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DISTRIBUTION AND POPULATION DYNAMICS OF SMALLMOUTH BASS IN ANCHOR BAY, LAKE ST. CLAIR[1]

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ABSTRACT

A smallmouth bass population which spawns in west-central Anchor Bay of Lake St. Clair was studied by netting and tagging from 1971–85, as well as by an intense on-site creel census in 1983–85.

Anchor Bay smallmouth bass grew faster than populations to the north and slower than some lake populations farther south. It was concluded that this rate of growth primarily relates to the temperature regime associated with the latitude.

The majority of bass tagged in Anchor Bay remained within that part of the lake. Significant numbers migrated into the St. Clair River as opposed to relatively few that moved into southeastern Lake St. Clair or the Detroit River. Estimates of survival and exploitation rates were independently generated from the tagging and recapture data. Estimated annual total mortality rate (0.58) of Anchor Bay bass was of intermediate level, while the conditional natural mortality rate (0.52) was the highest, and the conditional fishing mortality rate (0.13) was the lowest compared to eight other widely distributed populations. It is suspected that angler tag returns were generally under-reported, even with adjustment, resulting in unrealistically low estimates of exploitation and too high estimates of natural mortality.

The catch of adult smallmouth bass per net lift (CPUE) rose substantially in the years after the minimum size limit of bass was raised from 254 mm to 305 mm in 1976. It was concluded from this evidence that there had been a real increase in adult bass abundance. However, the reason for the increase in CPUE was not clear. Two factors, one biological and the other environmental showed correlation with the increased CPUE. The raising of the minimum size limit, by virtue of extending protection from exploitation to larger and older bass, was correlated and, in addition, correlation was noted relating the CPUE of age-4 bass to the June water temperature conditions present at their birth and early development.

Yield-per-recruit (Y/R) analyses predicted that maximum yield would occur at the minimum size limit considered (254 mm) for the period before as well as after the size limit increased. Yield, at the existing levels of estimated fishing mortality, was about the same for both periods.

Daily creel limit, size limit, or season changes are the most obvious options that could be used in any attempt to maximize bass harvest. However, it was not obvious that any of these would increase the present high abundance of adult bass. It was concluded that the most desirable scheme for the management of Lake St. Clair smallmouth bass is the present set of regulations.

INTRODUCTION

A long-term biological study of the smallmouth bass (*Micropterus dolomieui*) population in Anchor Bay, Lake St. Clair, was conducted because of the substantial recreational value of this sport fishery, and the fact that central Anchor Bay is a major spawning area for these fish. The goal was to acquire the broad and thorough knowledge necessary to assure a sound basis for managing the population and resultant fishery effectively. The only prior intensive study of smallmouth bass in Michigan's Great Lakes waters was by Latta (1963) in northern Lake Michigan. Populations in Ontario waters of Lake Huron have been studied in some detail by many investigators, e.g., Fry and Watt (1957); Coble (1967); Shuter et al. (1985); and Wismer et al. (1985). Dynamics of these smallmouth bass populations near the northern limit of range of the species could be expected to differ substantially from the more southerly Lake St. Clair population. Annual assessment of the Lake St. Clair population began in 1970, when a netting station was established near a buoy known as A-marker (Figure 1).

Lake St. Clair maintains a very valuable sport fishery, supported by excellent fish production, despite heavy urban development along the U. S. shoreline. Water of excellent quality entering from Lake Huron and very rich benthic food sources for fish are probably the main contributors to this productivity (Hiltunen 1980, Hiltunen and Manny 1982, Hudson et al. 1985). Lake St. Clair is a shallow basin, about midway in the St. Clair-Detroit River system (SCDRS), draining Lake Huron into Lake Erie. The lake is about 42 km long and 39 km wide. Surface area is about 1,100 km^2. Maximum natural depth is 6.4 m and the average depth is 3.4 m. A dredged 8.2-m deep navigation channel bisects the lake. The two major areas of Lake St. Clair are the main body, lying south and west of the St. Clair River delta, and the shallow northern portion, comprising Anchor Bay. A coolwater environment of high quality is insured by Lake Huron, which is the source of 97% of Lake St. Clair's water (Derecki 1984a). For example, in the 1969–77 period, the mean of July and August water temperatures in Anchor Bay was 21.6 °C (New Baltimore Water Department data), which Hallam (1959) found to be within the observed summer temperature range preference of smallmouth bass in Ontario streams.

Lake St. Clair has a diverse fish population and a correspondingly varied sport fishery. A total of 57 species was collected in trap nets in the SCDRS during an intensive 1983–85 survey (Haas et al. 1985). Smallmouth bass are abundant enough to sustain an important fishery as evidenced by the fact that they were exceeded in the net catches by only the rock bass (*Ambloplites rupestris*), yellow perch (*Perca flavescens*), walleye (*Stizostedion vitreum*), and white perch (*Morone americana*).

