VITAL STATISTICS OF THE LAKE WHITEFISH IN THREE AREAS OF GREEN BAY, LAKE MICHIGAN WITH COMPARISON TO LAKE MICHIGAN EAST OF DOOR COUNTY, WISCONSIN

By

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ABSTRACT

Lake whitefish (Coregonus clupeaformis) were sampled from commercial impoundment gear in 1976-1977 in Big Bay de Noc, Chambers Island, and Peshtigo Reef of Green Bay, Lake Michigan to calculate the vital statistics of the stocks. Results were compared among areas and with results from North-Moonlight Bays of Lake Michigan (Humphreys 1978) to determine if discrete stocks exist. The presence of a large 1972 year class at Peshtigo Reef, Chambers Island and North-Moonlight Bays, and its absence at Big Bay de Noc indicated stocks of whitefish in the former areas were similar, and discrete from the latter. Total mortality rates estimated for Peshtigo Reef and Chambers Island in spring were similar to the fall North-Moonlight Bays rate indicating movement of fish from Peshtigo Reef and Chambers Island to North-Moonlight Bays during spawning. Rates of tag return for whitefish tagged in North-Moonlight Bays (1975-1977) indicated substantial movement of whitefish to the Peshtigo Reef and Chambers Island areas and migration back to North-Moonlight Bays in fall to spawn. Growth, determined by instantaneous rates and mean back-calculated lengths, was similar for whitefish from all areas. Growth of the large 1972 year class was less than that of other year classes. Age at recruitment ranged from 3.3 to 3.5 years in Green Bay but was 3.7 years in North-Moonlight Bays. Length-weight regression equations indicated differences among areas and seasons, but weights predicted from the regression equation were similar among areas. Total instantaneous mortality rate was higher in Big Bay de Noc (0.79) than at Peshtigo Reef (0.53) and Chambers Island (0.52) indicating a younger age structure in Big Bay de Noc. Two assumed rates of instantaneous natural mortality, 0.34 and 0.47, for Green Bay yielded estimates of instantaneous fishing mortality for Big Bay de Noc of 0.45 and 0.32 and for Peshtigo Reef-Chambers Island of 0.20 and 0.06. Mean number of spawnings, based on mortality estimates, were 1.84 and 2.30 for whitefish from Big Bay de Noc and Peshtigo Reef-Chambers Island respectively. Yield per 1000 kg of recruits calculated for whitefish in Big Bay de Noc from the Beverton-Holt yield and Ricker equilibrium yield models differed by 12%. Higher yield per recruit was calculated for North-Moonlight Bays than for Big Bay de Noc. The Ricker equilibrium yield model fit for the Big Bay de Noc stock, predicted yield in excess of production by 19% for a natural mortality rate of 0.34, but production was greater than yield by 11% for natural mortality of 0.47.

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INTRODUCTION

Objectives of this study were to determine the vital statistics of lake whitefish (Coregonus clupeaformis) in three areas of Green Bay, Lake Michigan, compare the vital statistics to determine if different stocks of whitefish inhabit the bay, and to fit population models to the fishery. Vital statistics included: age composition, growth rates, mortality rates, length-weight relationships, mean age and length in the fishery, commercial turnover, von Bertalanffy growth equations, and Ricker and Beverton-Holt yield calculations. I considered a stock to be a group or unit of adult fish with homogeneous characteristics of recruitment, growth, and mortality, which probably returns to the same spawning grounds each year. The lake whitefish has been economically important to the commercial fishery of Lake Michigan, since the early 1800's (Frick 1965) and is presently the most valuable commercial species in Lake Michigan.

Green Bay is divided into three statistical districts, WM-1, WM-2, and MM-1 (Smith et al. 1961), and samples of whitefish were collected from each district (Figure 1). Statistical district MM-1, which includes Big Bay de Noc, has been the most productive district, producing more whitefish than WM-1 and WM-2 combined since 1949. The commercial catch in MM-1 has exceeded one million pounds of whitefish in 5 of the last 6 years (Appendix A). District WM-2, which includes Chambers Island, produced the largest catch of whitefish in Wisconsin waters of Lake Michigan in the period 1959-1974. The catch in WM-2 averaged one half million pounds in 1973-1976 (Appendix B). Statistical district WM-1, which includes Peshtigo Reef, has had the lowest harvest of whitefish in Green Bay since 1949. The catch in WM-1 averaged 150 thousand pounds in 1973-1976 (Appendix C).

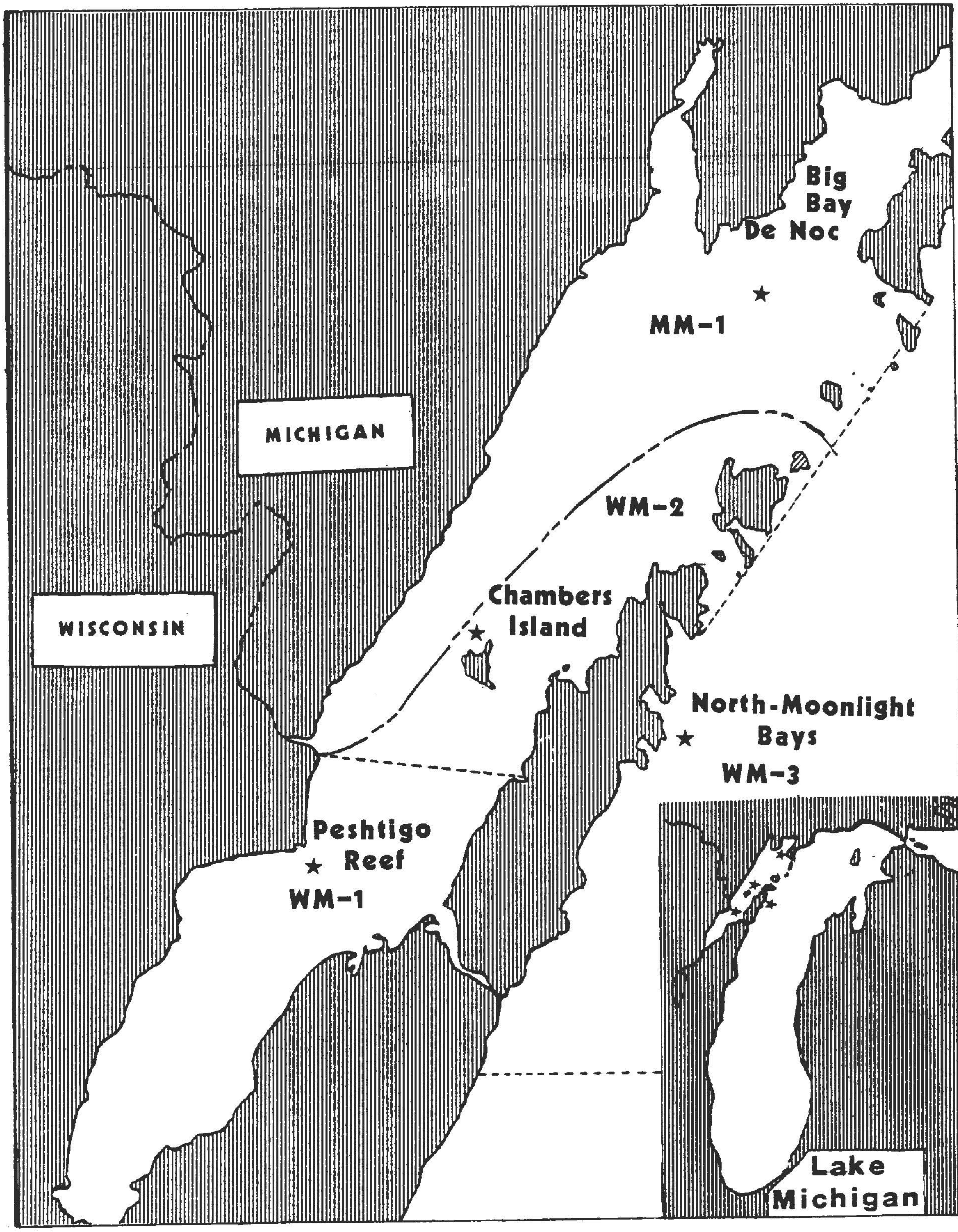

Figure 1. Green Bay and Lake Michigan east of Door County, Wisconsin statistical districts WM-1 (Peshtigo Reef), WM-2 (Chambers Island), WM-3 (North-Moonlight Bays), and MM-1 (Big Bay de Noc).

Vital statistics of lake whitefish were compared not only among the three districts of Green Bay, but also with those from whitefish in North and Moonlight Bays east of Door County in Lake Michigan, district WM-3 (Figure 1), which was studied by Humphreys (1978). The commercial whitefish catch in WM-3 increased from 132 thousand pounds in 1970 to a 27 year high of 939 thousand pounds in 1976 (Appendix D). Effort in all areas has increased substantially since 1970 (Appendix A-D).

Historically, the commercial whitefish catch has fluctuated greatly (Figure 2). Fluctuations have been attributed to overfishing, pollution of spawning grounds, cultural eutrophication, changing species composition and lamprey (*Petromyzon marinus*) predation (Smith 1968; Beeton 1969; Berst and Spangler 1972; Lawrie and Rahrer 1973; Wells and McClain 1973). The catch of whitefish in Wisconsin water of Lake Michigan recovered from an extreme low in the 1950's and exceeded one million pounds in the four consecutive years 1974-1977, for the first time in history (Figure 2). The catch in Green Bay also was near record levels in 1974-1977 (Figure 3).

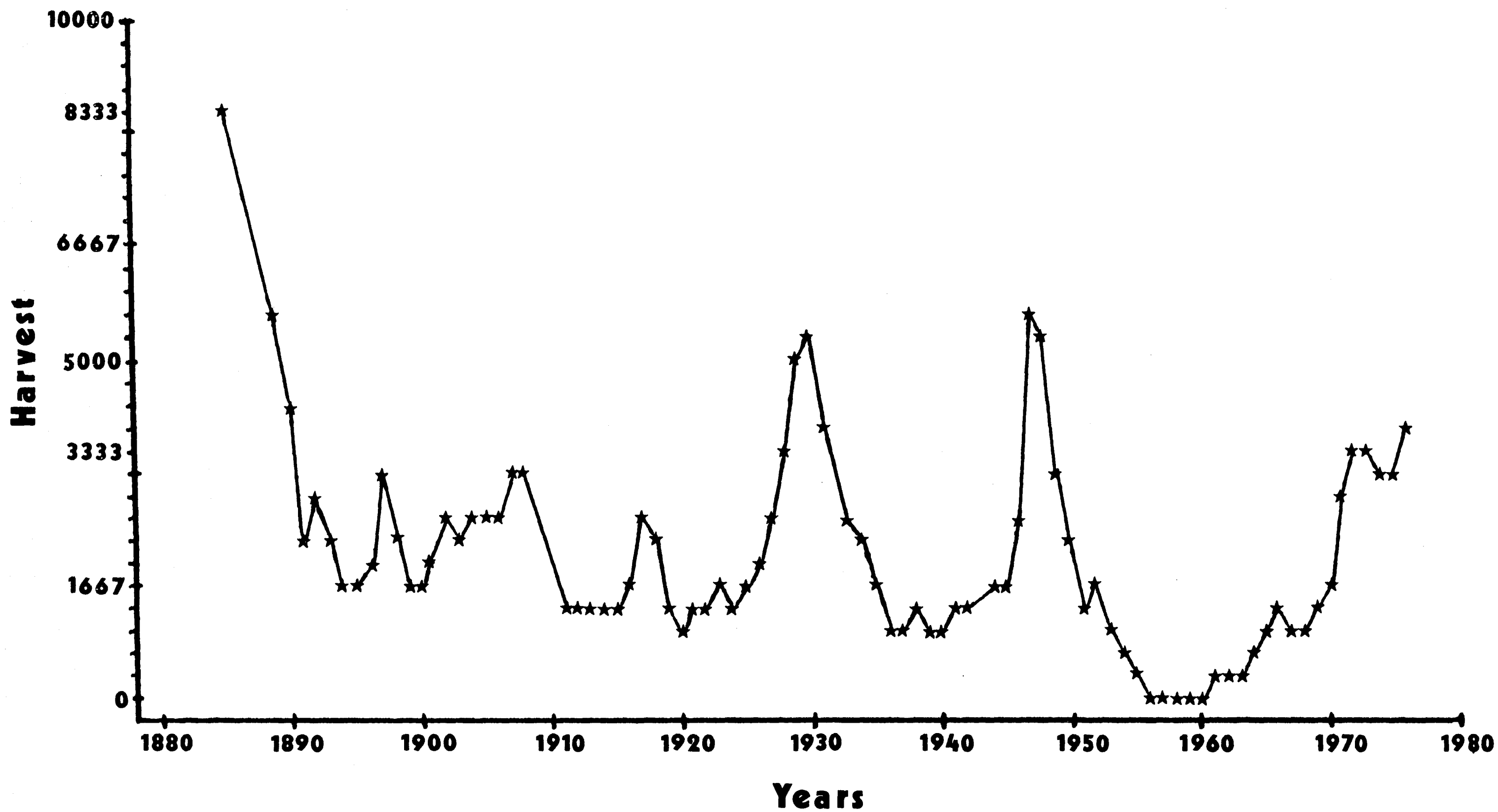

Figure 2. Commercial production (thousands of pounds) of lake whitefish in Lake Michigan 1885-1976. (Includes longjaws, blackfins and Menominee whitefish in 1879, 1885, 1890 and 1893.) (Baldwin and Saalfeld 1962)

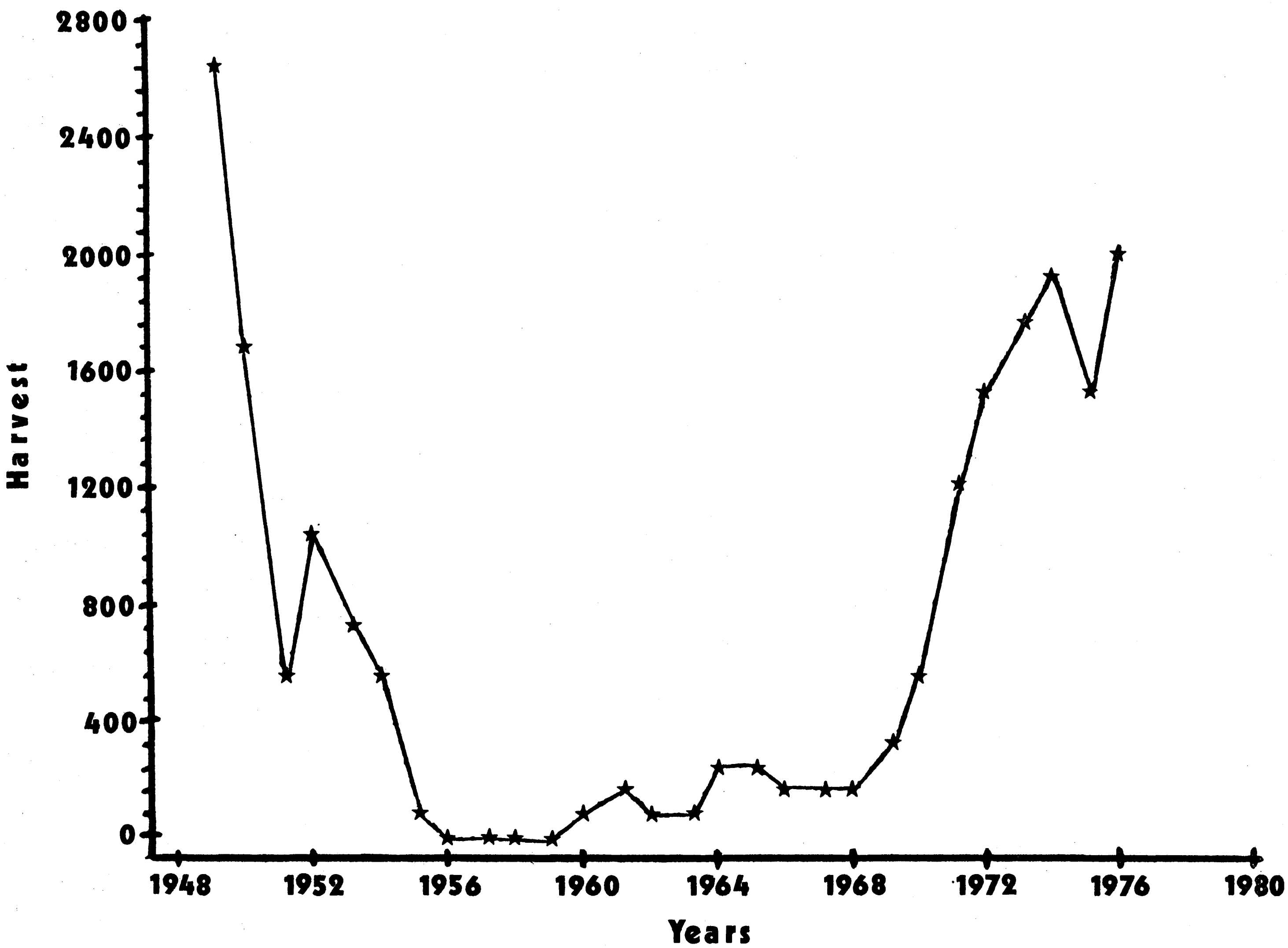

Figure 3. Commercial production (thousands of pounds) of lake whitefish in Green Bay, Lake Michigan in statistical districts WM-1, WM-2 and MM-1.

