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Mortality, Growth, and Yield of Channel Catfish in Saginaw Bay, Lake Huron

Raymond J. Haak

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MORTALITY, GROWTH, AND YIELD OF CHANNEL CATFISH IN SAGINAW BAY, LAKE HURON

by

Raymond J. Haak

A thesis submitted in partial fulfillment of

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MICHIGAN DEPARTMENT OF NATURAL RESOURCES
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MORTALITY, GROWTH, AND YIELD OF CHANNEL CATFISH IN SAGINAW BAY LAKE HURON[1]

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ABSTRACT

In Saginaw Bay, Lake Huron a higher catch per unit effort of channel catfish *Ictalurus punctatus* in recent years has prompted commercial fishermen to request the Michigan Department of Natural Resources to allow them to increase their fishing effort. Previous studies on the potential for increasing commercial harvest were incomplete or are dated, so a new study was needed. Of 2,460 channel catfish tagged in the Wild Fowl Bay area of Saginaw Bay in 1985, 277 tags were returned by sport and commercial fishermen. A catch curve constructed using data collected by sampling catfish from commercial trap nets in three management grids in the bay revealed that instantaneous total mortality rate for catfish in Saginaw Bay was 0.45, down from 0.67 in 1971 and 1981. An instantaneous fishing mortality rate of 0.26 and an instantaneous natural mortality rate of 0.19 were determined by partitioning the instantaneous total mortality rate using tag returns. A commercial reporting rate of 45% was determined by sampling the commercial catch for unreported tagged fish. Comparison of mean backcalculated lengths at age with previous studies revealed a decline in growth rate of catfish. A dynamic pool model indicated commercial fishing effort could be increased to obtain greater yields. Greatest increases in yield could be achieved by increasing both the commercial size limit and effort. Sensitivity analysis indicated that instantaneous total mortality rate, commercial reporting rate, and von Bertalanffy growth parameters were most important in determining the levels of commercial

fishing effort and commercial size limit to maxmize yield. Increasing the commercial size limit to 406.4 mm (16 in) was recommended to increase total, commercial, and sport yield per 1000 recruits, 2.6%, 0.6%, and 9.1%, respectively.

ACKNOWLEDGEMENTS

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All the members of my committee, Drs. Richard D. Clark, Jr., James S. Diana, and W. Carl Latta deserve thanks as without them this project would not have been possible. Drs. Latta and Clark helped with all aspects of this study. Their comments were indispensable in shaping this thesis. A very special thank you to Dr. Diana, chairman of my committee and academic advisor, for his guidance and support. He made my education and research at the University of Michigan possible.

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INTRODUCTION

Saginaw Bay is a relatively shallow, productive bay on the western side of Lake Huron. The bay supports extensive sport and commercial fishing. The channel catfish *Ictalurus punctatus* is an important species to the fisheries of Saginaw Bay. It usually ranks first or second in weight caught annually by commercial fishermen and has ranked as high as second in numbers of fish caught annually by sport fishermen. In recent years catch per unit effort (CPUE) of channel catfish by commercial fishermen has increased (Fig. 1). Sport fishermen have also been catching increasing numbers of channel catfish outside the bay (John Weber, Michigan Department of Natural Resources, personal communication). An earlier study on catfish in Saginaw Bay showed a decrease in the growth rate of catfish in the bay (Lorantas 1982). Increasing CPUE, increasing catch outside the bay, and decreasing growth rate all imply the population of channel catfish in the bay may be increasing. For the past several years commercial fishermen have requested the Michigan Department of Natural Resources (MDNR) to allow them to increase their effort on channel catfish. If the population of catfish is indeed increasing effort could be increased without a harmful effect on the population.

Two previous studies were conducted on the catfish fisheries of Saginaw Bay to determine if commercial harvest could be increased. The first in 1971 determined that a decrease in effort and an increase in the commercial size limit would maintain the current harvest while allowing

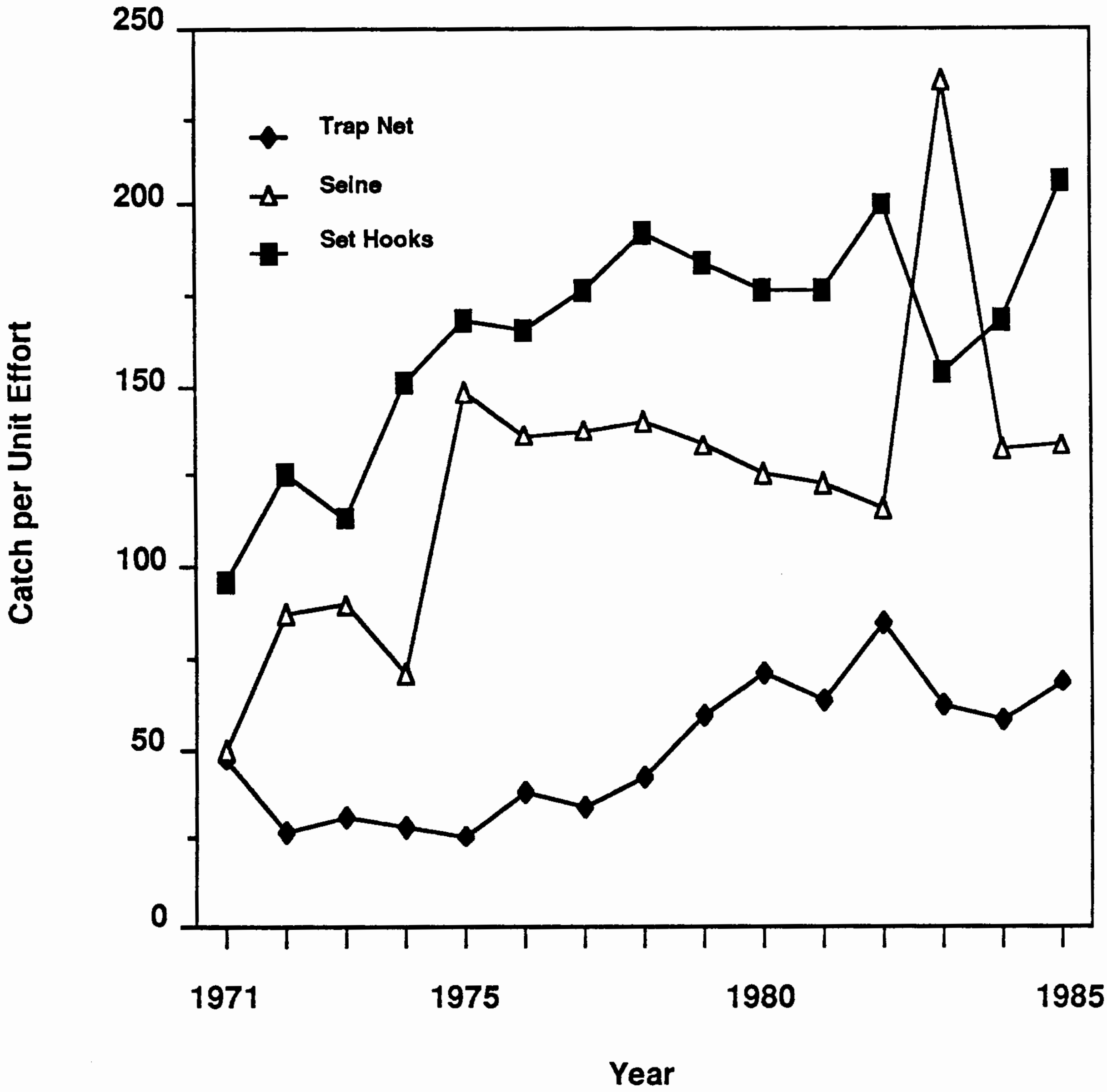

Figure 1. Catch per unit effort of channel catfish by commercial fishermen in Saginaw Bay, 1971-85 (see Hile (1962) for detailed information on effort units).

the reproductive population to increase (Eshenroder and Haas 1974). The authors believed the larger reproductive population would stablize recruitment between years. Eshenroder and Haas (1974) estimated that a harvest of 136,079 kg (300,000 lbs) would be possible by 1980 if the commercial size limit was increased from 381 mm (15 inches) to 432 mm (17 inches). This size limit was recommended because most of the fish they examined less than 432 mm were immature. Even though no regulation change was made the annual harvest easily exceeded 136,079 kg by 1976 and has increased since without any apparent damage to the population. The second study in 1981 came to similar conclusions but found that the management actions necessary to obtain the maximum harvest depended on the level of the sport harvest and the natural mortality rate used in the yield analysis (Lorantas 1982). The only estimate of the sport harvest was from a mail survey administered by the MDNR. This estimate was likely inaccurate, as has been shown with other mail surveys (Rybicki and Keller 1978), so the estimate of yield may have been in error. In addition, both studies assumed that the natural mortality rate of catfish in Saginaw Bay was the same as the natural mortality rate of catfish in Lake St. Clair. However, the applicability of this natural mortality rate to the catfish population of Saginaw Bay was unknown. Thus, a new study, directed at more accurate estimates of fishing and natural mortality rates for the channel catfish population of Saginaw Bay, was deemed necessary.

The objectives of this study were: (1) to determine the instantaneous total mortality rate for the channel catfish population in Saginaw Bay, (2) to determine the instantaneous fishing and natural mortality rates for the catfish population, and (3) to determine the effects of various management actions on yield.

METHODS

Age Structure and Size Composition of the Catch

Data for determining age and length frequency distributions were collected by sampling commercial trap nets in four management grids in Saginaw Bay (Fig. 2). Total lengths of catfish caught in commercial trap nets were measured to the nearest millimeter (Table 1). The left or right pectoral spine of five fish per 25 mm length interval was collected from fish measured for length frequency calculations or from fish caught in the same area. Spines were sectioned at the distal end of the basal groove (Sneed 1951) using a dental lathe with two aluminum oxide blades separated by a 0.52 mm spacer. The spine sections were mounted onto acetate slides with cyanoacrylate glue. The sections were magnified using a microfiche projector allowing annuli to be counted and annular radii to be measured. Radii were measured from the approximated center to the distal anterior point. More detailed information on spine preparation and aging is given by Lorantas (1982).