A sport fishery for smallmouth bass began in Lake St. Clair in the late 1800's. Recreational fishing in general has been important since about 1900, and was influential enough to cause elimination of the commercial fishery in the U. S. portion of the lake in 1909. Little was known of the size and success of the early Lake St. Clair fishery until the first creel census, conducted in 1942 and 1943 by Krumholz and Carbine (1945).

METHODS

Estimates of relative abundance, mean length at age, and mortality of the smallmouth bass in Anchor Bay were obtained from the series of annual trap-net surveys conducted 1971–85. The nylon-mesh trap nets had hearts and pots 1.8 m deep and leads 91.4 m long. Normally, five nets were set, dispersed over an approximate 2.6 km^2 area. Age determinations were made from scale samples impressed on acetate plastic.

Tagging of smallmouth bass captured during the netting survey began in 1971 and continued through 1985. The tags consisted of size 10 or 12 serially numbered monel strap tags, attached to the mandible (except in 1984, when half of the tags were attached to the maxilla). Bass over 381 mm total length were often tagged with self-piercing size-3 monel tags attached to the posterior border of the operculum.

The Michigan Department of Natural Resources (MDNR) conducted a stratified creel census in the 1983–85 period to provide estimates of the SCDRS angler harvest and effort (Haas et al. 1985). Shore anglers in Lake St. Clair were not surveyed, but personal observations have consistently confirmed that boat anglers provide the bulk of the Lake St. Clair smallmouth bass harvest. A stratified random schedule was used to sample boat anglers and their catch. Instantaneous, randomly scheduled counts of boats were made from an airplane. Mean numbers of anglers per boat were obtained from interviews. Estimates of hours fished were based on the product of mean instantaneous counts, the fishing hours in the daylight period, and the number of days in the month. Estimates of the catch per hour were based on randomly interviewed anglers. Estimates of hours fished and catch per hour represented the sum of estimates calculated separately for weekend and weekday periods. A more detailed description of the stratified creel census procedures used by MDNR is presented by Ryckman (1981).

A statistical analysis of tag recoveries, developed by Brownie et al. (1978), was performed to generate estimates of survival (S) and tag recovery rates based on maximum likelihood procedures with multiple years of tag return data. A null hypothesis (H_0) comparing the mean survival ($\bar{S}$) and the mean tag return rates for two separate periods of the survey was done by Z-test procedures, described by Brownie et al. (1985) where: $Z = (\bar{S}_1 - \bar{S}_2)/[V(S_1) + V(S_2)]$ and $V(S_i)$ = variance of the i^{th} mean survival rate.

RESULTS

Tag recoveries

A total of 12,586 smallmouth bass were tagged at the Anchor Bay station 1971–85. A total of 1,599 (12.7%) of these tags were returned by anglers through 1985. Location of tag return grids is shown in Figure 2, and distribution of the returns by grid is summarized in Table 1.

Most of the returns (85%) have come from within Lake St. Clair, 12% from the St. Clair River, and 2% from the Detroit River and western Lake Erie. The tag return distribution makes it quite apparent that few fish from this population move downstream into the Detroit River, particularly compared to the numbers that move upstream into the St. Clair River during the summer months. A total of 69% of the tag recaptures have come from within Anchor Bay. Tag recovery data showed smallmouth bass in Lake St. Clair moved considerably farther than found in other Great Lakes populations studied (Haas et al. 1985). This may be due to the migratory pattern of the forage base as well as the minimal obstruction to free movement of fish offered by the flat bottom of Lake St. Clair.

Only five tag returns from southern and eastern Ontario waters of Lake St. Clair indicate that there is relatively little movement of this population into that extensive area. A 1983–85 netting and tagging study of the SCDRS located another small population, which evidently, has spawning grounds near the head of the Detroit River in U. S. waters. This population has different movement patterns and was more likely to be taken on the east side of Lake St. Clair (Haas et al. 1985). Scattered nesting has also been observed in the delta area of the St. Clair River (Latta 1954).

Every other tag applied to the bass during the 1981–83 period had monetary value. The purpose of this was to evaluate the difference in numbers of tags reported by anglers (apparent exploitation) and actual numbers recovered (actual exploitation). Equal numbers of four different reward denominations ($2, $4, $6, and $8) were used to determine whether increased value would stimulate greater response. The numbers of reward and non-reward tags used and their recovery rates through 1985 are summarized in Table 2. The mean reward tag return rate was 25.47%, which was 1.35 times greater than the non-reward tag return rate of 18.80% for the same period (1981–85). This was a significant difference in return rates. A chi-square test rejected the null hypothesis (H_0) that the reward tag return rates were not significantly different from the non-reward tag rates ($\alpha = 0.05$).