METHODS

Samples of length, weight, and scales were obtained from lake whitefish caught in poundnets and trapnets of the commercial fishery. Samples were limited to commercial impoundment gear because gillnets are selective for whitefish of a restricted length range, determined by mesh size (McCombie and Fry 1960; Regier and Robson 1966; Hamley 1975). Selectivity of pound and trapnets is similar (Van Oosten and Hile 1947). The selectivity curve of poundnets (114 mm stretch mesh) for whitefish according to Cucin and Regier (1965) is an ogive from 0% at 317.5 mm (fork length) to 100% at 406.4 mm and remains constant at 100% beyond 406.4 mm. Trapnets were sampled at Peshtigo Reef and Big Bay de Noc and poundnets were sampled at Chambers Island and North-Moonlight Bays.

Data were collected in Big Bay de Noc in September and October of 1976 and May of 1977. Samples from Peshtigo Reef and Chambers Island were obtained in June of 1977, and North-Moonlight Bay samples were obtained in fall 1975 and 1976 and spring 1977.

Scales, which had been removed from the region between the lateral line and dorsal fin, were cleaned with a stiff brush and placed between glass slides. Scale impressions on cellulose acetate (Smith 1954) proved unsatisfactory because the last few circuli and edges of many scales were not clearly imprinted. Scales were viewed on a scale projector at a magnification of 40x and annuli were counted. Junction of the posterior and anterior fields was the best area for determination of annuli, identified by areas of cutting over and disruptions of the circuli.

The ages assigned were verified by four methods. Jim Humphreys, another student aging whitefish scales, compared ages that had been determined from the interoperculum bone with those from scales, and he obtained 86.5% agreement in a sample of 74 fish. Also, two samples of 10 scales each were sent to others studying whitefish in the Great Lakes, John Novak of Ontario and Mercer Patriarche of Michigan. Ages assigned by Patriarche and Novak agreed 100% with ages assigned by Jim Humphreys and myself. Also, Jim Humphreys and I read each other's scales with 95% agreement. From the tagging study of Humphreys (1978), scales were obtained at recapture from five fish for which number of annuli at tagging had been counted. In 4 of the 5 instances the number of annuli at recapture was the number of annuli expected, based on number of annuli at tagging and duration at liberty. The one discrepancy Humphreys attributed to possible error in collection of the scale sample.

I selected one scale from each fish for measurement, and the distance from focus to each annulus and to the margin along the anterior radius was recorded. Data were placed on computer cards and a linear body-scale relationship was calculated as a least squares GM functional regression (Ricker 1973). The body-scale relationship, in the form,

$$L = u + vS,$$

where L is total fish length (mm), S is scale length (mm) and u and v are the intercept and slope of the regression, was used to back-calculate lengths. Growth in length is similar for males and females (Hart 1931; Van Oosten 1939; Barker 1953; Mraz 1964; Piehler 1967); therefore, sexes were not separated.

A length-weight relationship for whitefish in each area was also determined from a GM functional regression of the form,

$$\text{Log}_e W = \text{Log}_e u + v(\text{Log}_e L),$$

where W is weight (kg). The slope (v) of the regression was used to calculate instantaneous growth in weight from the back-calculated lengths (Ricker 1975, p. 207) from the equation,

$$G = v(\text{Log}_e L_n - \text{Log}_e L_{n-1})$$

True growth rate (G), population growth rate (G_x) and true mean growth rate ($\overline{G}$) were calculated (Ricker 1975, p. 217). G was used for comparisons among areas because it showed the most uniform decline in growth rate with age, and it was based on the last two annuli of each year class in a sample. Therefore, G was an estimate of growth during the year of sampling and not subject to changes that took place in years before samples were collected. Calculation of $\overline{G}$, based on the mean back-calculated lengths from fish that have attained a given age or greater, may be biased by any change in growth that has occurred over the years. G_x, calculated from the lengths at last annulus for successive year classes, may be affected by any change in growth from one year to the next or by unequal sample size.

Von Bertalanffy growth equations were calculated for each area according to the method described by Ba ley (1977). The equation, as developed by Beverton and Holt (1957), has the form,

$$L = L_\infty (1 - e^{-K(t-t_0)}),$$

where L_∞ is asymptotic length, K is a constant determining rate of change in length increments, t is age, and t_o is the hypothetical age at which a fish would have been zero length if it had always grown in the manner described by the equation.

Age at recruitment was calculated by two methods; interpolation of weighted mean back-calculated lengths and from the von Bertalanffy growth equation. Recruitment was assumed to coincide with attainment of the legal minimum size (432 mm). Therefore, age at recruitment was calculated by interpolating the age at 432 mm from the weighted mean back-calculated lengths at ages immediately greater and less than 432 mm. From the von Bertalanffy growth equation, age at recruitment was calculated from,

$$t_r = t_o - 1/K \log_e \left(1 - \frac{L_r}{L_\infty}\right),$$

where t_r is age at recruitment and L_r is length at recruitment.

Mean age and mean length in the fishery, were calculated by weighting each age and 10-mm length interval by the corresponding number of fish, summing the weighted ages and lengths, and dividing by the total number of fish. In spring samples, fish were as old as the number of annuli, but in fall samples fish were closer to 1 + the number of annuli. Therefore, I determined mean age in the fall samples by adding 0.9 to each age before calculating the weighted mean.

Catch curves (Ricker 1975, p. 33) were used to estimate total mortality and survival rates (Z, A, S). Instantaneous natural mortality rate (M) could not be calculated for samples from Green Bay from available data. Therefore, I used estimates of instantaneous natural mortality from the North-Moonlight Bays area (Humphreys 1978) and from

Grand Traverse Bay (Patriarche 1977). Humphreys was able to calculate natural mortality by subtraction of instantaneous fishing mortality (F) from instantaneous total mortality (Z). F was calculated from recaptures of whitefish tagged in North and Moonlight Bays, Lake Michigan. Patriarche (1977) presented percent age composition and sample size of whitefish caught in graded-mesh gillnets in Grand Traverse Bay from 1972-1976. I pooled the numbers in each age group for the five years and constructed a catch curve for ages III - IX to estimate total instantaneous mortality (Z). Since Grand Traverse Bay had been closed to fishing since 1945, the only mortality affecting the stock was natural mortality; therefore, Z was an estimate of M. I calculated two estimates of instantaneous fishing mortality (F) from these two estimates of M (Humphreys and Patriarche). The two estimates of M for each area were also used to calculate critical size; the average size of a fish in a year class at the time when the instantaneous rate of natural mortality equals the instantaneous rate of growth in weight.

Commercial turnover (o), the mean time in years between hatching of a fish and harvest, was calculated according to the method described by Abrosov (1969). Abrosov stated that age determined by number of annuli should be converted to a specific quantity corresponding to the part of the year when samples were collected. Abrosov started the year with time of hatching. Since whitefish hatch in April (Hoagman 1973), 0.15 was added to the age of whitefish in spring samples and 0.50 was added to the age of whitefish in fall samples for calculation of commercial turnover. The extent to which commercial turnover (o) in the catch exceeds the age of onset of sexual maturity (z) is an indicator (t) of the degree of exploitation (Abrosov 1969). The quantity t was obtained by subtracting z from o. Age at sexual maturity for whitefish in the areas studied was considered to occur during the fourth year of life (Age III +), based on results of Piehler (1967) and Mraz (1964).

Mean number of psawnings per recruit was calculated for each sample based on estimated mortality rates and age at recruitment. The number of fish remaining at each age from III to X was calculated from the equation:

$$N_t = N_o e^{-zt},$$

where N_t is the number of fish at time t and N_o is the initial number of fish. The number of fish at each age was weighted by the number of times each age could spawn (1 for age III, 2 for age IV, etc.); the weighted numbers of fish at each age were summed and divided by the total number of fish to obtain the mean number of spawnings.

Yield was calculated according to the Beverton-Holt yield model (Ricker 1975, p. 253), which has the form,

$$Y = FRW_{\infty} (1/Z - 3_c^{-kr}/ (Z + k) = 3_e^{-2kr}/ (Z = 2k) - e^{-3kr}/ (Z + 3k)),$$

where Y is yield in weight units, R is number of fish at recruitment, W is asymptotic weight calculated from L_{∞} of the von Bertalanffy equation, k is a parameter of the von Bertalanffy equation, and r is age at recruitment minus the von Bertalanffy parameter, t_o. Estimates of yield from the Beverton-Holt model were compared with estimates from the Ricker yield model (Richer 1975, p. 238), which takes the form,

$$Y_E = \sum_{t=t_r}^{t=t_\lambda} F_t \bar{B}_t,$$

where equilibrium yield (Y_E) is the summation of rate of fishing (F) times mean biomass ($\bar{B}$) for time intervals t in the life span of vulnerable fish, with t_r the first vulnerable period and t_λ the last vulnerable period under consideration.

RESULTS AND DISCUSSION

Comparison of Age Composition

Percent age composition of the legal catch from Peshtigo Reef, Chambers Island, Big Bay de Noc and North-Moonlight Bays indicated the existence of discrete stocks of lake whitefish. Stocks at Peshtigo Reef, Chambers Island and North-Moonlight Bays seemed to be the same, whereas stocks at Big Bay de Noc were different. The presence of a large 1972 year class in the three former areas and its absence in the latter was the basis for this conclusion.

Percent age composition of the catch from Peshtigo Reef and Chambers Island was similar (Table, 1, Figure 4) and not significantly different ($\chi^2=3.433$, n=4, p .05). Chambers Island and Peshtigo Reef samples in spring 1977 were dominated by the 1972 year class (Age V), which made up 43% of the catch at Chambers Island and 50% as Peshtigo Reef. Ages III and IV were less important and contributed 16% and 22% of the catch at Peshtigo Reef and 23% and 24% at Chambers Island.

Percent age composition of spring 1977 samples from Big Bay de Noc was significantly different from samples from Peshtigo Reef and Chambers Island (Appendix E). The whitefish in Big Bay de Noc were younger than at Peshtigo Reef and Chambers Island; the stock was dominated by ages III and IV (Table, 1, Figure 4), which made up 37% and 42% of the catch respectively. The 1972 year class (Age V), comprised only 14% of the catch in the Big Bay de Noc area. Also ages VI-X were less abundant in Big Bay de Noc (1.8%) than at Peshtigo Reef (12.2%) or Chambers Island (12.0%).

The age composition of spring 1977 samples from North-Moonlight Bays was significantly different from Peshtigo Reef, Chambers Island and Big

Table 1. Percent age composition of lake whitefish from legal commercial catches at Peshtigo Reef, Chambers Island, Big Bay de Noc of Green Bay and North-Moonlight Bays of Lake Michigan. Spring and fall samples from Big Bay de Noc were divided into samples from inside and outside the Bay. Numbers in parentheses indicate sample size.

Location	Age II	III	IV	V	VI	VII	VIII	IX	X
Peshtigo Reef Spring 1977 (1673)		15.7	22.4	49.7	3.6	1.6	2.1	3.9	1.1
Chambers Island Spring 1977 (902)		22.9	22.1	43.0	4.0	1.5	2.7	1.4	1.4
Big Bay de Noc Spring 1977 (2360)		37.4	41.9	18.9	0.6	0.2	0.3	0.6	
Big Bay de Noc Spring 1977 inside (1650)		46.4	39.1	13.8	0.1		0.1	0.4	
Big Bay de Noc Spring 1977 outside (710)		12.6	49.4	34.1	1.5	1.0	0.3	1.0	0.1
North-Moonlight Bays Spring 1977 (1800)[a]		4.0	8.0	85.2	2.0	0.3	0.2	0.2	0.1
Big Bay de Noc Fall 1976 (2438)	0.3	69.1	22.6	1.2	2.2	1.4	1.7	1.2	0.2
Big Bay de Noc Fall 1976 inside (1670)	0.5	77.5	15.6	0.6	0.4	1.2	2.6	1.2	0.3
Big Bay de Noc Fall 1976 outside (768)		57.0	33.1	3.0	4.0	1.6	0.3	1.1	

[a]Data from Humphreys 1978.