A BASIC computer program was written to convert measured lengths into ages. The program first sorted lengths of aged fish into 25.4 mm length intervals. For each length interval the proportion of fish in each age class was calculated. Lengths of catfish measured from commercial trap nets were then converted to ages by multiplying the number of fish measured in a specific length interval by the proportion of fish in each age class of that length interval. The total number of fish at each age was then calculated by summing the number of fish in each age class for all lengths.

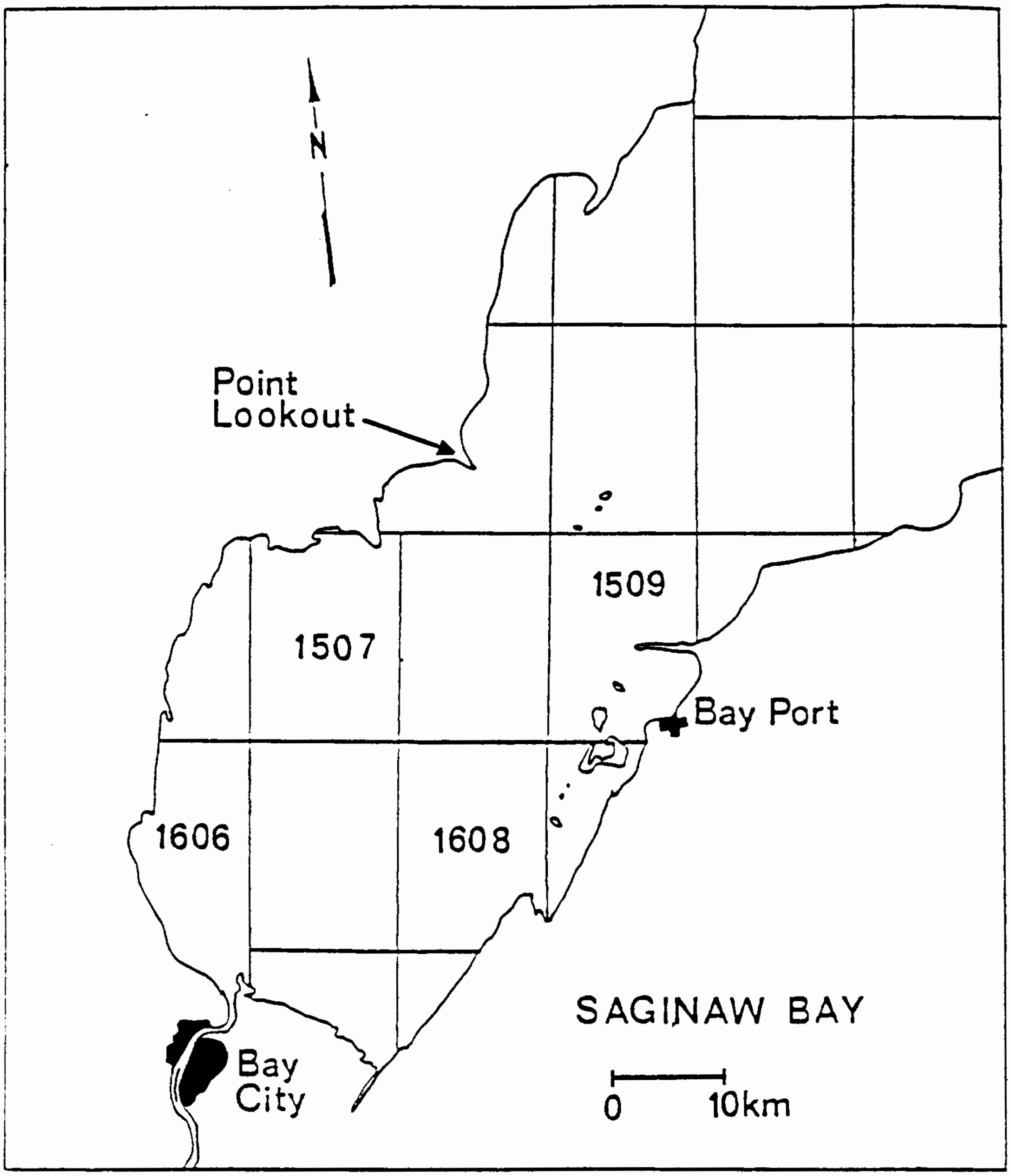

Figure 2. Management grids in Saginaw Bay where commercial trap nets were sampled in 1985.

Table 1. Number of fish in samples from commercial trap nets in four management grids in Saginaw Bay, 1985.

Date	Grid	Number of fish measured	Number of spines collected
August 2	1507	408	103
June 5 & October 31	1509	868	150
October 22	1606	650[a]	106
November 13	1606	0	52[b]
June 24 & October 30	1608	202	127[c]

[a] Only a portion of the fish in some nets were measured.
[b] Additional spines were collected from the same area of this grid.
[c] Most of the spines collected from fish caught in this grid were not from the fish measured for length frequency data.

Growth Analysis

Backcalculated lengths at each age were determined for 237 fish to calculate parameters of the von Bertalanffy equation and compare growth with previous studies. Annular measurements were transformed into lengths using a modification of the direct proportion method (Bagenal and Tesch 1978):

$$L_i = (S_i / S)(L_c - a) + a,$$

where L_i = total length of fish when annulus i formed,

L_c = total length of fish at capture,

S_i = spine radius at annulus i,

S = total spine radius,

a = intercept of regression equation when L_c regressed on S for all fish.

Parameters for the von Bertalanffy equation were calculated from mean backcalculated lengths at age using the method of Rafail (1973). This method involves determining K as the slope of the regression equation when the natural logarithm of the annual growth increment per unit of age is regressed on age. The other parameters are then calculated using a set of equations derived from the von Bertalanffy equation.

A length-weight equation was calculated from lengths and weights of catfish sampled from the commercial catch. The length-weight equation was linearized using a logarithmic transformation:

$$\text{Ln } W = \text{Ln } a + b \text{ Ln } L,$$

where W = weight measured to the nearest 0.001 kilograms,

L = total length in millimeters,

Ln a = y-intercept,

b = slope.

Tagging

Channel catfish were obtained for tagging using small trap nets set near shore and to depths of about 3.5 meters in the Wild Fowl Bay area of Saginaw Bay (Fig. 3). Tagging occurred from May through November 1985. From May through September, only catfish greater than the legal commercial size limit of 381 mm (15 inches) were tagged. After September, some fish between 355.6 mm (14 inches) and 381mm were tagged. Floy FD-68B anchor tags, encoded with a unique number and the address for the MDNR office in Mt. Clemens, Michigan, were implanted slightly below the dorsal fin on the left side of the catfish. Each fish was measured prior to release. In addition, the adipose fin was clipped so that a tag loss rate could be determined by later examining fish in the commercial catch.

Tags were recovered by sport and commercial fishermen. A lottery with a $200 prize for sport fishermen and a $100 prize for commercial

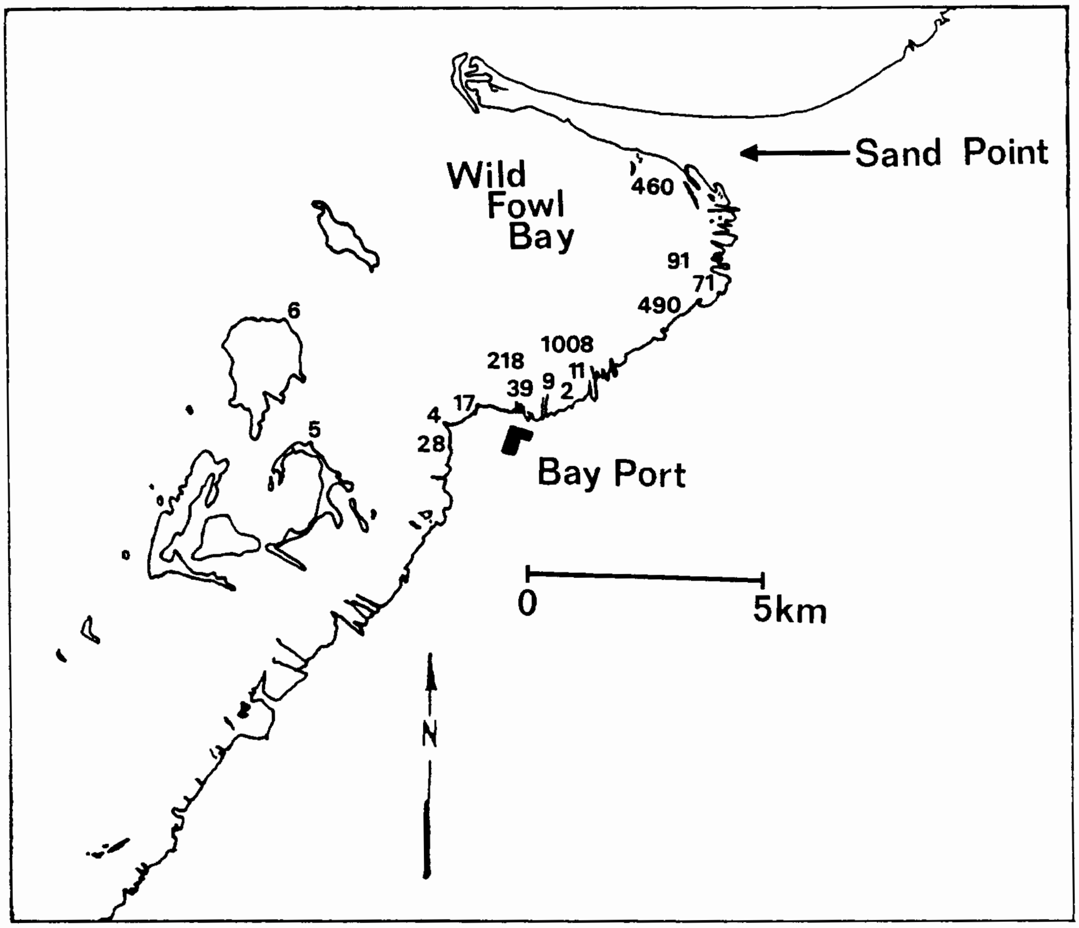

Figure 3. Sites where channel catfish were tagged in the Wild Fowl Bay area of Saginaw, 1985. Locations are marked by number of fish tagged at each site.

fishermen was conducted to ensure a high rate of return of tags. Each prize was awarded by drawing a tag randomly from tags returned by the respective group of fishermen. Posters informing fishermen of the study, the lottery, and where to return the tags were placed at public access sites, marinas, sporting goods stores, and bait dealers near Saginaw Bay. Michigan Sea Grant also announced the project in a news release to the media, sporting goods stores, and bait dealers. I also sent letters to commercial fishermen informing them of the study and the lottery for the $100 prize. Post cards were sent to the sport fishermen returning tags indicating where and when the tagged catfish had been tagged and released. Tag returns may also have been enhanced by a creel census done by the MDNR in 1986.

