished data, Michigan Department of Natural Resources

[3]Brown (1968)

[4]Piehler (1967)

Table 22. Predictive regressions of total fish length in millimeters (L_c) on the anterior scale radius in millimeters[1] (S) for combined 1980 - 1982 samples of lake whitefish from northeastern Lake Michigan. The spring 1981 and spring 1982 Beaver Island samples are presented separately for comparison.

Location (Grids)	N	Predictive Regression	r^2
Leland (714, 812, 814, 912)	784	$L_c = 131.31 + 3.36\ S$	.702
Grand Traverse Bay (615)	140	$L_c = 207.63 + 2.49\ S$	.614
North Shore (115, 116, 117, 216, 218)	1577	$L_c = 268.84 + 1.94\ S$	.430
Beaver Island (316, 317, 418)	407	$L_c = 260.51 + 2.03\ S$	.456
(316)	219	$L_c = 256.44 + 2.05\ S$	.452
(317, 418)	169	$L_c = 249.46 + 2.17\ S$	.498

[1] S is the radius of the 22X magnified scale.

governed the choice of using the combined spring data for all subsequent discussion regarding mean back-calculated growth.

Mean back-calculated growth may be influenced by differential fishing mortalities among locations, availability of food, differential competitive interactions, or genetic differences between stocks. Healey (1980) investigated the effects of various levels of experimental exploitation on previously unexploited stocks and concluded that growth rates of whitefish increase with increased exploitation.

The higher back-calculated growth rates in the Leland stock, compared to the more heavily exploited North Shore stock, indicates that some factor, other than exploitation rate, was responsible for the differernce observed. The abundant 1977 year class, which was more prevalent in the catch from the North Shore and Beaver Island areas, may exhibit slower growth as a result of more prevalent intraspecific density-dependent factors, such as intraspecific competition for food and space. Also, the higher fishing pressure in the North Shore and Beaver Island areas would tend to remove a significant portion of the faster growing members of a cohort as age III and age IV fish, thus leaving the slower growing fish to be used for the back-calculation of lengths at the later annuli.

Lee's phenomenon, a commonly observed systematic error associated with back-calculation techniques, was not present in my calculations (Appendix 13). This effect, which can be attributed to the selection of the faster growing fish at earlier ages or improper aging, results in calculated lengths that are higher at the early annuli for younger fish than for older fish.

Conversely, a reversed Lee's phenomenon appeared in this study. The same trend was present in the calculations for whitefish in northwestern Lake Michigan (Humphreys 1978, Gunderson 1978). The higher mean back-calculated lengths at the early annuli, when computed from the older fish, appears to represent a loss of predicting power of the scale-length regressions at the upper range of the values of scale radii. This in turn results in higher correction factors, which act to increase all back-calculated lengths that require adjustment.

Instantaneous Growth Rates

The instantaneous true growth rates (G) were larger for ages II-VII in the Leland samples than in the North Shore and Beaver Island samples (Table 23, Figure 11). Instantaneous growth rates, for the combined spring samples, ranged from 0.523 to 0.043 for ages III-XII from the Leland area and 0.435 to 0.085 for ages II-VI from the North Shore area. The instantaneous growth rates for the combined spring samples from the Beaver Island area ranged from 0.315 to 0.022 for ages III-XI. The values of G from Grand Traverse Bay are higher than the values from the North Shore and Beaver Island stocks. The instantaneous growth rates for fish from Grand Traverse Bay are less than those from the Leland stock.

An occasional fish older than age XII was encountered in the samples, yet difficulty in discerning the annuli while aging and their relative scarcity did not warrant the calculation of growth rates.

The instantaneous growth rates increased from spring to fall (Table 23). The change is primarily due to the higher slope values (b) of the predictive weight-length regressions for the fall samples (Table 18), a result of the development of reproductive products.

The growth rates computed in this study were within the range of those reported from northwestern Lake Michigan whitefish (Table 23). The more lightly exploited North-Moonlight Bays stock (u=30%) showed higher growth

Table 23. Instantaneous true growth rates (G) for lake whitefish from northern Lake Michigan. The predictive length-weight exponent and back-calculated lengths were used in the formula: $G = b\,(\log_e L2 - \log_e L1)$ (Ricker, 1975).

Location (Dates)	Slope (N)	Age 1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	Reference
North Shore Springs of 1981 & 82	2.92 (370)		.435	.301	.175	.102	.085							This study
Summer 1981	3.25 (300)			.332	.182	.114	.052							This study
Falls of 1981 & 82	3.31 (844)		.513	.314	.185	.136	.070	.106			.063			This study
Leland Springs of 1981 & 82	3.27 (310)			.523	.373	.170	.141	.111	.075	.059	.059	.043	.043	This study
Summer 1981	3.40 (94)			.595	.354	.201	.143	.109	.136	.061	.037		.020	This study
Falls 1981 & 82	3.48 (357)		1.326	.679	.393	.244	.191	.115	.087	.059	.038	.042	.049	This study
Beaver Island Springs of 1981 & 82	3.21 (388)			.315	.228	.128	.100	.087	.087	.048	.022			This study
Grand Traverse Traverse Bay Spring 1981	3.40 (140)				.289	.156	.128	.121	.081		.053	.040		This study
Big Bay de Noc Falls 1976-79	3.23 (1668)	1.249	.818	.471	.285	.196	.158	.089	.086	.068				Ebner, 1980
Springs 1977-79	2.95 (1462)	1.662	.925	.531	.279	.210	.147	.112	.108	.074				Ebner, 1980
North & Moonlight Bays Falls 1975-1979	3.51 (1623)	2.212	1.170	.655	.366	.243	.157	.112	.087	.074				Ebner, 1980
Springs 1975-1979	3.36 (1832)	1.678	.939	.562	.514	.235	.160	.116	.086	.071				Ebner, 1980
Peshtigo Reef & Chambers Island Spring 1977	3.15 (567)	1.767	.890	.515	.315	.198	.122	.112	.085	.074				Gunderson, 1978