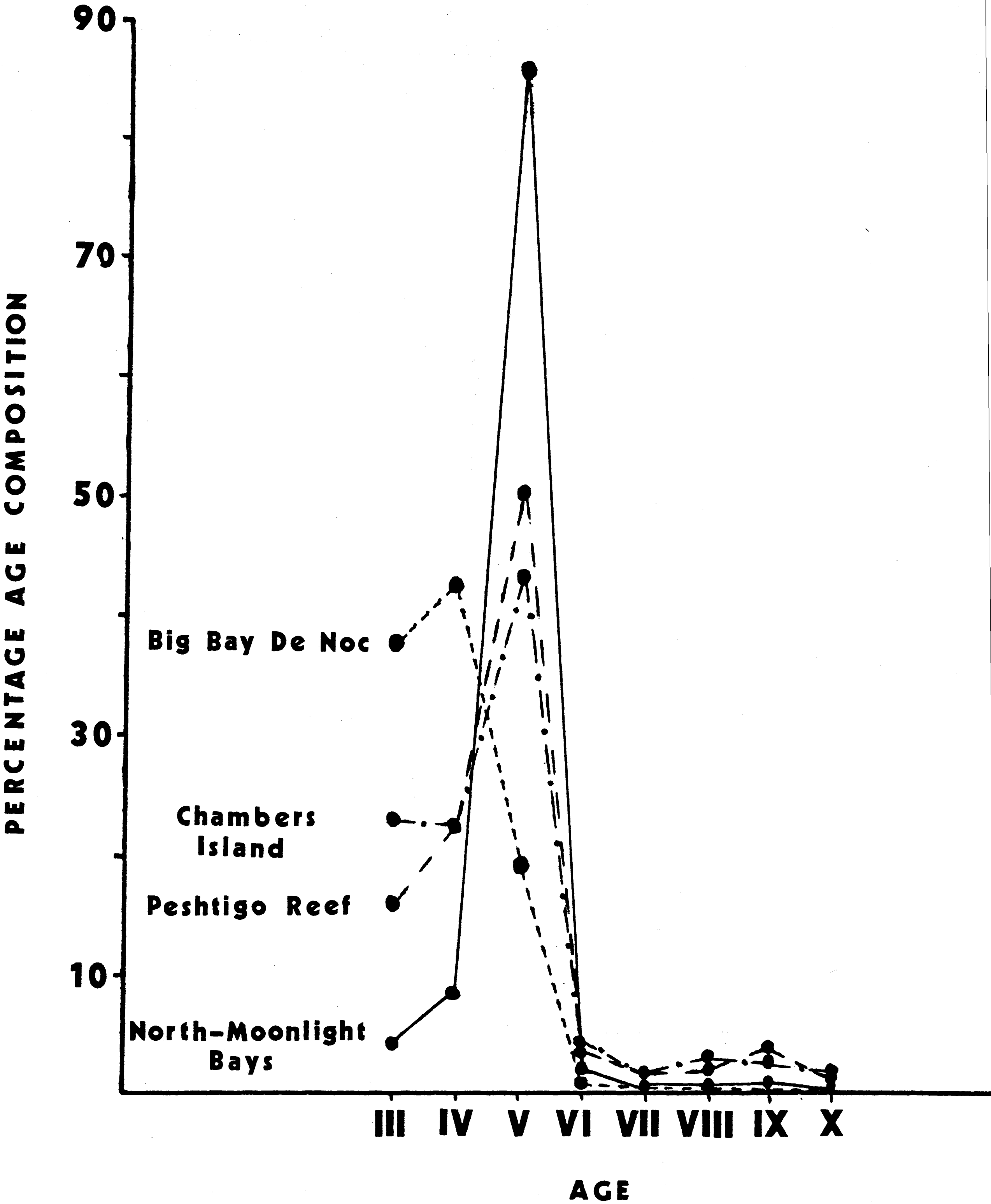

Figure 4. Percent age composition of lake whitefish from legal commercial catches in spring samples from Peshtigo Reef, Chambers Island, Big Bay de Noc of Green Bay and North-Moonlight Bays of Lake Michigan.

Bay de Noc (Appendix E); however, greater similarity existed between the Peshtigo-Chambers area and North-Moonlight Bays than with Big Bay de Noc. Age composition of the spring samples from Chambers Island and Peshtigo Reef were similar to North-Moonlight Bays in that the 1972 year class (Age V) was dominant in all three areas. Also, the 1973 year class (Age IV) was weak in North-Moonlight Bays (Humphreys 1978) and appeared to be weak at Chambers Island and Peshtigo Reef. The percent composition of year classes from the combined spring Peshtigo Reef-Chambers Island samples, compared with fall 1975 and 1976 samples from North-Moonlight Bays (Table 2), indicated an even greater similarity between the areas. The percent composition of the 1972 year class from fall North-Moonlight Bay samples was more like that of the Peshtigo Reef-Chambers Island area, and older year classes were better represented than in the spring North-Moonlight Bay sample.

Age composition of the fall 1976 Big Bay de Noc sample was significantly different from the spring 1977 sample (X^2=295.831, n=4, $p \leq .05$), but similarity existed in the predominance of ages III and IV (Table 1). Percent composition of ages III and IV combined from Big Bay de Noc was 92% in the fall sample and 79% in the spring sample. Age III whitefish, not fully recruited in the spring samples, decreased the percent composition of combined ages III and IV in the spring sample over that of the fall sample. Because age III whitefish were not fully recruited, comparison of spring and fall samples for determination of year class strength was not attempted. Fish older than VI were more abundant in the fall sample (8.0%) from Big Bay de Noc than in the spring sample (1.8%). Greater abundance of older fish in fall (spawning period) than in spring may indicate movement of whitefish to areas of less fishing pressure or lower natural mortality during the non-spawning period.

Table 2. Percentage year class composition of whitefish from the Peshtigo Reef-Chambers Island area and spring and fall samples from North-Moonlight Bays

Location	Year Class 1974	1973	1972	1971	1970	1969	1968	1967	1966
Peshtigo Reef and Chambers Island combined Spring 1977	18.05%	22.31%	47.59%	3.67%	1.62%	2.28%	3.41%	1.06%	
North-Moonlight Bays[a] Spring 1977	4.00%	7.98%	85.22%	1.97%	0.32%	0.22%	0.22%	0.06%	
North-Moonlight Bays[a] Fall 1976		5.84%	54.81%	7.99%	6.58%	11.01%	10.93%	2.83%	
North-Moonlight Bays[a] Fall 1975			67.93%	11.73%	7.70%	6.26%	5.12%	1.13%	0.12%

[a]Data from Humphreys 1978.

Younger whitefish were found inside Big Bay de Noc than were found immediately outside the Bay for both spring 1977 and fall 1976 samples. Samples from Lake Michigan statistical grids (Poff 1974) 307 and 308 were considered to be inside Big Bay de Noc and samples from grids 406,407 and 408 were considered to be outside the Bay. Samples from inside Big Bay de Noc contained a larger percentage of age III whitefish and samples from outside the Bay contained more IV and V year old whitefish for both spring and fall samples (Table 1). Age composition of inner and outer Big Bay de Noc was significantly different (Appendix E) for spring and fall samples. Differences in age composition between inner and outer Big Bay de Noc may indicate differences in stocks or an age specific schooling and movement of whitefish. Mraz (1964) reported that whitefish of similar size and age are frequently taken together, indicating age specific schooling, and Van Oosten et al. (1946) and Kennedy (1956) reported that large whitefish tend to occupy deeper water and do not move inshore in early summer to the same degree as smaller whitefish. Therefore, I feel differences in age composition between inner and outer Big Bay de Noc probably were caused by the tendency of whitefish age IV and older to inhabit deeper water outside the Bay. Samples from inner and outer Big Bay de Noc were combined for further analysis.

Age composition may vary among areas for a number of reasons. Factors that may affect age structure and year class strength are weather conditions during spawning, incubation and hatching (Price 1940; Miller 1952; Christie 1963; Lawler 1965), food available during the first year of life (Hart 1930; Dymond 1948), predation on eggs, larvae and adults (Hart 1930; Wells and McClain 1972; Christie 1974), and differential fishing mortality.

Strong Year Classes

The strong 1943 year class in Green Bay and parts of northern Lake Michigan when compared with the strong 1972 year class of this study, showed some similarity and also a difference. The 1943 year class, evident in 1949-1950 (Table 3), supported the fishery in Green Bay from 1946-1949 (Roelofs 1958). It was similar to the 1972 year class which supported the Wisconsin whitefish fishery from 1975-1977 (Humphreys 1978). The 1944 year class following the 1943 year class was relatively weak (Roelofs 1958) (Table 3), as was the 1973 year class which followed the strong 1972 year class. A difference between the 1943 and 1972 year classes was that the 1943 year class was abundant in Big Bay de Noc, Lake Michigan east of Door County, the Cedar River area, Michigan, and possibly Peshtigo Reef (Roelofs 1958; Mraz 1964), whereas the 1972 year class, dominant at Peshtigo Reef, Chambers Island and North-Moonlight Bays, was not strong in Big Bay de Noc (Age V; Figure 4). The difference between the 1943 and 1972 year classes may indicate that previously stocks mixed to a greater degree or that 1943 was coincidentally a good year for spawning and survival in Big Bay de Noc as well as in other areas. Since the 1943 year class of whitefish in Lake Huron (Cucin and Regier 1965) and the 1943 year classes of lake herring (Coregonus artedii) and walleye (Stizostedion vitreum vitreum) of northern Green Bay and Lake Michigan (Roelofs 1958) also were exceptionally large, the latter seems more likely. Age composition of the Big Bay de Noc area after 1950 shifted to a younger age structure with the majority of the catch coming from ages II, III, and IV (Table 3).

Mean Age and Length in the Fishery

Mean age and length from Peshtigo Reef, Chambers Island, and

North-Moonlight Bays samples were larger than mean age and length from Big Bay de Noc samples (Table 4) because of the large 1972 year class in the former areas and the dominance of the 1973 and 1974 year classes in the Big Bay de Noc area. Mean ages at Peshtigo Reef, Chambers Island, and North-Moonlight Bays were not significantly different (Appendix F), but all were different from Big Bay de Noc spring and fall samples (Appendix F). Although mean length at Peshtigo Reef, Chambers Island, and North-Moonlight Bays differed by only 9.7 mm and mean length from these areas was greater than at Big Bay de Noc by 33.2 mm, mean lengths among all samples were not significantly different (Appendix G).

Growth

Growth, as determined by instantaneous rates and mean back-calculated lengths, was similar for whitefish in all samples and did not indicate discrete stocks. Instantaneous rates of growth (Table 5), progressively decreased from an average of 1.581 (between ages I and II) to an average of 0.074 (between ages IX and X). Instantaneous growth rates of whitefish in all areas were not significantly different (Appendix H). Mean back-calculated lengths also were not significantly different (Appendix I) for whitefish from Peshtigo Reef, Chambers Island, spring and fall Big Bay de Noc and fall North-Moonlight Bays samples. The only significant difference in lengths that I found was the back-calculated lengths from spring North-Moonlight Bays samples which were less than, and significantly different (Appendix I) than calculated lengths from the other samples. The difference between spring and fall North-Moonlight Bays samples is discussed in the section relating stock size to growth.

Table 3. Percentage age composition of lake whitefish in the commercial catch of Green Bay from 1948-1973 and one sample from Lake Michigan, 1948.

Year	Location	Period	II	III	IV	V	VI	VII	VIII	IX	Source
1949	Big Bay de Noc	Sept.-Oct.	2	21	18	1	56	2			Roelofs 1958
1950	Big Bay de Noc	Aug.-Sept.	1	46	18	2		26			Roelofs 1958
1951	Big Bay de Noc	Oct.-Nov.	22	70	3						Roelofs 1958
1952	Big Bay de Noc	Sept.	tr	98	2						Roelofs 1958
1953	Big Bay de Noc	Sept.-Oct.	1	85	14						Roelofs 1958
1954	Big Bay de Noc	Oct.-Nov.	9	88	3						Roelofs 1958
1948	L. Mich (Europe Bay)	Oct.	20	13.3	10	53	1.5		0.5		Mraz 1964
1948	Peshtigo	Oct.		11.9	49.4	38.7					Mraz 1964
1949	Cedar River	May	1.7	19.5	8.6	1.7	65.2	1.1	1.1	1.1	Mraz 1964
1951	Cedar River	June		89.8	8.9	1.3					Mraz 1964
1951	Gills Rock	June	32.8	62.4	4.0						Mraz 1964
1952	Washington IS.	Feb.		80.9	19.1						Mraz 1964
1952	Minn. Shoals	July & Sept.	26	71.4	2.2						Mraz 1964
1951	Big Bay de Noc	Oct.-Nov.	80	17							Barker 1953
1952	Big Bay de Noc	May		80	16					1.7	Barker 1953

Table 3. continued

Year	Location	Period	II	III	IV	V	VI	VII	VIII	IX	Source
1952	Big Bay de Noc	Sept.	0.8	97.6	1.6						Barker 1953
1966	Big Bay de Noc	Oct.	94	6							Piehler 1967
1968	Big Bay de Noc		38	38	20	1	2	tr	tr		
1969	Big Bay de Noc		28	31	25	4	10	2	54		
1969	St. Martins IS.	July-Aug.	10	82	7	1					DeMuth 1970
1970	Big Bay de Noc	July-Aug.	12	48	36	3		tr			Tyra 1971
1971	Big Bay de Noc			91	8	1					M.D.N.R.
1972	Big Bay de Noc		2	73	22	2					M.D.N.R.
1973	Big Bay de Noc		3	58	34	tr					M.D.N.R.

[a]Data collected by the Michigan Department of Natural Resources and presented by Patriarche (1977).

Table 4. Mean age (years) and mean length (mm) in the fishery for lake whitefish from Peshtigo Reef, Chambers Island, Big Bay de Noc and North-Moonlight Bays.

Location	Mean Age	Mean Length
Peshtigo Reef-Chambers Island Combined	4.74	511.6
Peshtigo Reef Spring 1977	4.80	513.5
Chambers Island Spring 1977	4.64	507.5
Big Bay de Noc Spring 1977	3.88	469.2
Big Bay de Noc Fall 1976	4.35	484.9
North-Moonlight Bays Spring 1977[a]	4.88	503.8

[a]Data from Humphreys 1978.

Table 5. True growth rates, G, for lake whitefish from Peshtigo Reef, Chambers Island, Big Bay de Noc and North-Moonlight Bays. $G = v(\log_e L_n - \log_e L_{n-1})$ (Ricker 1975:207).

Location	Age 1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Peshtigo Reef-Chambers Island Combined	1.7669	0.8902	0.5149	0.3150	0.1978	0.1217	0.1118	0.0849	0.0742
Peshtigo Reef Spring 1977	1.6897	0.8486	0.4993	0.2982	0.1830	0.1190	0.1134	0.0847	0.0733
Chambers Island Spring 1977	1.8270	0.9284	0.5267	0.3405	0.2200	0.1223	0.1050	0.0785	0.0720
Big Bay de Noc Spring 1977	1.3249	0.9095	0.5188	0.3043	0.1939	0.1547	0.0944	0.0793	0.0923
Big Bay de Noc Fall 1976	1.6580	0.9283	0.4941	0.2571	0.1974	0.1413	0.1120	0.1150	0.0663
North-Moonlight Bays Spring 1977[a]	1.4070	0.9261	0.6146	0.4130	0.2428	0.1348	0.1130	0.0713	0.0651

[a]Data from Humphreys 1978.

Table 6. Weighted back-calculated mean total length (mm) at each annulus for lake whitefish from Big Bay de Noc, Peshtigo Reef, Chambers Island and North-Moonlight Bay.

Location	Annulus I	II	III	IV	V	VI	VII	VIII	IX	X
Peshtigo Reef and Chambers Island combined Spring 1977	174	303	407	472	518	564	594	614	633	663
n	1855	1855	1810	1295	943	205	149	122	84	30
SD	4.9	14.2	13.6	9.6	8.3	11.8	10.5	10.5	12.7	18.7
Peshtigo Reef Spring 1977	180	306	410	475	522	564	592	611	629	650
n	1177	1177	1155	886	654	140	104	85	61	13
SD	5.3	12.9	11.4	5.9	5.6	9.0	8.4	4.8	6.4	14.0
Chambers Island Spring 1977	168	399	402	466	509	566	600	619	643	682
n	677	677	654	408	288	64	44	36	22	17
SD	9.7	17.5	18.6	18.0	16.5	19.6	15.4	18.2	20.2	10.1
Big Bay de Noc Spring 1977	203	317	414	464	504	564	595	612	626	652
n	1181	1181	1065	493	157	20	14	12	9	1
SD	6.2	8.7	15.9	8.4	12.5	10.1	6.6	3.0	3.1	0
Big Bay de Noc Fall 1976	196	319	414	469	524	557	577	599	621	662
n	705	705	694	201	51	43	31	20	8	2
SD	4.6	6.5	9.0	13.4	13.8	11.6	10.9	12.2	17.7	0.4
North-Moonlight Bay[a] Spring 1977	194	289	397	445	497	563	576	594	614	660
n	1379	1379	1340	1138	1038	32	11	7	4	4
SD	7.1	13.5	4.7	9.3	5.8	8.6	13.0	17.6	22.2	0
North-Moonlight Bay[a] Fall 1976	161	281	385	462	541	579	603	627	649	
n	684	684	684	657	163	126	94	53	10	
SD	4.6	12.9	17.6	19.7	9.8	4.9	4.4	2.9	0.1	

An early advantage in growth may not be maintained throughout life. Although mean back-calculated lengths were not significantly different, some differences between areas were evident. Back-calculated lengths were greater for the first three years in Big Bay de Noc than in North-Moonlight Bays, Peshtigo Reef and Chambers Island (Table 6). However, after age III, growth of whitefish from Peshtigo Reef, Chambers Island and fall North-Moonlight Bays samples increased so that their lengths equaled or exceeded lengths at Big Bay de Noc for ages IV through X. In contrast, whitefish from spring North-Moonlight Bays maintained the early growth disadvantage throughout life. The difference between spring and fall North-Moonlight Bays samples may have been caused by whitefish moving from Peshtigo Reef and Chambers Island to North-Moonlight Bays in fall to spawn.