The reporting rate of tagged fish by commercial fishermen was determined by examining fish in holding tanks at Bay Port Fish Company. A majority of all the catfish caught in the bay are handled by Bay Port Fish Company and their facilities provided easy access to the fish. The reporting rate of sport fishermen was assumed equal to the commercial reporting rate because no estimate of the sport reporting rate was made. The commercial reporting rate was calculated for an area of the bay made up of grids 1508, 1509, 1608, and 1609. The area comprised by these grids will be called the Bay Port Fish Company Area for later reference. These grids were choosen because almost all the fish caught in these grids are handled by Bay Port Fish Company and sampling of the commercial catch for tagged fish only occurred at Bay Port Fish Company.

The total weight of catfish caught in the Bay Port Fish Company Area, as reported by commercial fishermen to the MDNR, was converted to the number of catfish caught (C) by dividing the total weight by the average weight of catfish caught commercially. The average weight of catfish caught was determined by weighing fish from the commercial catch. The total number of unreported tagged fish (T_u) was calculated as follows:

$$T_u = C\,(n_t / n),$$

where n_t = number of tagged fish in sample of commercial catch,

n = sample size.

The reporting rate could then be calculated:

$$RR = T_r / (T_u + T_r)$$

where RR = reporting rate,

T_r = number of reported tagged fish.

Mortality Rate Estimation

The instantaneous total mortality rate for each grid was calculated as the slope of a regression line fitted to the descending limb of a catch curve (Ricker 1975). The modal age group and oldest age group were not used in the analysis, as recommended by Everhart and Youngs (1981), to reduce problems with fish not being fully recruited to the fishery and small sample sizes at older ages. The instantaneous total mortality rate for Saginaw Bay was calculated from a catch curve constructed using data from three grids combined. Data for grid 1608 were not used because I felt the sample of fish measured was unrepresentative of fish present in the grid. This value for total mortality rate was assumed to be the correct value for the bay and was used in subsequent calculations. Regressions were considered significant if the slope was significantly different from zero at the 95% confidence level.

Instantaneous fishing mortality rate for the bay was determined by first calculating monthly exploitation rates for 1986 tag returns and then using the known total mortality rate to convert these exploitation rates to fishing mortality rates with the following equation (Ricker 1975):

$$F_i = u_i Z_i / A_i,$$

where F_i = instantaneous fishing mortality rate for month i,

u_i = exploitation rate for month i,

Z_i = instantaneous total mortality rate for month i,

A_i = fractional mortality rate for month i.

Fishing and natural mortality were assumed to occur concurrently and only during the eight-month fishing season. A method for calculating total and fishing mortality rates using tag returns from both years (Ricker 1975) was initially attempted but too few returns in 1985 caused the estimates to be dubiously small. The small number of returns in 1985 was probably due to nonrandom tagging and/or nonrandom fishing. Thus, only 1986 tag return data were used to calculate fishing mortality rate. To calculate monthly exploitation rates, an estimate of the number of tagged fish available for capture each month was necessary. This number was determined by reducing the initial number tagged over time using the known total mortality and tag loss rates in the following equations:

$$N_{i+1} = N_i e^{-(Zi + Ui)}$$

where N_{i+1} = number of tagged fish available for capture in month i +1,

N_i = number of tagged fish available for capture in month i,

Z_i = instantaneous total mortality rate for month i,

U_i = instantaneous rate of tag loss for month i.

All mortality as well as tag loss was assumed to occur during the fishing season.

Monthly exploitation rates were determined by dividing the number of tagged fish caught in a given month (number of tag returns adjusted for nonreporting) by the number of tagged fish available for capture that month. These rates were then converted to instantaneous fishing mortality rates and summed over the fishing season. Fishing mortality rates were also calculated for sport (FS) and commercial (FC) fisheries separately. Once instantaneous fishing mortality rate was determined for the bay, instantaneous natural mortality rate (M) was determined by subtracting fishing mortality rate from total mortality rate.

Yield Analysis

A yield isopleth diagram was constructed to determine the management actions necessary to achieve maximum yield. Yield isopleths connect points of equal yield attained by various combinations of commercial size limit and FC. A model developed by R. D. Clark, Jr. of the MDNR was used to calculate the yield per fish recruited to the fishery (Clark and Huang 1983). The number of recruits (N) was set at 1000 each year. The model is a modified Beverton and Holt yield per recruit model allowing incorporation of up to four competing fisheries. Between age at recruitment (x_r) and age at first capture (x_c), only natural mortality occurs. Age at recruitment is the age when fish first become vulnerable to capture by fishing gear. Age at first capture is the age when fish reach the commercial size limit or become acceptable for keeping by sport fishermen. After x_c, both natural and fishing mortality occur. The catch rate for a specific fishery (sport or commercial) was described as:

$$dC_t / dx = -F_t N \qquad x_c < x$$

where t = type of fishery.

Integrating this equation over a specific age range gives the catch for the age group and fishery:

$$C_{x,t} = N_x (F_t / Z_x)(1 - e^{-Zx}),$$

where $Z_x = (F + M)[(x + 1) - x]$.

Total catch is equal to the sum of the catches for each age group and fishery. Length at recruitment (l_r) and length at first capture (l_c) are input into the model and the von Bertalanffy equation is used to convert these lengths to the corresponding ages, x_r and x_c, respectively. Length at recruitment for both fisheries was defined as the weighted mean length of fish less than or equal to the modal length of all fish measured from the commercial trap nets. The l_c for the sport fishery was set equal to l_r. The l_c for the commercial fishery equals the commercial size limit (381 mm). The actual yield for a specific age and fishery was calculated by determining the average weight of a fish of that age (using the length-weight relationship) and multiplying this number by the catch for that age and fishery. Total yield per 1000 recruits for the population was then calculated as the sum of the yield for each specific age and fishery.

Management recommendations were based on the level of FC and l_c which maximized predicted yield per 1000 recruits when all other factors were held constant, FC (max) and l_c (max), respectively. The sensitivity of FC (max) and l_c (max) to various factors was determined by calculating the average percent change in FC (max) and l_c (max) from the existing conditions with a ±10% change in one of the factors.

RESULTS

Age Structure and Size Composition of Catch

Length frequency distributions for the grids showed smaller fish to be more prevalent on the western side of the bay (Fig. 4). The distribution for grid 1608 was unusual in that it had two peaks one at 318 mm and another at 546 mm. Combining the length frequency data from all grids gave a modal length of 330 mm, while excluding data from grid 1608 reduced modal length to 328 mm.

Age frequency distributions for each grid showed a peak at 5 years of age and increased frequency at 10 years of age (Fig. 5). However, younger fish were more prevalent among the grids of the western side of Saginaw Bay. The distribution for grid 1608 was again unusual with 10 year old fish occurring most frequently.

Growth Analysis

The von Bertalanffy growth equation, calculated from backcalculated length at age data for fish from all grids, was:

$$L_t = 1340\ [1 - e^{-0.049\ (t\ -\ 0.043)}].$$

This equation produced lengths that approximated actual length at age; however, there was a large deviation in length at age below 6 years of age possibly due to gear selectivity (Fig. 6).