Reward tag recovery rates varied from a mean of 14.77% for $2 tags applied in 1981, to a mean of 46.15% for $4 tags applied in 1983. There was no consistent relationship between reward tag value and rate of return. A chi-square test supported the H_0 that recapture rates of the different reward tag categories were not significantly different ($\alpha = 0.05$). Weaver and

England (1986) found no significant increase in returns of Floy dart-tagged rainbow trout with increased monetary award in a Lake Lanier, Georgia, multi-reward program.

Abundance

Peak numbers of smallmouth bass were taken in the nets at age 4 when they first became fully vulnerable to the gear (Table 3). The one exception was the 1973 year class, which had a higher catch per lift (CPUE) at age 5 than age 4.

In the years of 1972–75, mean annual CPUE of age-4 and older bass was 7.0, whereas, it was 20.2 (2.9 times greater) in the 1977–85 period. These catch data suggest that there may have been real gains in broodstock density due to increased recruitment of bass during this latter period. In the year (1976) between these two periods, the smallmouth bass size limit was increased from 254 mm to 305 mm.

Assuming that there was significant compliance, the new size limit increased the minimum age for legal harvest from 3 to 4. The mean CPUE of age-4 bass increased 3.4 times in the years after the size limit increase, which was a higher rate than for all adult ages combined. Since the angling season does not open until after most bass spawning has ended, the additional year of protection has theoretically afforded female bass, which mature at age 4, at least one spawning opportunity. Mean age of smallmouth bass in the trap nets was quite similar in the two time periods. The average age was 4.5 years prior to 1976 and 4.4 years in the post-1976 years. This makes it apparent that any expansion of the broodstock was a result of increased recruitment, and not of decreased mortality of adult bass 305 mm and longer.

The size limit increase coinciding with the population expansion suggests a cause-and-effect relation. However, other biological or environmental factors could also have been involved. Possible spawning temperature involvement was examined, at length, and is discussed later in the text.

Estimates were made of population sizes of several species tagged in trap nets set throughout the SCDRS during the intense 1983–85 study. An estimate of the stock of adult smallmouth bass in the SCDRS in that period was 941,873. This estimate was based on a total angler catch of 59,338, divided by an angler tag return rate of 0.063 (adjusted upward by the 1.35 non-reporting of tags estimate). This estimate must be viewed with reservation, since the data used to make the calculations did not satisfy the assumptions needed for precise estimates. Stock estimates of six other species were ranked ahead of smallmouth bass (Haas et al. 1985). These estimates do provide a measure of smallmouth bass relative abundance in the fish community of the SCDRS.

Growth

Reflecting the latitude, Anchor Bay smallmouth bass grew at a faster rate than bass in more northerly populations studied (Doan 1940, Stone et al. 1954, Latta 1963, Marinac-Sanders and Coble 1981) but slower than bass in lake populations examined farther to the south (Stroud 1948).

Lake St. Clair is relatively eutrophic and productive (Ryder 1965) which could, in part, account for the faster growth rate of Lake St. Clair bass compared to more northerly populations. However, the faster growth in southern populations is attributed to warmer temperatures and a longer growing season associated with that latitude (Carlander 1977). Anchor Bay bass grow at a substantially faster rate than a North American average rate compiled from many populations by Coble (1975). Mean length at age of Anchor Bay smallmouth bass from 1972 through 1985, compared with a northern (Waugoshance Point, Lake Michigan, Latta 1963); southern (Norris Reservoir, Tennessee, Stroud 1948); and average North American population, is presented in Table 4.

Weighted mean-length-at-age data were used in computing growth parameters of the von Bertalanffy growth equation, $l_t = L_{\infty}\{1\text{-}\exp[-K(t\text{-}t_0)]\}$ where:

l_t = length at age in mm;

L_{∞} = theoretical asymptotic length;

K = growth coefficient;

t_0 = theoretical time of zero length.

Separate calculations were made for the period before and after the bass size limit increased in 1976 and also for both periods combined. There were no statistical differences between the two time periods for any of the three parameters allowing the use of the pooled estimates in the yield-per-recruit model. No environmental or population density factors affecting the growth of Anchor Bay bass were evident from the growth statistics, which showed no significant trends during this 14-year period.

The smallmouth bass length-weight relationship was described by least square regression computations using the equation $W = aL^b$, transformed to $\log_e W = a+b\ (\log_e L)$, where:

W = weight in kg

L = length in mm

a = intercept

b = slope

A regression of weighted mean lengths and weights was computed for the period before as well as after the bass size limit increase. For the 1972–76 period, a = –17.86 and b = 2.98, while in the 1977–85 period, a = –18.95 and b = 3.16.