<u>Relationship of Stock Size to Growth</u>

Stock size of lake whitefish may influence growth; growth of large year classes of lake whitefish may be slower than that of other year classes. Growth of the large 1972 year class was less than growth of other year classes based on back-calculated lengths from Peshtigo Reef, Chambers Island, and North-Moonlight Bays samples (Appendix K). Similarly, Cucin and Regier (1965) reported slow growth of the large 1943 year class in South Bay, Lake Huron. Roelofs (1958), however, reported faster growth of the large 1943 year class than of other year classes present at that time in northern Green Bay, and concluded that factors responsible for production of the large 1943 year class also favored growth.

Slow growth of the 1972 year class was probably responsible for the significant difference observed between back-calculated lengths from spring North-Moonlight Bays sample and the back-calculated lengths from the other samples. The spring North-Moonlight Bays sample was composed of 85% of the 1972 year class while the other samples contained 50% or less. Therefore, the large percentage of the slow growing 1972 year class in spring North-Moonlight Bays, decreased the weighted mean back-calculated lengths from that area for ages I through V.

Stock size also seemed to influence growth during the period 1948-1977, as back-calculated lengths increased with decreasing stocks and then decreased as stock size increased. Mean back-calculated lengths of age III whitefish from the northern Green Bay area (Table 7, underlined values) increased from an average of about 370 mm (1948-1952), to an average of 460 mm (1966 and 1969). Harvest in Lake Michigan during this time decreased from over 5 million pounds (1948) to 31 thousand pounds (1959). The increased growth of whitefish may have been a compensatory reaction to reduced stock size which was caused largely by increased predation by sea lamprey. The sea lamprey had severely reduced stocks of lake trout (Salvelinus namaycush) by 1950 and was thought to be responsible for declines of lake whitefish after 1950 (Christie 1974; Smith 1968; Wells and McClain 1973). Compensatory growth of lake whitefish in response to exploitation was reported by Regier and Loftus (1972), Healey (1975), Bond and Turnbull (1973) and Schlick (1971). Lamprey were brought under control and lake trout, the preferred prey of sea lamprey, were reintroduced, and lake trout became abundant by the late 1960's, which should have reduced lamprey predation pressure on whitefish (Christie 1974). Harvest of whitefish in Lake Michigan in 1966 increased from the previous low to over 1 million pounds and continued to increase, with over 4 million pounds harvested in 1976. Mean back-calculated lengths decreased with the increase in stock size (Table 7, underlined values); mean back-calculated length of age III whitefish of this study (1977) in northern Green Bay was 414 mm.

Table 7. Mean back-calculated total length (mm) at each annulus for lake whitefish from Green Bay and northern Lake Michigan (1949-1973). Underlined values are discussed in the text.

Location	Years	I	II	Annuli III	IV	V	References
Lake Michigan	1948	142	249	<u>350</u>	437		Mraz 1964
Central Green Bay	1948-52	168	300	406	480		Mraz 1964
Big Bay de Noc	1949	136	252	<u>356</u>	438	493	Caraway 1951
Big Bay de Noc	1950	141	252	<u>366</u>	438	488	Caraway 1951
South Fox Island	1949	108	177	251	335		Roelofs 1958
Big Bay de Noc	1949	130	250	<u>358</u>	456		Roelofs 1958
Big Bay de Noc	1950	143	239	<u>350</u>	455		Roelofs 1958
High Island	1950	138	230	325	431		Roelofs 1958
Gull Island	1950	131	221	313	424		Roelofs 1958
Big Bay de Noc	1951	175	311	<u>397</u>	434	474	Barker 1953
Big Bay de Noc	1952	180	312	<u>395</u>	472	513	Barker 1953
Big Bay de Noc	1966	200	358	<u>465</u>			Piehler 1956
Northern Green Bay	1969	180	343	<u>455</u>	510	565	DeMuth 1970

Table 7. continued

Location	Years	I	II	Annuli III	IV	V	References
Big Bay de Noc	1969-73	170	310	419			Michigan DNR
Northern Green Bay	1970	170	317	414	462	515	Tyra 1971
Big Bay de Noc Fall	1976	196	319	414	469	524	This Study
Big Bay de Noc Spring	1977	203	317	414	464	504	This Study

[a]Data from Patriarche 1977.

Estimated growth histories by various methods of back-calculation are usually comparable except for the first year or two of life (Carlander 1969, p. 16). Various methods have been used to back-calculate lengths for lake whitefish. A correction factor of 40 mm was used by some (Caraway 1951; Piehler 1967; Brown 1968) based on the study of Van Oosten (1923) in which direct observation placed the length at scale formation at 35-40 mm. Others have used a direct proportion method of back-calculation (Dryer 1963; Mraz 1964). The body length-scale length regression (L=a+bS), the method used in this study, has also been applied. The intercept of this regression has been reported as the length of fish at scale formation, but this interpretation is not necessarily correct (Carlander 1969, p. 16).

My back-calculations did not reveal the presence of Lee's phenomenon (Carlander 1969, p. 17), which has been reported for lake whitefish by Van Oosten and Hile (1947) and Roelofs (1958), but not by Mraz (1964), Kennedy (1943), Piehler (1967), and Humphreys (1978).

Length-Weight Relationships

Length-weight regression equations, calculated for each area (Table 8), showed differences among areas, but weights predicted from the regression equations were similar, and discrete stocks could not be identified. The Peshtigo Reef sample, which had the lowest v value (3.0746), was significantly different from the Chambers Island sample (3.2344) ($t=2.25$, $n=532$, $p \leq .05$). The Big Bay de Noc spring sample, significantly different from the Peshtigo Reef sample ($t=2.51$, $n=720$, $p \leq .05$) was not different from the Chambers Island sample ($t=.42$, $n=700$, $p \leq .05$). The spring North-Moonlight Bays sample, which had the largest slope (3.6047) (Humphreys 1978), was significantly different

Table 8. GM functional and predictive length-weight regression equations for lake whitefish from Peshtigo Reef, Chambers Island, Big Bay de Noc and North-Moonlight Bays; total length was measured in millimeters and weight was in kilograms. Numbers in parentheses are sample size and r is the correlation coefficient of the predictive regression.

Location	Functional Equation	Predictive Equation	r
Peshtigo Reef-Chambers Island combined Spring 1977 (567)	$Log_eW = -19.3623 + 3.1514(Log_eL)$	$Log_eW = -18.6863 + 3.0426(Log_eL)$	.96
Peshtigo Reef Spring 1977 (269)	$Log_eW = -18.8699 + 3.0746(Log_eL)$	$Log_e = -18.1852 + 2.9643(Log_eL)$	.96
Chambers Island Spring 1977 (298)	$Log_eW = -19.8931 + 3.2344(Log_eL)$	$Log_e = -19.2759 + 3.1351(Log_eL)$	.97
Big Bay de Noc Spring 1977 (443)	$Log_eW = -20.1423 + 3.2677(Log_eL)$	$Log_e = -18.6145 + 3.0189(Log_eL)$	.92
Big Bay de Noc Fall 1976 (735)	$Log_eW = -21.5337 + 3.4890(Log_eL)$	$Log_e = -20.9246 + 3.3905(Log_eL)$	.97
North-Moonlight Bays Spring 1977[a] (320)	$Log_eW = -22.2478 + 3.6047(Log_eL)$	$Log_e = -21.1696 + 3.4251(Log_eL)$	.95

[a]Data from Humphreys 1978.

from all Green Bay samples (Appendix J). Weights predicted from the equation W=uL for lengths 200-600 mm were similar for all spring samples (Figure 5) regardless of significant differences among slopes. For example, weights predicted from the regression equations from spring samples for a length of 500 mm ranged from 1.17 to 1.25 kg.

Slopes of length-weight regression equations for lake whitefish in this study differed among locations and from spring to fall--similar to what has been reported in the literature, indicating the high variability of this parameter. The slope (v) of the GM functional regression of weight on length was used for comparison of samples, as suggested by Ricker (1973), but for comparison to slopes found in the literature, I used the predictive regression slope (b) because it has been used exclusively in the literature. Values of b were consistently lower than values of v (Table 8). Values of b in the literature (Table 9) have varied among areas in Lake Michigan, ranging from 3.862 west of Seul Choix Point (Piehler 1967) to 2.780 in the Big Bay de Noc area (Barker 1953; Piehler 1967). Values of b have also varied during the course of a year, ranging in Big Bay de Noc from 2.778 in spring to 3.437 in fall (Barker 1953). Values of b in this study (Table 8) ranged from 2.964 at Peshtigo Reef to 3.408 at North-Moonlight Bays (Humphreys 1978), and in Big Bay de Noc from 3.391 in fall to 3.019 in spring. The variability, from spring to fall was probably caused by the development of reproductive products, but differences among areas and times of sampling also may be caused by differences in sample size, differences in range of lengths and weights in samples, and true differences between stocks.

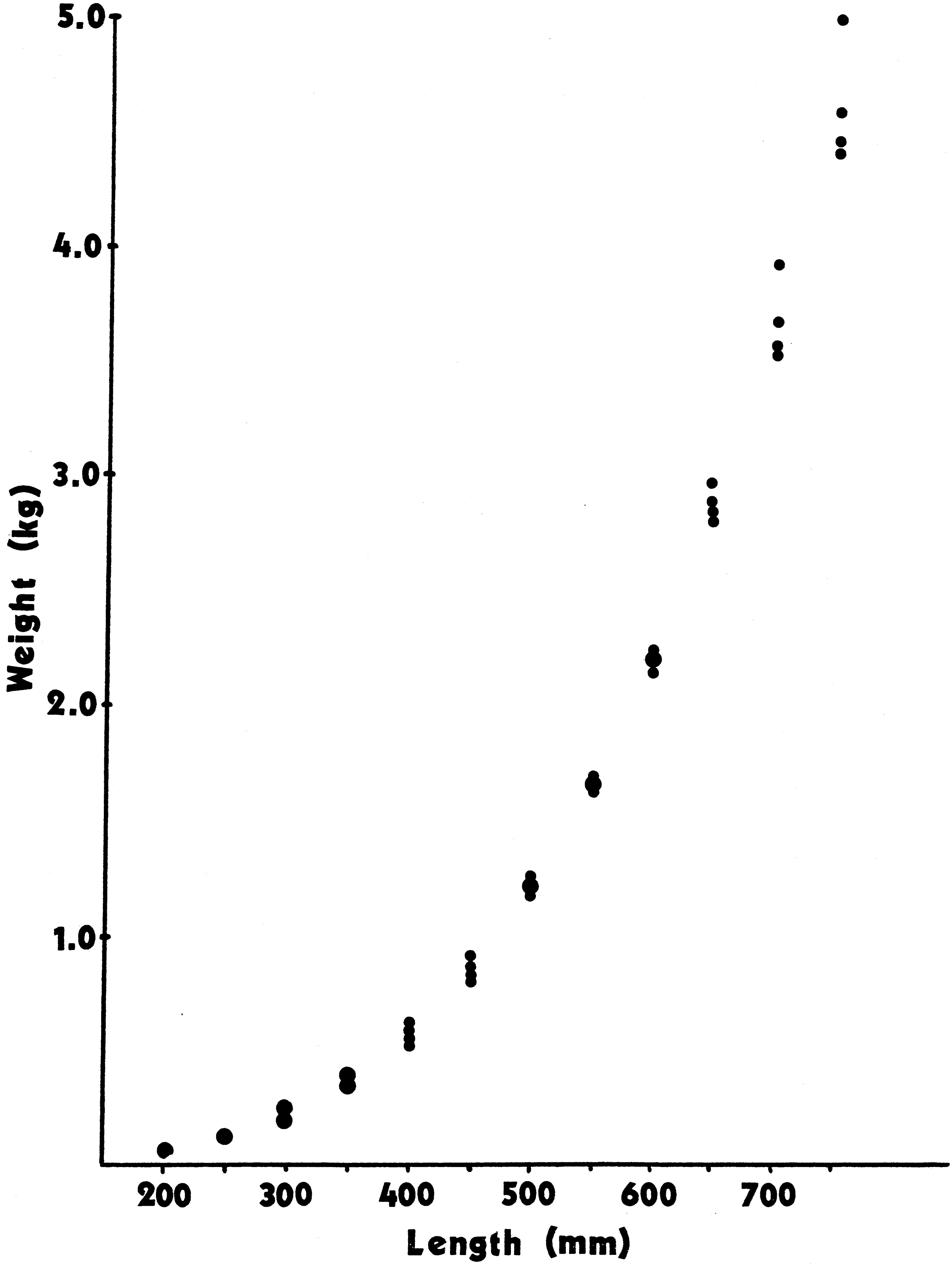

Figure 5. Length - weight relationship predicted from the GM functional regression for spring samples from Peshtigo Reef, Chambers Island, Big Bay de Noc of Green Bay and North-Moonlight Bays of Lake Michigan.

Table 9. Slopes (b) of the predictive Lt-Wt regressions found in the literature for lake white fish from Green Bay and northern Lake Michigan (1948-1973), sample size in parentheses.

Location	Years	b value	Reference
Lake Michigan (Europe Bay) (204)	1948 (Oct.)	3.3590	Mraz 1964
Central Green Bay (978)	1948-52 (All seasons)	3.3865	Mraz 1964
Big Bay de Noc (848)	1949 (Fall)	3.2544	Caraway 1951
Gull Island (254)	1950 (August)	2.9886	Caraway 1951
High Island (174)	1950 (August)	2.8166	Caraway 1951
Big Bay de Noc (294)	1951-52 (Fall)	3.4371	Barker 1953
Bif Bay de Noc (545)	1952 (Spring)	2.7783	Barker 1953
Big Bay de Noc (75)	1965-66	2.780	Piehler 1967
S. and S.E. of Naubinway (75)	1965-66	2.913	Piehler 1967
E. of Seul Choix Point (75)	1965-66	3.120	Piehler 1967
W. of Seul Choix Point (75)	1965-66	3.862	Piehler 1967
St. Martins Island[a]	1969	2.987	DeMuth 1970
Green Bay[a]	1971-73	3.1780	Patriarche 1977
Grand Traverse Bay[a]	1971-73	3.4552	Patriarche 1977
North Shore Lake Michigan[a]	1971-73	3.2783	Patriarche 1977

[a]Sample size not given.

