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Assessment Of The Channel Catfish Fishery In Saginaw Bay, Lake Huron

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This is a reprint of a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Fisheries, in the School of Natural Resources, The University of Michigan, 1983.

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[1]Contribution from Dingle-Johnson Study F-35-R, Michigan.

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by

Robert M. Lorantas

A thesis submitted in partial fulfillment of
the requirements for the degree of
Master of Science
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For
Justin, Nell
and
Kathy

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ABSTRACT

Channel catfish Ictalurus punctatus ranked second in weight harvested by commercial fishermen (231,000 kg), and third in number caught by sportfishermen (60,000) in Saginaw Bay in 1981. The commercial fishery employs trap nets, seines, and set hooks. Mean annual catch per unit effort for all gear types has increased in the past decade, in comparison to prior decades, and has lead commercial fishermen to request licensing of additional gear. The commercial fishery was assessed using a dynamic pool model, and an extension of the model was used to investigate the dynamics of gear competition. Growth and total mortality parameters, estimated from four management areas, were pooled for model analysis since no significant differences in these vital statistics were detected after the age of complete recruitment to the fishery. Parameters of the von Bertalanffy growth equation were estimated using mean back-calculated lengths at age derived from fin spine sections. Total instantaneous mortality was estimated from the slope of the descending limb of a catch curve. Fishing mortalities for each commercial gear type and for sportfishing gear were estimated by partitioning the total fishing mortality in proportion to the catch from that gear. Pooling all areas yielded a von Bertalanffy equation of the form $L_x = 921(1-e^{(-0.09(x-0.35))})$, and a total instantaneous mortality of 0.67. Model predictions indicated that yield

to the commercial fishery and to the sport fishery could be increased by increasing the minimum commercial size limit and/or reducing the commercial fishing mortality. Simulations also indicated that an increase in fishing mortality by any one gear type increased yield to that gear type, but reduced yield to all other gear types. The tenuous nature of the estimates of sportfishing mortality and natural mortality preclude specific management recommendations.

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INTRODUCTION

Channel catfish *Ictalurus punctatus* in Saginaw Bay, Lake Huron, support both commercial fishing and sportfishing. In 1981, sportfishermen harvested an estimated 29,000 kg and commercial fishermen a reported 231,000 kg. Channel catfish are a valuable segment of the commercial fishery and ranked second in weight harvested in 1981; common carp *Cyprinus carpio* ranked first (314,000 kg), and yellow perch *Perca flavescens* ranked third (80,000 kg). Yellow perch ranked first in number of fish harvested by sportfishermen, sunfish species ranked second (these included mostly bluegills *Lepomis machrochirus* and pumpkinseeds *L. gibbosus*), and channel catfish ranked third. It appears that there exists sufficient social and economic impetus for the continued coexistence of recreational and commercial fisheries throughout the Great Lakes. However, allocation of fishery resources to their respective users has been a difficult problem to solve (Francis et al. 1979; Bishop and Samples 1980; Talhelm 1979). In the existing fishing regime, the assessment of changes in yield or effort levels of sport and commercial fisheries becomes even more crucial to resource managers if yields acceptable to both users are to be maintained.

Efforts to quantitatively evaluate multiple use of a common fishery resource are limited (Clark and Huang 1983; Low 1982). Yet, managing only the commercial fishery without regard to the sport fishery or vice versa may be futile in achieving a desired management objective. Although sportfishing harvest records provide only an index of the harvest of channel catfish in Saginaw Bay, available records were utilized in this assessment. The objectives of this study were: (1) to examine the history of sport and commercial fisheries along with their regulation, (2) to collect timely information concerning growth and mortality rates of channel catfish in different areas of Saginaw Bay, (3) to determine whether these vital statistics differ between areas, and (4) to evaluate some management strategies using available information in a yield-per-recruit model.

BACKGROUND

Beeton et al. (1967) described the location, morphometry, and limnological aspects of Saginaw Bay. Hile (1959) described the multi-species and multi-gear character of the fisheries in Saginaw Bay and documented changes in species composition and gear composition utilizing commercial catch records. The Great Lakes Basin Commission (1975) summarized historical changes in sport and commercial fisheries as well as associated changes in water chemistry and aquatic biota and provided a broad perspective of the dynamic nature of the Bay. Characteristics and regulation of the commercial and sport fisheries for channel catfish make them unique among fisheries of the Great Lakes. The commercial fishery employs three major gear types: trap nets, seines, and set hooks. Trap nets harvest all commercially available species in the Bay, seines primarily harvest common carp and channel catfish, and set hooks harvest channel catfish exclusively. The contribution of channel catfish in weight to the commercial harvest in 1981 was 63% for trap nets, 9% for seines, and 28% for set hooks. All units of gear are licensed by the state; the type and amount of gear licensed have evolved through restrictions imposed by the state and by fishermen utilization of the various gear types. In 1981, 400 trap nets, 16 seines, and 39,400 set hooks were licensed to 28 commercial operators. Additional units of gear have not been available for licensing since 1970 in areas of the Bay open to commercial fishing (Great Lakes Fishery Commission 1971a). Commercially fishable areas of the Bay have been largely confined to the Inner Bay, that area southwest of a line connecting Sand Point and Point Lookout (Fig. 1). Minimum size and weight restrictions relating to commercial harvest of channel catfish date from at least 1895 during which a 0.45 kg (1.0 lb) minimum weight limit was in effect. This limit evolved into a 0.91 kg (2.0 lb) minimum weight limit in 1929, a 432 mm (17 inch) minimum size limit in 1945, and a 381 mm (15 inch) minimum size limit in 1960. The latter regulation remains in effect. There are no season restrictions governing commercial harvest.

Records of the annual commercial harvest of channel catfish date from 1919 (Baldwin et al. 1979). Since 1929, trap nets have accounted for the bulk of the commercial catch, except during the period 1959 - 1965 when set hooks produced the largest yields. Seines ranked second in weight harvested until about 1956 and have since accounted for the lowest yields. Change in effort was the apparent cause of fluctuation in yield to each gear until the mid 1960's (Fig. 2, A and B). Historically, the fishery has been uncharacteristically stable among the commercially important fisheries of the Bay (Hile 1959). Although catch, effort, and catch per unit effort (CPUE) fluctuated from very low to very high levels between 1940 and 1970, Eshenroder and Haas (1974) concluded that these changes were not indicative of

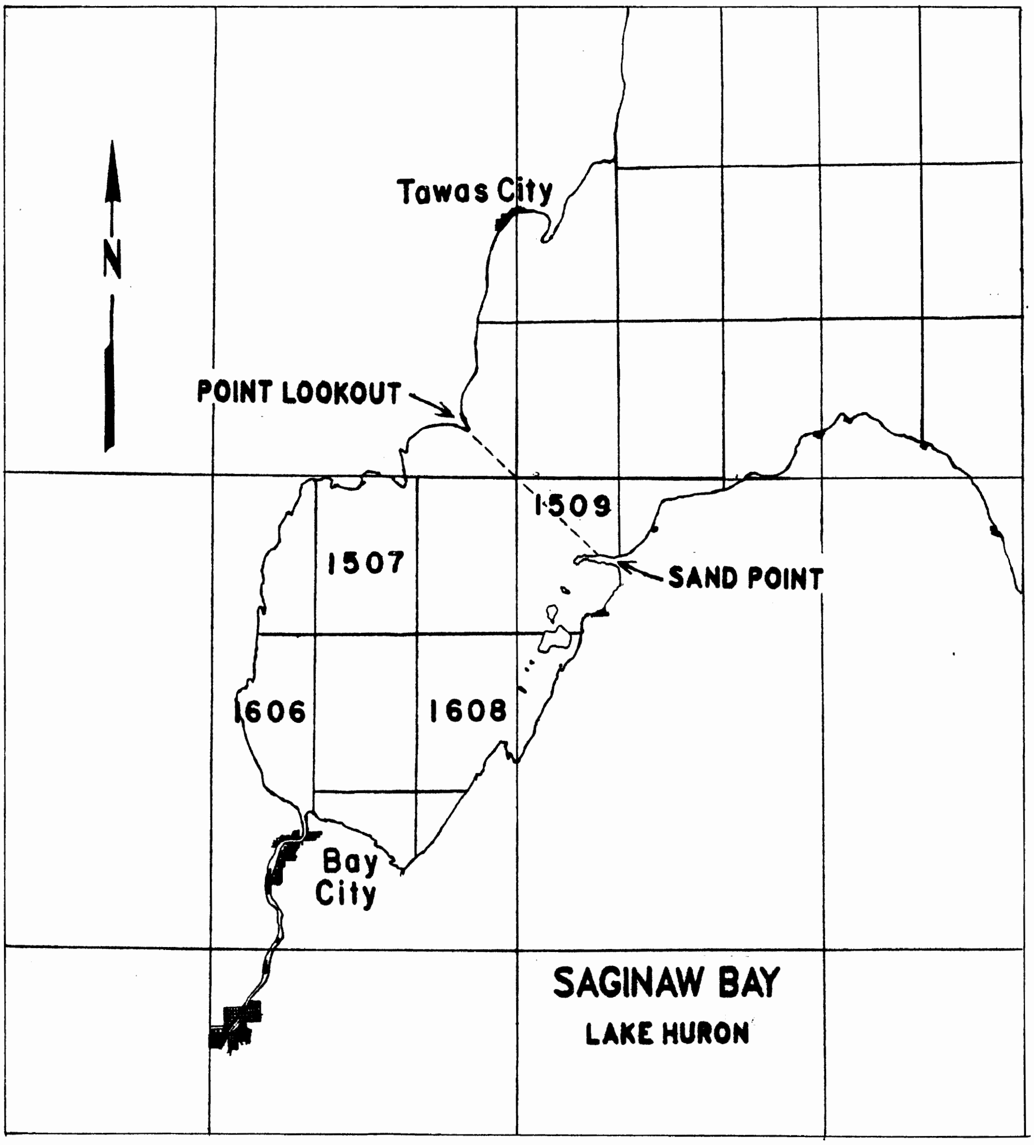

Figure 1. Map of Saginaw Bay, Lake Huron, illustrating the grid system used in sampling.

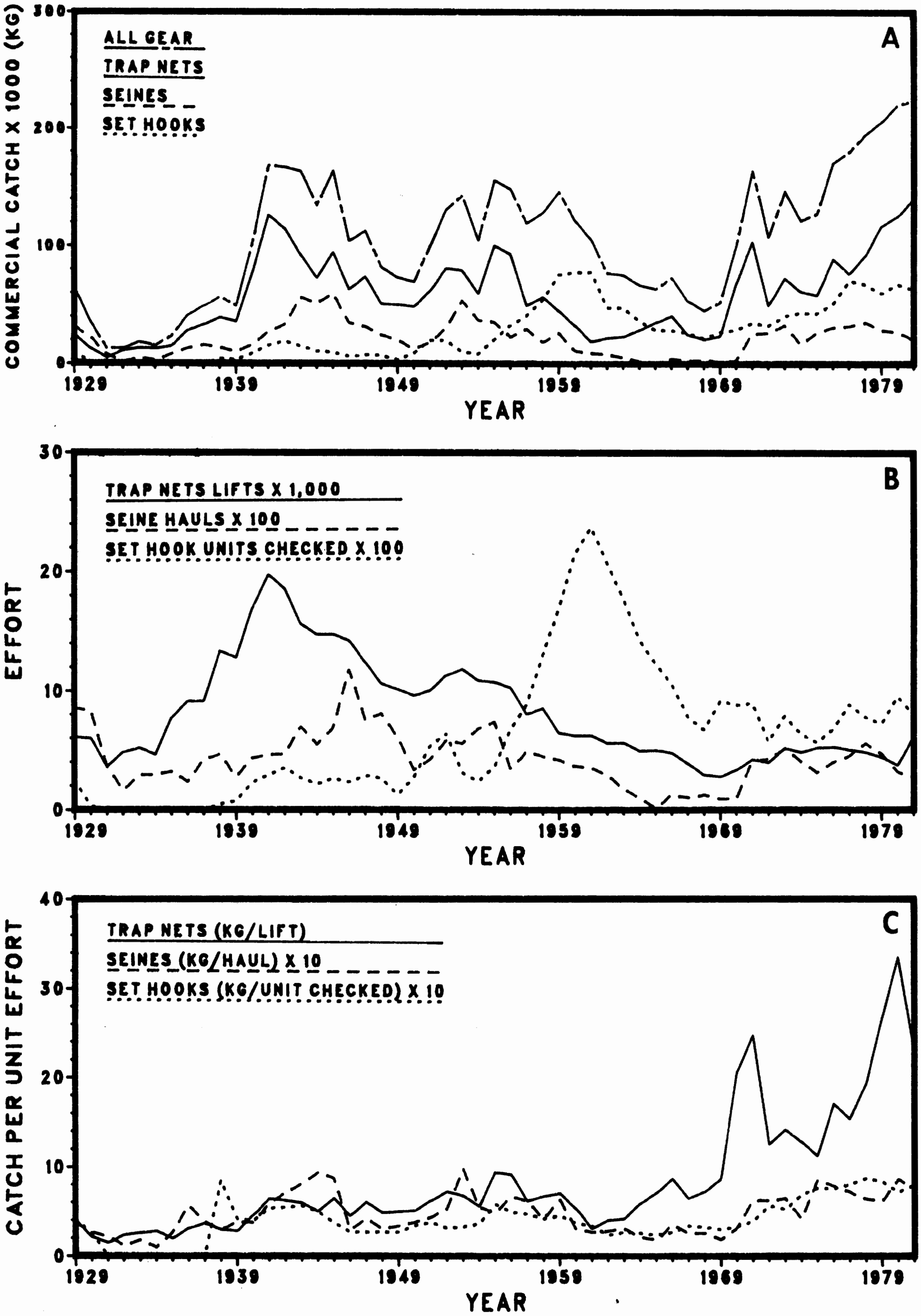

Figure 2. Annual catch, effort and catch per unit effort for trap nets, seines, and set hooks from 1929 to 1981. (See Hile (1962) for specific descriptions of effort units.)

significant changes or trends in population abundance (Fig. 2). The Great Lakes Basin Commission (1975), however, postulated that the downward trend in catch during the mid 1960's was probably due to a decline in abundance, since at this time the value per pound was increasing. The decline in catch, effort, and CPUE during the mid 1960's may, likewise be associated with fear of mercury contamination evident in catfish from other areas of the Great Lakes during that era (Great Lakes Fishery Commission 1971b). The mean annual catch in the period from 1970 to 1981 has increased; this increase has been associated with an increase in the mean annual CPUE for all gear types (Table 1). Thus, in contrast to the previous decade, these changes are probably indicative of an increase in abundance. The increases in CPUE have prompted requests by commercial fishermen for the licensing of additional gear (John Weber, Michigan Department of Natural Resources, personal communication). A goal of this assessment was to determine whether expenditure of additional commercial effort, perhaps through the licensing of additional commercial gear, was an appropriate management alternative.