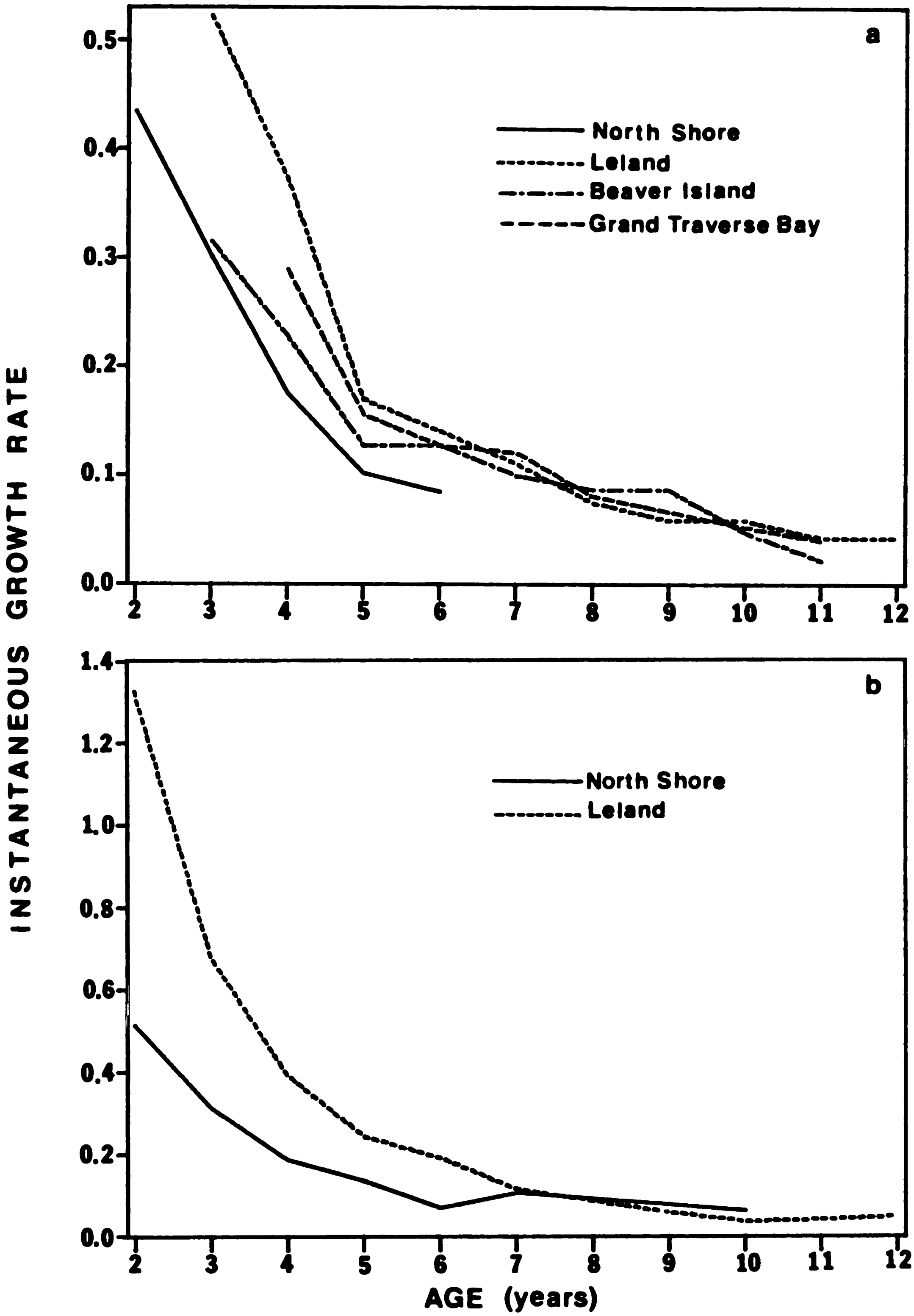


Figure 11. Instantaneous growth rates from spring (a) and fall (b) samples of lake whitefish at various ages from northeastern Lake Michigan.

rates than the more heavily exploited Big Bay de Noc stock (u=56%)(Ebner 1980). This is consistent with the findings from the North Shore and Leland stocks.

Age at Recruitment

The average lake whitefish from the North Shore and Beaver Island stocks was recruited into the trap net fishery at an earlier age than the average fish from the Leland stock (Appendix 14). The estimated age at recruitement for the North Shore and Beaver Island stocks was the same (3.1 years). Fish from the Leland stock were recruited at 3.2 years of age.

Ebner (1980) found whitefish from the more heavily exploited Big Bay de Noc stock to be recruited at an earlier age (3.25 years) than fish from the more lightly exploited North-Moonlight Bays stock (3.40 years). My results are consistent with the findings from this study.

The back-calculated lengths at the prerecruited ages are larger in the North Shore area than in the Leland area. At approximately 3.25 years of age, the Leland fish are longer than the North Shore fish and retain this advantage throughout their lives (Appendix 14). The fish from the Beaver Island area show nearly identical back-calculated growth as the North Shore stock, thus accounting for the similar ages at recruitment.

The fish from the Grand Traverse Bay sample are not directly comparable, due to the different minimum size limit and selectivity characteristics of the purse seine. These fish are recruited into the purse seine fishery at 5.1 years of age.

Sex and Maturity

The data pertaining to sex and maturity are rather limited. This information was collected only when the whitefish were not marketed in the round (not eviscerated). The two available samples were not obtained at the same time of the year, thus not lending themselves readily to comparison.

The male-female ratio of the fish in the North Shore sample was 1:1.7. This sample was collected in August 1981. The Leland sample, which was obtained in October 1981, exhibited a male-female ratio of 1.5:1 (Table 24). The observed differences in sex ratio are probably a result of the different sampling dates. Hoagman (1973) found that whitefish segregate by sex and arrive at the spawning grounds at different times. This may explain the differences in sex ratio observed between the areas.

Ninety-one percent of the North Shore sample was mature. All whitefish longer than 410 millimeters were mature. Essentially the same percentage of males (90%) and females (91%) were mature in the North Shore sample (Table 24).