Age at Recruitment

Age at recruitment was similar among whitefish from Green Bay, but because of smaller back-calculated lengths in North-Moonlight Bays than in the other areas, recruitment was later at North-Moonlight Bays than in Green Bay. Age at recruitment ranged from 3.3 to 3.5 in Green Bay and was 3.7 in North-Moonlight Bay samples (Table 10). Age at recruitment, calculated by interpolation of weighted mean back-calculated lengths and by von Bertalanffy growth equations (Appendix L), were similar, and estimates were within 0.1 year of each other (Table 10). For these calculations, ages were assigned to correspond to the period of growth, which was assumed to occur during the 5 month period from May through September. Based on this assumption, if a year class were recruited at age 3.5, it would enter the fishery by the midpoint of the growing season, about July, of the fourth year of life.

Total Mortality Rates Estimated from Catch Curves

Total instantaneous mortality rates (Table 11), estimated from catch curves, were higher in spring samples than in fall samples from both Big Bay de Noc and North-Moonlight Bays, indicating movement of older fish into the fishery in fall. Lake whitefish were recruited into the fishery during the growth period of the fourth year of life in all areas (Table 10); therefore, ages IV and older in spring samples and ages III and older in fall samples were used to estimate mortality. I considered the best estimate of mortality to be from a combined spring and fall sample.

Instantaneous total mortality rates (Table 11), when compared among samples obtained in the same season seemed to suggest discrete stocks of whitefish. Mortality rates from the spring Peshtigo Reef ($Z = 0.528$) and Chambers Island ($Z = 0.518$ samples were similar and lower than mortality

Table 10. Age at recruitment (minimum legal length of 432 mm) calculated by interpolation of mean back-calculated lengths and from von Bertalanffy growth equations for samples from Peshtigo Reef, Chambers Island, Big Bay de Noc and North-Moonlight Bays.

	Age at Recruitment	
Location	Interpolation	von Bertalanffy
Peshtigo Reef-Chambers Island Combined	3.48	3.58
Peshtigo Reef Spring 1977	3.39	3.40
Chambers Island Spring 1977	3.34	3.42
Big Bay de Noc Spring 1977	3.36	3.32
Big Bay de Noc Fall 1976	3.43	3.45
North-Moonlight Bays[a] Spring 1977	3.71	3.71

[a]Data from Humphreys 1978.

Table 11. Total annual mortality and survival rates (A,S) and instantaneous mortality rate (Z) estimated for lake whitefish from Peshtigo Reef, Chambers Island, Big Bay de Noc and North-Moonlight Bays. The value r is the correlation coefficient for the catch curve.

Location	A	S	Z	r
Peshtigo Reef, Spring 1977	0.410	0.590	0.528	0.80
Chambers Island, Spring 1977	0.404	0.596	0.518	0.83
Peshtigo-Chambers, Combined Spring 1977	0.414	0.586	0.535	0.82
Big Bay de Noc, Spring 1977	0.633	0.367	1.003	0.87
Big Bay de Noc, Fall 1976	0.477	0.523	0.648	0.80
Big Bay de Noc, Combined Spring and Fall	0.547	0.453	0.792	0.93
North-Moonlight Bays, Spring 1977[a]	0.641	0.359	1.024	0.88
North-Moonlight Bays, Combined[a] Fall 1975 and 1976	0.408	0.592	0.524	0.91
North-Moonlight Bays, Combined[a] Samples 1975-1977	0.668	0.332	1.102	0.88

[a]Data for North-Moonlight Bays from Humphreys 1978.

rates from Big Bay de Noc (Z = 1.003) and North-Moonlight Bays (Z = 1.024) spring samples, suggesting presence of older fish in the former areas than in the latter. Mortality rates were similar for spring samples from Big Bay de Noc and North-Moonlight Bays, which could indicate the stocks were the same and that the Peshtigo Reef-Chambers Island stock was different. Mortality rates from fall Big Bay de Noc and North-Moonlight Bays samples differed a bit more than rates from spring samples.

Mortality rates from spring Peshtigo Reef-Chambers Island (Z = 0.535) and fall North-Moonlight Bays samples (Z = 0.524) were similar suggesting that stocks of whitefish from spring Peshtigo Reef-Chambers Island samples may have contributed to the North-Moonlight Bays spawning stock in fall. The mortality rate of the fall North-Moonlight Bays samples (Z = 0.524) was lower than the spring sample from North-Moonlight Bays (Z = 1.024) and the mortality rate from the fall Big Bay de Noc sample (Z = 0.648) also was lower than in the spring sample (Z = 1.003). This difference at Big Bay de Noc also could have resulted from movement of whitefish from Peshtigo Reef-Chambers Island to that area during the spawning season. However, age compositions indicated that whitefish did not migrate from Peshtigo Reef-Chambers Island to Big Bay de Noc in fall, but that they probably moved into the North-Moonlight Bays area. The 1972 year class which made up 48% of the catch at Peshtigo Reef-Chambers Island in spring of 1977 made up only 23% of the catch in Big Bay de Noc in fall 1976. The fall 1976 catch in North-Moonlight Bays contained 55% of the 1972 year class. I concluded that the decrease in mortality in fall North-Moonlight Bay samples was at least partially due to the contribution of the older whitefish from Peshtigo Reef-Chambers Island and the decrease in mortality in fall in Big Bay de Noc was not caused by an influx of those fish.

Catch curves from data obtained in one year are subject to bias from fluctuations in year class strength (Robson and Chapman 1961), but the large 1972 year class in North-Moonlight Bays and Peshtigo Reef-Chambers Island probably did not destroy the usefulness of the catch curves in those areas. Combining data over a number of years helps to eliminate the effects of fluctuating year class strength (Ricker 1975, p. 33). Humphreys (1978) combined data from 1975-1977 for the North-Moonlight Bays area and obtained an estimate of 0.67 for total annual mortality (Table 12). My estimate of A for the spring 1977 sample from North-Moonlight Bays was 0.64. Its similarity to the estimate obtained from pooled data (0.67) suggests that although bias was possible, a reliable estimate of mortality for that population was obtained from data from a single season (spring). Healy (1975) reported that if data for only one or two years are available, the presence of a strong year class that was becoming fully vulnerable would make mortality calculated from age structure higher than the true mortality, while the converse would be true if a weak year class were becoming vulnerable at the time of sampling. The weak 1973 year class becoming vulnerable at the time of sampling in North-Moonlight Bays and Peshtigo Reef-Chambers Island areas may have offset the effects of the large 1972 year class.

The estimated total annual mortality rate for Big Bay de Noc was similar to what others have found in northern Green Bay and Lake Michigan (Table 12). The combined spring and fall estimate (0.55) was similar to that of other exploited whitefish populations, with the exception of the high annual mortalities of 0.94 (Roelofs 1958), 0.89 (Spangler 1970), and 0.93 (Budd and Cucin 1962), which the authors attributed largely to lamprey predation. The sea lamprey reached maximum abundance in Lake

Table 12. Total annual and instantaneous mortality rates (A,Z) of lake whitefish in this study and from studies of other lake whitefish populations.

Lake	A	Z	Period	Ages	Method of Estimation	Reference
Green Bay (Big Bay de Noc)	0.55	0.79	1976-1977	IV-X	Catch Curve	This study
Green Bay (Peshtigo-Chambers area)	0.41	0.53	1977	IV-X	Catch Curve	This study
Lake Michigan (North-Moonlight Bays)	0.67	1.10	1975-1977	IV-X	Catch Curve	Humphreys 1978
Lake Michigan	0.60	0.92	1968-1972	III-V	C P E [b]	Michigan D.N.R.[a]
Lake Michigan	0.69	1.17	1967	II-IV	Age Composition	Brown 1968
Northern Green Bay	0.64	1.02	1968-1972	II-V	C P E [b]	Michigan D.N.R.[a]
Green Bay (Big Bay de Noc)	0.94	2.81	1951-1954	III	Age Composition	Roelofs 1958
Huron	0.89	2.21	1964-1968	II-IV	Tagging Study	Spangler 1970
Huron	0.93	2.66	1960	II-IX	Catch Curve	Budd and Cucin 1962
Huron (Georgian Bay)	0.62	0.97	1957-1964		Catch Curve	Cucin and Regier 1965
Winnipeg	0.64	1.02			Catch Curve	Kennedy 1954
Winnipeg	0.79	1.56	1944-1969	IV-XII	Catch Curve	Davidoff et al. 1973

Table 12. continued

Location	A	Z	Period	Ages	Method of Estimation	Reference
Ontario	0.52	0.73			Catch Curve	Christie 1963
Nueltin (unexploited)	0.57	0.84	1948-1949	XII-XVI	Catch Curve	Kennedy 1963
MacDonald (unexploited)	0.81	1.66	1948-1949	XI-XIV	Catch Curve	Kennedy 1963
Macewan (unexploited)	0.74	1.35	1948-1949	VIII-XI	Catch Curve	Kennedy 1963
Lake Superior (Munising	0.44	0.58			Catch Curve	Edsall 1960
Bay, unexploited)	0.26	0.30			Catch Curve	Edsall 1960

[a]Data from Michigan Department of Natural Resources presented in Patriarche 1977.

[b]Mortality estimated from decrease in catch per effort for individual year classes from one year to the next.

Michigan in the mid-1950's which coincided with the high mortality rate reported in Big Bay de Noc. Sea lamprey control in Lake Michigan began in 1960 and was effective by 1967 (Smith 1968). Although lamprey are still present (I estimated less than 1% lamprey attacks on 2360 whitefish examined; spring 1977) in the Big Bay de Noc area, their effect on whitefish must be less than before lamprecide treatments and is reflected in the reduced mortality rates.

Total annual mortality rate of the Peshtigo Reef-Chambers Island area was low compared with mortality rates of other exploited populations. The total annual mortality of 0.41 for the Peshtigo Reef-Chambers Island area was considerably lower than the mean of values (0.68) from exploited populations found in the literature (Table 12). Reasons for the low mortality rate are not apparent, since fishing effort is not unusually low in the Peshtigo Reef (WM-1)-Chambers Island (WM-2) areas (Appendix B & C).

Results of Tagging Studies

The extent of tag returns from whitefish tagged during spawning seasons in North-Moonlight Bays indicated that the stock(s) was migratory. Whitefish tagged in autumn in North-Moonlight Bays (Humphreys 1978) were subsequently recaptured in all areas of Green Bay (WM-1, WM-2, MM-1), in northern Lake Michigan (MM-2, MM-3), and south of the tagging site (WM-4, WM-5) as well as in the area of tagging (WM-3). Whitefish seemed to return to the North-Moonlight Bays area in fall (Humphreys 1978). The migratory nature of the North-Moonlight Bays stock was similar to that of a stock of whitefish in South Bay, Lake Huron (Budd 1956), where whitefish migrated up to 150 miles into Lake Huron and Georgian Bay and returned to South Bay each year.

The North-Moonlight Bays tagging study provided evidence in support of my belief that whitefish at the Peshtigo Reef-Chambers Island area spawn in North-Moonlight Bays. Tags from the North-Moonlight Bays spawning stock were returned from all areas of Green Bay, but the rate of return was greater in statistical district WM-1 (which includes Peshtigo Reef) and WM-2 (which includes Chambers Island) than MM-1 (which includes Big Bay de Noc). Rate of return was determined by number of tags returned per 10,000 pounds of whitefish caught in the commercial fishery. Rate of return, for fish tagged during the spawning seasons of 1975 and 1976 combined, in WM-3 (tagging site) was 33.7 and was similar to the rate in WM-2 which was 30.2. Rate of return in WM-1 (12.5) was lower than in WM-2 and WM-3, but was considerably higher than MM-1 (3.8).

Roelofs (1958) reported results of a tagging study in Big Bay de Noc in 1954 and 1955 by Norcross (unpublished) which indicated whitefish in Big Bay de Noc were not migratory. Only 1 out of 209 tag returns was from Lake Michigan proper, the remainder were from the Green Bay-Big Bay de Noc area. Non-migratory stocks of whitefish have been reported in Lake Superior (Edsal 1960; Dryer 1964), Lake Huron (Budd 1956; Cucin and Regier 1965; Spangler 1970), and Lake Michigan (Smith and Van Oosten 1939).

<u>Conclusions Concerning Discrete Stocks</u>

Whitefish of the Big Bay de Noc area appear to be a stock separate from Peshtigo Reef and Chambers Island; Peshtigo Reef and Chambers Island are of the same stock and probably spawn with fish from Lake Michigan proper at North-Moonlight Bays. Reasons for these conclusions are:

1. Age composition-Spring 1977 catches at Peshtigo Reef and Chambers Island had similar age compositions and contained a large 1972 year class (Age V) and a weak 1973 year class (Age IV) and were similar in this

respect to catches at North-Moonlight Bays. In contrast at Big Bay de Noc, spring 1977 catches were dominated by the 1973 year class (Age IV) and the 1972 year class (Age V) was not abundant.

2. Mortality-Mortality rates for spring samples from Peshtigo Reef and Chambers Island were considerably lower than at Big Bay de Noc and North-Moonlight Bays, which were similar. However, spring mortalities at Peshtigo Reef and Chambers Island were similar to fall mortalities at North-Moonlight Bays, indicating a contribution of the Peshtigo Reef-Chambers Island stock at North-Moonlight Bays during spawning.

3. Tag returns-Analysis of rates of tag return from the North-Moonlight Bays fall tagging indicated substantial movement of whitefish into central and southern Green Bay and migration back to North-Moonlight Bays in fall to spawn (Humphreys 1978). Roelofs (1958) reported results of a tagging study in Big Bay de Noc in 1954 and 1955 which indicated whitefish from that area are non-migratory and, therefore, probably do not contribute to the fishery in central and southern Green Bay.

4. Results of other studies-Imhoff (1977) examined the population genetic structure of lake whitefish by electrophoresis of muscle enzymes and concluded that two populations of whitefish inhabited Green Bay and northern Lake Michigan. Imhoff reported similarity between the North-Moonlight Bays spawning sample and the Chambers Island spring sample, and differences between Big Bay de Noc and North-Moonlight Bay spawning samples. Other authors (Caraway 1951; Roelofs 1958; Piehler 1967) concluded that a different stock of whitefish was found in Big Bay de Noc than was found along northern Lake Michigan based on age, growth, year class strength, and some morphometric characters.

Critical Size

Maximum yield from a year class of fish may be obtained when the fish are harvested at the point where total weight of the year class is greatest, which occurs when instantaneous natural mortality (M) is equal to instantaneous growth in weight (G) (Ricker 1945; Ricker 1975, p. 241). The length of fish when M=G is the critical size. At lengths smaller than the critical size, more weight is added than is lost to natural mortality because growth exceeds natural mortality, but at lengths larger than the critical size more weight is lost to natural mortality than is added by growth. Harvest of a year class precisely at the critical si: in a natural, wild population is seldom possible; therefore, cropping should take place equally on both sides of the critical size. The distance below the critical size where cropping should begin is dependent on fishing rate (Ricker 1975, p. 241). Two estimates of critical size were calculated for each area (Table 13) from true growth rates (Table 5) and two estimates of natural mortality (Table 13). One estimate of natural mortality that I used, M=0.47, was from North-Moonlight Bays (Humphreys 1978) and the other estimate, M=0.34, was from Grand Traverse Bay.

Estimates of critical size, similar in Green Bay and North-Moonlight Bays, Lake Michigan, were within 15 mm for calculations from either estimate of M (Table 13). Critical size was larger for M=0.34 and ranged from 472 to 487 mm. Critical size for M=0.47 ranged from 444 to 459 mm.