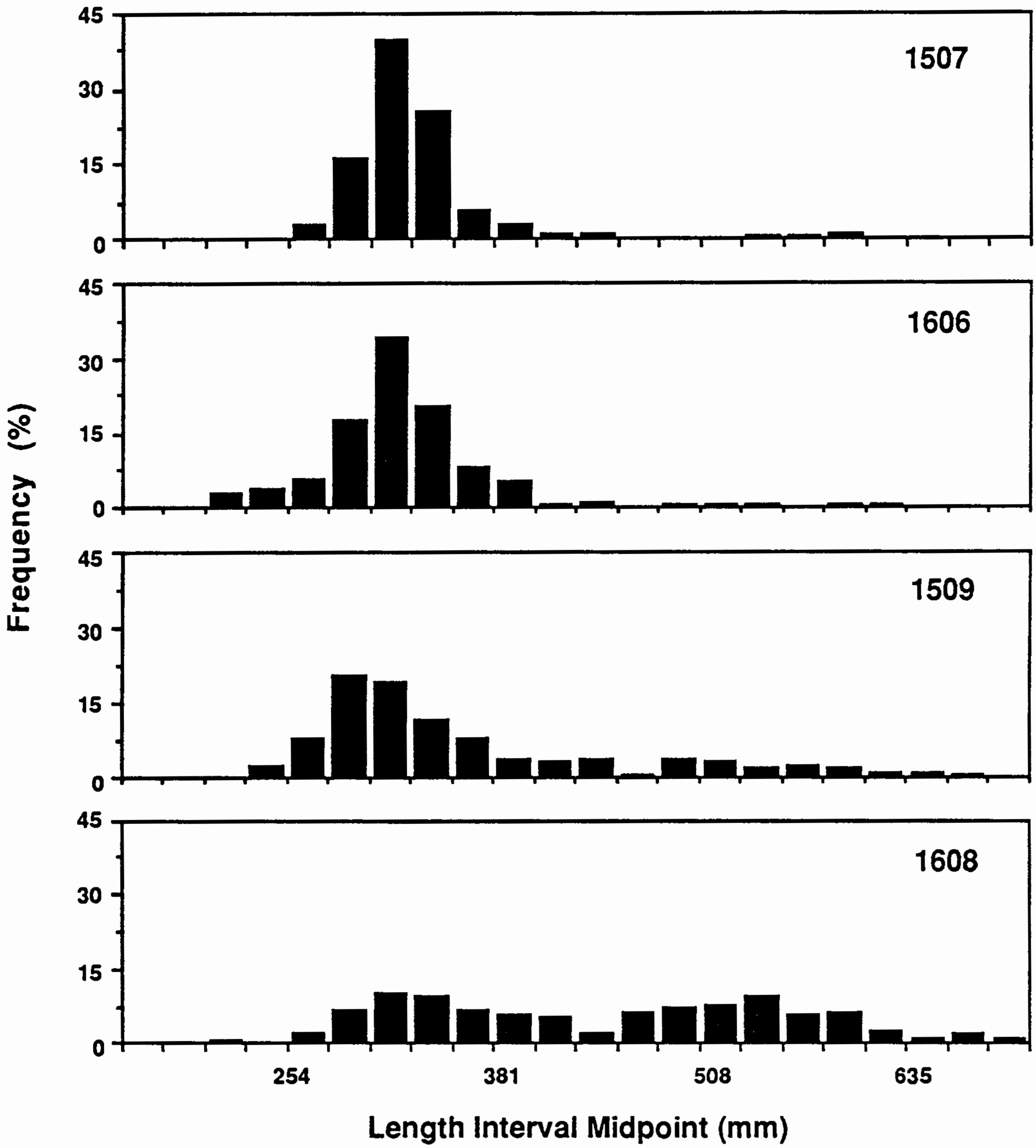

Figure 4. Length frequency distributions for channel catfish sampled from commercial trap nets in four management grids in Saginaw Bay, 1985.

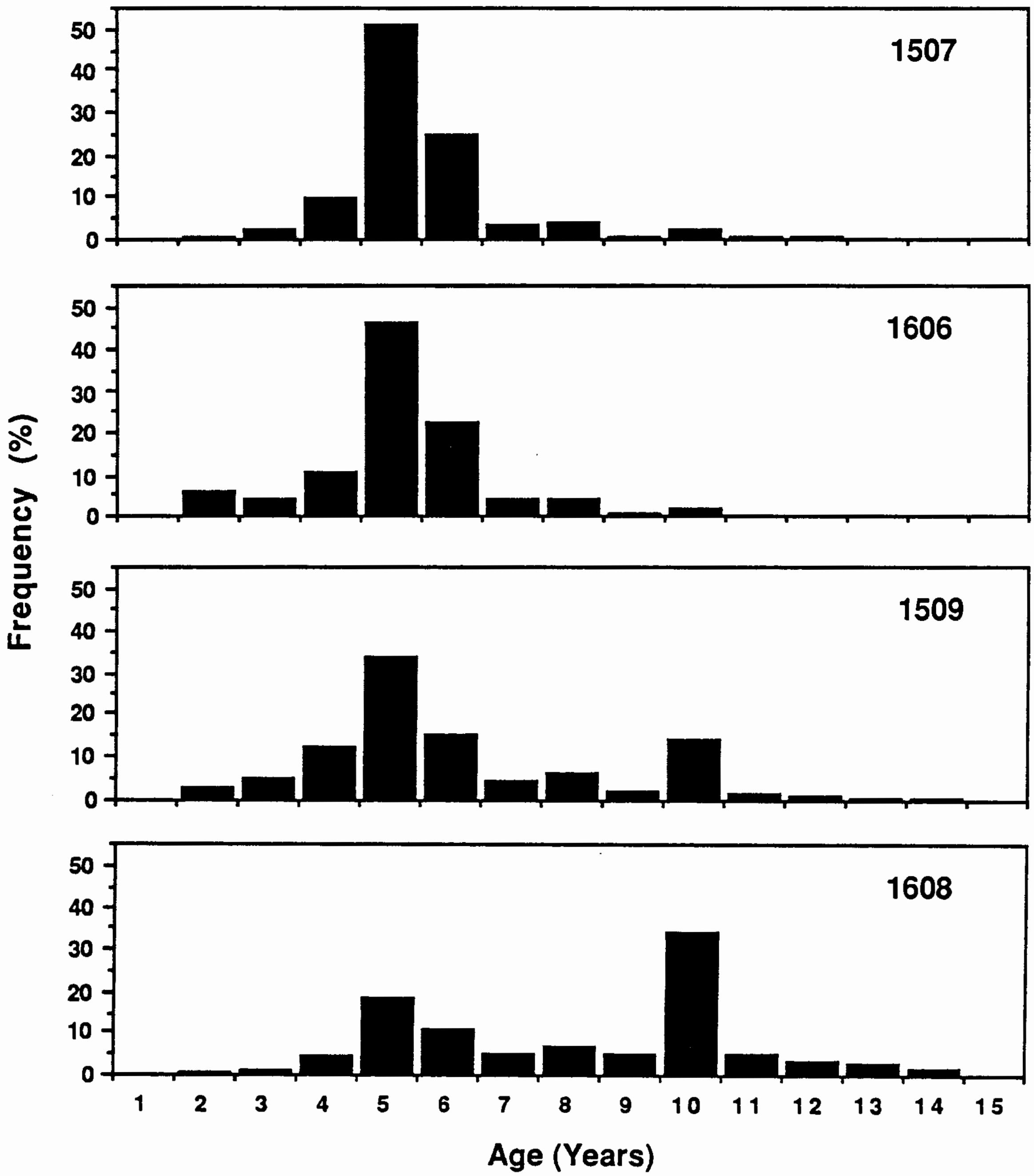

Figure 5. Age frequency distributions for channel catfish sampled from commerical trap nets in four management grids in Saginaw Bay, 1985.

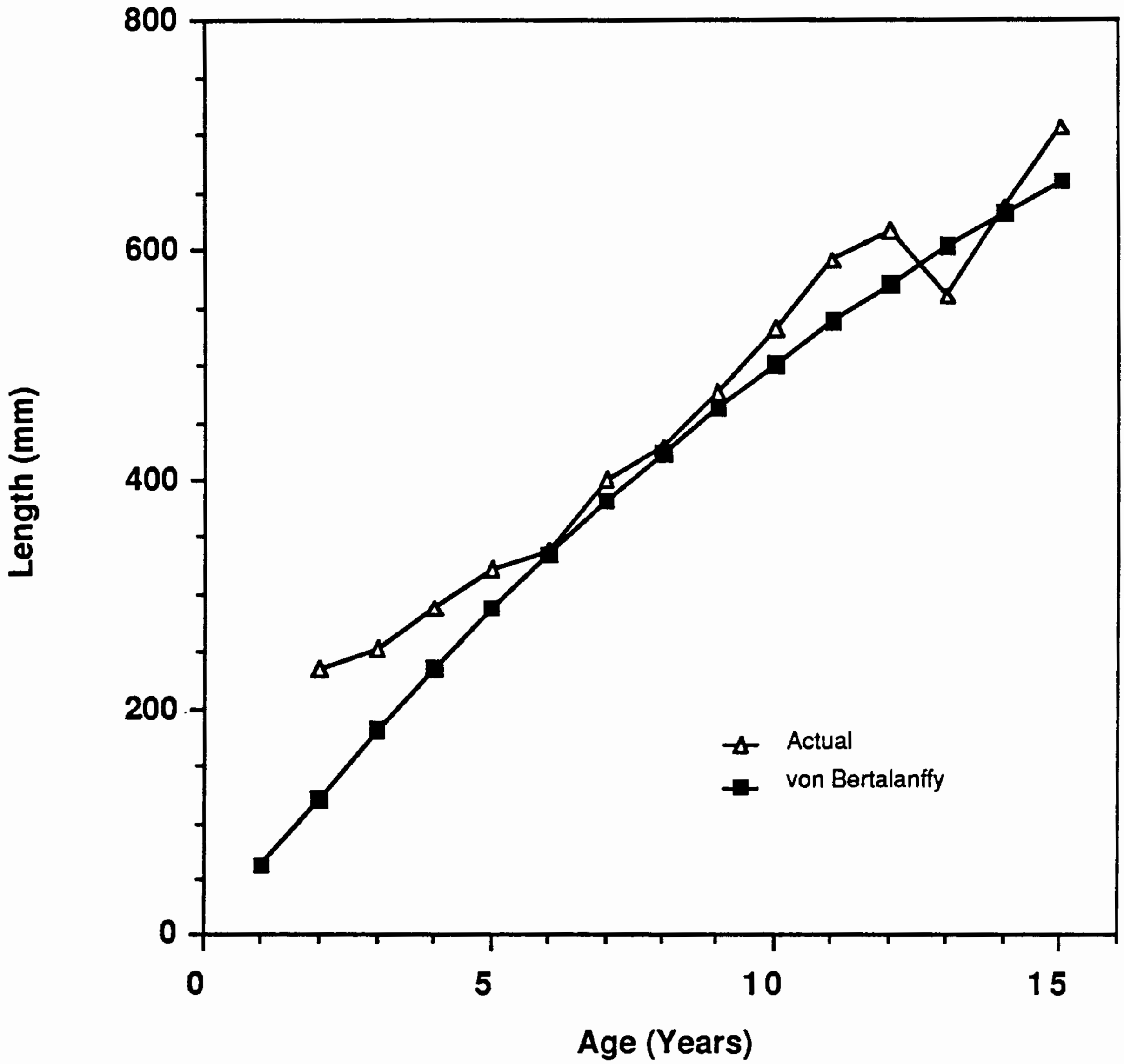

Figure 6. Comparison between lengths at age determined from the von Bertalanffy equation and actual lengths measured from channel catfish from Saginaw Bay, 1985.