Eighty-two percent of all fish in the Leland sample were mature. The Leland sample consisted of larger fish than the North Shore sample, yet only 66.7 percent of the females and 92.6 percent of the males were mature. All males longer than 460 millimeters were mature and 50 percent of the males 420-439 millimeters were mature. All females

Table 24. Percent maturity of male and female whitefish in 10 millimeter length categories from the North Shore and Leland areas.

Length (mm)	Females Immature	Females Mature	Females % Mature	Males Immature	Males Mature	Males % Mature
North Shore (June 1981)						
320	1	0	0.0			
360				1	0	0.0
380	4	0	0.0	1	0	0.0
390	0	2	100.0	1	1	50.0
400	1	3	75.0	1	3	75.0
410	0	3	100.0	0	2	100.0
420	0	6	100.0	0	4	100.0
≥430	0	46	100.0	0	25	100.0
Total	6	60	90.9	4	35	89.7
Leland (October 1981)						
360	1	0	0.0			
400	1	0	0.0	1	0	0.0
410	1	0	0.0	0	1	100.0
420				1	1	50.0
430				1	1	50.0
440	2	0	0.0	0	1	100.0
450	3	0	0.0	1	4	80.0
460	2	0	0.0	0	2	100.0
470	1	0	0.0	0	3	100.0
480	0	2	100.0	0	6	100.0
490	1	4	80.0	0	4	100.0
≥500	0	18	100.0	0	27	100.0
Total	12	24	66.7	4	50	92.6

shorter than 480 millimeters were immature.

The fish from the North Shore sample matured at an earlier age than those from the Leland sample (Table 25). Eighty percent of the age III fish and 93 percent of the age IV fish in the North Shore sample were mature, compared to 33 percent and 89 percent of the age III and age IV fish, respectively, in the Leland sample. All fish age V and older were mature in both areas.

Early maturation is one mechanism by which the whitefish from the North Shore stock may compensate for the removal of the older spawning fish by the fishery. This allows the stock to reproduce in large numbers prior to being fully vulnerable to the fishing gear. More data concerning length at maturity are necessary to determine the proportion of each stock of interest that reproduces prior to reaching legal size. The data suggest that the difference between the length at recruitment and the length at maturity may be quite small. Since the trap nets used for whitefish only exhibit 31 percent efficiency of capture for fish 432 millimeters in total length and exhibit a peak for fish 489 millimeters in total length (Eschenroder et al 1980), the margin of safety for reproduction is broadened. It appears from the consistently high yields of whitefish from the North Shore area that reproduction is not a factor limiting whitefish abundance in that area.

Piehler (1967) found 41 percent of the females and 77 percent of the males in northern Lake Michigan to be mature.

Table 25. Percentage of lake whitefish that were mature at each age in the North Shore and Leland areas of Lake Michigan.

Age	Leland[1]			North Shore[2]		
	# Immature	# Mature	% Mature	# Immature	# Mature	% Mature
2	1		0	1		0
3	4	8	33	3	12	80
4	7	57	89	6	77	93
5	0	1	100		6	100
6		9	100			
7		1	100			
9		1	100			
11		1	100			
13		1	100			
Total	16	74	82	10	95	90

[1] sampled October 1981
[2] sampled June 1981

His samples contained primarily age II fish. Of the age III fish in his samples, all of the females (n=42) and 92 percent of the males (n=22) were mature. Healey (1975) noted an inverse relationship between age at maturity and the level of exploitation for whitefish in several northern lakes. The results of the present study are consistent with this trend.

Bell et al (1977) found mature whitefish of a given age to be considerably larger than the immature fish of the same age. They suggest that maturity is reached at a given length, irrespective of age. Spangler (1970) found male whitefish in Lake Huron to mature for the first time at age III and females at age IV. Growth rates for female versus male whitefish at the prerecruited ages are necessary to discern whether maturity is truly reached at a given length, or at a given age.

Dryer (1963) found that Lake Superior whitefish which were shorter than 368 millimeters were immature, and those which were larger than 442 millimeters were mature. These studies indicate that exploited populations of whitefish tend to mature when they reach a total length of 400-450 millimeters in total length, corresponding to three or four years of age. Also, males tend to mature at an earlier age and smaller size than females.

SUMMARY

1. The results of this investigation suggest the existence of three discrete stocks of whitefish within the study area. These include one North Shore stock, one Leland stock, and at least one Beaver Island stock.

2. The samples from the Leland, Grand Traverse Bay, and Beaver Island (grid 316) areas contained broader age compositions than those from the North Shore and Beaver Island (grids 317 and 418) areas. The differences between the age compositions for the 1981 Beaver Island sample (grid 316) and the 1982 Beaver Island sample (grids 317 and 418) suggest that separate subpopulations, or distinct stocks, were sampled at these times.

3. The 1977 year class was extremely abundant and dominated the catch in all areas on all sampling dates. This year class ranged from 32-56 percent of the Leland catch, 63-64 percent of the Beaver Island catch, and 74-86 percent of the North Shore catch (Table 6). The mean age and the mean size of the sampled whitefish were strongly influenced by the presence of the 1977 year class.

4. The North Shore stock is considerably larger than the Leland stock. Population numbers were estimated at 1.7 million legal sized whitefish in the North Shore area and 260 thousand in the Leland area. No population estimates were possible for the Beaver Island and Grand Traverse Bay areas.

5. Annual exploitation rates were estimated at 49.6 percent in the North Shore stock and 24.1 percent in the Leland stock. The annual mortality rates were estimated at 70.7 percent and 58.6 percent in these areas, respectively.

6. The instantaneous total mortality rate (Z) estimated from tag returns, was larger in the North Shore stock (1.229) than in the Leland stock (0.881). Estimates of the total instantaneous mortality in the Grand Traverse Bay and Beaver Island areas, computed from catch curves, were 1.195 and 1.073, respectively.

7. The instantaneous fishing mortality (F) represented a larger percentage (70.1%) of the total instantaneous mortality in the North Shore area than in the Leland area (41.3%). Instantaneous natural mortality rates (M) were estimated to be 0.368 in the North Shore area and 0.517 in the Leland area. These mortality figures are well within the range of the values reported for other stocks of whitefish in the Great Lakes and Canada.