Whitefish were being harvested at a more optimum level in Big Bay de Noc than in other areas based on the relationship of critical size to mean length in the fishery and percentage of the catch less than the critical size. Mean length in the fishery from Big Bay de Noc was closer to

Table 13. Critical size and percentage of the catch below the critical size by weight and number for two estimates of natural mortality for lake whitefish sampled at Peshtigo Reef-Chambers Island, Big Bay de Noc and North-Moonlight Bay.

Location	Critical Size		Percentage Below Critical Size			
			M=0.47		M=0.34	
	M=0.47	M=0.34	by weight	by number	by weight	by number
North-Moonlight Bays Spring 1977[a]	459		4.7%	7.5%		
Peshtigo Reef-Chambers Island Spring 1977	446	481	6.2%	10.4%	21.6%	32.6%
Average			10.8% by weight, 16.8% by number			
Big Bay de Noc Spring 1977	449	472	30.7%	39.3%	51.1%	61.3%
Big Bay de Noc Fall 1976	444	472	5.1%	7.4%	36.9%	47.4%
Average			30.9% by weight, 38.8% by number			

[a]Data from Humphreys, 1978.

estimated values of critical size than mean lengths from the Peshtigo Reef-Chambers Island area and North-Moonlight Bays. Percentages by weight of the catch below critical size averaged 10.8% (89.2% above critical size) in Peshtigo Reef-Chambers Island and North-Moonlight Bays samples whereas, percentages of the catch below critical size averaged 30.9% (69.1% above critical size) in Big Bay de Noc samples. Percentages of the catch above and below critical size in Peshtigo Reef-Chambers Island and North-Moonlight Bays samples indicated that many whitefish were harvested at lengths greater than the critical size and, therefore, potential yield was lost to natural mortality.

Effects of Raising the Minimum Size Limit

There have been suggestions to increase the present minimum size limit of 432 mm (17") to 483 mm (19"). The growth and mortality data obtained in this study indicated that such an increase in the size limit would reduce the harvest; it would place the legal size at or above the critical size, where natural mortality exceeds growth. During the period of this study, an increase in the size limit to 483 mm would have reduced weight of the harvest by 23% (35% by number) at Peshtigo Reef and Chambers Island, 16% (22% by number) at North-Moonlight Bays, and 57% (67% by number) in the Big Bay de Noc area (Table 14). The effect, by age class (Appendix M) at Peshtigo Reef and Chambers Island would be a reduction by weight in the spring catch of 100% of age III, 48% of age IV and 6% of age V. At Big Bay de Noc, weight of age III would be reduced by 87%, age IV by 47%, and age V would be reduced by 16%.

Although harvest of whitefish above the critical size would lower yield, an increased size limit would allow more time for spawning, and therefore could provide greater stability for the fishery. Whitefish

Table 14. Percent of the catch less than 457 mm (18") and less than 483 mm (19") for samples of lake whitefish from Peshtigo Reef, Chambers Island, Big Bay de Noc, and North-Moonlight Bays.

Location	Less Than 457 mm		Less Than 483 mm	
	by weight	by number	by weight	by number
Peshtigo Reef-Chambers Island Combined	11%	19%	23%	35%
Peshtigo Reef Spring 1977	10%	17%	21%	33%
Chambers Island Spring 1977	13%	21%	24%	36%
Big Bay de Noc Spring 1977	37%	46%	61%	71%
Big Bay de Noc Fall 1976	17%	23%	52%	64%
Big Bay de Noc Fall 1976 and Spring 1977 Combined	26%	36%	57%	67%
North-Moonlight Bays Spring 1977[a]	4%	7%	16%	22%

[a]Data from Humphreys 1978.

typically have a large fluctuation in year class strength (Christie and Regier 1973), and the recruited part of many whitefish populations is comprised of one or two year classes (Cucin and Regier 1965; Spangler 1974; Patriarche 1977). Whitefish stocks in this study were also largely dominated by one or two year classes. Reproductive failure for one or two years would cause a severe loss to the fishery. An increased size limit could increase the number of fish available for reproduction which could reduce the chances of severe stock reductions from reproductive failure.

"t" and Mean Number of Spawning

Values of t, extent (years) to which commercial turnover in the catches exceeds the age of onset of sexual maturity (Abrosov 1969), and mean number of spawnings were greater in Peshtigo Reef-Chambers Island and North-Moonlight Bays than in Big Bay de Noc, indicating a younger age structure in the fishery in Big Bay de Noc than in the former areas. Estimates of t ranged from one year in Big Bay de Noc to two years in North-Moonlight Bays, and mean number of spawnings ranged from 1.6 to 2.3 in Big Bay de Noc and Peshtigo Reef-Chambers Island, respectively. Mean number of spawnings and t values reported by Patriarche (1977) for data collected in 1973 from Big Bay de Noc (Table 15) were substantially lower than those found in this study. Since 1973, whitefish ages IV and V have increased in commercial catches from Big Bay de Noc and consequently number of spawnings and t have increased.

Optimal values of t and mean number of spawnings have not been documented for stocks of lake whitefish. However, Christie and Regier (1973) reported that only one of six year classes which had less than one spawning replaced itself, and that of five year classes which spawned at least

Table 15. Commercial turnover, extent to which commercial turnover exceeded age of onset of sexual maturity (t) and mean number of spawnings for lake whitefish from Big Bay de Noc, Peshtigo Reef, Chambers Island, North-Moonlight Bays and Lake Michigan statistical districts MM-1 and MM-3. Commercial turnover and t expressed in years.

Location	Commercial turnover	t	Mean Number of Spawnings	Reference
Big Bay de Noc				
Fall 1976	4.04	1.04	2.05	This Study
Spring 1977	4.03	1.03	1.58	"
Combined spring & fall	4.03	1.03	1.84	"
Peshtigo Reef				
Spring 1977	4.95	1.95	2.32	"
Chambers Island				
Spring 1977	4.79	1.79	2.34	"
Peshtigo-Chambers combined	4.89	1.89	2.30	"
North-Moonlight Bays				
Spring 1977	5.03	2.03	1.56	Data from Humphreys 1978
Combined fall 1975 & 1976	4.76	1.76	2.31	"
Combined 1975-1977 samples	5.02	2.02	1.50	"
MM-3 Northern Lake Michigan	3.61	.61	.60	Patriarche 1977
MM-1 Big Bay de Noc	3.37	.37	.40	"

once, three replaced themselves and two were close to replacement. Abrosov (1969) reported a t value of 1.46 for the Russian whitefish, Coregonus lavaretus, and from his results authors have inferred that t for the Russian whitefish should not become less than 1.5 to 3.5 years (Christie and Regier 1973; Spangler 1974; Patriarche 1977); they also suggest these values may be applicable to lake whitefish.

Fishing Mortality

Estimates of instantaneous fishing mortality were similar among Big Bay de Noc, North-Moonlight Bays and estimates in the literature, but the Peshtigo Reef-Chambers Island area had lower estimates of F than expected for exploited populations (Table 16). Two estimates of instantaneous fishing mortality were calculated (Ricker 1975, p. 10) for each sample based on estimates of Z from each sample (Table 11) and estimates of M from Grand Traverse Bay (0.34) and North-Moonlight Bay (0.47). Estimates of F for the Peshtigo Reef-Chambers Island area (0.06 and 0.20) appear to be unrealistic and were lower than most estimates reported in the literature for exploited lakes, but were similar to estimates in Lesser Slave Lake (0.06-0.28) (Bell et al. 1977).

Estimates of F and M from spring Big Bay de Noc samples were similar to those in North-Moonlight Bays and Georgian Bay of Lake Huron (Table 16). Estimates of F in combined spring and fall Big Bay de Noc samples, which I considered to be the best estimates, were lower than the mean values of Patriarche (1977) (Table 16) for data collected in 1973 from the same area. The cause for the decrease in F since 1973 seems to be an increase of older whitefish, which lowered the total mortality of this study, but the reason for the increase of older whitefish is not known.

Table 16. Instantaneous fishing & natural mortality rates of lake whitefish in various large lakes.

Lake	Instantaneous Fishing Mortality (F)	Instantaneous Natural Mortality (M)	Ages	Reference
Big Bay de Noc spring 1977	0.53 0.66	0.47 0.34	IV-X	This Study
Big Bay de Noc fall 1976	0.18 0.31	0.47 0.34	III-X	This Study
Big Bay de Noc combined	0.32 0.45	0.47 0.34	IV-X	This Study
Peshtigo-Chambers area spring 1977	0.06 0.20	0.47 0.34	IV-X	This Study
Michigan	0.52	0.30	III	Patriarche (1977)
	1.27	0.16	IV	
	0.37	0.43	V	
	0.72	0.30	Mean	
Michigan	0.63	0.47	IV-X	Humphreys (1978)
Huron (Georgian Bay)	0.55	0.42	a	Cucin and Regier (1965)
Huron	0.76	2.53	III-IV	Spangler (1970)
Winnipeg	1.81	0.72	a	Davidoff et al. (1973)
Winnipeg	1.17	0.60	a	Rybicki and Doan (1966)
Lesser Slave Lake	0.06-0.28	0.64	a	Bell et al. (1977)

[a] Ages vulnerable to the commercial fishery.

Yield

Yield per recruit was calculated from the Beverton-Holt and Ricker models with two estimates of F and M for samples from Big Bay de Noc. Since values of F were considered to be unrealistically low for Peshtigo Reef-Chambers Island, yield was not calculated for that area. To provide comparable estimates with the Ricker model, the Beverton-Holt yield, based on yield for 1000 recruits, was converted to yield per 1000 kg of recruits from mean weights of individuals at recruitment. Since recruitment was approximately at the midpoint of the growing season of the fourth year of life, 1/2F was used for age III whitefish in the Ricker model. Yield estimates by the two methods differed by a maximum of 12%.

Higher yield per recruit was calculated for North-Moonlight Bays than for Big Bay de Noc (Table 17) which was not expected in view of calculations of critical size and mean length in the fishery. Yield per 1000 kg of recruits from combined samples from the Big Bay de Noc area was estimated to be 733 kg and 1031 kg for the two values of F. These estimates for Big Bay de Noc were less than the estimate for North-Moonlight Bays of 1295 kg per 1000 kg of recruits (Humphreys 1978). Since the fishery in North-Moonlight Bays was harvesting whitefish at a time when a greater portion of the weight of a year class was being lost to natural mortality than in the Big Bay de Noc fishery, yield per 1000 kg of recruits should have been larger in Big Bay de Noc than in North-Moonlight Bays. The reason for this discrepancy may be that the large 1972 class, dominant in North-Moonlight Bays, temporarily raised the mean length in the fishery above the critical size.

Table 17. Yield calculated from the Beverton-Holt yield and Ricker equilibrium yield models and production calculated from the Ricker model for samples of lake whitefish from Big Bay de Noc and North-Moonlight Bays. Yield and production are in kilograms. The percentage difference between production and yield is in parentheses.

Location	M	F	Beverton-Holt	Ricker	
			Yield per 1000 kg. recruits	Yield per 1000 kg. recruits	Production
Big Bay de Noc	0.47	0.32	732.8	651.0	731.9 (+0.11)
Combined Spring and Fall	0.34	0.45	1030.5	944.8	766.9 (-0.19)
North-Moonlight Bays 1975-77 Samples Combined	0.47	0.63	1295.0	1112.7	1133.6 (+0.06)

I do not suggest raising the size limit in Big Bay de Noc based on application of the Ricker equilibrium yield model and Patriarche's (1977) definition of overharvest. Patriarche concluded that stocks of whitefish in Big Bay de Noc and northern Lake Michigan in 1973 were overharvested because yield exceeded production in the Ricker model. He suggested increasing the size limit to 483 mm, which would decrease fishing mortality to a level where yield was approximately equal to production. Results of this study (Table 17, Appendix N) indicated that the 432 mm size limit presently in effect may or may not be leading to overharvest (defined as yield exceeding production) in Big Bay de Noc, yield exceeded production by 19% for M=0.34, but production was greater than yield by 11% for M=0.47. Overharvest was not indicated for North-Moonlight Bays, for production was greater than yield by 6% (Humphreys 1978).

With lake whitefish, one year or other small time periods are not sufficient to conclude, based on the relation of yield to production, that stocks are or are not overharvested. Growth rates, mortality rates and year class strength are known to fluctuate among whitefish stocks, and with time, within whitefish stocks. Therefore, the relation of yield to production will also fluctuate, and yield may exceed production in some years and vice versa in other years. In a virgin fishery where stocks contain many old individuals, production tends to be minimal (Ricker 1975, p. 309) and yield should exceed production. In an established fishery, it may be desirable to increase stock size if it is low or it may need to be sustained if equilibrium yield per biomass is at an optimum level. If stock size is to be increased, yield should be lower than production, and if yield is to be sustained, yield should equal production.

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APPENDIX

APPENDIX A

Catch and effort statistics (1948-1976) for lake whitefish MM-1. Gillnet effort is in 1000's of feet of net lifted and poundnet effort is number of lifts.

YEAR	CATCH	EFFORT	CATCH PER EFFORT			
					Trapnet	
			Gillnet	Poundnet	Deep	Shallow
1976	1287705	12704.5	38.92	288.67		298.99
1975	926764	14921.5	37.06	162.64		269.56
1974	1044098	18467.9	35.30	336.97		324.77
1973	1300850	20943.0	48.89	265.85		168.59
1972	1093352	18249.0	46.62	346.23		82.21
1971	975571	19472.0	41.01	213.96		110.51
1970	352309	10921.0	22.69	115.60		26.61
1969	210011	7855	17.96	109.28	50.17	
1968	111779	7124	12.43	49.60		4.00
1967	114578	6303	12.20	68.30		
1966	85800	3890	11.61	90.85		
1965	117560	3765	10.20	424.10		75.53
1964	81478	4896	10.30	85.22		37.41
1963	73636	2884	7.87	256.15		17.86
1962	34179	1634	10.16	89.62		45.53
1961	48793	4255	8.69	50.40		33.07
1960	8424	799	7.55	13.83		17.48
1959	505	1	4.00			
1958	2057	168	1.26	10.56		25.86
1957	3767	213	.55	7.73		73.89
1956	11284	1187	4.12	14.41		36.62
1955	69771	5932	6.98	26.32		12.28
1954	501904	22736	10.27	87.40		32.91
1953	635769	27743	14.25	97.11		51.45
1952	933047	34387	17.12	144.95		124.29
1951	441042	23632	12.41	63.81		29.45
1950	1493564	66070	16.74	88.18		29.78
1949	2262963	104939	15.58	106.37		93.79
1948	2066290	108038	20.76	171.15		239.85

APPENDIX B

Catch and effort statistics (1949-1976) for lake whitefish from district WM-2. Gillnet effort is in 1000's of feet of net lifted and poundnet effort is number of nets lifted.