Sportfishing has been found to have significant impacts on fisheries exploited both commercially and by sportfishermen (McHugh 1980). Sportfishing demand for channel catfish has not been assessed in Michigan. However, since 1975, estimates of the sport harvest of catfish of all species have been made by the Michigan Department of Natural

Table 1. Mean annual catch per unit effort (CPUE) for trap nets, seines, and set hooks and mean annual yield for all commercial gear types combined during selected time periods.

Years	Mean annual CPUE			Mean annual yield (kg)
	Trap net	Seine	Set hook	
1940-49	12	115	86	133,655
1950-59	15	123	90	126,795
1960-69	13	56	64	75,261
1970-81	42	130	142	166,153

Resources. From 1975 to 1981 no distinct trends were evident in sport fishery yield of channel catfish from Saginaw Bay. (More specific information concerning the estimation of sport fishery yield of channel catfish will be provided in later sections.) The sport fishery for channel catfish has no season, size, or possession restrictions; and there are no limitations on the number of sportfishing licenses sold. In the present study, the impact of sportfishing mortality and variation in sportfishing mortality on channel catfish was considered in assessing the commercial fishery.

METHODS

Data Collection

To estimate parameters which describe the growth and mortality of channel catfish, commercial trap net catches were sampled in each of four management areas (in grids 1608, 1509, 1507, and 1606) within the Inner Bay (Fig. 1). The total length of all channel catfish from a trap net catch was recorded to the nearest millimeter. A subsample of approximately 10 to 20 specimens per 25 mm group were collected for further analysis. These fish were weighed to the nearest gram using a spring scale, dissected to determine sex, and the left pectoral spine was removed for growth analysis. Sampling dates, the number of lifts sampled, characteristics of the commercial sampling gear, number of specimens collected, and number of specimens subsampled from each grid are listed in Table 2.

Fin Spine Preparation

Specimens were aged from annuli observed on sections of pectoral fin spines (Sneed 1951). Use of pectoral fin spine sections for age determination of channel catfish has been validated with known age specimens by Sneed (1951), Marzolf (1955), and Prentice and Whiteside (1974). Spines were removed as described by Sneed (1951), air dried, and sectioned at the distal end of the basal recess. The thickness of a section was determined by the thickness of a spacer between two cutting discs similar to the method of

Table 2. Sampling dates, number of lifts sampled, average trap net pot height, pot stretch mesh size, number of specimens sampled for total length measurement, and number of specimens subsampled for weight, spine removal, and sex from each grid in 1981. When a pot consisted of two mesh sizes the size comprising the lesser area of the pot is listed in parenthesis.

Grid	Month/day	Number of lifts sampled	Mean pot height (m)	Pot mesh size (mm)	Number of lengths sampled	Number of specimens sub-sampled
1608	5/16-6/13	2	3.05	6.35 (4.44)	1051	264
1509	6/2-6/20	4	3.05	6.35 (4.44)	740	211
1507	7/16-8/4	18	1.07	4.76 (5.17)	640	206
1606	8/1	6	2.13	4.76	542	236

Chugunova (1959). I used aluminum oxide cutting discs and a 0.52 mm spacer rotated at 2750 RPM with a dental lathe. A stream of water directed on the discs served as a lubricant and coolant. After sawing, sections were air dried, and then mounted on cellulose acetate slides with viscous cyanoacrylate adhesive. Spine sections prepared in this manner could be viewed with transmitted light using a scale projector. Sections too thick for light transmission could be made thinner with a fine toothed file.

Back-calculation Using Fin Spines

Back-calculated lengths were computed using the formula described by Everhart and Youngs (1981). Several problems have been encountered in calculating lengths using spine sections. Muncy (1959) and Marzolf (1955) identified the following causes of bias:

(1) Pectoral spines are tapered, and sections obtained at the basal recess, which expands distally with increasing age, decrease in relative size with increasing age.

(2) The maximum expanded portion of annuli in the commonly measured posterior field does not always lie in a straight line along the maximum radius.

(3) The center of the lumen of the spine, commonly used as the origin in making radial measurements to annuli, does not always correspond to the center of the first annulus.

(4) Spine sections are not always sectioned precisely perpendicularly.

DeRoth (1965) addressed the first problem by sectioning spines at the same relative location. However, I had difficulty in consistently determining the appropriate point of sectioning. DeRoth's method also produced sections without a lumen or complete first annulus, making radial measurement difficult. To counter both the first and the second problems, Marzolf (1955) recommended measurement of the anterior radius, which he suggested was less affected by spine taper. To check this assumption I computed intercepts (correction factors) and mean back-calculated lengths at age for specimens from grid 1608 for both posterior and anterior fields of spines sectioned at the distal end of the basal recess. Total length was regressed on each spine radius; a straight line adequately described these relationships. The intercepts estimated for the anterior and posterior fields were -46.1 and -198.7, respectively. The anterior radius

Table 3. Mean back-calculated lengths (mm) at age derived from the posterior and anterior fields of spine sections from the basal recess, mean empirical lengths (mm) at age, and number of specimens aged in grid 1608.

	Age											
	1	2	3	4	5	6	7	8	9	10	11	12
Calculated posterior	-100	11	140	237	300	350	410	460	499	542	580	597
Calculated anterior	51	129	196	254	307	353	413	460	500	542	582	597
Empirical	...	144	228	255	316	340	398	479	505	539	589	597
Number of specimens	0	1	2	28	1	46	9	3	12	24	9	1

produced calculated lengths similar to empirical lengths at age, while the posterior radius produced calculated lengths which were negative and erroneous (Table 3).

The degree to which the third and fourth problems affect the analysis depends upon how carefully spines are measured and sectioned. I took the following precautions to mitigate or eliminate all the previously described problems:

(1) The anterior radius was measured which alleviated problems associated with spine taper at the basal recess.

(2) Annuli in the anterior field were concentric with respect to the center of the first annulus of the section. Therefore, measurement along this field reduced the error associated with measurement of expanded annuli in the posterior field.

(3) The approximate center of the first annulus was used as the origin for radial measurement which decreased error associated with use of an irregularly positioned or irregularly shaped lumen.

(4) Spines were marked prior to sectioning which facilitated cutting perpendicular sections and reduced mechanical difficulties associated with positioning the spine during the sectioning process.

Age Composition and Size Structure of the Catch

Age distributions of catches were estimated using age-length keys (Allen 1966). Age-length keys were constructed for each grid sampled and applied to the length distribution of the catch from that grid. This procedure afforded independent estimation of the age distribution of the catch from each grid, and thus avoided possible bias due to age composition differences among grids (Kimmura 1977). Estimated age distributions from each grid were then compared with a G-test (Sokal and Rohlf 1981). The computer program, CHITAB, facilitated computation of the attained significance level for the G-test (Statistical Research Laboratory 1976). A length-frequency polygon of the combined catch of all grids was also constructed to determine the size of complete recruitment to the trap net fishery.

Growth in Length

Total length was regressed on anterior spine radius for each sex in each grid using least squares. A straight line adequately described these relationships. The intercepts of the regression equations were compared between sexes and grids. Data were pooled for grids and sexes with similar intercepts and a common intercept (correction factor) was used to compute back-calculated lengths. Back-calculated lengths were used to check for growth differences which would preclude use of an average growth function to describe growth of each sex and growth in each of the four management areas of the Bay. Although the von Bertalanffy function is appropriate for and was fitted to the length-at-age data in this study, interpretations of the parameters of this function for comparative purposes and statistical tests concerning these parameters have been controversial (Gallucci and Quinn 1979; Kingsley et al. 1980). To statistically compare growth, back-calculated lengths were regressed on age for both sexes in each grid. Visual inspection of the relationship between back-calculated length and age, and residual analysis indicated that a second degree polynomial adequately described this relationship.

$$Y = B_0 + B_1X + B_2X^2,$$

where

Y = back-calculated length in mm;

X = age in years;

B_0 = intercept;

B_1 = linear effect coefficient;

B_2 = curvature effect coefficient.

Regression equations and regression parameters were compared to test for growth differences. Linear and curvature effect coefficients, which describe the shape of the length-age relations, were compared between regression equations to check for differences in growth rate. If differences did not exist, intercepts were compared to check for differences in the magnitude of lengths-at-age.

Weight-Length Relation

The weight-length relation, $w = al^b$, was linearized with a natural log transformation:

$$\log_e(w) = \log_e(a) + b \bullet \log_e(l),$$

where

w = weight in kg;

l = length in mm;

$\log_e(a)$ = intercept;

b = slope.

The natural log of weight was regressed on the natural log of length for each sex in each grid, and the equality of these regression equations was tested. All weight-length data were later pooled to estimate an average weight-length relation for use in yield calculations.

Mortality

The total instantaneous mortality rate (Z) was estimated for each grid sampled by determining the slope of a straight line fitted to the descending limb of a catch curve (Ricker 1975). Everhart and Youngs (1981) recommended fitting the regression line to age groups which include the age group 1 year older than the modal age group and extend to the age group 1 year younger than the oldest age group captured. These recommendations were intended to reduce bias due to gear selectivity and small sample variation. Catch curves in this study, however, exhibited considerable variability. Variability near the domes did not permit accurate determination of the first fully recruited age group, therefore in fitting regression lines to the descending limbs, the modal age group was assumed to be fully recruited. The oldest age group was also assumed to be appropriately represented and was used in calculating the slope of the descending limb. Instantaneous total mortality rates were compared by testing for differences in the slope parameters of the regression equations.

All regression parameters, test statistics, and attained significance levels were computed using MIDAS, a computer program for data analysis developed by the Statistical Research Laboratory at the University of Michigan (Fox and Guire 1976). All statistical tests were based upon a 5% level of significance.

The total instantaneous fishing mortality rate (FT) was estimated by subtracting the instantaneous natural mortality rate (M) from the instantaneous total mortality rate (Z):

$$FT = Z - M.$$

I could not estimate the natural mortality rate from my data, so I used the rate of 0.1 reported by Eshenroder and Haas (1974). The instantaneous fishing mortality for each gear type or fishery was estimated by multiplying the total instantaneous fishing mortality by the proportion of yield attributable to each gear or fishery for 1981. Partitioning forces of fishing mortality in this manner assumes that these competing risks of capture are independent, and thus additive. Therefore,

$$FT = FS + FR + FE + FH,$$

where

FT = instantaneous total fishing mortality;

FS = instantaneous sportfishing mortality;

FR = instantaneous trap net fishing mortality;

FE = instantaneous seine fishing mortality;

FH = instantaneous set hook fishing mortality.

The Michigan Department of Natural Resources annually compiles the weight of fish harvested by each commercial gear type from reports submitted by commercial fishermen, and annually conducts a mail survey to estimate numbers of fish harvested by sportfishermen. Several adjustments of the mail survey data had to be made to make this information suitable for my use. First, the survey estimated the combined harvest of all ictalurids[2] from Saginaw Bay. To estimate the sport harvest of channel catfish alone, I assumed the fraction of channel catfish in the combined commercial harvest was the same as in the sport harvest. (The weight harvested commercially was available to the

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[2] *Ictalurus* spp. in Saginaw Bay includes *nebulosus*, the brown bullhead; *natalis*, the yellow bullhead; and *punctatus*, the channel catfish.