8. The slopes of the natural log transformed weight-length relationships were higher in the Leland area than in the North Shore and Beaver Island areas. The slope values were higher in the fall samples than in the spring samples.

9. The length compositions were broader, and the mean lengths were higher in the Leland, Grand Traverse Bay, and Beaver Island (grid 316) samples than in the North Shore and Beaver Island (grids 317 and 418) samples. The 1977 year

class stongly influenced the mean lengths and the length compositions of the sampled catch in all areas, throughout the study.

10. The mean length at age of the members of the 1977 year class in the Leland area were significantly larger, at all sampling dates, than the corresponding mean lengths in the North Shore area.

11. Comparisons of length compositions between the North Shore and Leland samples all showed significant differences ($p<.001$). The Beaver Island (316) length composition was not different from the Leland sample in June 1981 ($p>.10$), but was different from the North Shore sample ($p<.001$). The May 1982 Beaver Island sample (grids 317 and 418) was similar to the North Shore sample ($p>.25$) and significantly different from the Leland sample ($p<.001$).

12. Back-calculated growth and the instantaneous growth rates indicate that the Leland stock is faster growing than the other stocks for all of the recruited ages. The mean back-calculated lengths at age are nearly identical for the North Shore, Grand Traverse Bay, and Beaver Island areas.

13. The North Shore and Beaver Island fish are recruited into the trap net fishery at earlier ages than are the fish from the Leland area. The Leland fish are not only recruited at an older age but also mature at a larger size than the North Shore fish.

APPENDICES

Appendix 1. Monthly tag returns (R) and commercial catch (C) of lake whitefish by statistical grid during 1981 for the North Shore area. Catch is in pounds and recaptures are in numbers.

Grid	January C	January R	February C	February R	March C	March R	April C	April R	May C	May R	June C	June R
115									1,443		3,672	
116	3,154		11,364		359				40	7	13,227	2
117									7,061		1,869	
118			238						4,858		2,051	
213			660		433		22,612		104,061	1	33,080	
214					11,740				8,065			
215					4,675		10,753	4	14,210		6,766	
216			?	5			83,940	14	41,567	19	30,743	21
217							13,490	8	74,395	2	35,757	14
218							3,672		79,290		36,970	
219	20								49,775	4	13,906	2
220	3,070		29		2				58		181	
313	1,083				882							
314	1,274				1,183		4,996		400		2,040	
315							8,364		18,320	1	3,910	
316							51,584	1	49,030		41,253	
317									1,053	2	2,160	
318	70						4,923		9,254		899	
319	4,652		4,825				1,981		1,197		976	
320							105		500		206	
408	2,065		681		3,090		14,184		652	2		
604							3,265		190		3,006	
806									359		1,781	1
301[1]											3,203	
302												
303												
Sub Total				5		0		27		38		40
Unknown Grid				1		1		2		1		3
Total	15,388		17,797	6	22,364	1	223,829	29	465,778	39	237,656	43

Appendix 1. (Continued)

Grid	July		August		September		October		November		December		Unknown	Totals	
	C	R	C	R	C	R	C	R	C	R	C	R	R	C	R
115					101		50,398	10	3,396					61,010	10
116	41,522		14,545		17,025		21,172	58	7,593		966		1	130,967	68
117	?	11	83		13,705		165,427	18	10,572		12,379			211,094	19
118					725		8,509							16,381	0
213	1,007		161		26,189		59,943	5	1,894					250,040	6
214			5,278											25,083	0
215	9,326		12,003		4,524		23,678	2			9,447		4	95,382	10
216	82,872	15	47,425	6	8,202	13	14,864	3	?	1	21,356		4	330,969	101
217	44,565		16,100		7,630								5	191,937	29
218	98,888		47,324		27,980		2,799							296,923	0
219	33,993	12	18,910	1	10,298		1,043				952			128,897	19
220	21		822		60		1,129							5,372	0
313	3,723						60							5,748	0
314	21,719		4,946								17,952			54,480	0
315	4,270		2,500		19,140		14,977		150					71,631	1
316	41,973		37,021		34,005		54,290		290		3,399			312,845	1
317	100		500				1,285				11,788			16,886	2
318	1,053		5,899		5,415		1,798							29,311	0
319	51		684		368		5,863							20,597	0
320	164		133		1,115		21,906							24,129	0
408	2,324		1,299		6,507		821				16,727	1		48,350	2
604	160										5,010	1		11,631	1
806	1,473		90		3,335		11,266							18,304	1
301[1]	4,924		4,734		1,903		20							14,784	0
302		1		1											2
303				1											1
Sub-Total		29		9		13		96		1		1	14		273
Unknown Grid		16		16		11		11							62
Total	394,128	45	220,457	25	188,227	24	463,248	107	23,895	1	99,974	1	14	2,372,751	335

[1]301, 302, and 303 are Lake Huron grids.

Appendix 2. Monthly tag returns (R) and commercial catch (C) of lake whitefish by statistical grid during 1981 for the Leland and Grand Traverse Bay areas. Catch is in pounds and recaptures are in numbers. Grand Traverse Bay tag returns are in parentheses.

Grid	January		February		March		April		May		June	
	C	R	C	R	C	R	C	R	C	R	C	R
614											287	
615							694		2,147		24,634	2(1)
616	1,287				1,980		10,657		6,781		12,459	
712	18				73				243			
713									1,492			
714	690	1					6,060		2,194	3	771	1
715	2,795		1,289		572		2,848		14,437		12,738	
812					2,125		3,755		6		?	1
813					375		7,626		367			
814							6,494	21	4,173	4	2,819	1
911					2,668				3,358			
912					498		11,910		1,880		10,904	4
1810							25,909		51,522	2	37,864	1
706 (Wisc)	5,950		6,342		10,345	1	13,128		26,825		10,410	
Total	10,740	1	7,631	0	18,636	1	89,081	23	115,425	9	112,886	10(1)

Appendix 2. (Continued)