Anchor Bay smallmouth bass males usually mature at age 3 and females at age 4. This is typical of faster-growing populations in this latitude. Latta (1975) summarized age data from many smallmouth bass populations and found that, in the Great Lakes and other large northern lakes, males mature when they are about 254 mm (age 3 or 4) and females when they are about 305 mm total length (age 4 or 5). Anchor Bay bass are longer-lived (up to 12 years old) than reported for southern populations. Stroud (1948) found few smallmouth bass 6 years old in Norris Reservoir, Tennessee, and concluded that their early senility and death were a result of their rapid growth.

Creel census

Smallmouth bass were the fifth most abundant species taken by boat anglers in Lake St. Clair during both years of the 1983–85 on-site creel census (Tables 5 and 6). More numerous in the catch were yellow perch, walleye, rock bass, and white bass (*Morone chrysops*). The estimated boat angler harvest of smallmouth bass in Michigan waters of Lake St. Clair was 24,073 ± 13,733 (0.0158 ± 0.0091 fish per hour) in 1983, and 16,035 ± 4,462 (0.0111 ± 0.0031 fish per hour) in 1984.

It is important to note that creel estimate errors of significant magnitude were possible. This is because many of the most skilled bass anglers reside locally and were not apt to be found at public sites where creel interviews were conducted. The estimates also do not account for the illegal harvest which may be substantial because of an increased angler inclination to harvest bass before the season opens (1 month later than anywhere else in the state).

The most effort expended in the SCDRS during the 1983–85 creel census was in Lake St. Clair, where the estimated total of 2.97 million boat angler hours was slightly more than boat and shore angling effort combined for the Detroit River. Detroit River anglers, in a fishery dominated by white bass (67% of the total harvest), had an annual harvest of 1.4 million fish and a catch rate of 1.1 fish per hour. The next highest catch and catch rate was in Lake St. Clair, with 740,000 fish and 0.5 fish per hour, respectively, followed by the St. Clair River with 139,000 fish and 0.3 fish per hour.

The Krumholz and Carbine (1945) creel census of 1942 and 1943 measured only boat angler harvest and effort. In that period, an estimated 40,461 smallmouth bass were harvested throughout the SCDRS, compared to 49,432 (or only 1.2 times more) in the boat angler portion of the creel census of 1983 and 1984. However, the bass catch rate per hour was twice as great in the earlier census, 0.018 versus 0.009, respectively. Boat angling effort in particular, as expected, has increased steeply in the 40-year period between creel surveys. Boat angling effort was estimated at 5.56 million hours for 1983 and 1984 combined, compared to 2.23 million hours expended in the 1942–43 years combined.

Year class strength

Correlation of smallmouth bass year class recruitment with water temperatures has been widely studied and the conclusions drawn have generally been in close agreement for northern populations. Survival of northern bass is closely dependent on the size attained by first winter, since overwinter mortality is significantly dependent on size (Oliver et al. 1979, Shuter et al. 1980, Serns 1982). No study has revealed a suppression by a large year class of a subsequent year's recruitment. Watt (1957) suggested that temperature may regulate smallmouth bass abundance near their northern limit of range. Low summer water temperatures can affect survival of broods of these northern stocks at two critical stages. The first temperature-critical period occurs in the first few weeks after spawning. A water temperature drop below 15 °C in this period may reduce brood survival (Rawson 1945, Latta 1963). The increased mortality is associated with nest desertion by the male (Shuter et al. 1980). Premature withdrawal of this adult protection increases opportunities for predation on the eggs or young fry.

MacLean et al. (1981) concluded that the entire summer's mean temperature can be associated with survival of young-of-the-year (YOY) in northern populations. This condition occurs when low temperatures induce late or repeated spawnings. The YOY, without a full season's growth, are undersized and subject to starvation caused by insufficient energy reserves to sustain them through their first winter. Even when spawning is not delayed, prolonged low summer water temperatures slow growth rate, causing undersized YOY, and resultant poor winter survival (Serns 1982, Clady 1975). Forney (1972) found only June temperatures showed a strong positive correlation with year class strength of smallmouth bass in Oneida Lake, New York. Various combinations of July through October temperature indices were low in correlation. Oneida Lake summer water temperatures of 21 °C to 27 °C were recorded during Forney's study, which are far warmer than have been associated with first year mortality, and are, in fact, within the temperature range reported for maximal YOY bass growth rate (Horning and Pearson 1972).

In Anchor Bay, the relative strength of smallmouth year classes was compared with the summer temperature regime to detect any of the correlations noted in these farther north populations. A basic assumption held that the trap net CPUE represented the true age structure of the adult population. The catch data generally did not contradict the validity of this assumption, except in 1976 and 1982 when the netting was done later in the summer than had been established for the survey period. Data from these two irregular surveys were not considered representative and were not used in the analyses.