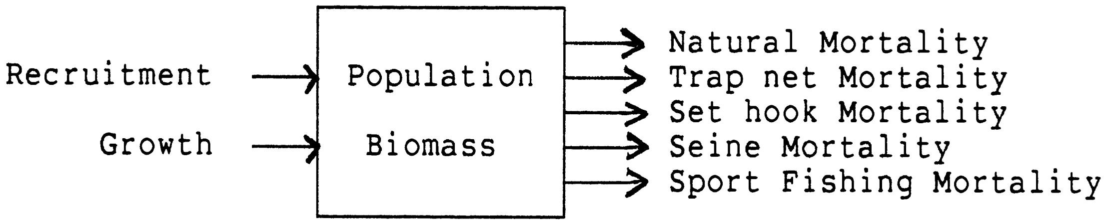
species level.) Second, sport harvest estimates were reported in numbers of fish harvested, while commercial harvest was reported in weight. Thus, I had to estimate the average weights of fish harvested in the respective fisheries to get harvest in common units of measure. Using pooled weight and length data from this study I calculated the average weight of a channel catfish in the commercial catch to be 1.0 kg, 2.2 lb (fish ≥ 381 mm, 15 inches in length), and the average weight of a sport-harvested fish to be 0.4 kg (0.9 lb) (assumed to be the average weight of fish ≥ 299 mm, 12 inches, in length). The average weight of a bullhead species was assumed to be 0.2 kg (0.4 lb), as reported for brown bullheads by Blumer (1982). Finally, Rybicki and Keller (1978) reported that mail survey estimates were inflated for some species by factors of 5 to 20. Overestimation of harvest by a factor of 5 has been substantiated by other research and is used as a standard correction for mail survey estimates of catch for most species in Michigan (Talhelm et al. 1979). Thus, as a final adjustment, I reduced estimates of sport harvest in weight of channel catfish to one-fifth of their estimated values. Putting all these adjustments together it was possible to estimate the weight of channel catfish harvested by sportfishermen (Table 4). The 1981 sport harvest estimate and reported commercial harvest by gear type were then used to partition FT.

Table 4. Annual mail survey estimates of sport harvest of ictalurids, fraction of channel catfish in the commercial harvest, and adjusted estimate of sport-harvested channel catfish in Saginaw Bay.

Year	Mail survey estimate of ictalurids (numbers)	Fraction of channel catfish in commercial harvest (numbers)	Adjusted yield of sport-harvested channel catfish (kg)
1975	523,430	0.587	29,919
1976	426,880	0.715	29,721
1977	263,235	0.794	20,353
1978	297,120	0.941	27,225
1979	337,600	0.964	31,691
1980	205,700	0.982	19,670
1981	310,500	0.975	29,479

Yield Analysis

An idealized view of the dynamics of a catfish fishery could be described schematically as follows:



Additions to the population come in the form of growth and recruitment and losses arise from natural, trap net, seine, set hook, and sportfishing mortality. This approach is an extension of the cohort-yield approach of Beverton and Holt (1957) and Ricker (1975), and accounts for fishing mortality from four independent sources rather than one. The model I used, developed by R. D. Clark, Jr. of the Michigan Department of Natural Resources, was parameterized so that it accommodated four independent sources of fishing mortality. The model was used to calculate the yield per number of fish recruited (N) at the age of first vulnerability to fishing (x_r). (In all analyses the number of fish recruited at age x_r was set at 1000.) From age x_r to the age at which fish were harvested (x_c), losses were assigned to natural mortality. When fish reached an age (x) greater than x_c, losses were assigned both to natural mortality and fishing mortality due to all gear types (FT):

$$dN/dx = -MN \quad x_r \leq x \leq x_c$$

$$dN/dx = -(FT+M)N \quad x > x_c.$$

Catch rate was then described in terms of each gear type (C_g):

$$dC_g/dx = -F_g N \quad x > x_c.$$

Integrating and combining these equations resulted in a catch equation where the number of fish at each age caught by each gear ($C_{x,g}$) was:

$$C_{x,g} = N_x (F_g / Z_x)(1-e^{-Z_x});$$

where

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

The von Bertalanffy equation of growth in length was used to calculate mean length at age and the weight-length relation was used to estimate the mean weight at age. Mean weights at age multiplied by the mean number harvested at age for each gear produced the weight harvested at each age by each gear. Summing the weights harvested at all ages for each individual gear type produced the yield in weight by gear per 1000 recruits.

The model utilized length at capture (l_c) and length at recruitment (l_r) data which were converted to age at capture (x_c) and age at recruitment (x_r). The length at recruitment (l_r) to all gear types was defined to be the mean length of fish less than or equal to the modal length of fish in the length frequency distribution of the commercial catch. This length was also assumed to be the size acceptable to sportfishermen. A more detailed mathematical description of a similar model is presented in Clark and Huang (1983).

Yield to the commercial fishery per 1000 recruits was sensitive to changes in FS and M. These parameters were combined (FS + M) to examine this sensitivity. Yield to the commercial fishery per 1000 recruits was examined for FS + M values of: 0.1, 0.16, 0.2, 0.25, 0.3, 0.35, 0.4, and 0.45. Yield-per-recruit analyses were performed in conjunction with various commercial minimum size limit regimes and commercial fishing mortality regimes to identify conditions under which maximum yield occurred. Only changes in regulation of the commercial fishery were considered, however the implications of these changes were evaluated for both sport and commercial fisheries.

RESULTS

Age Composition and Size Structure of the Catch

Estimated age distributions of channel catfish caught in commercial trap nets were significantly different between grids (G-test, P<0.01). The modal age of fish captured in grids 1509 and 1608 was age 6, in grid 1507 age 7, and in grid 1606 age 5. In grids 1608 and 1606, a greater proportion of individuals less than age 6 were captured than in grids 1509 and 1507 (Table 5). Differences in catch characteristics were probably associated with differences in availability of channel catfish at the time of sampling, and differences in the selective properties of the sampling gear. With all ages pooled, age 6 was the modal age captured (Table 5), and 340 mm (13 inches) was the modal length of channel catfish captured (Fig. 3).

Table 5. Estimated age distributions of channel catfish caught in commercial trap nets for each grid sampled and for all grids pooled.

	Age												
Grid	1	2	3	4	5	6	7	8	9	10	11	12	13
1608	0	0.1	0.6	8.6	2.5	69.0	4.7	1.6	4.2	7.0	1.2	0.5	0
1509	0	0	0	5.0	0.7	60.4	12.7	2.4	5.9	8.7	2.7	1.4	0.1
1507	0	0	0	1.0	9.5	12.7	56.4	9.5	1.1	4.6	3.6	1.3	0.3
1606	0	0.6	5.7	17.5	38.7	4.6	22.0	3.3	1.3	3.0	2.2	1.1	0
All	0	0.1	1.2	7.7	10.2	43.1	20.9	3.8	3.4	6.2	2.3	1.0	0.1

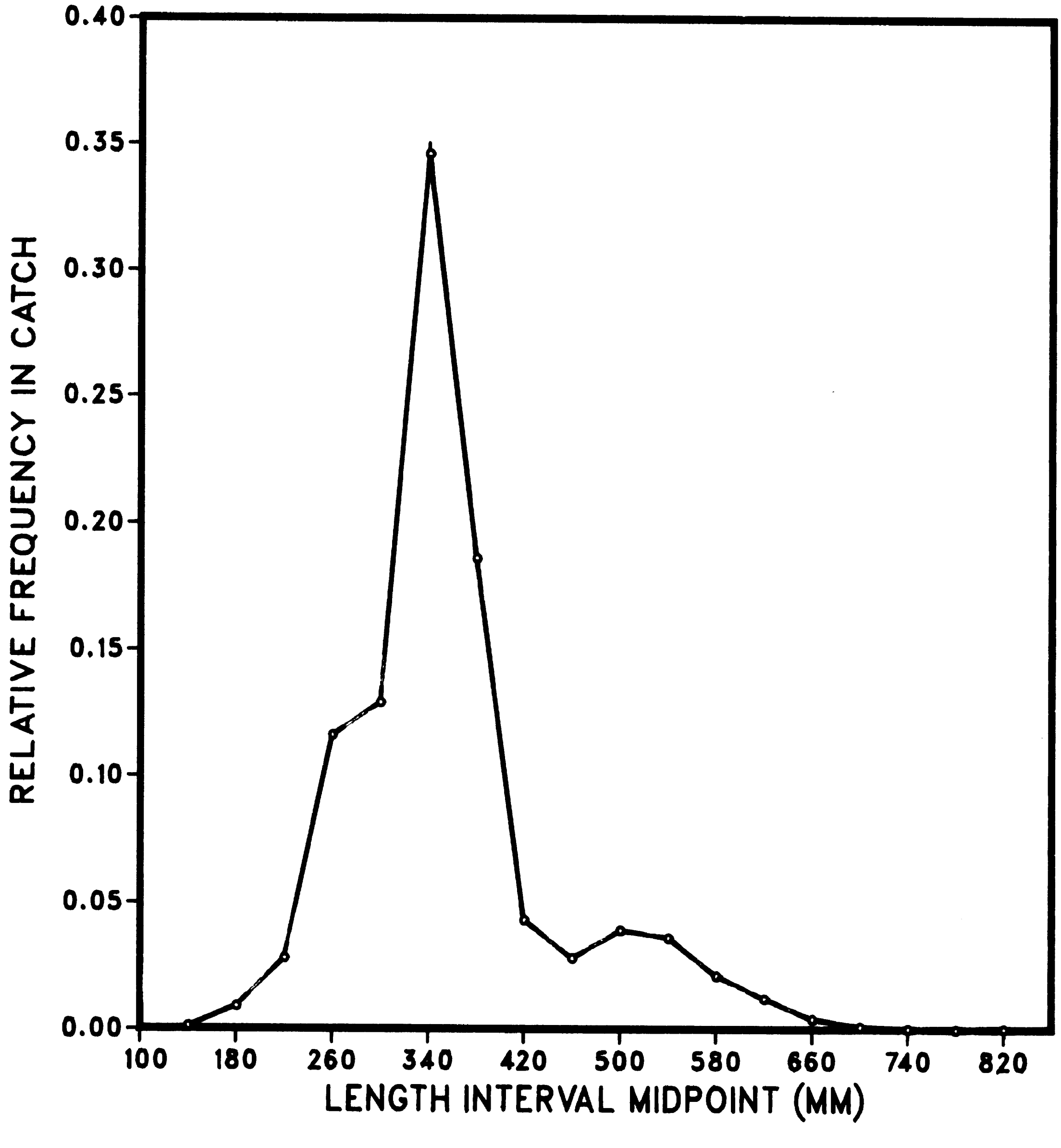


Figure 3. Length frequency polygon of channel catfish caught in commercial trap nets for all grids pooled (interval width = 40.0 mm).

Growth in Length

Length-age regressions were significantly different between sexes and grids (f-test, P<0.0001). To identify where these differences occurred, regressions between sexes within grids were compared. These regressions were not significantly different in grids 1507 (f-test, P=0.82) and 1606 (f-test, P=0.57), but were significantly different in grids 1509 (f-test, P<0.0001) and 1608 (f-test, P=0.0003). There were significant differences between shape parameters (B_1's and B_2's) in grids 1509 (f-test, P<0.0001) and 1608 (f-test, P=0.0001) which indicated that differences in growth rate existed between males and females in these grids. Mean back-calculated lengths at age were greater for females after age 6 in grid 1608 and greater for males at all ages in grid 1509 (Appendix A). These conflicting growth differences were probably due to differential vulnerability of the sexes to capture during the spawning season rather than real growth differences. Although statistically significant differences in growth rate existed between sexes in grids 1509 and 1608, sexes were pooled to check for spatial growth differences.

With sexes pooled length-age regressions were significantly different between grids (f-test, P<0.0001). The shape parameters of the regression equations were not significantly different (f-test, P=0.06), however the intercepts (B_0's) were significantly different (f-test, P<0.0001). Pairwise comparisons indicated that regression equations were identical in grids 1507 and 1509 (f-test, P=0.89). The intercepts of the length-age regressions in grids 1608 and 1606 were less than the intercepts in grids 1509 and 1507 (Appendix B). In grid 1608, mean back-calculated lengths at age were less from age 1 to age 9 than in other grids (Appendix A). These differences were probably associated with differences in vulnerability of various size classes to capture during the spawning season. In grid 1606, mean back-calculated lengths at age were less than those in grids 1507 and 1509 (Appendix A). These differences were probably associated with differences in availability of various size classes, as well as differences in selective properties of the sampling gear. A regression equation fitted to back-calculated lengths versus age after age 6, the age of complete recruitment to the fishing gear, indicated that the length-age relation was the same between all grids (f-test, P=0.3). Differences in length-at-age did not appear great enough to treat growth between sexes or management areas separately, therefore growth was described by a single function in the yield-per-recruit analysis. The von Bertalanffy function was fitted to the mean back-calculated lengths at age, for grids and sexes pooled, using the method of Rafail (1973). The equation derived was:

$$L_x = 921(1-e^{(-0.09(x-0.35))}),$$

where

L_x = length at age x (mm);

x = age in years.

The model agreed quite closely with the empirical data (Fig. 4).

Weight-Length Relation

Weight-length regressions between sexes and grids were significantly different (f-test, P<0.0001). To identify where these differences occurred, regressions between sexes within grids were compared. Regressions between sexes were not significantly different [1608 (f-test, P=0.34), 1509 (f-test, P=0.10), 1507 (f-test, P=0.10), and 1606 (f-test, P=0.10)]. However, with sexes pooled equations were significantly different between grids (f-test, P<0.0001). Differences in weight-length equations probably reflect differences in condition associated with the time of year the samples were collected (Table 2). Pooling all grids and sexes yielded the following weight-length relation used to compute mean weight from mean length in yield calculations:

$$\log_e(w) = -20.71 + 3.36 \bullet \log_e(l).$$

Regression equations for each sex within each grid and for sexes pooled within grids are listed in Appendix C.