YEAR	CATCH	EFFORT	CATCH PER EFFORT	
			Gillnet	Poundnet
1976	467284	15190.0	28.15	250.19
1975	495732	17735.3	25.11	265.23
1974	739606	16634.8	41.11	226.53
1973	337690	9511.1	30.95	197.06
1972	344524	6844.4	35.62	359.48
1971	220030	3030.0	42.98	190.43
1970	173920	2978	32.07	174.36
1969	134233	3232	21.65	122.36
1968	38955	1478	11.56	70.10
1967	76926	2767	18.74	78.99
1966	83537	3757	17.03	54.43
1965	128896	4582	18.98	101.42
1964	150682	8162	13.34	123.56
1963	32530	1547	17.87	38.24
1962	56714	4284	11.05	67.82
1961	91894	5063	13.73	74.62
1960	50870	3330	14.91	27.29
1959	10989	474	10.89	44.96
1958	4153	175	6.00	45.78
1957	5522	382	14.58	10.50
1956	2338	110	14.82	36.94
1955	30002	917	11.49	54.25
1954	73181	2017	13.73	86.51
1953	58467	1582	18.24	69.29
1952	88767	1969	19.19	86.27
1951	64966	1770	13.55	92.22
1950	87266	3947	14.83	44.15
1949	190099	9449	10.66	96.69

APPENDIX C

Catch and effort statistics (1949-1976) for lake whitefrom from statistical district WM-1. Gillnet effort is in 1000's of feet of net lifted and poundnet effort is number of lifts.

YEAR	CATCH	EFFORT	CATCH PER EFFORT			
					Trapnet	
			Gillnet	Poundnet	Deep	Shallow
1976	206083	5678.7	23.50	613.44	183.07	474.30
1975	154790	5435.8	21.19	169.31	278.27	
1974	137963	4255.3	25.40	455.42	221.55	
1973	137327	5185.4	27.00		9.91	
1972	60138	2699.0	22.84	57.50		55.00
1971	29196	1473.0	18.20	315.90		
1970	1500	153.0	12.39	1.67		
1969	388	127.0	3.60	3.25		
1968	2458	176.0	2.22	25.25		
1967	741	40.0		42.94		
1966	729	55	16.55			
1965	743	120.0	8.47			
1964	8032	510	16.68			
1963	275	51	5.16			
1962	1074	67	15.94			
1961	2680	359	6.97			
1960	31	12	3.00			
1959	25	0				
1958	16	0				
1957						
1956						
1955	23	0				
1954	866	128	5.31	7.61		
1953	5089	314	18.22	13.67		
1952	20794	1354	13.92	18.71		
1951	52175	3119	16.27	22.70		
1950	73689	6138	10.31	23.38		
1949	173142	8074	18.32	38.04		

APPENDIX D

Catch and effort statistics (1949-1976) for lake whitefish from statistical district WM-3. Gillnet effort is in 1000's of feet of net lefted and poundnet effort is number of nets lifted.

YEAR	CATCH	EFFORT	CATCH PER EFFORT	
			Gillnet	Poundnet
1976	938629	2312.0	32.27	521.39
1975	614268	15280.6	36.53	370.22
1974	295916	8810.0	29.42	240.21
1973	274507	7561.2	30.05	172.20
1972	291452	5893.4	37.70	176.05
1971	232424	6934.0	32.56	93.44
1970	132549	3084.0	30.96	325.40
1969	71211	1082.0	36.18	159.37
1968	24411	495.0	8.46	127.48
1967	19335	495.0	17.50	110.31
1966	46022	1960.0	14.79	99.00
1965	23761	801.0	17.75	166.17
1964	24386	1835.0	11.88	49.28
1963	9157	940.0	9.34	25.21
1962	16569	1319.0	10.45	56.16
1961	38875	1830.0	14.35	57.52
1960	17077	960.0	14.53	79.62
1959	8343	459.0	11.26	78.83
1958	5024	310.0	12.67	32.92
1957	6741	498.0	13.52	
1956	15768	1178.0	10.46	34.57
1955	67177	2481.0	14.42	49.91
1954	121894	3431.0	18.36	78.77
1953	123254	3041.0	15.11	80.50
1952	176354	3641.0	20.80	85.30
1951	120440	2158.0	12.55	89.57
1950	93313	2015.0	13.31	75.28
1949	105235	1889.0	10.29	79.76

APPENDIX E

Age composition compared among samples with Chi square goodness of fit test (Zar 1974, p. 41). Table values of X^2 are at 0.05 level of significance. Ages VI through X were combined for analysis.

Samples Compared	Calculated X^2	n	Table X^2	Significant Difference	No Significant Difference
Peshtogi Reef vs. Chambers Island	3.443	4	9.488		X
Peshtigo Reef-Chambers Island vs. Big Bay de Noc spring 1977	125.115	4	9.488	X	
Peshtigo Reef-Chambers Island vs. North-Moonlight Bays spring 1977	122.086	4	9.488	X	
North-Moonlight Bays vs. Big Bay de Noc, spring samples	290.540	4	9.488	X	
North-Moonlight Bays spring 1977 vs. Big Bay de Noc fall 1976	5953.034	4	9.488	X	
Peshtigo Reef-Chambers Island vs. Big Bay de Noc fall 1976	1835.971	4	9.488	X	
Big Bay de Noc spring 1977 vs. Big Bay de Noc fall 1976	295.831	4	9.488	X	
Big Bay de Noc spring 1977, inside bay vs. outside bay	72.674	4	9.488	X	
Big Bay de Noc fall 1976, inside bay vs. outside bay	19.206	4	9.488	X	

APPENDIX F

Mean age compared among samples with the t-test (Zar 1974, p. 121).
Table values of t are at 0.05 level of significance.

Samples Compared	Calculated t	n	Table t	Significant Difference	No Significant Difference
Peshtigo Reef vs. Chambers Island	0.750	2432	1.962		X
Peshtigo Reef vs. Big Bay de Noc spring 1977	6.495	4031	1.962	X	
Peshtigo Reef vs. North-Moonlight Bays spring 1977	0.474	3243	1.962		X
Chambers Island vs. Big Bay de Noc spring 1977	4.316	3119	1.962	X	
Chambers Island vs. North-Moonlight Bays spring 1977	1.134	2331	1.962		X
Big Bay de Noc spring 1977 vs. Big Bay de Noc fall 1976	3.024	4795	1.962	X	
Big Bay de Noc spring 1977 vs. North-Moonlight Bays spring 1977	6.967	3930	1.962	X	

APPENDIX G

Mean length compared among samples with a t-test (Zar 1974, p. 121). Table values of t are at 0.05 level of significance.

Samples Compared	Calculated t	n	Table t	Significant Difference	No Significant Difference
Peshtigo Reef vs. Chambers Island	2.309	2433	1.962	X	
Peshtigo Reef vs. North-Moonlight Bays spring 1977	5.907	3246	1.962	X	
Chambers Island vs. North-Moonlight Bays spring 1977	2.134	2333	1.962	X	
Chambers Island vs. Big Bay de Noc spring 1977	21.517	3125	1.962	X	
Peshtigo Reef vs. Big Bay de Noc spring 1977	29.597	4038	1.962	X	
Peshtigo Reef vs. Big Bay de Noc fall 1976	23.417	4112	1.962	X	
Chambers Island vs. Big Bay de Noc fall 1976	11.359	3199	1.962	X	
Big Bay de Noc spring 1977 vs. North-Moonlight Bays spring 19777	30.289	3938	1.962	X	
Big Bay de Noc spring 1977 vs. Big Bay de Noc fall 1976	13.110	4804	1.962	X	
Big Bay de Noc fall 1976 vs. North-Moonlight Bays spring 1977	14.430	4012	1.962	X	

APPENDIX H

Instantaneous rates of growth (G) compared among samples with the Wilcoxon paired sample signed rank test (Zar 1974, p. 124). Table values of T are at 0.05 level of significance.

Samples Compared	Calculated T	n	Table T	Significant Difference	No Significant Difference
Peshtigo Reef vs. Chambers Island	9	9	8		X
Peshtigo Reef-Chambers Island vs. North-Moonlight Bays, spring 1977	15	9	8		X
Peshtigo Reef-Chambers Island vs. Big Bay de Noc spring 1977	22.5	9	8		X
Peshtigo Reef-Chambers Island vs. Big Bay de Noc fall 1976	18	9	8		X
Big Bay de Noc spring 1977 vs. North-Moonlight Bays spring 1977	10	9	8		X
Big Bay de Noc spring 1977 vs. Big Bay de Noc fall 1976	16	9	8		X

APPENDIX I

Mean back-calculated lengths compared among samples with the Wilcoxan paired sample signed rank test (Zar 1974, p. 124). Table values of T are at 0.05 level of significance.

Samples Compared	Calculated T	n	Table T	Significant Difference	No Significant Difference
Peshgito Reef vs. Chambers Island	32	11	13		X
Peshtigo Reef-Chambers Island vs. North-Moonlight Bays spring 1977	8	10	10	X	
Peshtigo Reef-Chambers Island vs. North-Moonlight Bays fall 1976	20	9	8		X
Peshtigo Reef-Chambers Island vs. Big Bay de Noc spring 1977	26	10	10		X
Peshtigo Reef-Chambers Island vs. Big Bay de Noc fall 1976	25	10	10		X
Big Bay de Noc spring 1977 vs. North-Moonlight Bays spring 1977	0	10	10	X	
Big Bay de Noc fall 1976 vs. North-Moonlight Bays spring 1977	5.5	10	10	X	
Big Bay de Noc fall 1976 vs. North-Moonlight Bays fall 1976	20	9	8		X

APPENDIX I (continued)

Samples Compared	Calculated T	n	Table T	Significant Difference	No Significant Difference
Big Bay de Noc spring 1977 vs. North-Moonlight Bays fall 1976	22	9	8		X
North-Moonlight Bays spring 1977 vs. North-Moonlight Bays fall 1976	10	9	8		X
Big Bay de Noc spring 1977 vs. Big Bay de Noc fall 1976	22	10	10		X

APPENDIX J

Slopes of the length-weight regressions compared among samples with the t-test (Zar 1974, p. 228). Table values of t are at the 0.05 level of significance.

Samples Compared	Calculated t	n	Table T	Significant Difference	No Significant Difference
Peshtigo Reef vs. Chambers Island	2.253	532	1.965	X	
Peshtigo Reef vs. Big Bay de Noc spring 1977	2.506	720	1.963	X	
Peshgito Reef vs. Big Bay de Noc fall 1976	7.442	991	1.962	X	
Peshgito Reef vs. North-Moonlight Bays spring 1977	6.245	588	1.964	X	
Chambers Island vs. Big Bay de Noc fall 1976	4.525	971	1.962	X	
Chambers Island vs. North-Moonlight Bays spring 1977	3.539	568	1.964	X	
Big Bay de Noc spring 1977 vs. North-Moonlight Bays spring 1977	4.293	756	1.964	X	
Big Bay de Noc fall 1976 vs. North-Moonlight Bays spring 1977	0.359	1027	1.962		X
Big Bay de Noc spring 1977 vs. Big Bay de Noc fall 1976	5.723	1159	1.962	X	
Chambers Island vs. Big Bay de Noc spring 1977	0.422	700	1.963		X

APPENDIX K

Back-calculated lengths for lake whitefish from Peshtigo Reef and Chambers Island combined, spring 1977.

AGE	# FISH	Length	SD	CALCULATED MEAN LENGTH AT EACH AGE (0=MARGIN) 0	1	2	3	4	5	6	7	8	9	10	11
11	8	485.38	26.3	698.0	169.8	336.2	477.0	527.8	569.0	602.2	628.5	752.2	670.7	686.1	696.7
10	13	681.08	11.8	649.4	172.3	338.2	445.4	497.8	535.0	566.0	591.2	614.5	633.4	648.5	
9	62	660.48	20.2	626.3	186.0	321.2	423.7	487.5	529.8	561.6	588.7	610.8	627.5		
8	38	641.87	21.5	611.9	164.6	304.3	411.7	484.4	530.2	563.5	588.1	609.3			
7	27	612.89	15.9	409.2	173.7	311.7	427.4	500.6	546.5	582.5	605.4				
6	56	566.18	42.6	558.5	164.7	285.6	393.9	473.4	519.2	552.8					
5	738	522.61	26.5	521.4	172.9	289.1	394.6	465.0	513.9						
4	352	480.41	26.6	485.5	169.4	302.4	404.3	476.0							
3	515	428.44	25.6	433.8	177.5	318.3	422.2								
2	45	388.36	22.5	348.1	191.0	334.6									
1	0	0.00	0.0	0.0	0.0										
0	0	0.00	0.0	0.0											
Column Means				554.2	174.2	314.2	422.3	489.1	534.8	571.4	600.4	621.7	643.9	667.3	696.7
Stand. Dev.				107.5	8.6	19.0	26.4	19.8	18.4	17.9	17.2	20.5	23.4	26.6	0.0
Increment					140.0	108.1	66.8	45.7	36.6	29.0	21.3	22.1	23.4	29.4	-696.7
Weighted Mean				495.5	174.0	303.0	406.9	471.5	517.6	564.2	594.0	613.5	632.6	662.8	696.7
Stand Dev.				581.	4.9	14.2	13.6	9.6	8.3	[illegible]	10.5	10.5	12.7	18.7	0.1
Increment					129.0	103.9	64.6	46.1	46.6	29.8	19.5	19.1	30.2	33.9	-696.7

APPENDIX K (continued)

Back-caulculated lengths for lake white from Peshtigo Reef, spring 1977.

AGE	# FISH	Mean Length	SD	CALCULATED MEAN LENGTH AT EACH AGE (0=MARGIN) 0	1	2	3	4	5	6	7	8	9	10	11
11	3	691.00	42.3	686.3	149.9	309.9	457.8	506.9	546.5	584.8	611.7	635.2	656.7	674.2	684.3
10	10	678.60	12.1	643.1	177.7	339.8	440.2	585.8	523.1	556.4	582.8	607.4	627.2	642.3	
9	48	660.50	21.3	625.1	187.4	322.1	424.7	486.3	528.4	560.7	588.0	610.5	627.6		
8	24	641.71	19.7	612.1	171.5	311.8	415.9	485.3	530.9	563.1	587.7	609.9			
7	19	613.79	15.3	609.9	175.9	313.7	427.9	497.9	545.8	583.4	606.5				
6	36	565.25	47.4	561.7	169.9	288.8	198.2	479.4	525.2	556.4					
5	514	524.31	26.5	525.0	182.5	295.7	401.9	471.3	519.3						
4	232	477.88	24.0	482.3	172.4	304.3	404.2	475.4							
3	269	429.06	27.0	434.2	181.1	323.4	426.2								
2	22	341.00	18.3	350.6	195.2	338.2									
1	0	0.00	0.0	0.0	0.0										
0	0	0.00	0.0	0.0											
Column Means				553.0	176.4	314.8	421.9	486.0	531.1	567.6	595.3	615.8	637.2	658.3	684.3
Stand. Dev.				104.7	12.1	16.6	19.4	11.7	10.8	13.0	12.9	13.1	17.0	22.6	0.0
Increment					138.4	107.1	64.1	45.3	36.3	27.7	20.4	21.4	21.1	26.0	-684.3
Weighted Mean				502.3	179.8	306.4	410.0	474.7	521.6	563.5	591.5	610.8	629.0	649.7	684.3
Stand Dev.				56.6	5.3	12.9	11.4	5.9	5.6	910	8.4	4.8	6.4	14.0	0.2
Increment					126.6	103.6	64.7	46.9	41.9	27.9	19.4	18.1	20.7	34.6	-684.3

APPENDIX K (continued)