Grid	July		August		September		October		November		December		Unknown	Totals	
	C	R	C	R	C	R	C	R	C	R	C	R	R	C	R
614														287	0
615	10,551	5	?	(1)			?	1						38,026	8 (2)
616	25,007	2 (1)	4,682	1	5,161	1	5,535	1			9,684		1	83,233	6 (1)
712											516			850	0
713														1,492	0
714	676	4												10,391	9
715	29,614	1	16,087	1 (1)	13,711		9,955	1 (1)			3,173			107,219	3 (2)
812	?	1	21,894		5,964		5,986							39,730	2
813					482		601							9,451	0
814							99		464	1				14,049	27
911														6,026	0
912	24,365		3,083	1	5,395	2	3,897	2						61,922	9
1810	55,288	1	13,926		24,931		41.191							250,631	6
706 (Wisc)	3,745		4,336		30,261		198,812				34,697			344,851	1
Total	149,246	14 (1)	64,008	3 (2)	85,895	3	266,076	5 (1)	464	1	48,070	0	1	968,158	71 (5)

Appendix 3. Estimation of the instantaneous rate of tag loss (L) for the 1980 Floy dart tags.

Relationship: $(1 - \pi) = e^{-Lt}$

where π = percentage of double-tagged fish which are returned with only 1 tag

e = base of the natural logarithm

L = instantaneous rate of tag loss

t = time in years

Information required to estimate L:

$\pi = 1/15 = .0667$

Date of return of the incomplete double tag: 6/21/82

Date of double tagging: 11/3/81

Number of days between 11/3/81 and 6/21/82: 231 days

Midpoint of interval between 11/3/81 and 6/21/82: 115.5 days
115.5 days/365 days = 0.316 years

Estimate of L:

$$(1 - .0667) = e^{-L(.316)}$$

$$.9333 = e^{-L(.316)}$$

$$.0690 = L(.316)$$

$$L = .2184$$

Appendix 4. Comparison of ages assigned by the two principal scale readers, including calculation of the index of average percent error.

Age assigned by reader #1	N	Agreement by reader #2: Total		+/- 1 year	
		Number	Percent	Number	Percent
3	74	71	95.9	74	100.0
4	63	51	81.0	63	100.0
5	33	23	69.7	33	100.0
6	13	8	61.5	13	100.0
7	6	4	66.7	6	100.0
9	1	0	0.0	1	100.0
11	1	0	0.0	1	100.0
14	1	1	100.0	1	100.0
7-14	9	5	55.6	9	100.0
Total	192	158	82.3	192	100.0

Index of average % error (I): 2.35 %

$$I = 1/N \sum_{i=1}^{N} \left[1/R \sum_{i=1}^{R} \frac{|X_{ij} - X_j|}{X_j} \right] \times 100$$

$$I = (4.51/192) \times 100 = 2.35\ \%$$

Appendix 5. Comparison of ages assigned by scales and fin rays from lake whitefish in the North Shore area of Lake Michigan, including calculation of the index of average percent error.

Scale Age	N	Fin Ray Agreement: Total		Fin Ray Agreement: +/- one year	
		Number	Percent	Number	Percent
3	7	5	71.4	7	100.0
4	29	29	100.0	29	100.0

Index of average % error (I): 0.79 %

$$I = 1/N \sum_{i=1}^{N} \left[1/R \sum_{i=1}^{R} \frac{|X_{ij} - X_j|}{X_j} \right] \times 100$$

$$I = (0.286/36) \times 100 = 0.79\ \%$$

Appendix 6. Comparison of girth - length relationships between northeastern Lake Michigan and Hammond Bay, Lake Huron. Girth (G) and length (L) are in millimeters.

Location	Predictive Equation	r^2	N	Reference
Hammond Bay, Lake Huron	$G = -29.1 + 0.572\ L$	.935	2142	Eschenroder et al, 1981
North Shore, Lake Michigan (grids 216, 218)	$G = -32.98 + 0.578\ L$	.701	86	This study
Empire-Leland, Lake Michigan (grid 812)	$G = -68.8 + 0.695\ L$	.962	25	This study

Appendix 7. Population estimates of lake whitefish (≥430 mm) in Lake Michigan for the North Shore, Leland and Leland spawning grounds during November 1980. The North Shore estimate includes grids 115-119, 213-220. The Leland estimate includes grids 615, 714, 812-814 and 911-912. Estimates include only catch and recaptures from cooperating fishermen.

	North Shore area	Leland area	Leland spawning grounds
M	1603	376	415
C	797,130	126,872	2039
C_a	717,338	121,840	-
R	313	57	39
R_a	363.22	63.08	40.40
Mean weight (kg)	0.8634	1.2474	1.2474
Biomass (kg)	1,435,996	329,422	9501
95% Confidence Interval[1]	(1,295,697-1,591,501)	(256,884-420,294)	(6986-13272)
Numbers	1,663,207	264,087	7616
95% Confidence Interval[1]	(1,500,708-1,843,316)	(205,907-336,942)	(5601-10640)

M = number of fish tagged in November 1980 that were larger than 430 mm.

C = total catch of cooperating fishermen in pounds during 1981

C_a = C adjusted for recruitment of fish that were less than 430 mm in November 1980

R = total number of recaptures of M marked fish

R_a = R adjusted for tag loss

[1] Confidence intervals are Poisson approximations (Ricker 1975)

Appendix 8. Calculations of the adjustment of the 1981 commercial harvest by cooperating fishermen, of lake whitefish in the North Shore and Leland areas for the recruitment of those fish that were sublegal (430 mm) in November 1980, yet grew into the harvestable portion of the population during 1981.

Mean Length of legal portion of the 1977 year class in sampled catch. Standard deviation is in parentheses.

Area	Sampling dates			
	11/4/80	6/29/81	8/24/81	10/17,24/81
North Shore	456.2 (17.3)	458.9 (20.7)	461.9 (19.0)	474.0 (19.0)
Leland	465.9 (15.5)	469.0 (23.7)	474.0 (19.4)	494.3 (31.0)

Estimated mean length of fish that were 430 mm in November, 1980, at subsequent sampling dates.