The length-weight equation calculated from data for 562 catfish measured and weighed from the commercial catch at Bay Port Fish Company in 1985 was:

$$\mathrm{Ln}\ W = -20.575 + 3.351\ \mathrm{Ln}\ L,$$

$$r^2 = 0.96,$$

$$p < 0.00001.$$

Tagging

A total of 2460 catfish were tagged from May through November 1985 (Table 2). Tag returns were received from June 1985 through November 1986. Most returns were from commercial fishermen (Table 3). Overall, 11.3% of the tags were returned, and 72.2% (200) of the returns were from areas within 7 miles of the tagging sites. However, tags were also recovered from other areas of Saginaw Bay and areas of Lake Huron outside the bay (Fig. 7)

Sampling holding tanks at Bay Port Fish Company produced only 3 tagged fish out of 2872 fish examined in 1985 and 1986. The total catch for the Bay Port Fish Company Area (grids 1508, 1509, 1608, and 1609) in 1985 was 181,286 kg (399,667 lbs) or 134,116 fish. The average weight of 1.35 kg (2.98 lbs) per fish was calculated by weighing 562 fish from the commercial catch. The catch for 1986 was 185,305 kg (408,527 lbs) or 137,090 fish. I calculated 271 tags not reported for 1985 and 1986 using this sampling and catch data. The number of tags reported from the Bay Port Fish Company Area was 218. The reporting rate was calculated to be 45%.

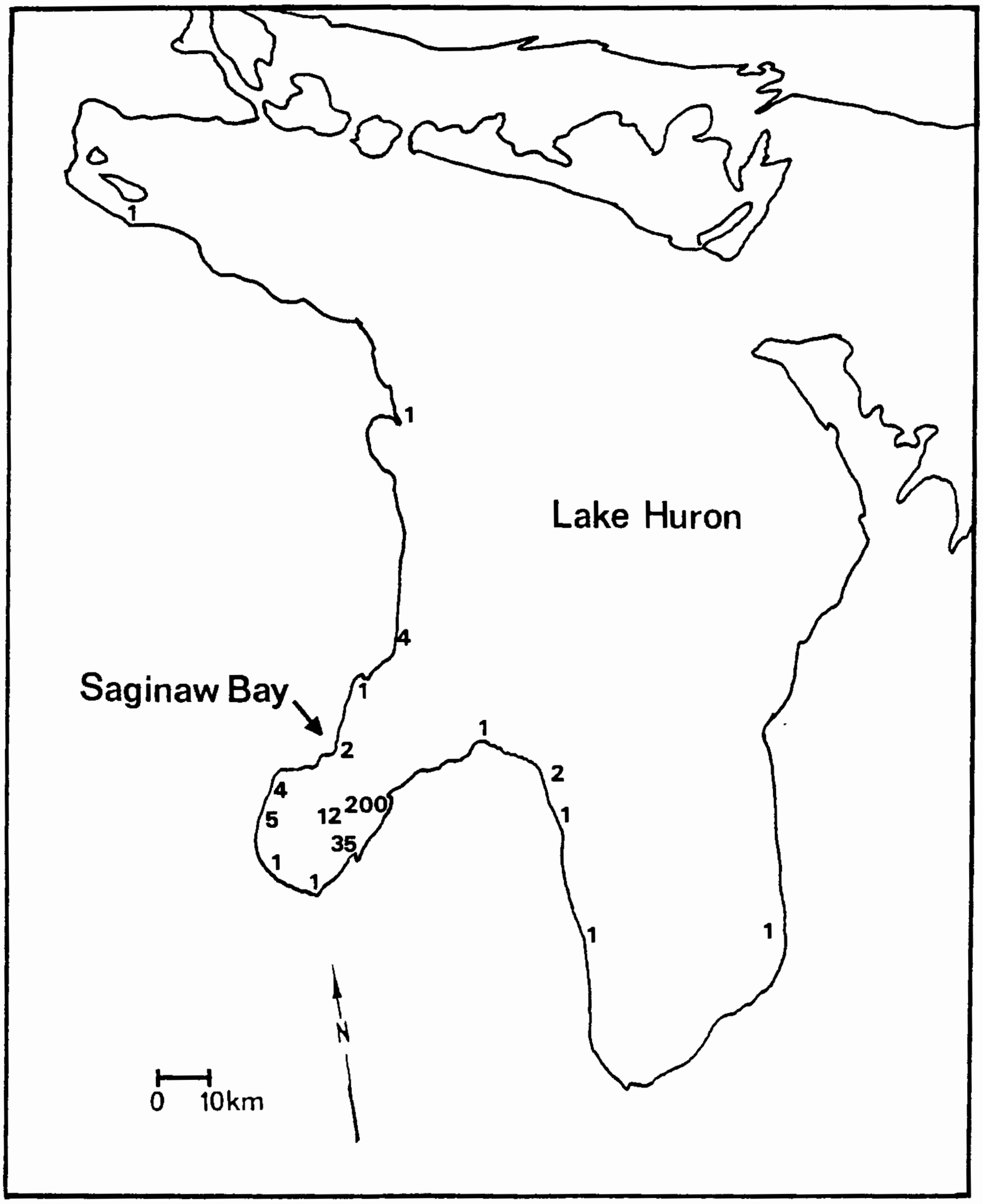

Figure 7. Locations where tagged channel catfish were recaptured and reported by sport and commercial fishermen in 1985 and 1986.

Table 2. Number of channel catfish tagged each month in Saginaw Bay, 1985.

Month	Number of fish
May	67
June	764
July	732
August	5
September	5
October	641
November	246
Total	2460

Table 3. Number of tags returned by sport and commercial fishermen in 1985 and 1986.

Fishery	1985	1986	Total
Sport	9	40	49
Commercial	68	162	230
Total	77	202	279

No fish with a clipped adipose fin was identified among the fish examined in the commercial catch, so no estimate of tag retention was possible. Hale et al. (1983) using Floy FD-68B tags found a tag loss rate of 5.8% per year for catfish. This rate was used in subsequent calculations.

Mortality Rate Estimation

Instantaneous total mortality rates with 95% confidence intervals calculated from catch curves for grids 1507, 1509, 1606, and 1608 were, 0.59 (±0.25), 0.35 (±0.21), 0.72 (±0.24), and 0.17 (±0.23), respectively. Differences in these mortality rates reflected differences seen in the age frequency distributions among grids (Fig. 5). The low total mortality rate for grid 1608 reflected the unusual age frequency distribution for that grid. In addition, all regressions were significant except the one for grid 1608 ($p > 0.1$).

Instantaneous total mortality rate for Saginaw Bay, determined from a catch curve constructed from the combined data for grids 1507, 1509, and 1606, was 0.45 (±0.21) (Fig. 8). This rate was assumed to be the correct total mortality rate for the bay for later calculations. Data from grid 1608 were excluded from mortality rate calculations because I felt that the sample collected was not representative of fish present in that grid, which resulted in the unusual age and length frequency distributions. Lorantas (1982) found the age frequency distribution for grid 1608 to be similar to age frequency distributions of other grids so the considerable difference in frequency distributions I found between grid 1608 and the other grids is unlikely.

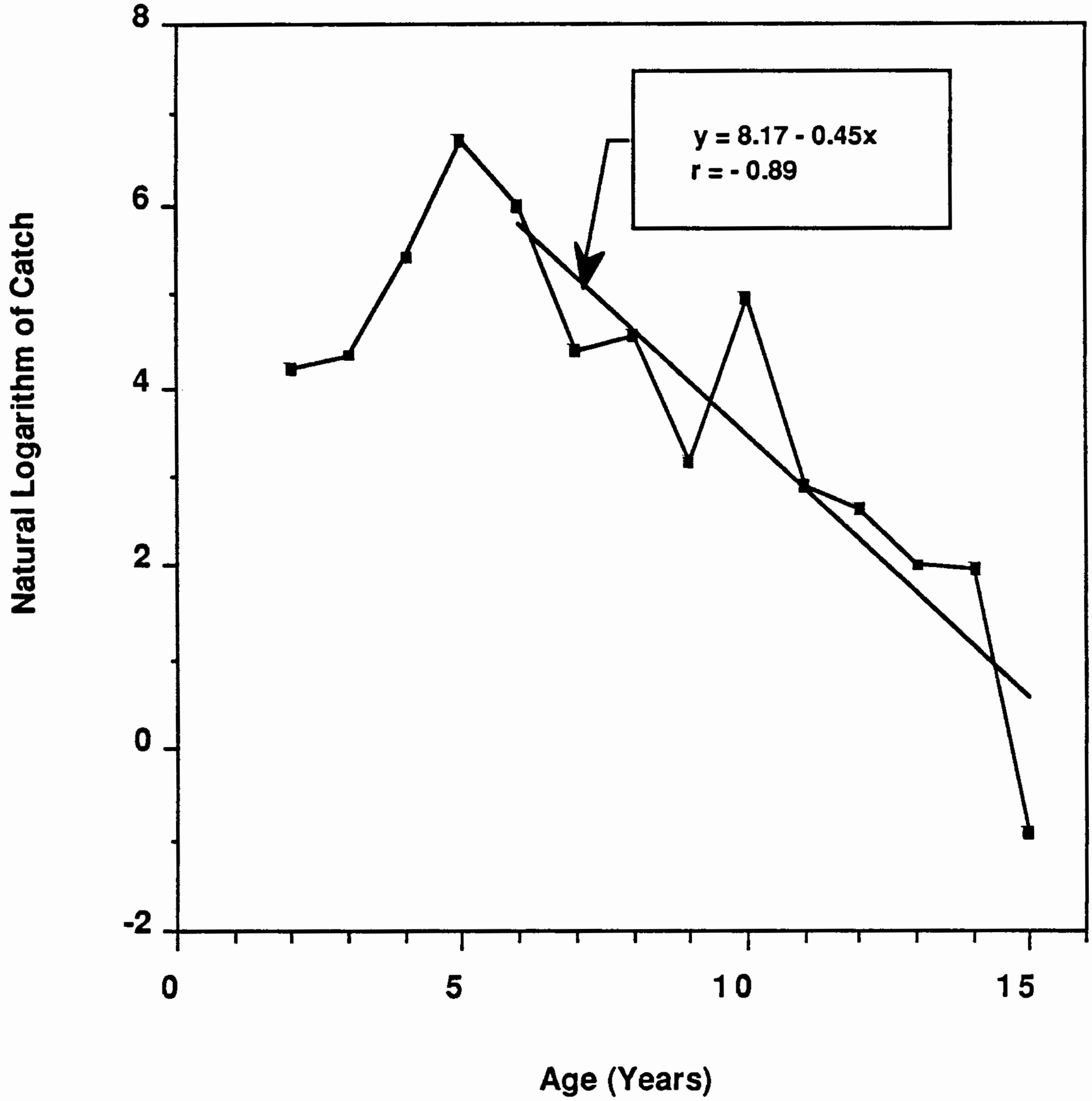

Figure 8. Catch curve constructed using combined data from management grids 1507, 1509, and 1606 of Saginaw Bay, 1985. Regression line fitted to ages 6 to 14 of the descending limb is shown.