Fry and Watt (1957) noted direct correlation of smallmouth bass year class strength with the algebraic sum of monthly deviations from mean air temperatures, July through October in South Bay, Lake Huron. This type of correlation was not detected in Anchor Bay. It should be noted that any comparison between Anchor Bay water and air temperatures is complicated by the influx of St. Clair River water, often of a different temperature. Temperature fluctuations also probably occur due to the complex pattern of currents which change whenever the prevailing wind direction changes (Derecki 1984a).

A comparison of Anchor Bay water temperatures (New Baltimore Water Department data) with Mt. Clemens air temperatures (National Oceanic and Atmospheric Administration 1986) indicates the amount of deviation (Table 7). Thermal differences peaked, as expected, when air temperatures were changing most rapidly (June and September). The deviation had reversed by August, with higher water than air temperatures recorded. For the June-October period combined, thermal differences were nullified. The air and water temperature mean for both was 18.5 °C.

The monthly means of summer water temperatures were compared singly and in combinations with the CPUE of age 4, age 4 and age 5 combined, and age 4 through age 6 combined. No correlation was detected. Correlation of year class abundance with means of June water temperatures was not observed in Anchor Bay as it was in the Oneida Lake study.

A series of regression analyses were run, comparing relative year class strength with the number of days with water temperature less than 15 °C during June, which was the most important spawning period. Regression analysis of age-4 CPUE versus $\log_e$ of June days less than 15 °C had the best correlation ($r^2 = 0.58$). The nonlinear, inverse regression curve in Figure 3 is described by the semi-logarithmic equation, $Y = 17.46 - 5.51 \log_e (X+1)$, where Y = age-4 CPUE and X = number of June days with water temperatures less than 15 °C.

The highest age-4 CPUE's were observed in 1981 and 1985 (whose year classes originated in 1977 and 1985, respectively, when there were no June days less than 15 °C). The third largest CPUE was in 1980 (the year class born in 1976 when only two June days less than 15 °C were recorded early in the month). At the other extreme, the lowest age-4 CPUE occurred in 1973 (whole year class originated in 1969, which was one of the 2 years with the most June days less than 15 °C).

Year-class strength correlation with June water temperatures was evident. However, unlike more northerly populations, correlation with other characteristics of summer temperature was not observed. There was no evidence, during the period of this study, that summer-long, or even June-long water temperature averages played a role in brood survival, and ultimately, of year class abundance. As previously discussed, the climate at the latitude of Lake St. Clair is far more temperate than at the species' northern limit of habitat. The spring warm-up of Lake St. Clair is most likely slower than for inland lakes of the same latitude due to the flow-through of cooler Lake Huron water. However, a reverse condition probably occurs in the fall when tempered water is supplied by Lake Huron with its vast heat storage capacity (Derecki 1984b). A compensating extension of the growing season into the fall is a possible result.

Mortality

No bass were tagged in 1977, which effectively separated the tag recapture data from before and after the 1976 change in size limit. An assumption was made that, in both time series, the mean tag recovery rate was a valid representation of exploitation (u) after multiplication by a 1.35 reward:non-reward tag return rate factor previously discussed. No tests were conducted to verify the correctness of the assumption. Unanswered questions were (1) Is the 1.35 correction factor a truly representative adjustment for any year, particularly for the pre-1977 period? and (2) Has the rate of reporting changed, e.g., due to increased publicity about the tagging program?

In the 1978–85 period, estimated annual survival rate ($\bar{S}$) was 41.5% ± 1.7, and the mean tag recovery rate was 9.6% ± 0.4 (Table 8). The 9.6% rate times the 1.35 adjustment factor provided the estimate of u = 13.0%. For the 1972–76 period, $\bar{S}$ was 51.1% ± 6.7, and mean recovery rate was 5.5% ± 0.5 (Table 9). The estimate of u = 7.4% was derived by applying the 1.35 adjustment to the tag return rate.

A statistical test (developed by Brownie et al. 1985) showed no significant difference ($\alpha = 0.05$) in the $\bar{S}$ estimates for the two periods, but mean tag return rates for the two periods were significantly different at the 0.05 level. The inference is that survival had remained at a similar rate, but fishing mortality had increased significantly in the latter period.

Annual total and natural mortality rate estimates were high, but the estimated fishing mortality rate was very low compared to eight other populations (Table 10). The Anchor Bay bass conditional natural mortality rate for the 1978–85 period was the highest, total mortality rate (A) was third highest, and conditional fishing mortality rate was the lowest of the nine populations compared.

The estimates of $\bar{S}$ from tag return analyses were quite similar to estimates derived from the descending limb of catch curves where $S = e^{-Z}$. The estimate of $\bar{S}$ from tag recoveries for 1972–76 was 0.511 and for 1978–85 was 0.415. From the catch-curve analysis the estimate of $\bar{S}$ for 1972–76 was 0.480 and for 1978–85 was 0.424.