Area	Sampling dates			
	11/4/80	6/29/81	8/24/81	10/17,24/81
North Shore	430.0	432.7	435.7	447.8
Leland	430.0	433.1	438.1	458.1

<u>Recruitment estimate</u>: Proportion of the catch at each sampling date that was shorter than the estimated mean length of those fish that were 430 mm in November 1980.

	Sampling dates		
	6/29/81	8/24/81	10/17,24/81
North Shore	.3171[1]	.1015	.0981
Leland	.0321	.0249	.0913

Appendix 8. (continued)

Catch adjustment: The total catch of cooperating fishermen was adjusted to estimate only those fish that were in the legal portion of the November 1980 population. This was done by multiplying the catch during each interval between sampling dates, times the proportion of fish larger than the estimated mean length of a November 1980 sublegal fish, at the time of the later sample.

Area	Date	Proportion	Catch [2]	Adj. Catch
North Shore	8/24/81	.8985	468,730.4	421,154.3
	10/20/81	.9019	328,399.6	296,183.6
			TOTAL	717,337.9
Leland	6/29/81	.9679	37,230.5	36,035.4
	8/24/81	.9751	65,478.8	63,848.1
	10/20/81	.9087	24,163.0	21,956.9
			TOTAL	121,840.4

1 The June 1981 sample was omitted from adjustment calculations due to the atypical disproportionate numbers of sublegal fish in the catch.

2 Total harvest in pounds for the cooperating fishermen during the interval between sampling dates. The catch for partial months was estimated by the fraction of the month times the monthly catch.

Appendix 9. Annual exploitation rates, after correction for tag loss, for lake whitefish (>430 mm) tagged in the Leland and North Shore areas of Lake Michigan. Values were calculated from the catch and returns from known cooperating fishermen, then expanded by the ratio of their catch to the total catch in each area.

Location	M	R_c	adj. R_c	C	C_t	u_c	ST DEV	u_t	ST DEV
North Shore area	1603	313	363.22	797,130	1,744,055	.2266	(.0119)	.4958	(.0176)
Leland area	376	57	63.08	126,872	182,224	.1678	(.0212)	.2410	(.0254)

M = number of tagged fish larger than 430 mm.

R_c = recaptures by cooperating fishermen that were larger than 430 mm when tagged

adj. R_c = R_c adjusted for tag loss

C = total catch in pounds of cooperating fishermen

C_t = total catch for all fishermen

$u_c = \text{adj. } R_c/M$

$u_t = (\text{adj. } R_c/M)(C_t/C)$

$V(u) = (R(C - R))/M^2C$

$\text{ST DEV} = \sqrt{V(u)}$

Appendix 10. Details of an analysis of variance on mean length (mm) at age for representatives of the 1976, 1977, and 1978 year classes of lake whitefish in northeastern Lake Michigan during 1980-1982. Analyses were conducted on all samples where N $\geq$ 20 fish.

Date and Locations	Year Class (age)	N	Mean Length (mm)	Variance	Source of Variation	df	SS	MS	F ratio
October 1980									
North Shore	1977	398	453.37	362.35	between	1	5,986	5,986	16.76
Leland	(III)	65	463.72	326.17	within	461	164.725	357	(p < .001)
Total						462	170,712		
North Shore	1976	107	478.35	549.08	between	1	920	920	1.457
Leland	(IV)	33	472.30	906.53	within	138	87,211	631	(p > .10)
Total						139	88,132		
June 1981									
North Shore	1977	85	444.79	928.46	between	2	30,618	15,309	22.59
Leland	(IV)	36	466.11	673.07	within	267	180,931	677.6	(p <.001)
Beaver Island		146	468.05	536.39					
Total						269	211,549		
August 1981									
North Shore	1977	251	461.13	380.43	between	1	7,304	7,304	18.86
Leland	(IV)	63	473.18	414.76	within	312	120,821	387	(p < .001)
Total						313	128,125		
October 1981									
North Shore	1977	284	474.05	361.28	between	1	40,600	40,600	68.79
Leland	(IV)	164	493.81	987.69	within	446	263,263	590	(p < .001)
Total						447	303,836		
North Shore	1976	20	508.75	612.83	between	1	5,370	5,370	5.818
Leland	(V)	27	530.37	1149.86	within	45	41,540	923	(p < .05)
Total						46	46,910		
May 1982									
Leland	1978	30	462.33	521.95	between	2	5,883	2,942	8.815
North Shore	(IV)	45	445.22	278.36	within	125	41,714	334	(p < .001)
Beaver Island		53	456.51	275.56					
Total						127	47,597		
Leland	1977	123	595.77	554.93	between	2	25,791	12,896	27.952
North Shore	(V)	209	478.30	383.76	within	437	201,609	461	(p < .001)
Beaver Island		108	479.63	505.47					
Total						439	227,400		

Appendix 11. Tests of the assumptions of homogeneous variance and normally distributed residuals for the analyses of variance on mean length at age.

Date Locations	Year Class (age)	N	Kolomorov-Smirnoff Normality Test		Bartlett Test for Homogeneous Variance (X^2)	
			Z	α	Q	Decision (α=.25)
October 1980						
North Shore	1977	398	.985	.287	0.29444	accept
Leland	(III)	65	.719	.680		
North Shore	1976	107	.512	.956	3.3197	reject
Leland	(IV)	33	1.077	.197		
June 1981						
North Shore	1977	85	.622	.878	8.32624	reject
Leland	(IV)	36	.696	.719		
Beaver Island		146	1.135	.152		
August 1981						
North Shore	1977	251	1.336	.056	0.18835	accept
Leland	(IV)	63	.795	.553		
October 1981						
North Shore	1977	284	1.300	.068	54.83912	reject
Leland	(IV)	164	.788	.565		
North Shore	1976	20	.562	.911	2.02693	reject
Leland	(V)	27	.710	.695		

Appendix 11. (continued)

Date / Locations	Year Class (Age)	N	Kolomorov-Smirnoff Normality Test		Bartlett Test for Homogeneous Variance (X^2)	
			Z	α	Q	Decision (α=.25)
May 1982						
Leland	1978	30	.558	.914	4.097	reject
North Shore	(IV)	45	.750	.628		
Beaver Island		53	1.157	.138		
Leland	1977	123	1.105	.174	5.9702	reject
North Shore	(V)	209	1.541	.017		
Beaver Island		108	.990	.281		

Appendix 12. Results of the quadrant test of the joint distribution of length and weight for bivariate normality (Cramer 1946). The hypothesis was rejected when the calculated Chi square value exceeded the tabular value at the 0.05 level of significance.