At the calculated tag reporting rate of 45% and the assumed tag loss rate of 5.8% per year, instantaneous fishing mortality rate calculated from 1986 tag returns was 0.26. Instantaneous fishing mortality rates for the commercial (FC) and sport fisheries (FS) were 0.21 and 0.05, respectively. By subtraction, the instantaneous natural mortality rate was 0.19.

Yield Analysis

Lorantas (1982) determined that the fish from each grid were part of a single unit stock of catfish in Saginaw Bay. Movement of catfish between grids as determined from tag returns supports this conclusion (Fig. 7). Thus, data for the yield model were derived by pooling data from all grids except when calculating the instantaneous total mortality rate for the bay in which case only data from grids 1507, 1509, and 1606 were used.

The l_r was unknown but assumed to be 300 mm. This assumption agrees favorably with the assumed age of complete recruitment (6) for calculating total mortality rates as 92.7% of the age 6 fish I aged and measured were greater than 300 mm.

Given current conditions that exist in the bay, the predicted commercial and sport yield per 1000 recruits was 388.9 kg and 116.8 kg, respectively. Commercial yield could be increased by either increasing the commercial effort alone or in combination with an increased size limit (Fig. 9). The yield model predicted total yield (commercial plus sport) per 1000 recruits would be maximized at a commercial size limit of 511 mm if fishing rates remained constant. On the other hand, commercial yield alone

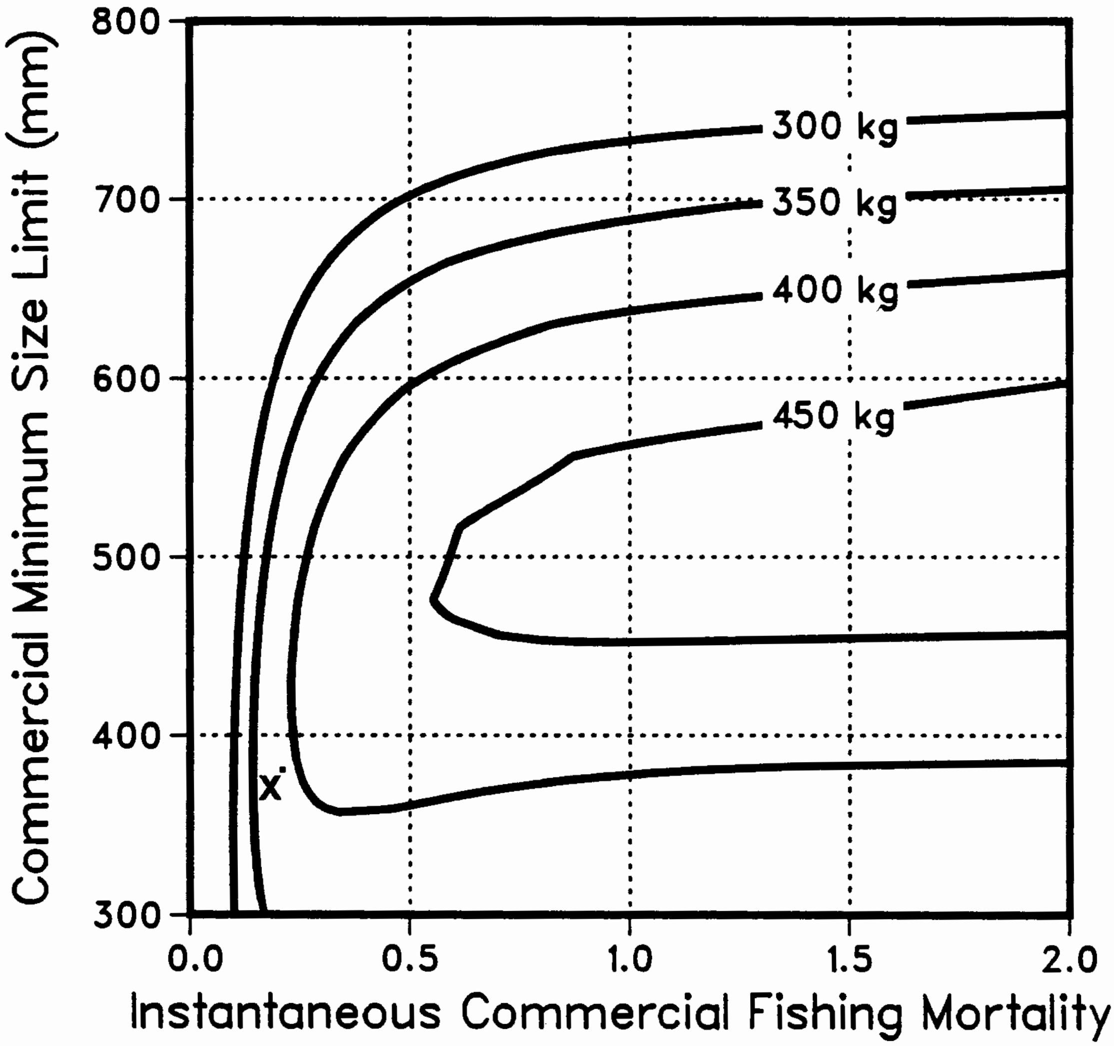

Figure 9. Yield isopleth diagram for commercial yield per 1000 recruits of channel catfish from Saginaw Bay, 1985. Instantaneous natural and sport fishing mortality rates were 0.19 and 0.05, respectively. The commercial fishery was operating a point x in 1985.

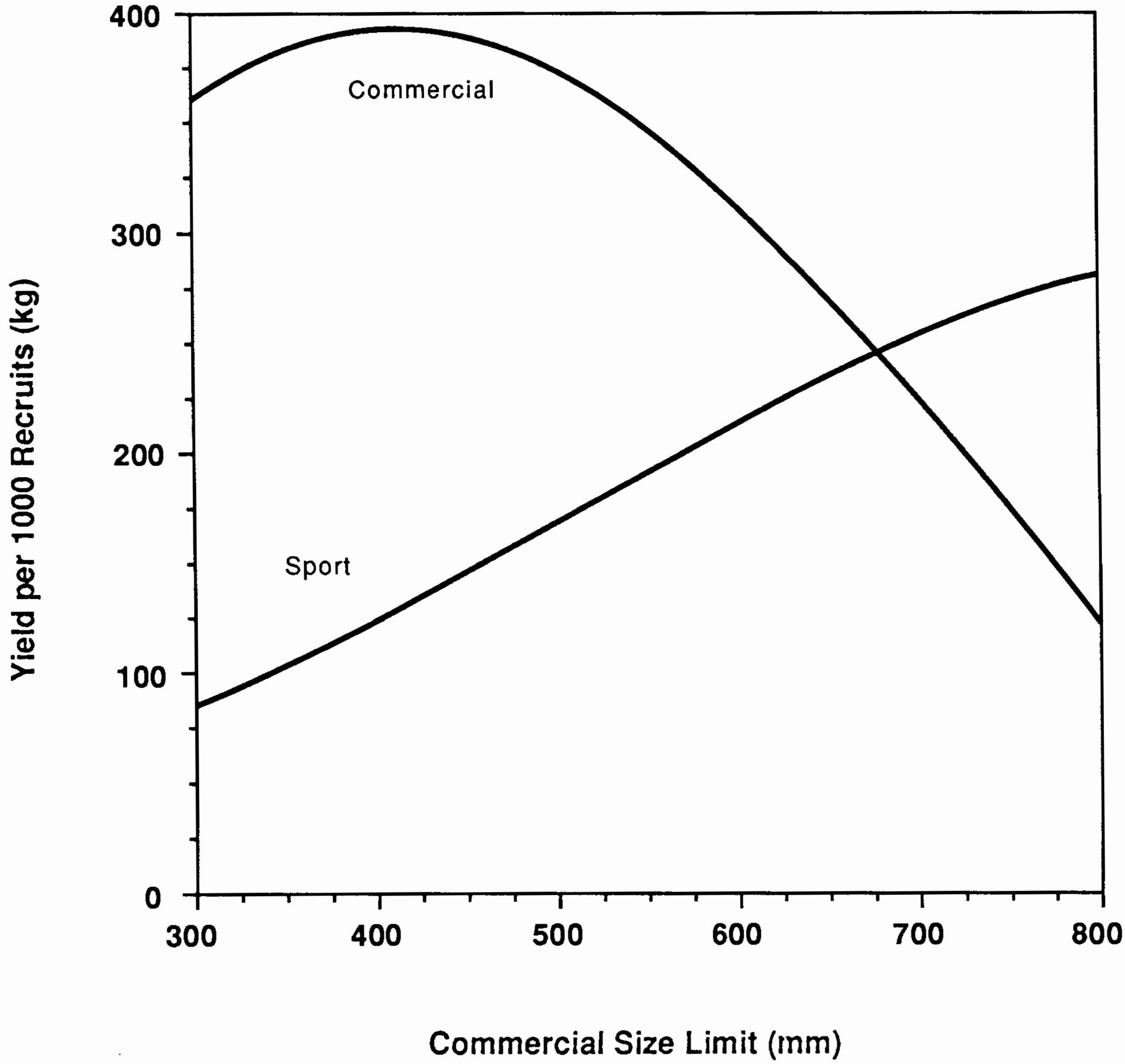

Figure 10. Commercial and sport yield for channel catfish from Saginaw Bay as a function of commercial size limit. Instantaneous commercial and sport fishing mortality rates are 0.21 and 0.05, respectively.

maximized when no commercial fishing existed. If size limit was increased from 381 mm to 511 mm, commercial yield would decrease 5.0% and total yield would increase 7.4%, while sport yield would increase 48.8% (Fig. 10). An increase in the size limit to 416 mm would increase total yield 3.4%, commercial yield 0.7%, and sport yield 12.5%. At the current commercial size limit (381 mm), the predicted commercial and total yield per 1000 recruits was maximized at a FC of 0.42 and 0.22, respectively. If FC was increased to 0.42, commercial yield would increase by 6.8% while total and sport yield would decrease by 3.3% and 37.0%, respectively (Fig. 11). Increasing FC to 0.22 would increase total yield per 1000 recruits by 0.02% and increase commercial yield by 0.9%. Sport yield would decrease by 2.9%.