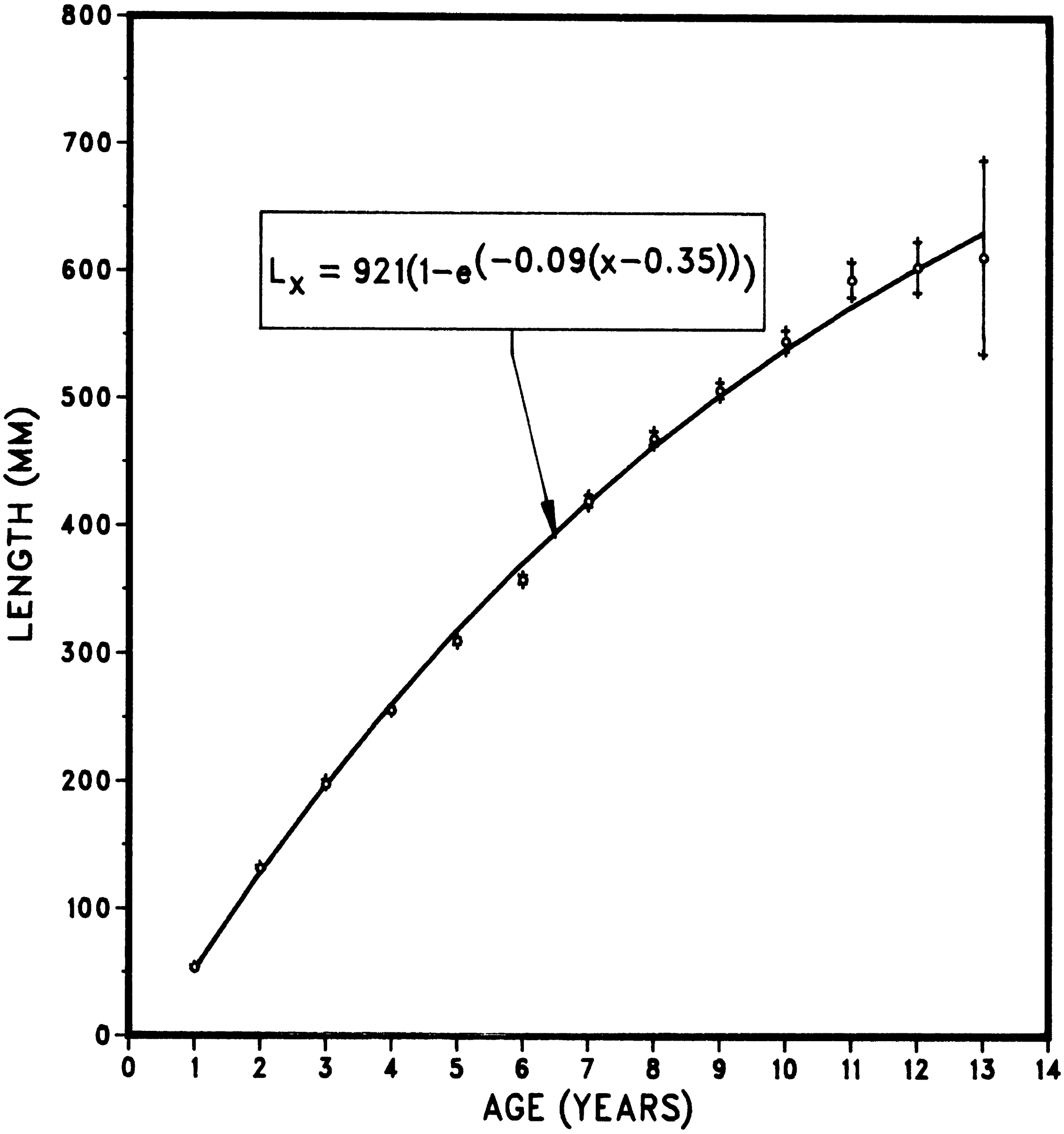


Figure 4. Estimated von Bertalanffy growth curve and empirical mean back-calculated lengths at age with 95% confidence limits.

Mortality

Total instantaneous mortality rates and 95% confidence intervals for grids 1608, 1509, 1507, and 1606 were 0.57 (±0.53), 0.63 (±0.36), 0.66 (±0.48), and 0.45 (±0.30), respectively. The slopes of the descending limbs of the catch curves were not significantly different between grids (f-test, P=0.79). Combining age frequencies reduced some variability in the descending limb of the catch curve, however considerable variability remained (Fig. 5). The total instantaneous mortality rate (Z) and 95% confidence interval for all grids pooled was 0.67 (±0.27). (Regression equations fitted to catch curves are listed in Appendix D.) Thus, the instantaneous fishing mortality rate was 0.57, (0.67 less the natural mortality of 0.1). This rate was partitioned in proportion to the yield to each gear type to obtain an estimate of the instantaneous fishing mortality rate for each gear type (Table 6). Using this information the instantaneous commercial fishing mortality rate was 0.51 and defined as:

$$FC = FR + FH + FE.$$

Yield

Similarities in the growth and mortality rates of channel catfish from each management area in Saginaw Bay indicated that fish from the entire Bay comprised a unit stock for the purposes of a yield-per-recruit analysis (Gulland 1969). Parameters estimated from pooled growth and mortality data were used in yield computations. Using the

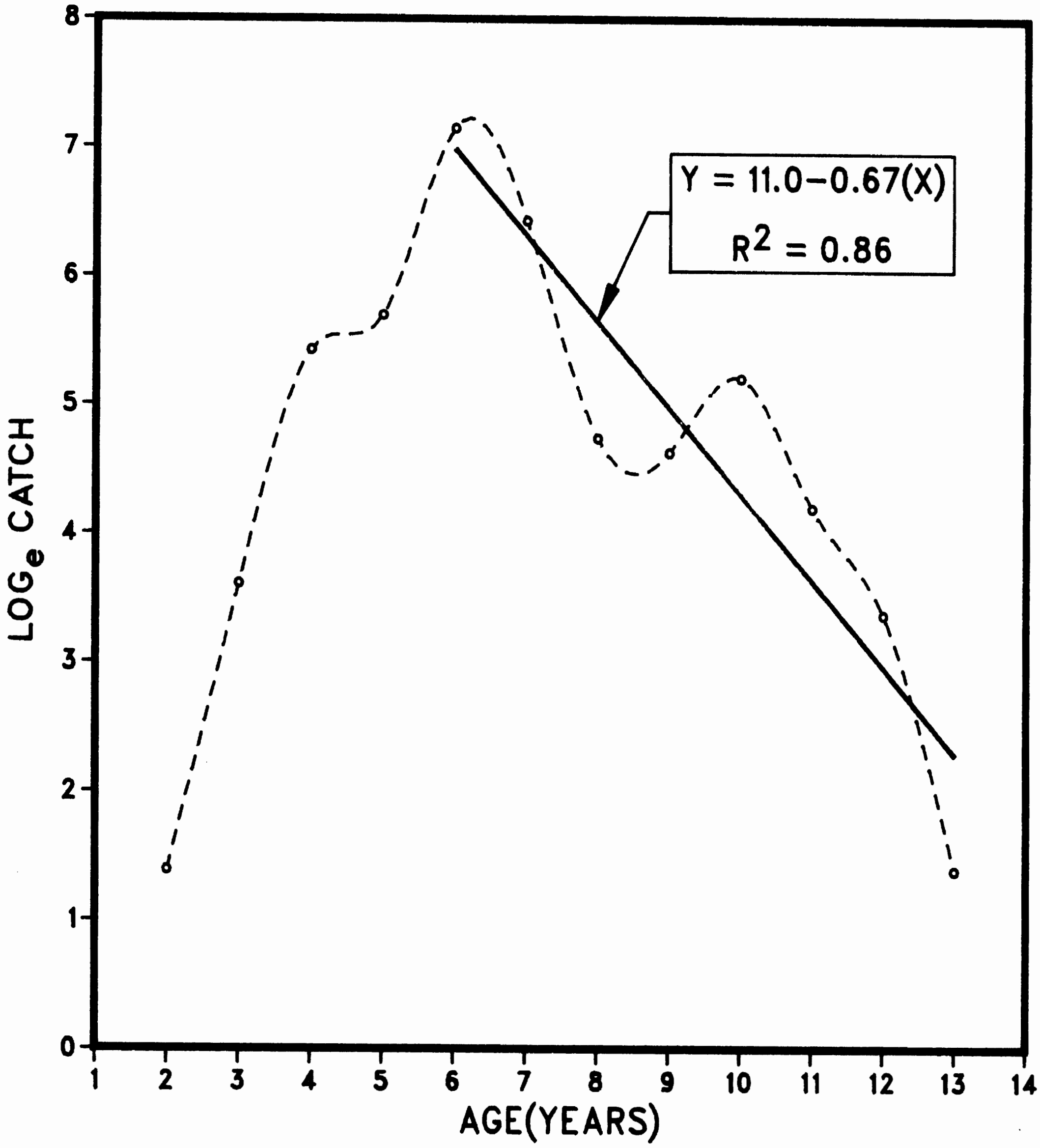


Figure 5. Catch curve with regression line fitted to the descending limb (grids combined).

Table 6. Yield to each gear type, fraction of total yield attributable to each gear type, and estimates of the instantaneous fishing mortalities due to each gear type in 1981.

Gear	Yield (kg)	Fraction of total yield	Instantaneous fishing mortality
Trap nets	146,626	0.563	0.32
Set hooks	63,481	0.244	0.14
Seines	20,809	0.080	0.05
Sport gear	29,479	0.113	0.06
Total	260,395	1.00	0.57

best estimate of sportfishing mortality (0.06) and natural mortality (0.1), yield to the commercial fishery per 1000 recruits was examined as a function of the instantaneous commercial fishing mortality (FC) and the age at entry to the fishery (x_c), or commercial minimum size limit (l_c). Model predictions indicated that yield per 1000 recruits could be increased by increasing x_c and/or decreasing FC from their existing or estimated values of 381 mm (15 inches) and 0.51, respectively (point Q in Fig. 6). The largest gains in commercial yield could be realized by increasing l_c.

One approach to evaluate the effects of changes in FC and l_c upon commercial yield was to examine each of these parameters independently as a function of yield per 1000 recruits. At the existing or estimated values of FS (0.06),

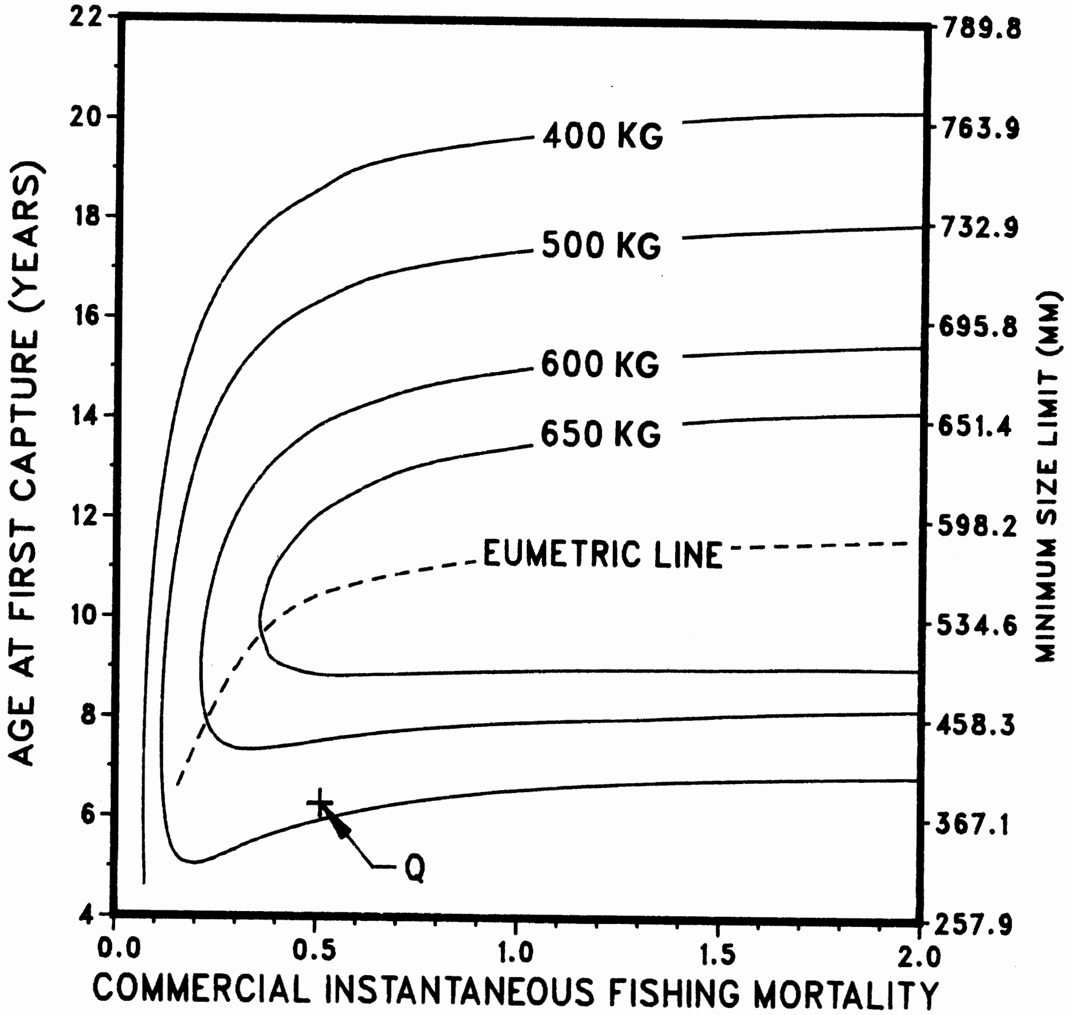


Figure 6. Yield isopleths per 1000 recruits as a function of FC and x_c (corresponding values of l_c are indicated), with M=0.1 and FS=0.06. The commercial fishery was operating at point Q in 1981.