Yield per recruit

A management change increased the smallmouth bass minimum size limit from 254 mm to 305 mm beginning in 1976. This alteration in legal minimum length of capture, about midway in the survey period, provided an opportunity to evaluate any change in the population resulting from the increase in the size limit.

Separate Y/R analyses were computed for the time period before and after the size limit increase to evaluate and predict rates of exploitation optimal for the smallmouth bass stock. This model assesses parameters of growth with estimates of instantaneous fishing and natural mortality rates (F and M, respectively).

The von Bertalanffy growth equation was obtained from pooled 1972 through 1985 mean-length-at-age data. Weighted mean length-weight regressions, computed separately for the two time periods, provided the intercept (a) and slope (b) parameters. Total instantaneous mortality rate (Z) was derived from the $\bar{S}$ estimate obtained from tag return analyses, i.e., $Z = -\log_e(\bar{S})$. Instantaneous natural mortality rate (M) was consequently obtained from $M = Z - F$. All parameter estimates are summarized in Table 11.

For the 1972–76 period, when the legal minimum size limit (LC) was 254 mm and the estimate of F was 0.103, yield isopleths were computed by varying F and LC. The resulting plot predicted that maximum Y/R would be attained, given a 254-mm minimum size limit, if F were increased to 0.789 (Figure 4).

Attaining the maximum yield presented in the isopleth graph is not necessarily a desirable objective. It considers maximum biomass available for harvest, whereas fewer but larger fish is the likely goal of most ardent bass anglers. It also assumes constant recruitment which is not true for smallmouth bass. The Y/R analyses of the 1978–85 years examined the period after state law increased the length of entry to the fishery to 305 mm. Results of this analysis, plotted in an isopleth graph, indicated that at the level the fishery was operating, Y/R was about the same for both periods (Figure 5). The Y/R was slightly lower for given values of F and LC, than in the 1972–76 period. Maximum yield, as in the earlier period, was predicted for a minimum size limit of 254 mm.

DISCUSSION

The 15-year tag study revealed that the movement of most Anchor Bay smallmouth bass was confined to the bay and, to a lesser extent, adjoining Michigan waters of Lake St. Clair and the St. Clair River. Relatively few of these fish moved into Ontario waters of the lake. This distribution helps simplify the management of this population by eliminating the need to account and adjust for lengthy migrations and mixing of stocks from other jurisdictions and bodies of water.

The smallmouth bass minimum size limit was increased by state law from 254 mm to 305 mm in 1976. This regulation helped assure that females, which first became sexually mature at the new size limit (age 4), would have at least one spawning opportunity. In the 1977–85 period after the size limit increased, the mean CPUE of age-4 smallmouth bass in the survey nets was 3.5 times higher than the mean for the 1972–75 period immediately prior to the change. The consistently higher CPUE of this latter period was indicative of a real population increase. However, caution is needed in assessing the reason for this increase, since any of a number of factors could have been the cause.

The timing of the higher CPUE's with the size limit increase does not necessarily confirm a correlation. Although increased numbers of age-4 bass could be expected due to the additional year of protection from exploitation afforded by the new regulation, no other increase in adult recruitment would be expected. No relationship has been demonstrated linking smallmouth bass abundance to the abundance of adult spawners in an established population (Fox 1975).

Significant positive correlation was found between recruitment of the strongest year classes of age-4 bass and the presence of optimal spawning water temperatures (few or no days below 15 °C) during the month of June of the year of their birth. This correlation can be demonstrated by comparing the mean of June days below 15 °C and the mean CPUE of age-4 bass before and after 1976. In the 1977–81 period, number of June days with water temperatures below 15 °C averaged 2.8 days, but the mean in the 1969–75 period was 8.0 days, 2.9 times higher. Similarly, the mean CPUE of age-4 bass was 5.34 in the 1969–75 period, but 14.10 in the 1977–81 period, or 2.6 times higher.

Increased adult bass CPUE could result if the catch efficiency of the nets improved, e.g., as the netting personnel became more experienced. If this occurred, an increase in the CPUE of other species could be expected. However, a plot of the total CPUE of all species, except smallmouth bass, with sample years, did not reveal significant correlation. An increased CPUE trend in other species was not demonstrated.

The available evidence indicates there was a real expansion of the adult smallmouth bass population after 1976. However, the causes of the increase cannot be confidently assessed. The environmental factor appearing to be most responsible was June water temperatures.

Population density or environmental changes were not large enough to be detected by growth statistics collected over a 14-year period. Anchor Bay smallmouth bass grow at a faster rate than a North American average compiled from many populations. They grow faster than populations farther north and slower than in some reservoir populations to the south. Coble (1967) found a clear relationship between smallmouth bass growth rate and mean summer water temperatures, with more growth associated with warmer temperatures.