In the sensitivity analysis, variations in commercial reporting rate, instantaneous total mortality rate, and von Bertalanffy parameters had a large impact on FC (max) and l_c (max) (Table 4). Variations in sport reporting rate did not affect FC (max) and l_c (max) for commercial yield because of the way in which the natural mortality rate was calculated. Variations in tag loss rate and length at recruitment had a small effect on FC (max) and l_c (max). Thus, the accuracy of instantaneous total mortality rate, commercial reporting rate, and von Bertalanffy parameters determine reliability of this yield analysis. Obviously, improving the accuracy of these factors would increase confidence in the yield predictions.

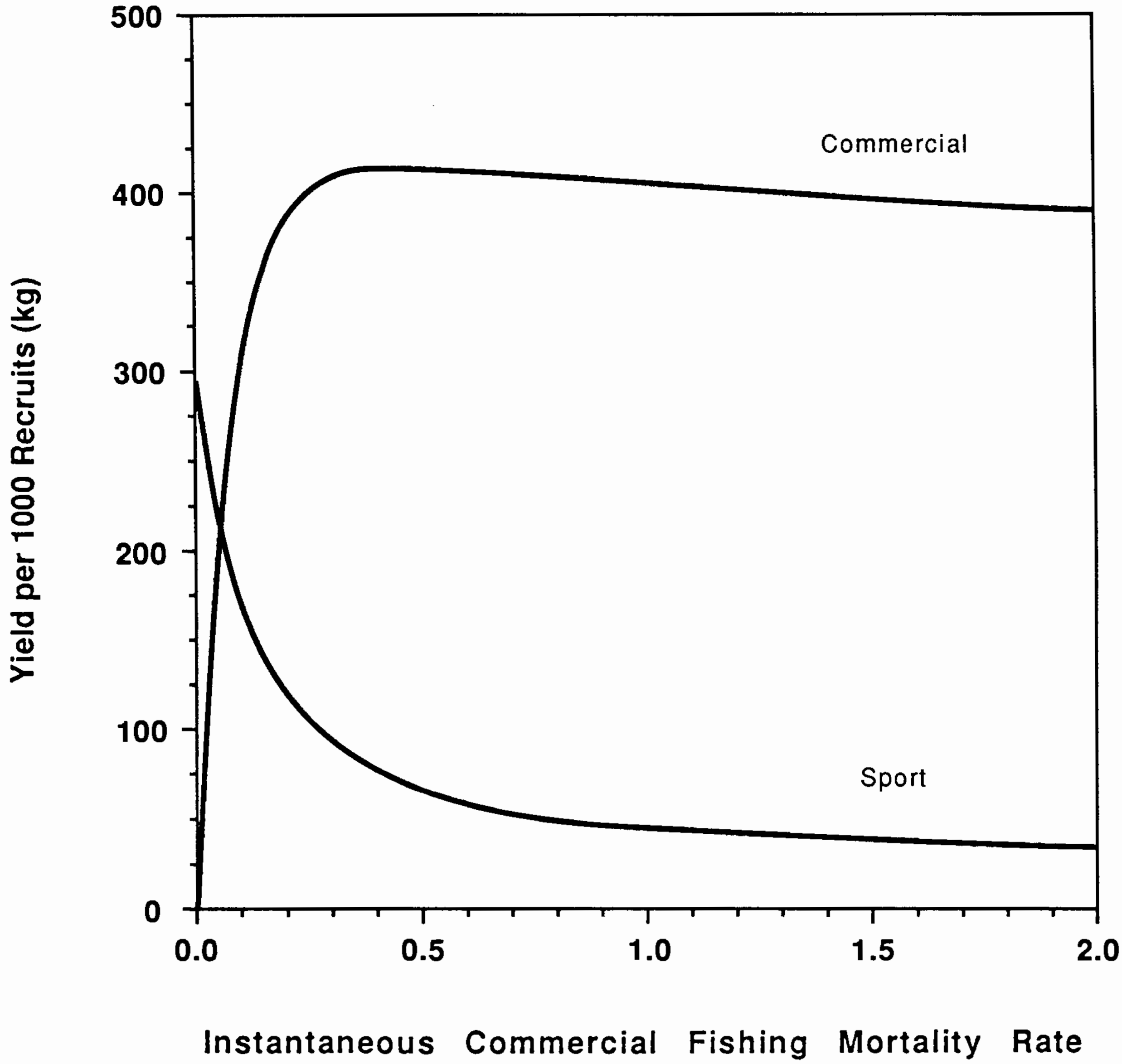

Figure 11. Commercial and sport yield, for channel catfish from Saginaw Bay, as a function of commercial fishing mortality rate. Commercial size limit is 381 mm.

Table 4. Average percent change from existing conditions in FC (max) and l_c (max) with corresponding yields when input parameters of yield model are varied ±10%.

Parameter	FC (max)	Yield	l_c (max)	Yield
Instantaneous Total Mortality Rate	51.2	15.2	11.7	22.7
Commercial Reporting Rate	27.9	10.1	10.4	18.6
Sport Reporting Rate	0	0	0	0
von Bertalanffy Growth Parameters	69.8	24.0	15.5	32.5
Tag Loss Rate	1.2	0.4	1.1	0.7
Length at Recruitment	1.2	14.3	0.9	14.3

DISCUSSION

Commercial yield per 1000 recruits of channel catfish could be increased by increasing commercial fishing effort. However, management objectives must be carefully considered if such a change were allowed, as increased effort would decrease sport yield. Greatest increases in commercial yield would be achieved with increases in both effort and commercial size limit. Previous studies (Eshenroder and Haas 1974, Lorantas 1982) found that commercial yield could be maintained or increased if effort was reduced; however, my results indicate that only sport yield would be increased by this sort of change. Reasons for the differences between these studies include higher natural mortality rate, slower growth rate, and lower fishing mortality rate found in the present study.

The instantaneous total mortality rate of 0.45 was lower than the total mortality rate calculated by Eshenroder and Haas (1974) and Lorantas (1982). The total mortality rate is low compared to total mortality rates for channel catfish from other studies (Table 5). One possible reason for the decline in the instantaneous total mortality rate since 1981 is that during the years affecting the studies in 1971 and 1981 recruitment was probably increasing. Thus, the assumption of constant recruitment for the catch curve analysis was violated. This increased recruitment would cause the total mortality rates calculated to be too high. By the time I did this study recruitment may have stabilized so that the true instantaneous total mortality rate could be calculated from a catch curve.

Table 5. Instantaneous total mortality rates (with 95% confidence intervals when calculated) for channel catfish from Saginaw Bay and other selected locations.

Location	Year(s) of study	Instantaneous total mortality rate
Saginaw Bay	1985	0.45 (±0.21)
Saginaw Bay [a]	1981	0.67 (±0.27)
Saginaw Bay [b]	1971	0.67
Des Moines River, Iowa [c]	1966-69	0.64
Upper Mississippi River, Iowa [d]	1977-79	0.94
Lake Sharpe, South Dakota [e]	1945-56	0.37
Rivers of Sacramento Valley, California [f]	1955-59	0.82

[a] Lorantas (1982)
[b] Eshenroder and Haas (1974)
[c] Mayhew (1972) cited by Lorantas (1982)
[d] Pitlow and Bonneau (1979) cited by Lorantas (1982)
[e] Elrod (1974)
[f] McCammon and LaFaunce (1961)

The natural mortality rate of 0.19 which I calculated for the bay was higher than the assumed rate of 0.1 used by Eshenroder and Haas (1974) and Lorantas (1982). The natural mortality rate calculated in this study lies within the range of published values. McCammon and LaFaunce (1961) calculated a natural mortality rate of 0.38 for channel catfish in the rivers of the Sacramento Valley and the natural mortality rate calculated for an unexploited stock of channel catfish in Lake St. Clair was 0.105 (Great Lakes Fishery Commission, Lake Erie Committee Report for 1971 cited by Eshenroder and Haas 1974). If Lorantas (1982) had used this higher natural mortality rate his conclusions would have been similar to mine. At the 381 mm commercial size limit , commercial yield would have been maximized at a FC greater than 1.00 instead of the FC of about 0.25 calculated by Lorantas.

Backcalculated total lengths at age for the three Saginaw Bay studies revealed a decrease in growth rate of channel catfish since 1971 (Table 6). The growth rate in this study was also slower than for catfish from many other areas (Table 6). Two factors could explain the decline in growth rate of the catfish. First, channel catfish may compete with other bottom feeders and predatory species utilizing the same habitat (Scott and Crossman 1979). Interspecific competition has likely increased as walleye *Stizostedion vitreum* and salmonid populations in Lake Huron have increased through stocking or natural reproduction (Great Lakes Fishery Commission 1985). In addition, perch production has been good for the past several years (Great Lakes Fishery Commission 1985). Second, intraspecific competition has probably intensified as the population of catfish increased.