M (0.1), and l_c (381mm, 15 inches) model predictions indicated that the maximum commercial yield per 1000 recruits occurred when the value of FC was approximately 0.20 (Fig. 7). Thus, at the estimated FC value of 0.51 the commercial fishery was growth overfishing (Cushing 1981). Model predictions indicated that a decrease in FC from 0.51 to 0.20 produced a 5.7% increase in equilibrium yield per 1000 recruits to the commercial fishery and a 117.6% increase in equilibrium yield per 1000 recruits to the sport fishery. Commercial fishing mortality could be reduced by reducing the total amount of fishing gear licensed on the Bay, further restricting areas of the Bay open to commercial fishing, restricting the length of the fishing season, imposing taxes, and in other ways (Clark 1976).

To evaluate the implications of gear requests by commercial fishermen only changes in the total amount of gear licensed were considered. Thus, an increase or decrease in FC would be controlled by increasing or decreasing the amount of gear licensed. Using this management framework, a change in FC could be accomplished in two ways: (1) by proportionally changing the fishing mortality caused by all commercial gears, or (2) by selectively changing the fishing mortality caused by any combination of commercial gear types or any one gear type. Proportional changes in the instantaneous fishing mortality caused by each commercial gear type would not change the distribution of catch among gear types. However, selective

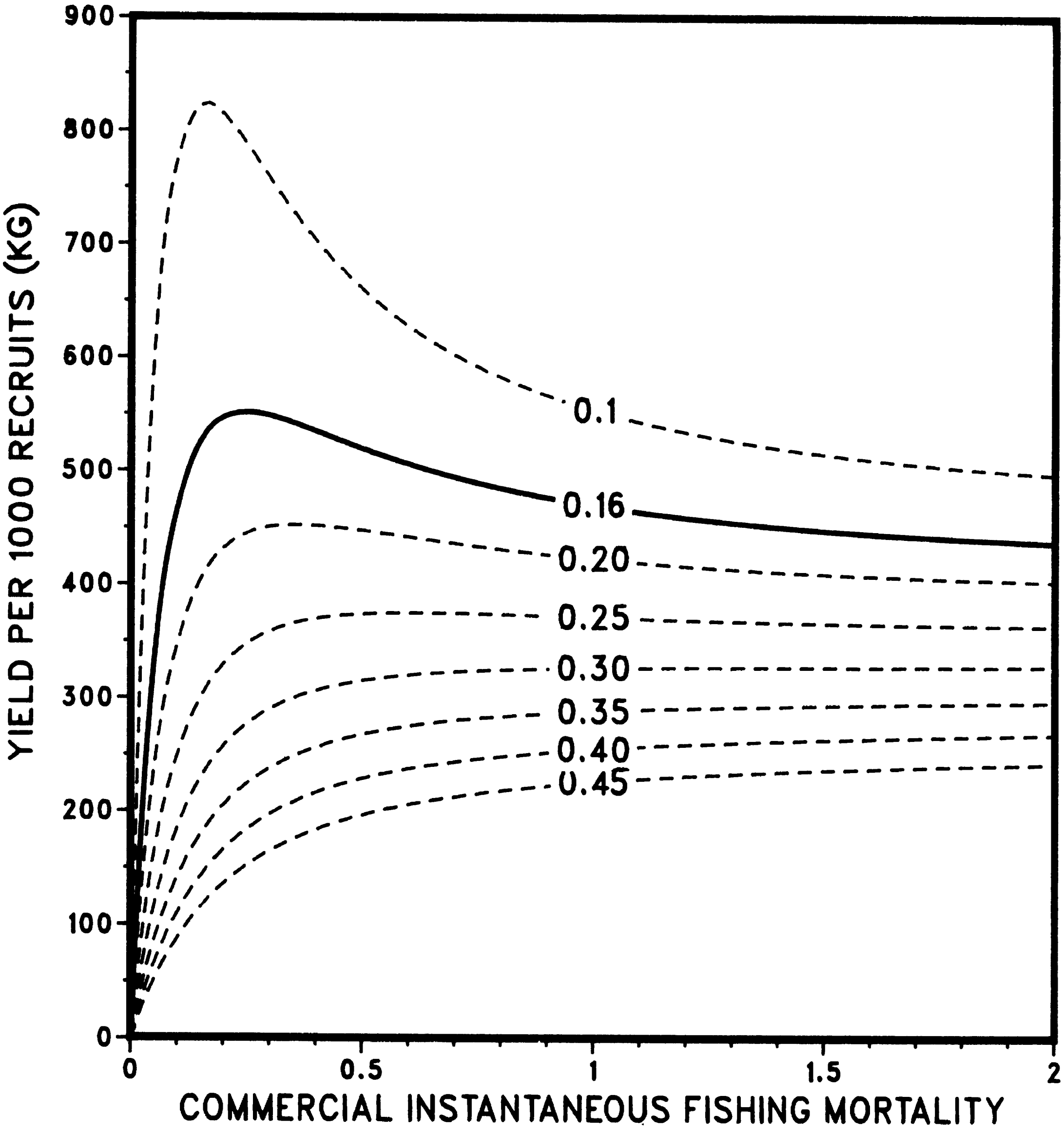


Figure 7. Yield per 1000 recruits as a function of FC with FS=0.06, M=0.1, and l_c=381 mm (solid line); and for a range of FS + M values, with l_c=381 mm (broken lines).

changes in fishing mortalities due to each gear type would alter the distribution of catch among each gear type. For simplicity, the change in yield per 1000 recruits was examined for each gear type as a function of the instantaneous fishing mortality caused by only one commercial gear type. A reduction in fishing mortality of a single commercial gear type reduced the yield to that gear type and increased yield to other gear types. Conversely, increases in fishing mortality of a single commercial gear type increased the yield to that gear and reduced yield to other gear types (Figs. 8, 9, and 10). Any net reduction in commercial fishing mortality increased yield to sportfishermen.

Considering the commercial fishery as a whole, the value of FC which produced the maximum yield per 1000 recruits increased as values of FS + M increased (Fig. 7). Therefore, errors in the estimates of FS, M, or both; or changes in the values of FS, M, or both could affect the conclusions derived from this analysis. I examined the potential consequences of these problems by analyzing the relation of FC to commercial yield per 1000 recruits for a range of FS + M values (Table 7). For each FS + M value examined a total instantaneous mortality rate of 0.67 was maintained by adjusting the estimate of FC so that:

$$FS + M + FC = 0.67.$$

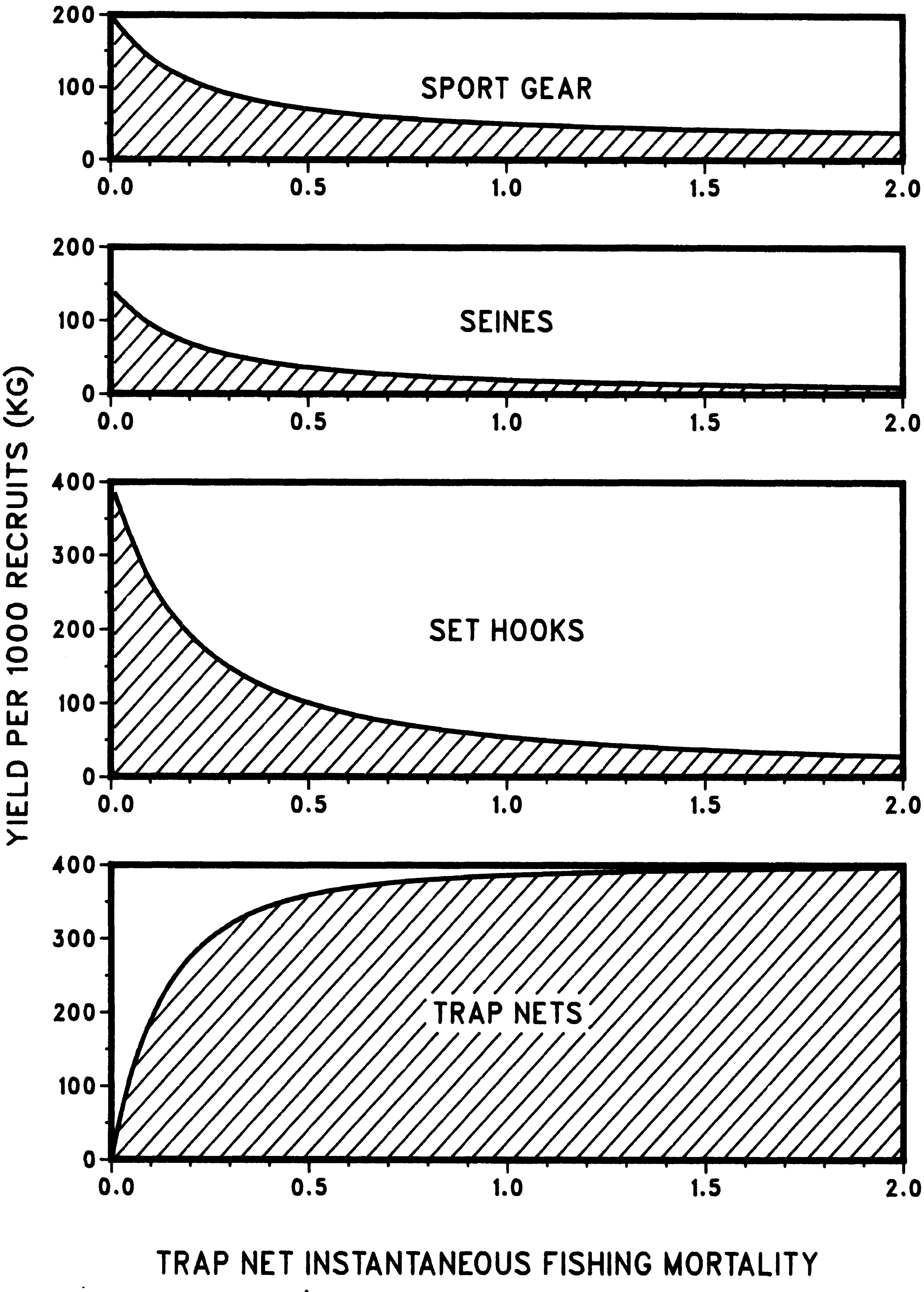


Figure 8. Yield per 1000 recruits to sport gear, seines, set hooks, and trap nets as a function of FR, where FS=0.06, FE=0.06, FH=0.14, M=0.1, and l_c=381 mm.

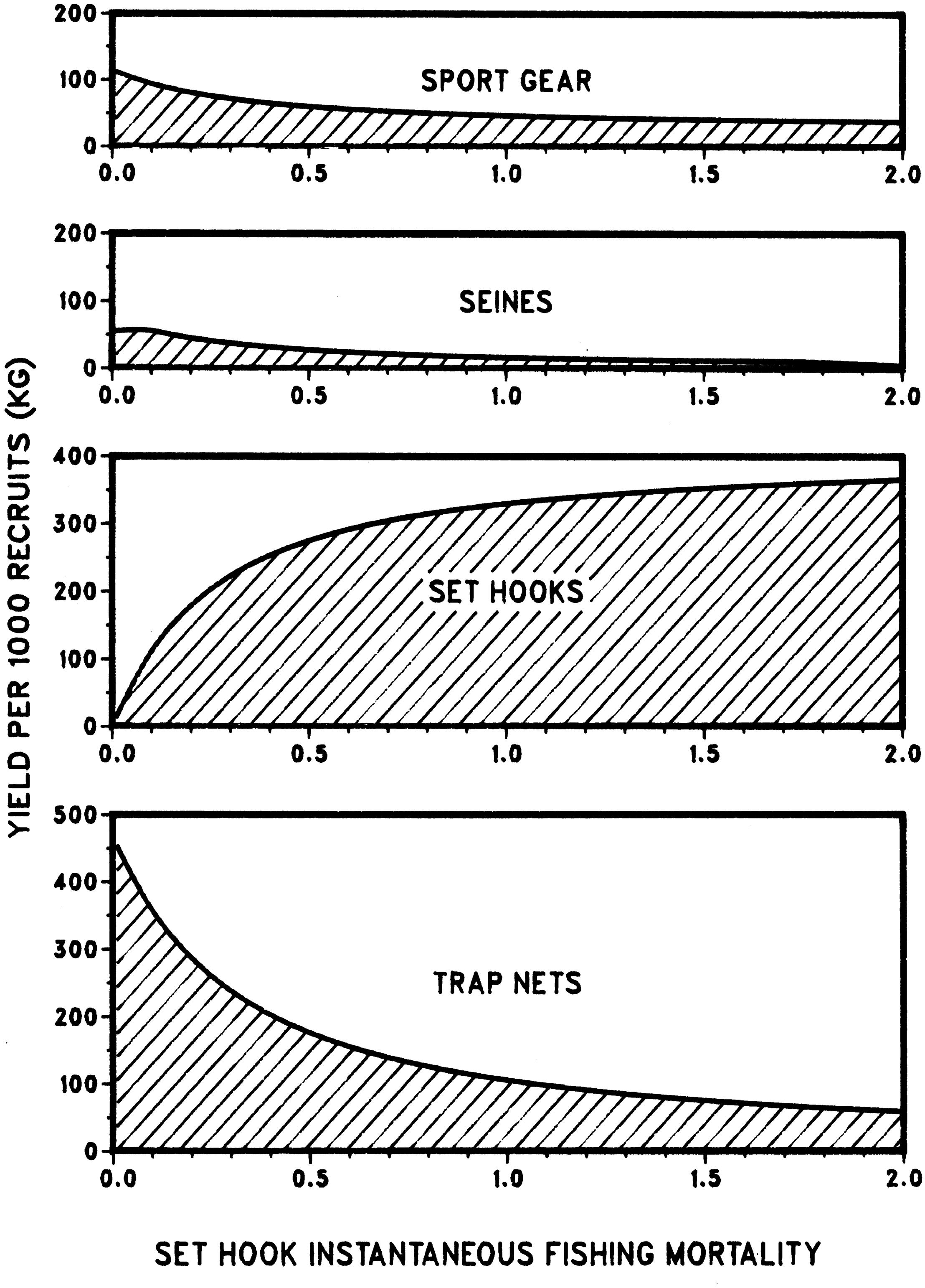


Figure 9. Yield per 1000 recruits to sport gear, seines, set hooks, and trap nets as a function of FH where FS=0.06, FE=0.05, FR=0.32, M=0.1, and l_c=381 mm.