Smallmouth bass ranked fifth in numbers harvested by boat anglers in Lake St. Clair during the 2 years of creel census, 1983–85. This amounted to 2.7% of the total number of fish of all species harvested in this period. The first creel census of Lake St. Clair conducted in 1942–43 estimated a smallmouth bass harvest of nearly the same size as estimated in the 1983–

85 catch. It is conceivable that the numbers of bass caught by anglers have remained rather even over this long time period despite apparent intensified angling effort in recent years.

Analyses of the tag recapture data provided the means for estimating bass exploitation rates. One of the assumptions made was that the tag return rate, multiplied by the one calculation of reward versus non-reward tag return rate ratio of 1.35, was a valid representation of $\bar{u}$ for all years under consideration. The estimate of $\bar{u}$ was 13.0% for the post-regulation years of 1978–85, or nearly twice the $\bar{u}$ estimate for the pre-regulation years of 1972–76. Statistical analyses of the tag return data indicated that although there was no significant difference in $\bar{S}$, there was a significant difference in $\bar{u}$ for the two periods.

Serious questions arise in envisioning a bass population that was apparently expanding at the same time that the exploitation rate had apparently nearly doubled, but survival rate, or total mortality rate, had not significantly changed. It is important to note that the statistical program derived survival estimates from the tag data independent of the tag recovery rates and consequently are not influenced by the non-reporting of tags.

As previously discussed, the estimate of the Anchor Bay bass exploitation rate was the lowest and natural mortality rate was the highest compared to eight other widely distributed populations. However, total mortality was in the intermediate range compared to these other populations. It is difficult to believe that bass fishing mortality would be exceptionally low and natural mortality exceptionally high in the heavily exploited environment of Lake St. Clair.

The 1981–83 reward tag program confirmed that there was significant underestimation of tag recovery rates. However, the assignment of a single, mean non-reward to reward tag recovery rate ratio (1.35) to all years of tag data was necessarily very error-prone. It is logical to suspect that the tag reporting rate was significantly lower in the years before the reward tag program began in 1981. The 1.35 adjustment of non-reward tag recovery rates may have been unrepresentative for data of most years. Although the reward tag program was intentionally never publicized, it obviously became widely known to anglers with the passage of time. This knowledge quite possibly stimulated a greater reporting rate in the short-term. For example, the rate of return of reward-tagged bass caught in the year of release was 9.89% in 1981, 19.41% in 1982, and increased to 27.5% in 1983, or 2.8 times the 1981 rate.

The reward tag program served to verify that bass tag recapture rates were underestimated, but it was not capable of projecting accurate estimates of $\bar{u}$ over the long tagging period. We conclude that, to varying unknown degrees, the estimates of $\bar{u}$ were too low and estimates of natural mortality rates too high. There is basis for doubting that there was a real increase in $\bar{u}$ after 1976.

Analyses indicated that Y/R, at the existing rates of exploitation, were about the same for the period before as well as after the 1976 size limit increase. In both periods, yield increased as F increased. This is based on the unreal model assumption of constant recruitment, which does not occur in the Anchor Bay bass population. The Y/R isopleths also predicted that maximum yield is attained at a minimum length of capture of 254 mm in both periods. However, larger fish, not maximum biomass harvest, is the generally accepted preferred goal when managing a species such as smallmouth bass, which is most valued for its superior sporting quality. The Y/R assessment did not represent real conditions to the extent that F and M estimates were in error.

Management recommendations

The effects of regulation changes on fish populations have become easier to study with the advent of population modeling. Changes in creel limits, size limits, and/or seasons are all regulation options to consider, if an attempt was made to increase harvest of Anchor Bay bass. The prior Lake St. Clair experience with a smaller (254-mm) size limit did not, in the years that it was studied (1972–76), show increased harvest compared to the period of 305-mm size limit.

Raising harvest by increasing the daily creel limit, e.g., to 10 bass, is questionable, since few anglers are apt to reach this maximum. Redmond (1974) in a Missouri lake study, found that only 0.2 percent of the anglers caught the limit of 10 largemouth bass during the first 4 days of fishing, and 59% caught no bass at all in the same period. Similar results have been recorded for smallmouth bass in Michigan (Latta 1975). Maintaining the present creel limit may also enhance anglers' evaluation of satisfactory bass fishing quality in Lake St. Clair. Fox (1975) reasoned that maximum creel limits become the automatic goal of anglers who then evaluate fishing quality as high, if the creel limit is low enough to compare favorably with their daily catch. Keeping the SCDRS creel limit at the current five bass also maintains the statewide uniformity of that regulation.

The most effective means of increasing yield, at least short-term, would involve changing the SCDRS bass season, which does not open until the third Saturday in June, 4 weeks later than anywhere else in Michigan. The late season opening unquestionably deletes the most effective period of bass exploitation. There is no scientific basis for deciding that Lake St. Clair bass need more spawning season protection than populations anywhere else in Michigan. Returning Lake St. Clair to the regular May 15 opener would be beneficial by making regulations uniform statewide. However, the present bass season opening is close to the season opener for Ontario waters of Lake St. Clair.