Sampling Date	Grids	Sample Size	r	X^2	Decision
October 1980	115,116	513	.886	11.91	reject
	714,814	114	.967	53.89	reject
June 1981	117	197	.931	2.41	accept
	812,814,912	81	.970	9.70	reject
	316	219	.930	2.09	accept
August 1981	218	300	.885	17.90	reject
	812,814,912	94	.943	26.87	reject
October 1981	116,117	331	.872	17.29	reject
	812	244	.933	38.92	reject
May 1982	216,218	263	.862	3.54	accept
	812,814,912	232	.949	45.08	reject
	317,418	169	.904	7.59	accept

Appendix 13a. Mean back-calculated lengths for lake whitefish from the North Shore area of Lake Michigan. Standard deviations are in parentheses.

Age	N	Annulus 1	2	3	4	5	6	7	8	9	10	11	12
2	2	297.9 (40.2)	347.0 (48.4)										
3	479	332.9 (15.1)	390.0 (19.0)	429.3 (19.2)									
4	772	332.8 (16.5)	387.2 (29.3)	427.1 (22.1)	452.1 (23.4)								
5	249	340.7 (14.0)	398.7 (18.3)	438.4 (20.5)	463.8 (22.9)	480.7 (25.8)							
6	10	348.4 (21.8)	408.9 (19.3)	457.3 (26.8)	486.2 (24.1)	505.2 (21.7)	519.1 (21.0)						
7	1	325.3 -	362.7 -	400.0 -	425.6 -	468.8 -	488.5 -	504.2 -					
10	1	423.5 -	507.5 -	556.9 -	596.4 -	611.3 -	623.6 -	636.0 -	645.8 -	653.2 -	665.6 -		
Weighted Totals		334.2	390.1	429.9	455.3	482.1	525.3	570.1	645.8	653.2	665.6		
Standard Deviation		(16.2)	(20.3)	(21.7)	(24.4)	(27.1)	(37.3)	(93.1)	-	-	-		

Appendix 13b. Mean back-calculated lengths for lake whitefish from the Leland area of Lake Michigan. Standard deviations are in parentheses.

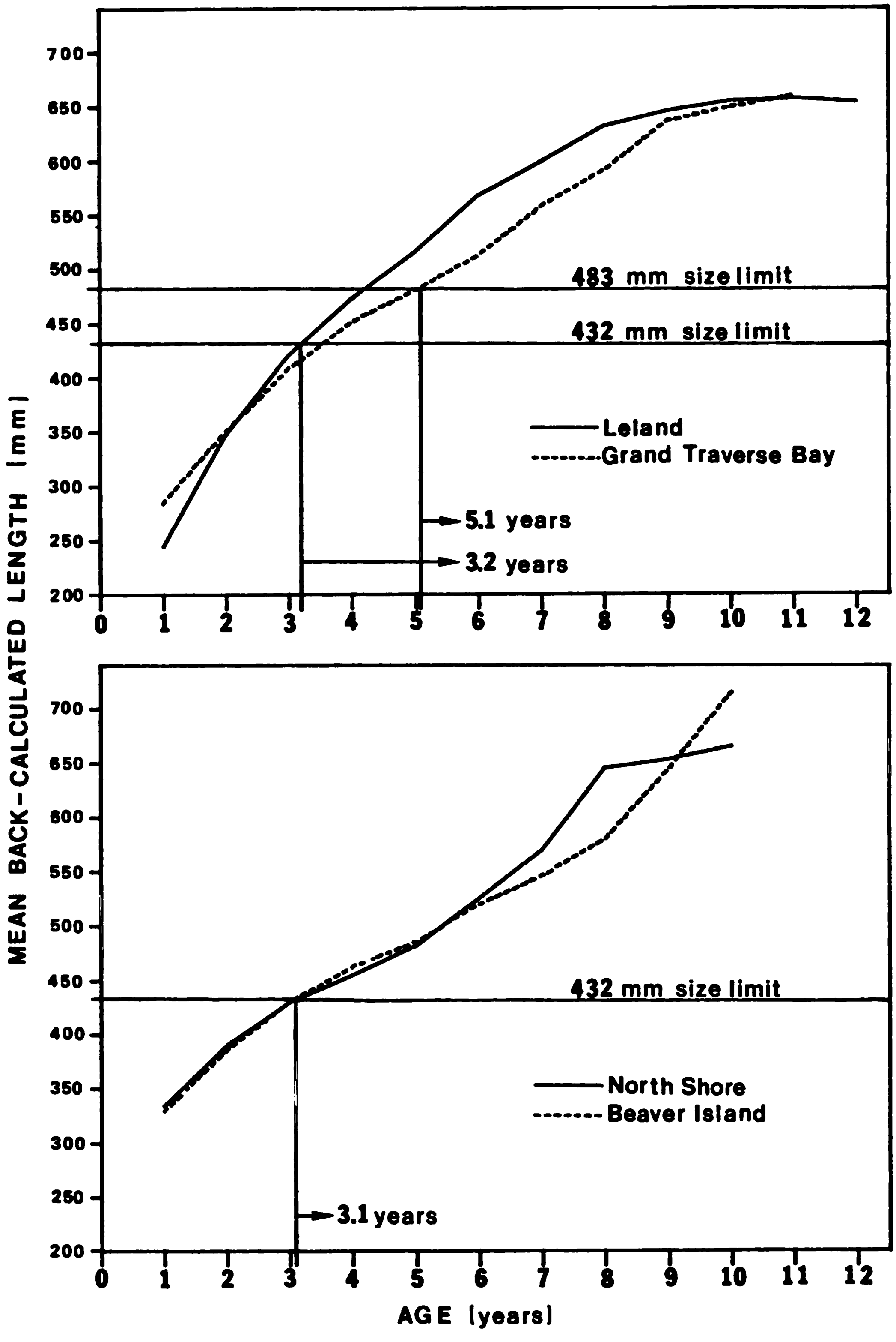
Age	N	Annulus 1	2	3	4	5	6	7	8	9	10	11	12
2	1	219.0 -	320.6 -										
3	93	240.1 (17.9)	342.4 (23.8)	414.4 (22.5)									
4	326	239.1 (17.7)	340.1 (23.3)	412.0 (25.2)	460.5 (28.3)								
5	181	243.9 (17.5)	343.3 (23.4)	417.0 (26.9)	466.2 (28.0)	494.4 (40.1)							
6	53	250.6 (21.0)	352.4 (27.5)	430.7 (29.6)	485.5 (31.0)	520.3 (30.8)	545.2 (30.5)						
7	43	256.4 (26.4)	358.2 (45.2)	436.0 (49.9)	491.9 (51.3)	527.3 (52.0)	554.9 (51.5)	574.0 (52.0)					
8	8	250.2 (28.8)	361.9 (26.1)	442.8 (35.5)	509.5 (48.2)	553.1 (50.3)	585.1 (51.5)	605.6 (49.0)	621.4 (48.5)				
9	14	273.1 (27.5)	402.8 (45.8)	482.2 (35.2)	542.3 (33.5)	577.9 (30.9)	604.2 (25.2)	624.0 (24.5)	638.0 (21.9)	649.2 (20.1)			
10	19	278.4 (26.2)	407.1 (29.4)	489.5 (42.1)	543.4 (47.1)	577.7 (44.1)	604.2 (41.8)	624.2 (39.0)	640.8 (35.6)	653.2 (33.7)	662.9 (32.2)		
11	11	267.9 (26.9)	388.3 (42.0)	468.2 (42.8)	527.2 (43.3)	564.3 (46.0)	595.1 (46.6)	618.7 (43.9)	635.6 (42.1)	649.8 (40.4)	661.5 (39.1)	669.7 (37.1)	
12	12	268.0 (35.9)	386.8 (53.9)	456.3 (56.5)	509.5 (61.5)	543.4 (64.6)	570.1 (54.4)	594.4 (66.3)	611.5 (66.7)	625.8 (67.8)	636.9 (68.4)	646.2 (68.2)	653.7 (68.2)
Weighted Totals		244.7	347.5	421.2	472.7	516.0	567.3	598.7	631.4	645.6	655.1	657.4	653.7
Standard Deviation		(21.6)	(31.0)	(34.0)	(38.7)	(49.9)	(48.5)	(51.9)	(43.7)	(42.4)	(47.1)	(55.7)	(68.2)