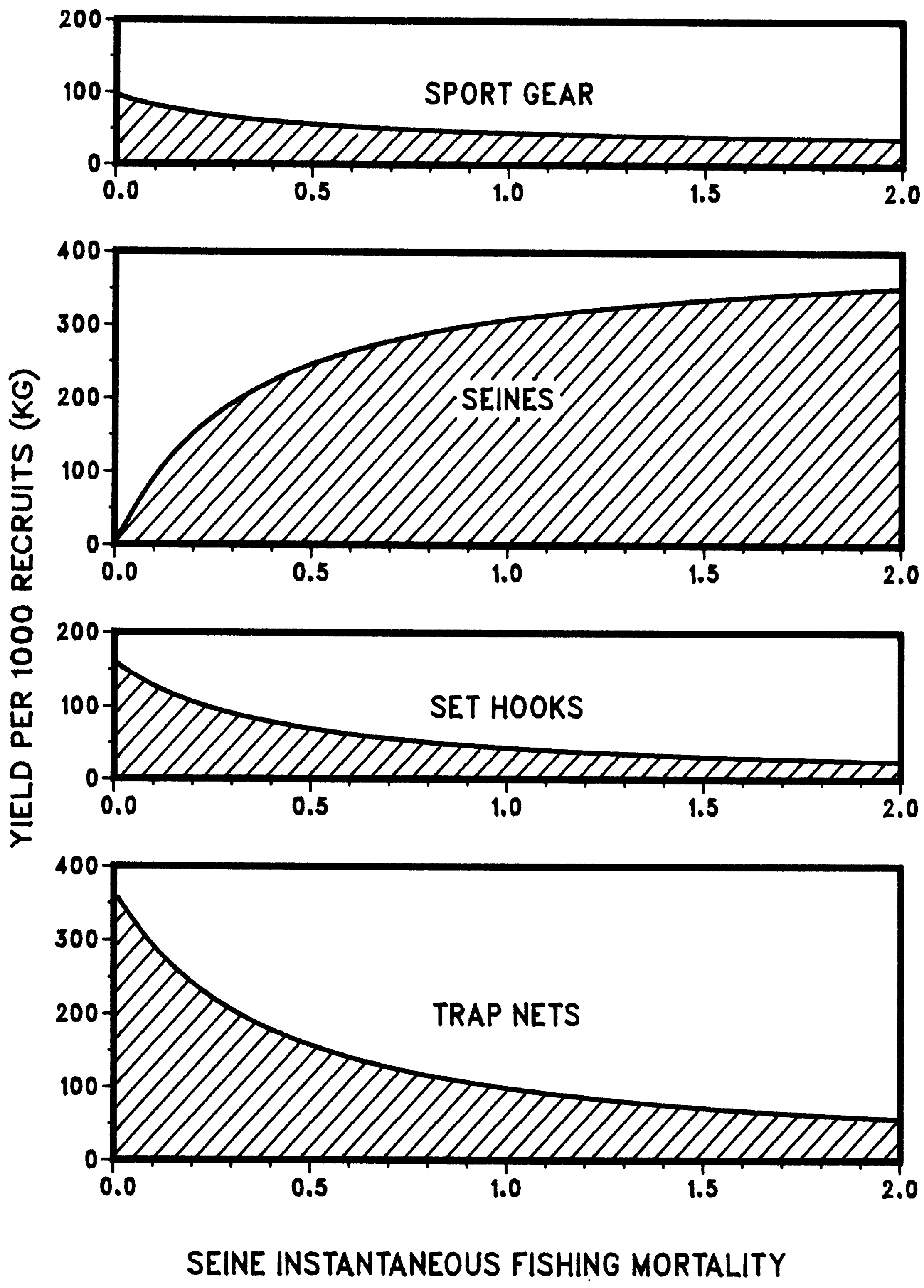


Figure 10. Yield per 1000 recruits to sport gear, seines, set hooks, and trap nets as a function of FE where FS=0.06, FH=0.14, FR=0.32, M=0.1, and l_c=381 mm.

Table 7. Range of FS + M values used to examine the sensitivity of yield per 1000 recruits as a function of FC, and range of FS + M (and FC) values used to examine the sensitivity of yield per 1000 recruits as a function of l_c.

Mortality parameter(s)	Values							
FS + M	0.10	0.16	0.20	0.25	0.30	0.35	0.40	0.45
FC	0.57	0.51	0.47	0.42	0.37	0.32	0.27	0.22

At the FS + M value of 0.25, and corresponding FC value of 0.42, model predictions indicated that the commercial fishery was fishing at a rate that produced the maximum yield per 1000 recruits. In analyses where FS + M values were less than 0.25, a growth overfishing condition existed, which indicated that a decrease in FC would increase the yield per 1000 recruits. Model predictions also indicated that where FS + M values were greater than 0.25 a condition existed where commercial fishing mortality was not great enough obtain the maximum yield, and an increase in FC would increase the yield per 1000 recruits. At the estimated FS + M value of 0.16 commercial fishing mortality was excessive and resulted in a condition of growth overfishing. However, if FS, M, or both increased or were underestimated by an amount greater than 0.9 (so that FS + M was greater than 0.25) model results would favor granting commercial fishermen an increase in the amount of gear licensed. Therefore, in situations where an increase in FC is being considered the importance of accurately estimating and monitoring changes in FS and M is clearly demonstrated.

At the existing or estimated values of FC (0.51), FS (0.06), and M (0.1), model predictions indicated that the maximum commercial yield per 1000 recruits occurred when l_c was approximately 550 mm, 22 inches (Fig. 11). Increasing l_c from 381 mm (15 inches) to 550 mm (22 inches) produced a 28.8% increase in equilibrium yield per 1000 recruits to the commercial fishery and a 171.6% increase in equilibrium yield per 1000 recruits to the sport fishery. Increases in l_c up to 550 mm (22 inches) resulted in increases in yield per 1000 recruits to both the sport fishery and commercial fishery, however when l_c became greater than 550 mm (22 inches), yield to the commercial fishery declined (Fig. 11).

The value of l_c, which produced the maximum yield per 1000 recruits, was also sensitive to changes in the value of FS + M, and this sensitivity was examined for the range of values presented in Table 7. At the FS + M value of 0.30, and corresponding FC value of 0.37, model predictions indicated that the current minimum commercial size limit of 381 mm (15 inches) produced the maximum yield per 1000 recruits (Fig. 12). In analyses where FS + M values were less than 0.3, a condition existed where fish were harvested at a size less than that which produced the maximum commercial yield, which indicated that an increase in l_c

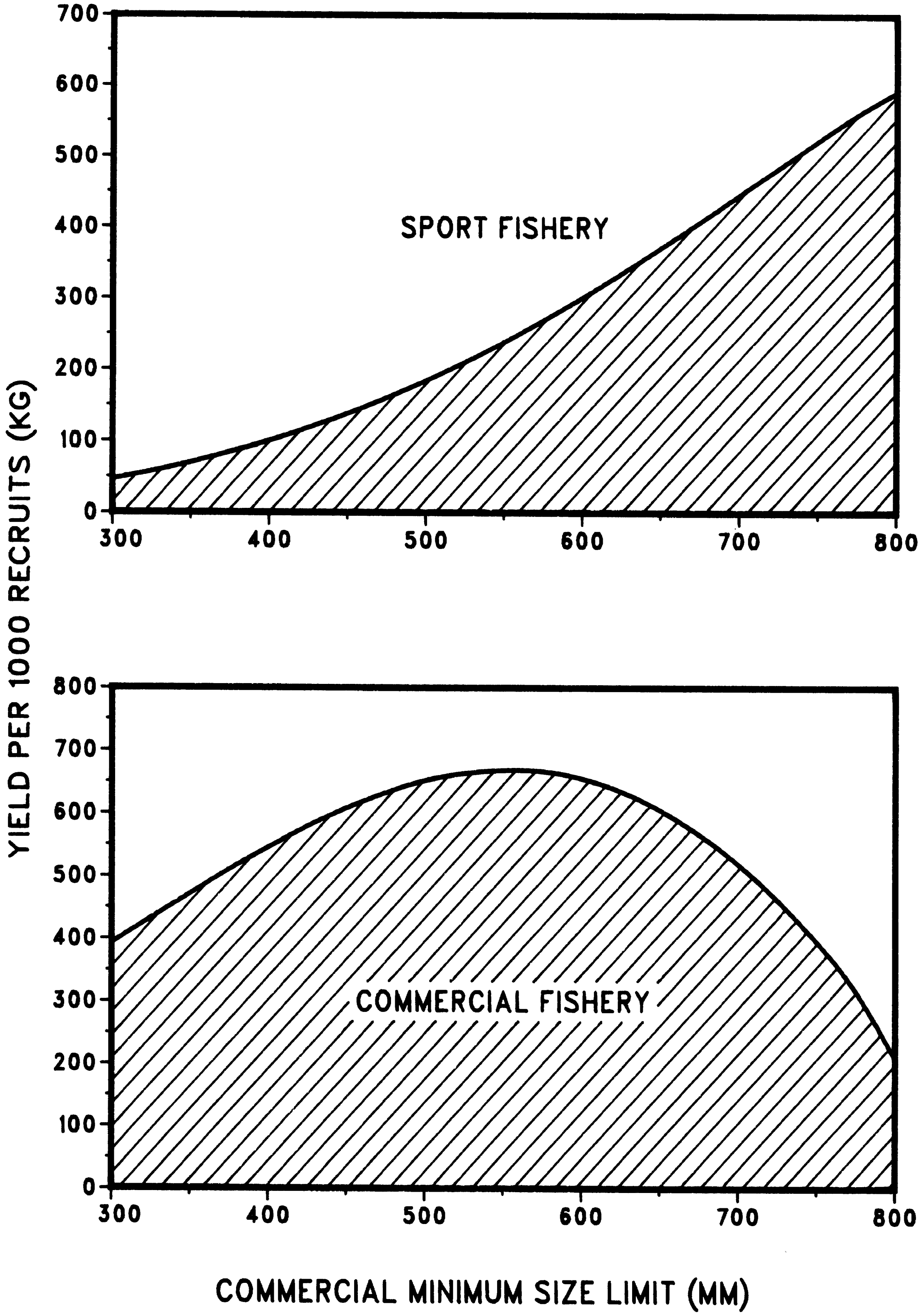


Figure 11. Yield per 1000 recruits to the commercial fishery and sport fishery as a function of l_c where FS=0.06, FC=0.51, and M=0.1.

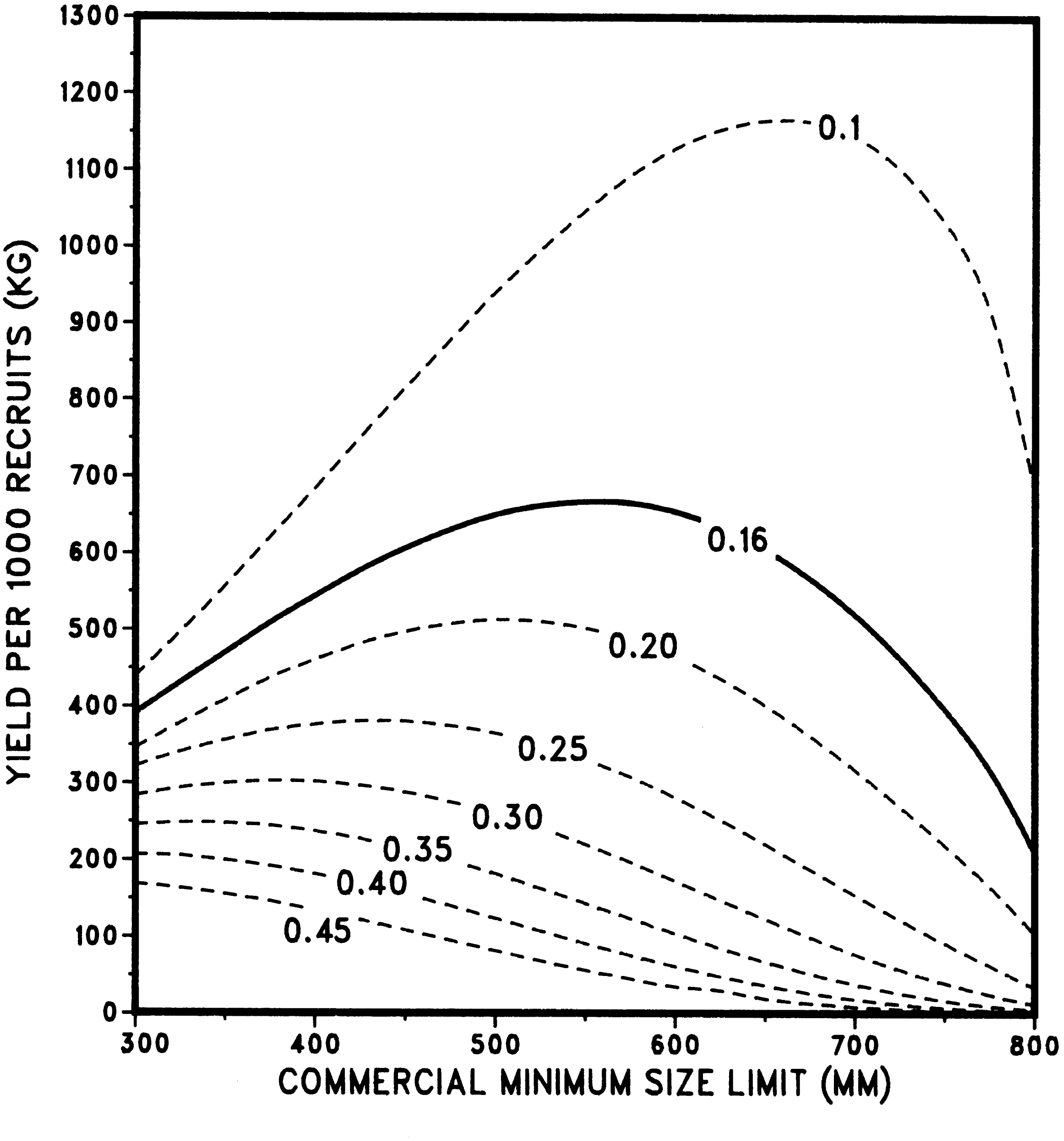


Figure 12. Yield per 1000 recruits as a function of l_c with FC=0.51, FS=0.06, and M=0.1 (solid line); and for a range of FS + M values (broken lines), with FC=0.51.