Back-calculated length for lake whitefish from Chambers Island, spring 1977

AGE	# FISH	Mean Length	SD	CALCULATED MEAN LENGTH AT EACH AGE (0=MARGIN) 0	1	2	3	4	5	6	7	8	9	10	11
11	5	682.00	16.6	700.9	181.9	350.7	486.2	537.6	579.5	609.2	634.9	658.6	675.1	689.2	700.0
10	3	689.33	5.9	671.1	163.3	538.8	466.8	541.1	577.3	600.1	620.9	639.6	655.0	669.8	
9	14	660.43	16.5	631.6	190.2	324.7	425.0	495.4	537.7	567.0	593.3	613.4	628.5		
8	14	642.14	25.1	610.1	156.7	293.5	405.4	482.9	528.5	563.3	587.5	606.9			
7	8	610.75	18.2	607.3	174.1	311.1	428.7	508.3	548.8	580.4	602.8				
6	20	567.85	33.3	552.1	159.3	282.6	387.5	463.1	508.3	544.1					
5	224	518.71	26.3	514.1	156.5	277.9	380.6	452.2	502.5						
4	120	485.31	30.4	492.2	168.1	301.4	406.0	477.8							
3	246	427.76	24.1	432.5	175.3	313.1	417.2								
2	23	335.83	26.0	345.3	188.2	331.1									
1	0	0.00	0.0	0.00	0.00										
0	0	0.00	0.0	0.0											
Column Means				555.7	171.3	312.5	422.6	494.8	540.4	577.3	607.9	629.6	652.9	679.5	700.0
Stand Dev.				111.1	12.6	24.1	34.7	32.5	30.5	24.3	19.7	23.9	23.4	13.7	0.0
Increment					141.1	110.1	72.2	45.5	37.0	30.5	21.8	23.2	26.6	20.6	-700.0
Weighted Mean				483.5	167.6	299.3	402.5	565.6	509.2	565.6	599.8	619.3	642.7	681.9	700.0
Stand Dev.				59.4	9.7	17.5	18.6	18.0	16.5	[illegible].6	15.4	18.2	20.2	10.1	0.2
Increment					131.7	103.2	63.1	43.6	56.3	34.2	19.6	23.3	39.2	18.1	-700.0

APPENDIX K (continued)

Back-calculated lengths for lake whitefish from Big Bay de Noc, spring 1977

AGE	# FISH	Mean Length	SD	CALCULATED MEAN LENGTH AT EACH AGE (0=MARGIN) 0	1	2	3	4	5	6	7	8	9	10
10	1	702.00	0.0	652.4	232.0	323.7	410.9	505.3	539.8	565.2	592.5	612.5	634.3	652.4
9	8	657.88	17.8	625.9	219.5	343.4	435.1	398.3	537.8	564.6	540.9	610.0	625.0	
8	3	647.33	15.7	617.3	236.8	329.7	436.3	499.9	546.5	576.1	599.1	616.7		
7	2	599.50	16.3	609.7	234.7	362.7	657.2	511.7	548.9	580.7	608.8			
6	6	562.67	32.1	552.8	206.8	376.4	411.2	482.3	519.8	551.6				
5	137	505.37	30.0	501.0	195.1	30o.7	392.8	454.9	499.3					
4	338	468.97	21.1	465.2	196.5	309.5	397.9	466.4						
3	572	431.68	16.3	431.4	267.3	324.0	428.0							
2	116	306.83	23.3	319.2	211.2	316.8								
1	0	0.00	0.0	0.0	0.0									
0	0	0.00	0.0	0.0										
Column Means				530.9	208.9	324.0	421.2	488.4	532.0	567.6	597.6	613.0	629.6	652.4
Stand Dev.				110.4	12.2	19.0	21.8	21.2	19.0	11.3	8.2	3.4	6.6	0.0
Increment					113.1	97.2	67.2	43.6	35.6	30.3	15.2	16.6	22.8	-652-4
Weighted Mean				441.8	203.3	316.7	414.0	464.3	503.8	564.1	595.3	611.9	626.0	652.4
Stand Dev.				50.9	6.2	8.7	15.9	8.4	12.5	10.1	6.6	3.0	3.1	652.4
Increment					113.3	97.3	50.4	39.5	60.2	31.3	16.5	14.1	26.4	-652.4

APPENDIX K (continued)

Back-calculated lengths for lake whitefish from Big Bay de Noc, fall 1976.

AGE	# FISH	Mean Length	SD	CALCULATED MEAN LENGTH AT EACH AGE (0=MARGIN)										
				0	1	2	3	4	5	6	7	8	9	10
10	2	700.00	14.1	672.3	199.8	361.7	505.5	553.5	576.5	595.6	615.8	633.0	649.5	661.8
9	6	659.17	30.4	621.5	193.4	333.3	436.8	486.7	521.8	547.1	572.0	591.2	411.0	
8	12	650.58	16.5	609.0	218.9	342.4	430.1	484.9	523.6	553.6	578.1	596.9		
7	11	611.36	25.7	584.7	190.3	307.0	395.0	464.7	510.4	548.2	570.9			
6	12	597.00	28.5	584.3	214.3	334.0	421.3	498.5	535.2	566.4				
5	8	548.13	23.4	538.1	191.6	307.6	406.3	479.4	516.1					
4	150	500.67	25.1	496.6	194.4	312.1	401.8	463.0						
3	493	465.44	18.4	469.2	195.0	320.0	417.5							
2	11	417.55	15.1	422.2	212.6	341.9								
1	0	0.00	0.0	0.0	0.0									
0	0	0.00	0.0	0.0										
Column Means				555.4	201.1	328.9	426.8	490.1	530.6	562.2	584.2	607.0	630.1	661.8
Stand Dev.				80.2	11.0	18.6	34.8	30.6	24.0	20.2	21.3	22.7	27.1	0.0
Increment					127.8	97.9	63.3	40.5	31.6	22.0	22.9	23.1	31.6	-661.8
Weighted Mean				483.1	195.8	319.2	414.4	468.8	524.2	556.8	576.8	595.8	602.6	661.8
Stand Dev.				33.7	4.6	6.5	910	13.4	13.8	11.6	10.9	12.0	17.7	0.4
Increment					123.4	95.2	54.4	55.4	32.7	19.9	22.0	21.8	41.2	-661.8

APPENDIX K (continued)

Back-calculated lengths for lake white from North-Moonlight Bays, spring 1977.

AGE	# FISH	Mean Length	SD	CALCULATED MEAN LENGTH AT EACH AGE (0=MARGIN) 0	1	2	3	4	5	6	7	8	9	10
10	1	667.00	0.0	659.7	192.3	315.4	418.4	506.1	548.3	583.7	612.4	632.7	647.9	659.7
9	3	669.00	7.9	605.1	216.4	315.4	425.1	513.4	542.8	562.4	577.6	591.6	603.4	
8	3	666.33	13.3	588.8	185.5	285.1	395.9	484.4	516.2	542.7	565.2	583.2		
7	4	588.25	16.7	578.7	204.5	325.1	409.5	482.5	517.9	553.4	574.5			
6	21	578.05	35.1	572.2	208.8	315.0	413.8	481.8	529.4	566.3				
5	1006	505.84	22.4	504.3	189.7	280.8	397.5	442.4	496.1					
4	100	475.68	27.0	475.9	205.0	303.1	391.1	463.8						
3	202	415.95	22.2	423.8	205.8	314.9	407.2							
2	39	307.10	25.4	321.1	204.3	301.9								
1	0	0.00	0.0	0.0	0.0									
0	0	0.00	0.0	0.0										
Column Means				525.5	201.4	306.3	407.3	482.3	525.1	561.7	582.4	602.5	625.7	659.7
Stand Dev.				105.5	10.0	15.0	11.8	24.1	19.2	15.3	20.7	26.5	31.4	0.0
Increment					104.9	101.0	75.0	42.8	36.6	20.7	20.1	23.2	34.0	-659.7
Weighted Mean				487.1	194.0	288.8	398.9	445.5	497.1	562.7	576.2	593.9	614.5	659.7
Stand Dev.				42.5	7.1	13.5	4.7	9.3	5.8	8.6	13.0	17.6	22.2	659.7
Increment					94.8	110.1	46.6	51.6	65.6	13.6	17.6	20.7	45.1	-659.7

APPENDIX L

Parameters of the von Bertalanffy growth equation calculated by Bayley's (1977) method for samples of lake whitefish from Peshtigo Reef, Chambers Island, Big Bay de Noc, and North-Moonlight Bays. Von Bertalanffy equation is in the form; $L = L_{\infty} (1-3^{-k(t-t_0)})$. Sample size in parentheses.

Location	L (mm)	-k	t_0
Peshtigo Reef-Chambers Island Combined Spring 1977 (1854)	659.08	.36183	.4506
Peshtigo Reef Spring 1977 (1177)	656.81	.36633	.49526
Chambers Island Spring 1977 (677)	660.61	.35470	.58645
Big Bay de Noc Spring 1977 (1181)	688.84	.26491	-.40723
Big Bay de Noc Fall 1976 (705)	637.30	.35618	.27147
North-Moonlight Bay Spring 1977 (1379)	688.02	.24104	-.39272

APPENDIX M

Percent of the legal catch less than 457 mm (18") and less than 483 mm (19") by weight and number for each age class (III-V) of lake whitefish from the Peshtigo Reef-Chambers Island and Big Bay de Noc areas.

Location		Less Than 457 mm by weight	Less Than 457 mm by number	Less Than 483 mm by weight	Less Than 483 mm by number
Peshtigo Reef-Chambers Island Combined	III	78.4%	80.8%	99.5%	99.6%
	IV	12.8%	16.1%	48.1%	54.4%
	V	0.5%	0.8%	5.8%	8.1%
Big Bay de Noc Fall 1976 and Spring 1977 Combined	III	48.1%	53.7%	86.6%	89.4%
	IV	12.6%	16.2%	47.0%	53.6%
	V	2.8%	4.4%	15.9%	21.2%

APPENDIX N

Ricker equilibrium yield calculation for the spring 1977 Big Bay de Noc sample.

Age	Mean Wt.	G	M	F	G-M-F	Wt. Change Factor	Biomass	Mean Biomass	Yield	Mean Wt. of Individuals At Midpoint	Number Caught	Production
3	0.637						1000.0					
		0.3748	0.4700	0.3150	-0.410	0.633		821.7	262.0	0.769	341.	331.7
4	0.927						663.5					
		0.2667	0.4700	0.6300	-0.833	0.435		475.9	299.8	1.059	283.	126.9
5	1.211						288.4					
		0.3695	0.4700	0.6300	-0.731	0.482		213.6	134.6	1.456	92.	78.9
6	1.752						139.9					
		0.1759	0.4700	0.6300	-0.924	0.397		97.0	61.1	1.913	32.	17.1
7	2.089						55.1					
		0.0899	0.4700	0.6300	-1.010	0.364		37.6	23.7	2.185	11.	3.4
8	2.285						20.1					
		0.0744	0.4700	0.6300	-1.026	0.359		13.6	8.6	2.372	4.	1.0
9	2.482						7.2					
		0.1350	0.4700	0.6300	-0.965	0.381		5.0	3.1	2.633	1.	0.7
10	2.817						2.7					
Total								1674.5	793.0		763.8	593.7

Mean Wt. of Catch = 1.038

APPENDIX N (continued)

Ricker equilibrium yield calculation for the spring 1977 Big Bay de Noc sample.

Age	Mean Wt.	G	M	F	G-M-F	Wt.Change Factor	Biomass	Mean Biomass	Yield	Mean Wt. of Individuals At Midpoint	Number Caught	Production
3	0.637						1000.0					
		0.3748	0.3400	0.3450	-0.310	0.733		866.6	299.0	0.769	389.	324.8
4	0.927						733.3					
		0.2667	0.3400	0.6900	-0.763	0.466		537.5	370.9	1.059	350.	143.4
5	1.211						343.8					
		0.3695	0.3400	0.6900	-0.661	0.517		259.2	178.8	1.456	123.	95.8
6	1.752						176.6					
		0.1759	0.3400	0.6900	-0.854	0.426		125.9	86.8	1.913	45.	22.1
7	2.089						75.2					
		0.0899	0.3400	0.6900	-0.948	0.391		52.3	36.1	2.185	17.	4.7
8	2.285						29.4					
		0.0744	0.3400	0.6900	-0.956	0.348		20.3	14.0	2.372	6.	1.5
9	2.462						11.3					
		0.1350	0.3400	0.6900	-0.895	0.409		8.0	5.5	2.633	2.	1.1
10	2.817						4.6					
Total								1869.8	991.1		931.7	593.3
Mean Wt. of Catch = 1.064												

APPENDIX N (continued)

Ricker equilibrium yield calculation for the fall 1976 Big Bay de Noc sample.

Age	Mean Wt.	G	M	F	G-M-F	Wt.Change Factor	Biomass	Mean Biomass	Yield	Mean Wt. of Individuals At Midpoint	Number Caught	Production
3	0.603						1000.0					
		0.4303	0.3400	0.1540	-0.064	0.938		969.2	149.3	0.748	200.	417.1
4	0.928						938.3					
		0.3897	0.3400	0.3080	-0.258	0.772		831.5	256.1	1.127	227.	324.0
5	1.370						724.7					
		0.2105	0.3400	0.3080	-0.437	0.646		596.3	183.7	1.522	121.	125.5
6	1.691						467.9					
		0.1231	0.3400	0.3080	-0.525	0.592		372.4	114.7	1.798	64.	45.8
7	1.912						276.8					
		0.1306	0.3400	0.3080	-0.517	0.596		220.9	68.0	2.041	33.	28.9
8	2.179						165.0					
		0.1248	0.3400	0.3080	-0.523	0.593		131.4	40.5	2.319	17.	16.4
9	2.468						97.8					
		0.2243	0.3400	0.3080	-0.424	0.655		80.9	24.9	2.761	9.	18.1
10	3.089						64.0					
Total								3202.6	837.2		637.1	975.9

Mean Wt. of Catch = 1.247

APPENDIX O

Numbers of whitefish sampled (sublegals and legals) for each area, by age, based on the percentage of respective ages in each 10 mm length interval for which scales were taken and ages assigned. Number of fish for which ages were assigned is given in parentheses.

Location	Age								
	II	III	IV	V	VI	VII	VIII	IX	X
Big Bay de Noc fall 1976 (705)	25	1734	557	29	54	35	42	28	6
Big Bay de Noc fall 1976 inside (393)	23	1315	288	8	14	22	40	20	6
Big Bay de Noc fall 1976 outside (312)	2	419	269	21	40	13	2	8	-
Big Bay de Noc spring 1977 (1181)	157	1352	1014	446	14	5	8	15	1
Big Bay de Noc spring 1977 inside (868)	45	1159	644	216	2	-	2	7	-
Big Bay de Noc spring 1977 outside (313)	112	193	370	230	12	5	6	8	1
Peshtigo Reef spring 1977 (1177)	26	410	385	832	60	27	35	65	18
Chambers Island spring 1977 (677)	23	319	176	327	30	11	21	18	11

APPENDIX P

Numbers of whitefish of legal size or greater, by age, based on the percentage of respective ages in each 10 mm length interval for which scales had been taken and ages assigned. Number of fish for which ages were assigned is given in parentheses.

Location	Age II	III	IV	V	VI	VII	VIII	IX	X
Big Bay de Noc fall 1976 (705)	6	1686	552	29	54	35	42	28	6
Big Bay de Noc fall 1976 inside (393)	6	1271	283	8	14	22	40	20	6
Big Bay de Noc fall 1976 outside (312)		415	269	21	40	13	2	8	-
Big Bay de Noc spring 1977 (1181)		882	989	446	14	5	8	15	1
Big Bay de Noc spring 1977 inside (868)		783	640	216	2	-	2	7	-
Big Bay de Noc spring 1977 outside (313)		99	349	230	12	5	6	8	1
Peshtigo Reef spring 1977 (1177)		262	374	832	60	27	35	65	18
Chambers Island spring		174	168	328	30	11	21	18	11