Appendix 13c. Mean back-calculated lengths for lake whitefish from the Beaver Island area of lake Michigan. Standard deviations are in parentheses.

		Annulus											
Age	N	1	2	3	4	5	6	7	8	9	10	11	12
3	6	304.1 (15.0)	354.4 (22.4)	394.3 (27.7)									
4	149	321.5 (16.8)	382.8 (20.8)	429.4 (22.7)	462.4 (22.7)								
5	41	327.6 (21.8)	386.2 (27.0)	437.6 (33.3)	472.8 (31.1)	496.7 (29.6)							
6	12	333.7 (13.0)	377.7 (18.3)	423.4 (22.8)	466.2 (28.1)	490.2 (27.7)	510.5 (24.1)						
7	5	337.3 (20.1)	385.2 (27.4)	419.7 (30.3)	456.2 (25.0)	481.1 (22.4)	501.6 (23.6)	517.9 (23.5)					
8	5	335.6 (18.8)	389.8 (26.4)	435.5 (36.9)	472.2 (36.2)	505.1 (33.0)	525.1 (30.4)	543.3 (29.0)	558.4 (26.2)				
9	1	343.8 -	391.5 -	427.8 -	475.5 -	514.1 -	539.1 -	559.6 -	570.9 -	580.0 -			
Weighted Totals		323.6	382.6	429.5	464.8	495.2	513.0	533.3	560.5	580.0			
Standard Deviation		(18.4)	(22.7)	(26.3)	(25.3)	(28.8)	(25.7)	(28.2)	(24.1)	-			

Appendix 13d. Mean back-calculated lengths for lake whitefish from the Grand Traverse Bay area of Lake Michigan. Standard deviations are in parentheses.

		Annulus											
Age	N	1	2	3	4	5	6	7	8	9	10	11	12
4	6	293.7 (17.4)	362.7 (27.9)	415.1 (29.8)	454.9 (23.0)								
5	80	283.2 (18.2)	351.4 (24.4)	408.2 (22.2)	449.2 (19.1)	473.8 (35.0)							
6	41	281.4 (18.4)	344.5 (27.2)	405.1 (30.4)	451.4 (28.8)	485.9 (24.2)	506.2 (21.1)						
7	5	285.4 (21.9)	342.1 (44.7)	396.9 (41.5)	449.5 (28.8)	489.5 (18.4)	515.5 (17.4)	536.0 (15.1)					
8	3	299.1 (28.2)	355.1 (40.3)	405.8 (43.9)	456.4 (44.0)	489.3 (53.4)	520.2 (45.4)	542.4 (41.6)	556.5 (40.5)				
10	2	296.3 (19.4)	380.3 (19.8)	444.6 (20.2)	500.6 (4.7)	556.6 (12.9)	580.4 (15.0)	604.1 (13.1)	622.3 (3.3)	636.3 (3.4)	647.5 (3.5)		
11	1	306.3 -	394.7 -	483.1 -	537.3 -	560.2 -	591.5 -	617.2 -	631.5 -	637.2 -	551.4 -	660.0 -	
Weighted Totals		283.9	350.3	408.2	451.7	480.4	512.4	557.5	591.0	636.6	648.8	660.0	
Standard Deviation		(18.7)	(26.8)	(27.2)	(24.9)	(33.9)	(28.3)	(39.3)	(45.7)	(2.5)	(3.3)	-	



Appendix 14. Graphical estimation of age at recruitment from the mean back-calculated length (mm) at age of lake whitefish from northeastern Lake Michigan.

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