Table 6. Mean backcalculated total length (mm) at age for channel catfish from Saginaw Bay and other selected areas.

Location	Year(s) of study	Sample size	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Saginaw Bay, Lake Huron	1985	237	42 ±2	111 ±4	168 ±4	233 ±5	283 ±5	328 ±6	376 ±7	420 ±8	473 ±12	509 ±13	533 ±21	566 ±27	592 ±33	630 ±42	685 ±694
Saginaw Bay, Lake Huron [a]	1981	916	54 ±1	132 ±2	198 ±2	256 ±2	310 ±3	358 ±3	420 ±5	469 ±6	507 ±6	546 ±8	594 ±14	604 ±20	612 ±76	...	...
Saginaw Bay, Lake Huron [b]	1971	253	69	157	254	335	404	490	561	569	589	607	630	...	...	...	...
Lake Erie, Michigan waters [b]	1971	495	170	221	264	305	340	373	386	417	452	505	549	...	...	...	...
Lake St. Clair [b]	1969-71	507	76	208	226	272	305	383	434	485	531	564	604	...	...	...	...
St. Lawrence River [c]	1975	28	119	164	204	239	272	302	330	353	377	400	432	455	...	...	...
Lake Sharpe, South Dakota [d]	1945-56	535	46	124	196	256	312	381	442	490	546	617	645	640	676	...	...
Santee-Cooper reservior system, South Carolina [e]	1959	210	86	185	284	368	442	531	602	665	726	772	807	853	917	904	...
Lake of the Ozarks, Missouri [f]	1951	434	53	109	155	196	234	264	292	330	...	...	...	...	...	...	...
Farm ponds, Central Texas [g]	1972	82	178	333	429	516	...	...	...	...	...	...	...	...	...	...	...

[a] Lorantas (1982)
[b] Eshenroder and Haas (1974)
[c] Maguin and Fradette (1975)
[d] Elrod (1974)
[e] Stevens (1959)
[f] Marzolf (1955)
[g] Prentice and Whiteside (1974)

The increase in catfish population is indicated by several factors, including older fish appearing in the commercial catch (Table 6) and increasing catch per unit effort (Fig. 1).

Variations in the instantaneous total mortality rate, commercial reporting rate, and von Bertalanffy growth parameters were most important in affecting FC (max) and l_c (max) values. Instantaneous total mortality rate and growth rate seem reasonable when compared with results from earlier studies. On the other hand, no previous data exists for comparison of reporting of tags from channel catfish caught in Michigan by commercial fishermen. Thus, improving estimates of commercial reporting rate would increase confidence in predictions from the yield model. Sport reporting rate was not important in determining FC (max) and l_c (max) for commercial yield because of the way in which the natural mortality rate was calculated. If an independent estimate of natural mortality rate was available, sport reporting rate may have been important in determining FC (max) and l_c (max) for commercial yield. The effect on these values would probably be less than the effect of the three factors above.

All assumptions necessary for the catch curve analysis (Ricker 1975) and the yield per recruit model (Clark and Huang 1983) were probably violated to some extent, but I feel that these deviations did not significantly affect results. The assumption of constant mortality rates would probably cause the most problems. Constancy of the total mortality rate with time is unknown. If the total mortality rates calculated by

Lorantas (1982) and I are both correct, then the mortality rate has not been constant. Examination of the commercial catch indicates that from 1975 to 1980 the catch increased steadily without any trend in effort. Specific reasons for the increased catch are unknown but may include decreased natural mortality. The environment in Saginaw Bay is continually changing as water quality, water levels, and species composition change. This changing environment might affect natural mortality. If so, the natural mortality rate is probably never constant. Thus, some of the age classes used to determine the total mortality rate may have experienced higher mortality rates than others. Adjusting for a decline in the natural mortality rate would mean a further reduction in the total mortality rate. A lower natural mortality rate would favor increasing the commercial size limit to maximize yield. Yield per 1000 recruits at all levels of fishing effort and commercial size limit would also increase.

Another assumption for the yield per recruit model which appearedto be violated was that of constant growth rate. Examination of backcalculated length at age data for the three studies on catfish in Saginaw Bay (Table 6) revealed that the growth rate has slowed. Although the sensitivity analysis revealed that variations in von Bertalanffy growth parameters were important in determining FC (max) and l_c (max) values, I redid the yield analysis using von Bertalanffy growth parameters calculated by Lorantas (1982) and found only slight changes in model predictions. Thus, the change in growth rate that has occurred since 1981 should not affect the reliability of model predictions.

Accuracy of tag reporting rate by all commercial fishermen is contingent upon two assumptions. The first is that reporting by fishermen associated with Bay Port Fish Company did not differ significantly from reporting by other fishermen in the bay. The second is that the sample of fish examined from the commercial catch was of adequate size. The first assumption is likely to be violated somewhat because fishermen associated with Bay Port Fish Company were more informed of the project and seemed to be more watchful for tagged catfish. Catfish caught by Bay Port Fish Company were handled more frequently and held in indoor tanks so that tagged fish were more likely to be detected than at other locations. Fishermen in other areas used ponds or floating cages to hold catfish. Thus, the tag reporting rate may actually be too high. However, a majority of all catfish caught in Saginaw Bay were handled by Bay Port Fish Company, so variability in reporting among commercial fishermen should not be a large problem. The second bias (sample size) could be a significant problem. Even though 2,872 fish were examined, this amounted to only 1% of the combined commercial catch in the study area for 1985 and 1986. In addition, some of the daily sample sizes were small (range 20-375), and overly small sample sizes would make the reporting rate estimate conservative. I feel that if the reporting rate was in error, it most likely was too low. If so, harvesting at larger sizes would be favored to maximize yield.

No estimate was made of the reporting rate of tags by sport fishermen. The lottery was conducted because I hoped this would entice a majority of fishermen catching tagged fish to return the tags. Other studies have found that people will keep tags as momentos even though a reward is offered (Rawstron 1971). I know of at least two people who wanted to keep the tags (both did report the catch though) and I suspect other people, especially if they did not know of the reward, kept tags. Other studies examining reporting rate of tags taken from various fish species by sport fishermen have found reporting rate to range from 15% to 66% (Table 7). Thus, the assumed sport reporting rate of 45% seems reasonable.

One reason for the differences seen in the length and age frequency distributions among grids may be the habitats where the nets were set. Nets on the western side of the bay were set in deeper water several miles offshore. In grid 1509, nets were set a short distance offshore of the islands bordering Wild Fowl Bay (Fig. 3). Wild Fowl Bay is used extensively for spawning by catfish; thus, large fish have only a short distance to travel to get to the nets. Nets set in grid 1608 were much smaller than nets set in other grids and set so the lead abutted the shore. They were also set within an area of good spawning habitat. Thus, large fish were probably very abundant near these nets, and this may explain the unusual frequency distribution.

The age and length frequency distributions may not have been entirely representative of the true frequency distributions in the various grids. Many of the nets sampled contained an extremely large number of small fish, so that measuring every fish would have taken an inordinate amount of time. Thus, most fish less than about 250 mm were not measured. The modes of the age and length frequency distributions and the frequencies greater than the modes should not be affected by this selection. The distributions for grid 1606 may have been affected by this, because only a subsample of all the fish in some nets was measured.

Table 7. Tag reporting rates of sport fishermen for various species.

Location	Species	Year of Study	Reporting Rate
Folsom Lake, California [a]	White catfish (*Ictalurus catus*)	1962-68	0.61
	Largemouth bass (*Micropterus salmiodes*)		0.54
	Bluegill (*Lepomis macrochirus*)		0.16
Merle Collins Reservoir, California [b]	Largemouth bass	1966-71	0.66
Sacramento-San Joaquin river system, California [c]	Striped bass (*Morone saxatilis*)	1957-67	0.39
West Point Reservoir, Alabama-Georgia [d]	Largemouth bass	1976-79	0.34[e] 0.60[f]

[a] Rawstron (1971)
[b] Rawstron (1972)
[c] Chadwick (1968)
[d] Folmar et al. (1979)
[e] No reward offered.
[f] Five dollar reward offered.

RECOMMENDATIONS

In recent years conflicts between commercial and sport fishermen in Saginaw Bay have been increasing. Sport fishermen have become angered over the use of trap nets in the bay, because they entangle fishing lines and obstruct fishing in certain areas. Sport fishermen have also blamed the perceived lack of large yellow perch *Perca flavescens* and poor walleye catches on commercial fishing. Although competition for large yellow perch is minimal and allegations against walleye catches is false, a regulation change increasing commercial yield at the expense of sport yield would likely be opposed by sport fishermen. Increasing the commercial size limit for channel catfish is the only way to increase both the commercial and sport yield of catfish. Increasing the size limit to 406.4 mm (16 inches) would increase total, commercial, and sport yield per 1000 recruits, 2.6%, 0.6%, and 9.1%, respectively. Yield was actually predicted to reach a maximum at 416 mm (16.4 inches). However, for management purposes the smaller size limit is more convenient because it is a whole number when converted to inches and corresponds to a 1 inch (25.4 mm) increase in the current size limit (381 mm). A greater increase in total yield could be obtained by increasing the commercial size limit to 432 mm and doubling the commercial fishing effort. Then the predicted increase in total, and commercial yield per 1000 recruits, would be 5.3% and12.0%, respectively. However, sport yield would decrease 16.8%. Other types of gear besides trap nets, such as seines, could be used to increase commercial fishing effort without increasing conflicts with sport fishermen.

Increasing the commercial size limit would increase the biomass of channel catfish in Saginaw Bay, which would cause some prey items to be more heavily utilized. Species interactions within the bay are poorly understood so the exact effect of an increased catfish biomass cannot be determined. However, interspecific and intraspecific competition may increase. If fishing effort was also increased, any effect resulting from the increased size limit would be reduced because increasing fishing effort would reduce the biomass of catfish. Management objectives must be considered before any changes are made because of the decrease in sport yield that would occur with an increase in commercial effort and the fact that sport yield is maximized when commercial fishing is prohibited.

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