would increase the yield per 1000 recruits. Model predictions also indicated that where FS + M values were greater than 0.3 a condition existed where fish were harvested at a size greater than that which produced the maximum yield, and a decrease in l_c would increase the yield per 1000 recruits. At the estimated FS + M value of 0.16, a low commercial minimum size limit resulted in a condition of growth overfishing. However, if either FS, M, or both were were underestimated or increased by an amount greater than 0.14 (so that FS + M was greater than 0.3) model results would favor a l_c of 381 mm (15 inches), or perhaps less. Thus, accurately estimating and monitoring changes in FS and M is also important in situations where a change in l_c is being considered.

DISCUSSION

Age Composition and Size Structure of the Catch

Estimated age distributions of the catch of channel catfish were different in each grid sampled. Differences in age distributions could be attributed to age-specific differences in availability, age-specific differences in vulnerability to the sampling gear, and real differences in age composition between grids. Greater proportions of younger age groups were captured in grids 1608 and 1606 (Table 5). Randolph and Clemens (1976) found that smaller channel catfish occupied shallower water areas in culture ponds, and larger channel catfish occupied deeper water areas. Grids 1608 and 1606 are characterized by more extensive shallow water areas, perhaps attractive to younger age groups, and grids 1509 and 1507 are characterized by more extensive deep water areas, perhaps attractive to older age groups. This suggests that the observed differences in age distributions were due to differences in availability of various age groups. Although it appeared that younger age groups were captured in proportion to their availability in grids 1608 and 1606, even larger proportions were retained in nets in grid 1606, which had smaller pot mesh than nets in grids 1608, 1509, and 1507. This suggests that some age-specific differences in vulnerability to the fishing gear also existed.

Growth in Length

There were significant differences in the growth rate of channel catfish between sexes in grids 1509 and 1608. Mean back-calculated lengths at age were greater for males in grid 1509 and greater for females in grid 1608 (Appendix A). Few studies have compared growth in length of channel catfish between sexes. Elrod (1974) and Ambrose and Brown (1971) contended that growth in length between sexes was similar enough in their studies to be combined. DeRoth (1965) found that the average back-calculated lengths of males and females in Lake Erie was similar up to age 4. After age 4, mean back-calculated lengths at age were greater for males. In experimental ponds, Beaver et al. (1966) found that the average length of males was greater than the average length of females. Thus, growth differences between sexes in this study, in particular in grid 1608, were more likely due to differential vulnerability of males and females to capture rather than real growth differences. Grids 1509 and 1608 were sampled near the spawning season at a time when behavioral differences have been observed between sexes. Trap nets are passive sampling devices, and vulnerability to capture was dependent upon movement. Larger channel catfish spawn earlier in the spawning season, and males drive away females and care for the eggs after spawning (Clemens and Sneed 1957). Thus, larger males may have been less vulnerable to capture in grid 1608, if sampling took place early in the spawning season when larger males were on their nests. Also, hatching has been observed to take place after approximately 1 week of incubation (Clemens and Sneed 1957). If adult males disperse soon after the eggs hatch, it is plausible that larger males were more vulnerable to capture at this time. This may explain the larger back-calculated lengths at age observed for males in grid 1509, although growth differences evident in grid 1509 were consistent with other reported results.

When sexes were pooled, no significant differences in growth rate were detected between grids. However, mean back-calculated lengths at age were less for channel catfish from grids 1608 and 1606 than from other grids. These differences may be real, may be associated with age-specific differences in availability, or may be associated with net selectivity. More younger fish were captured in grids 1608 and 1606 than in grids 1509 and 1507 (Table 5). In grid 1608, a greater proportion of smaller channel catfish may have been captured, because larger fish, in particular males, were probably on or near nests and less available at the time of sampling. In grid 1606, the smaller pot mesh utilized may have selected greater proportions of smaller fish. Although mean back-calculated lengths at age were smaller in grids 1608 and 1606 than in other grids, no significant differences in growth rates or intercepts were detected between grids when regression equations were fit to lengths after age 6, the age of complete recruitment to the commercial fishery.

Pooled mean back-calculated lengths at age in this study were about average when compared to those reported from other northern regions, and were smaller than those reported from more southerly locations (Table 8). Mean back-calculated lengths in this study were less than those reported 10 years earlier by Eshenroder and Haas (1974). In their study, channel catfish were captured with commercial and experimental nets; experimental nets captured younger age classes of channel catfish in greater proportion than commercial gear types (Eshenroder and Haas 1974). I sampled fish from commercial trap nets exclusively. If differences in selectivity of the gear caused the observed growth differences, one would expect fish in the present study to be larger on the average at each age, since commercial nets probably selected greater proportions of larger fish. However, mean back-calculated lengths at age were greater in the study conducted by Eshenroder and Haas (1974), thus, gear selectivity probably did not account for the observed growth differences.

Physical, chemical, and biological conditions have been demonstrated to be quite dynamic in Saginaw Bay (Rossman and Treese 1982), and these changes may explain the observed differences in growth. Conditions which may have caused a decrease in growth of channel catfish include:

Table 8. Mean back-calculated lengths (mm) at age of channel catfish from Saginaw Bay in 1981 (with 95% confidence intervals) and 1971, and from other selected locations.

Location	Year(s) of study	Sample size	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Saginaw Bay, Lake Huron	1981	916	54	132	198	256	310	358	420	469	507	546	594	604	612	...
			±1	±2	±2	±2	±3	±3	±5	±6	±6	±8	±14	±20	±76	...
Saginaw Bay, Lake Huron[1]	1971	253	69	157	254	335	404	490	561	569	589	607	630	...	...	...
Lake Erie, Western Basin[2]	1965	1,478	63	165	226	269	297	330	363	...	...	...	...	...	...	...
Lake Erie, Michigan Waters[1]	1971	495	170	221	264	305	340	373	386	417	452	505	549	...	...	...
Lake St. Clair[1]	1969-71	507	76	208	226	272	350	383	434	485	531	564	604	...	...	...
St. Lawrence River[3]	1975	28	119	164	204	239	272	302	330	353	377	400	432	455	...	...
Lake Sharpe, South Dakota[4]	1945-56	535	46	124	196	256	312	381	442	490	546	617	645	640	676	...
Oklahoma[5]	1946-54	7,717	101	215	302	368	409	452	504	555	607	630	644	648	655	731
Santee-Cooper Reservior System, South Carolina[6]	1959	210	86	185	284	368	442	531	602	665	726	772	807	853	917	904
Farm Ponds, Central Texas[7]	1972	82	178	333	429	516	...	...	...	...	...	...	...	...	...	...

[1] Eshenroder and Haas (1974)

[2] DeRoth (1965)

[3] Maguin and Fradette (1975)

[4] Elrod (1974)

[5] Jenkins (1954)

[6] Stevens (1959)

[7] Prentice and Whiteside (1975)

(1) A decrease in primary productivity as demonstrated by a decrease in median chlorophyll a levels from 1974 to 1979 (International Joint Commission 1980).

(2) Intraspecific competition due to an increase in channel catfish abundance as demonstrated by the increases in catch per unit of effort (Fig. 2).

(3) Interspecific competition due to intensified salmonid and walleye Stizostedion vitreum stocking programs.

Numerous other factors could contribute to the observed decrease in mean length at age.

Weight-Length Relation

Differences in the linearized weight-length relations between management areas probably reflect seasonal change in weight and length (Bagenal 1978). Grids were not sampled during the same time period and the slope of the relations decreased from spring to summer (Appendix C). This indicated that condition or plumpness decreased (Lagler 1956). Simco and Cross (1966) noted a similar decline in condition of channel catfish in the late summer. Despite these seasonal changes in condition, pooled weight and length data were used in yield analyses to calculate the approximate weight of the catch.

Total Mortality Rate

Ricker (1975) identified the following conditions or assumptions implied in interpreting the descending right limb of a catch curve:

(1) The age groups under study are equal in number when each is recruited to the fishery.

(2) Survival rate is uniform with age.

(3) Fishing and natural mortality rates are uniform with age, since both comprise the total mortality rate which is the complement of the survival rate.

(4) The sample is random.

Catch curves for each grid were characterized by irregular right limbs which were probably caused by variable recruitment. The right limbs exhibited the usual decreasing trend with age and the variability appeared to be random. Thus, I assumed that the slope of a line fitted by least squares to the descending limb adequately estimated the total instantaneous mortality rate. The irregularity of the right limbs of the catch curves also precluded detection of curvature, useful in evaluating the assumption of uniform survival. However, commercial fishing effort information provided insight to the constancy of survival, since commercial fishing accounts for the bulk of total mortality. Commercial fishing effort, and thus commercial fishing mortality were relatively constant in years just prior to 1981, therefore survival rate was also probably constant (Fig. 2, B).

The assumption of random sampling implies that differences did not exist in age-specific vulnerability to trap nets after the age of maximum vulnerability. Differences in age structure of the catch were detected between grids, however no differences in total mortality were detected after the age of complete recruitment. This indicated that differences in age composition were primarily due to differences in availability or selectivity before the age of complete recruitment to the fishing gear. Latta (1959), and Laarman and Ryckman (1982) demonstrated that trap nets were size selective for a number of species. Ricker (1975) contended that error from catch curve mortality estimates due to size-specific vulnerability was unlikely to be large for trap nets, but encouraged efforts to assess selectivity. Yeh (1977) showed that trap nets were more effective in representing the length class frequency of a population of channel catfish than gill nets and hoop nets in large inland lakes in Texas. Assessment of the selectivity of commercial trap nets for channel catfish and collection of age frequency data over a series of years, to minimize the effects of variable recruitment, would enhance the reliability of the total mortality estimate.

The total instantaneous mortality rate for channel catfish estimated in this study was identical to the value estimated by Eshenroder and Haas (1974). This value also lies within the range of other published values (Table 9). Thus, it appears that the physical, chemical, and biological changes that have occurred since the study by Eshenroder and Haas (1974), have had little effect on total mortality.

Fishing Mortality Rates

The method used to estimate the instantaneous fishing mortality rate for each gear or fishery was contingent upon

Table 9. Instantaneous total mortality rates estimated for Saginaw Bay in 1981 (with 95% confidence interval) and 1971, and for other selected locations.

Location	Year(s) of study	Z
Saginaw Bay, Lake Huron	1981	0.67 (±0.27)
Saginaw Bay, Lake Huron[1]	1971	0.67
Des Moines River, Iowa[2]	1966-69	0.637
Upper Mississippi, Iowa[3]	1977-79	0.94
Lake Sharpe, South Dakota[4]	1945-56	0.37
Rivers of Sacramento Valley, California[5]	1955-59	0.82

[1]Eshenroder and Haas (1974)

[2]Mayhew (1972)

[3]Pitlo and Bonneau (1979)

[4]Elrod (1974)

[5]McCammon and LaFaunce (1961)

the reliability of the catch statistics used to partition FT. Commercial records provided the catch for each gear type as reported by commercial fishermen. These records were assumed to be reliable. Sportfishing post card survey estimates, however, have been demonstrated to be inflated, and corrections for this have been described. These correction factors were largely derived from exploitation studies of lake trout Salvelinus namaycush and yellow perch. Specific corrections for channel catfish would improve the reliability of sport harvest estimates used here, and thus improve the estimates of the instantaneous fishing rates for each gear or fishery. A sportfishing mortality estimate of approximately 0.20 would result if the estimate of sportfishing yield were not corrected. Coupling this FS value with the best estimate of M (0.1) yielded an FS + M value of 0.30. Using this FS + M value model predictions indicated that the commercial fishery was operating at a minimum size limit and fishing rate very near that which produced the maximum yield per 1000 recruits (Fig. 12). Thus, results of the yield analysis greatly depend upon the correction factor used in the estimation of sportfishermen yield. An inaccurate correction factor could change the conclusions drawn from this analysis.

Ultimately, the reliability of all of these fishing mortality estimates depend upon the accuracy of the estimate of FT. The indirect procedure used to estimate FT in Saginaw Bay was exclusively dependent upon the estimate of Z and the value of M estimated by Eshenroder and Haas (1974). The degree to which FT and M make up Z can significantly influence yield computations. Model results indicated that when natural mortality accounted for a larger percentage of total mortality; maximum yield was obtained at greater fishing rates (Fig. 7) and/or lower minimum size limits (Fig. 12). Estimates of M and FT from the Sacramento Valley were 0.38 and 0.44, respectively (McCammon and LaFaunce 1961); each mortality parameter constituted approximately one half of Z. In contrast, values from Saginaw Bay were 0.1 and 0.57 for M and FT, respectively. Here, the instantaneous fishing mortality constituted a significantly larger portion of Z, and model predictions indicated that maximum yield was obtained at a relatively low fishing rate and high minimum size limit. A more direct estimation procedure to assess fishing and natural mortality (such as a tag-recapture procedure) would ultimately be necessary to improve estimates of natural and fishing mortalities and/or validate the method used to estimate fishing mortalities.

<u>Yield</u>

Beverton and Holt (1957) listed the following assumptions implied in a cohort yield-per-recruit model:

(1) Yields predicted are those which exist under equilibrium conditions.

(2) Extrapolation of model results to a population requires constant recruitment.

(3) Rates of growth and natural mortality remain constant in response to other changes.

(4) All fish older than age x_r are equally vulnerable to capture.

Ricker (1975) identified the following assumptions applicable to the competing gear types modeled in the present study:

(5) The units of gear are distributed such that all fish are equally vulnerable to capture and there is no possibility of localized depletion of the stock.

(6) There is no physical interference among gear types with respect to their operation.

The utility of the results of this analysis depend to a large degree, upon how well all of these assumptions were met. With respect to the first assumption it is important to recognize that predictions from this analysis in response to a particular management action will not be realized immediately. Lag time to attainment of a new equilibrium will depend upon the management action, the generation time, and recruitment (Walters 1969). For example, an increase in the commercial minimum size limit would ultimately increase yield, yet upon implementation a short-term reduction in yield to the commercial fishery would result. Clark (1976) discusses strategies which minimize these short term losses.

The impacts of management actions upon recruitment cannot be assessed with this yield-per-recruit model. Although recruitment has exhibited some variability, the history of stable landings indicates that the assumption of constant recruitment is probably appropriate for the current total mortality rate and growth regime. However, fishing mortality could become great enough to affect recruitment. Russell (1942) documents some devastating consequences of recruitment overfishing in the North Sea, and symptoms of recruitment overfishing have been documented for channel catfish in the Mississippi River (Pitlow and Bonneau 1979). An understanding of the relation between stock and recruitment would significantly enhance management capability.

Changes in growth and natural mortality in response to changes in management actions or environmental changes have not been evaluated, yet model predictions hinge upon the constancy of these vital statistics. Using the best mortality and growth parameter estimates, model predictions indicated that an increase in the minimum commercial size limit and/or reduction in commercial fishing mortality would increase both commercial and sportfishermen yield. Either of these changes would ultimately change the relative abundance of some age classes of channel catfish (Ricker 1975). These density changes could affect growth and natural mortality. Model results indicated that small changes in natural mortality significantly affected model predictions (Figs. 7 and 12). However, the apparent increase in abundance of channel catfish and changes in environmental conditions, since the study by Eshenroder and Haas (1974), have not resulted in any apparent changes in natural mortality as evidenced by the constancy of total mortality and fishing effort from 1971 to 1981. Growth, however, may change in response to changing environmental conditions or changes in density as a consequence of a management action. The growth of channel catfish in Saginaw Bay in 1971 and in Michigan waters of Lake Erie were used to study model predictions under different growth regimes. Mean back-calculated lengths at age of channel catfish in Saginaw Bay in 1971 were greater than those in the present study and mean lengths at age after age 6 were less in

Michigan waters of Lake Erie than in the present study (Table 8). Using the 1971 growth regime in a yield analysis similar to that performed in the present study, Eshenroder and Haas (1974) concluded that an increase in the minimum commercial size limit would increase yield. I concluded the same using von Bertalanffy parameters fit to Lake Erie growth data with the Saginaw Bay mortality regime. Thus, it appears that small changes in growth that may occur in response to a management action, or change in environmental conditions, will not significantly affect model predictions.

The assumption of equal vulnerability to each gear type was not directly assessed. Not all areas of Saginaw Bay are commercially fishable, yet all areas are accessible by sportfishermen. Each commercial gear type is suited to exploit fish at a particular depth, on a particular bottom type, and to some degree during a particular season. Thus, all fish were probably not equally vulnerable to all gear types. Since it appears that fishing does not result in localized depletions of the stock, model bias due to differences in vulnerability would probably be small. However, a better understanding of the characteristics of the catch from each gear would permit refinement of the model and enhance predictions. The nature of the distribution of the different types of fishing gear in time and space indicates that physical competition between gear types would be minimal.

Although the assumptions of the yield-per-recruit model cannot be rigidly met, some useful management insights can be gleaned from this study. First, examination of gear competition in a realistic management framework was interesting. With the best available growth and mortality estimates, I determined that increases in commercial fishing mortality through the licensing of additional gear, would not increase yield to the fishery as a whole. Each commercial gear type was operating at a level which produced less than the maximum yield per 1000 recruits to that particular gear (Figs. 8, 9, and 10), thus, yield to any one gear type could be increased by increasing fishing mortality due to that particular gear type. These increases, however could only be realized with accompanying losses to other gear types and a net loss to the fishery as a whole. Second, yield-per-recruit analyses of the commercial fishery indicated a condition of growth overfishing. This condition could be corrected by increasing the minimum commercial size limit, reducing the commercial fishing mortality, or a combination of both. The largest gains in yield could be obtained by increasing the minimum commercial size limit (Fig. 6).

Increasing the minimum commercial size limit would appear to benefit both the commercial and sport fishery. Although all model results presented suggest that catfish yield could be increase by increasing the commercial minimum size limit, the tenuous nature of the mortality parameter estimates precludes any immediate recommendation for a change. However, efforts should be made to more accurately estimate mortality parameters, and entry should remain limited until these assessments are completed and specific management plans can be formulated.

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APPENDIX A.

Mean back-calculated lengths at age for both sexes in each grid and for sexes combined.

Table A-1. Mean back-calculated lengths (mm) at age for both sexes in each grid and for sexes combined. (Sample size and 95% confidence interval are indicated for each length. Sex was not determined for all specimens, therefore the sample sizes of males and females may not sum to the combined sample size.)

Grid		Age 1	2	3	4	5	6	7	8	9	10	11	12	13
	Male	47	126	193	254	308	356	409	452	489	533	572	533	...
		±3	±4	±4	±5	±7	±7	±10	±14	±16	±22	±61	...	...
		(135)	(135)	(135)	(133)	(105)	(104)	(58)	(49)	(46)	(34)	(10)	(1)	...
1608	Female	46	126	193	251	302	348	416	468	512	549	594	613	...
		±3	±5	±5	±5	±7	±8	±12	±15	±16	±18	±42	±86	...
		(123)	(123)	(122)	(121)	(100)	(98)	(50)	(42)	(37)	(28)	(8)	(4)	...
	Combined	46	126	193	252	305	352	412	459	500	542	582	597	...
		±2	±3	±3	±4	±5	±5	±7	±9	±11	±14	±35	±73	...
		(265)	(265)	(264)	(261)	(212)	(209)	(115)	(98)	(90)	(67)	(18)	(5)	...
	Male	59	137	204	265	322	370	434	495	541	581	630	637	...
		±4	±6	±6	±6	±9	±10	±15	±15	±15	±19	±23	±78	...
		(96)	(96)	(96)	(96)	(78)	(78)	(47)	(39)	(36)	(28)	(15)	(4)	...
1509	Female	57	135	201	259	313	359	421	461	497	537	583	592	612
		±3	±5	±6	±6	±8	±9	±12	±16	±16	±19	±19	±27	±222
		(108)	(108)	(108)	(108)	(99)	(98)	(65)	(55)	(53)	(41)	(18)	(8)	(2)
	Combined	58	136	202	262	317	364	427	476	515	555	604	607	612
		±2	±4	±4	±4	±6	±7	±9	±11	±12	±14	±16	±27	±222
		(210)	(210)	(210)	(210)	(181)	(180)	(113)	(95)	(90)	(70)	(33)	(12)	(2)
	Male	59	135	201	258	311	361	426	479	513	562	585	570	...
		±3	±4	±5	±5	±7	±9	±16	±19	±19	±23	±56	...	...
		(106)	(106)	(106)	(102)	(84)	(78)	(32)	(26)	(23)	(12)	(5)	(1)	...
1507	Female	59	139	202	258	311	360	420	475	516	555	625	621	...
		±4	±5	±6	±7	±9	±11	±19	±20	±23	±41	±158	...	...
		(91)	(91)	(91)	(87)	(76)	(70)	(32)	(24)	(21)	(10)	(3)	(1)	...
	Combined	59	137	202	258	311	360	421	474	511	550	599	596	...
		±2	±3	±4	±4	±5	±7	±11	±13	±14	±22	±38	±321	...
		(205)	(205)	(205)	(197)	(166)	(154)	(69)	(54)	(48)	(25)	(9)	(2)	...
	Male	54	131	194	253	304	352	422	467	496	537	...	...	...
		±3	±3	±4	±6	±9	±11	±21	±24	±26	±60	...	...	...
		(117)	(116)	(99)	(86)	(62)	(54)	(21)	(19)	(15)	(3)	...	...	...
1606	Female	55	131	194	253	309	360	421	474	505	516	576	605	...
		±3	±3	±4	±5	±8	±11	±16	±21	±24	±22	±91	...	...
		(116)	(115)	(100)	(84)	(61)	(55)	(29)	(20)	(16)	(12)	(3)	(1)	...
	Combined	55	131	194	253	307	356	421	470	501	522	558	605	...
		±2	±2	±3	±4	±6	±8	±12	±15	±16	±19	±74	...	...
		(236)	(234)	(202)	(173)	(125)	(111)	(52)	(41)	(33)	(17)	(4)	(1)	...

APPENDIX B.

Table B-1. Polynomials fitted to back-calculated lengths at all ages for each sex in each grid and for sexes pooled within grids. (Sample sizes and coefficients of determination are indicated. Sex was not determined for for all specimens, therefore the sample sizes of males and females may not sum to the combined sample size.)

Grid		Regression equation	N	R^2
	Male	$Y = -23.7 + 77.8(X) - 2.3(X^2)$	945	0.95
1608	Female	$Y = -18.7 + 72.9(X) - 1.6(X^2)$	856	0.95
	Combined	$Y = -20.8 + 75.3(X) - 1.9(X^2)$	1869	0.95
	Male	$Y = -8.8 + 73.9(X) - 1.5(X^2)$	709	0.94
1509	Female	$Y = -10.4 + 75.0(X) - 2.0(X^2)$	871	0.93
	Combined	$Y = -10.7 + 75.1(X) - 1.9(X^2)$	1616	0.94
	Male	$Y = -8.5 + 73.3(X) - 1.7(X^2)$	681	0.95
1507	Female	$Y = -3.1 + 70.8(X) - 1.5(X^2)$	597	0.94
	Combined	$Y = -6.1 + 72.5(X) - 1.7(X^2)$	1339	0.95
	Male	$Y = -14.5 + 74.3(X) - 1.9(X^2)$	592	0.95
1606	Female	$Y = -16.9 + 76.3(X) - 2.1(X^2)$	612	0.96
	Combined	$Y = -16.4 + 75.8(X) - 2.1(X^2)$	1229	0.96

APPENDIX C.

Table C-1. Linearized weight-length regressions for each sex in each grid, for sexes pooled within grids, and for grids and sexes pooled. (Sample sizes and coefficients of determination are indicated. Sex was not determined for all specimens, therefore sample sizes of males and females may not sum to the combined sample size.)

Grid		Regression equation	N	R^2
	Male	Y = -21.6 + 3.5(X)	135	0.98
1608	Female	Y = -21.3 + 3.5(X)	125	0.99
	Combined	Y = -21.5 + 3.5(X)	267	0.98
	Male	Y = -20.5 + 3.3(X)	96	0.99
1509	Female	Y = -21.0 + 3.4(X)	109	0.98
	Combined	Y = -20.8 + 3.4(X)	211	0.99
	Male	Y = -20.7 + 3.3(X)	106	0.97
1507	Female	Y = -20.8 + 3.4(X)	92	0.96
	Combined	Y = -20.8 + 3.4(X)	206	0.97
	Male	Y = -19.8 + 3.2(X)	117	0.99
1606	Female	Y = -19.8 + 3.2(X)	116	0.99
	Combined	Y = -19.8 + 3.2(X)	236	0.99

APPENDIX D.

Table D-1. Equations fitted to the descending limbs of catch curves for each grid and grids combined. (Sample sizes, and coefficients of determination are indicated.)

Grid	Regression equation	N	R^2
1608	Y = 8.8 - 0.57(X)	7	0.61
1509	Y = 9.4 - 0.63(X)	8	0.75
1507	Y = 9.6 - 0.66(X)	7	0.71
1606	Y = 6.7 - 0.45(X)	9	0.63
All	Y = 11.0 - 0.67(X)	8	0.86