Lake St. Clair supports an excellent smallmouth bass population and sport fishery, which is perhaps reflected in a general lack of public sentiment to alter their management. Altering the angling regulations under present conditions is not justified. We recommend that the present regulations remain in place.

ACKNOWLEDGMENTS

The support and guidance of Robert C. Haas and W. C. Latta were deeply appreciated. Richard D. Clark, Jr., provided valuable assistance with yield-per-recruit isopleth graphs. The field and laboratory work was provided by the dedicated effort of many permanent and temporary employees. Alan D. Sutton drafted the figures, Bonnie M. Menoske typed the rough draft, and Grace M. Zurek typed the final manuscript.

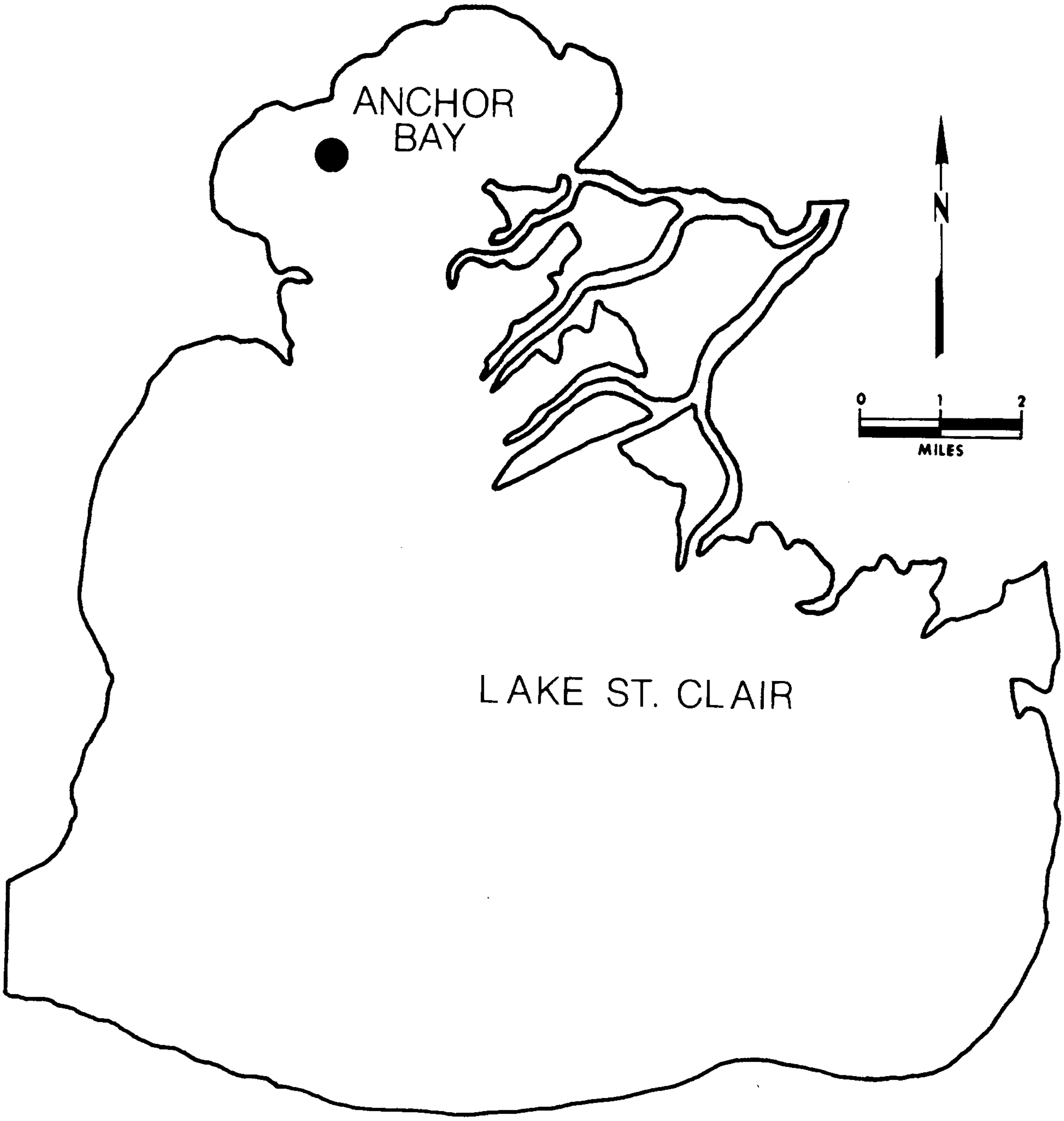

Figure 1. Location of A-marker trap net station in western Anchor Bay, Lake St. Clair.

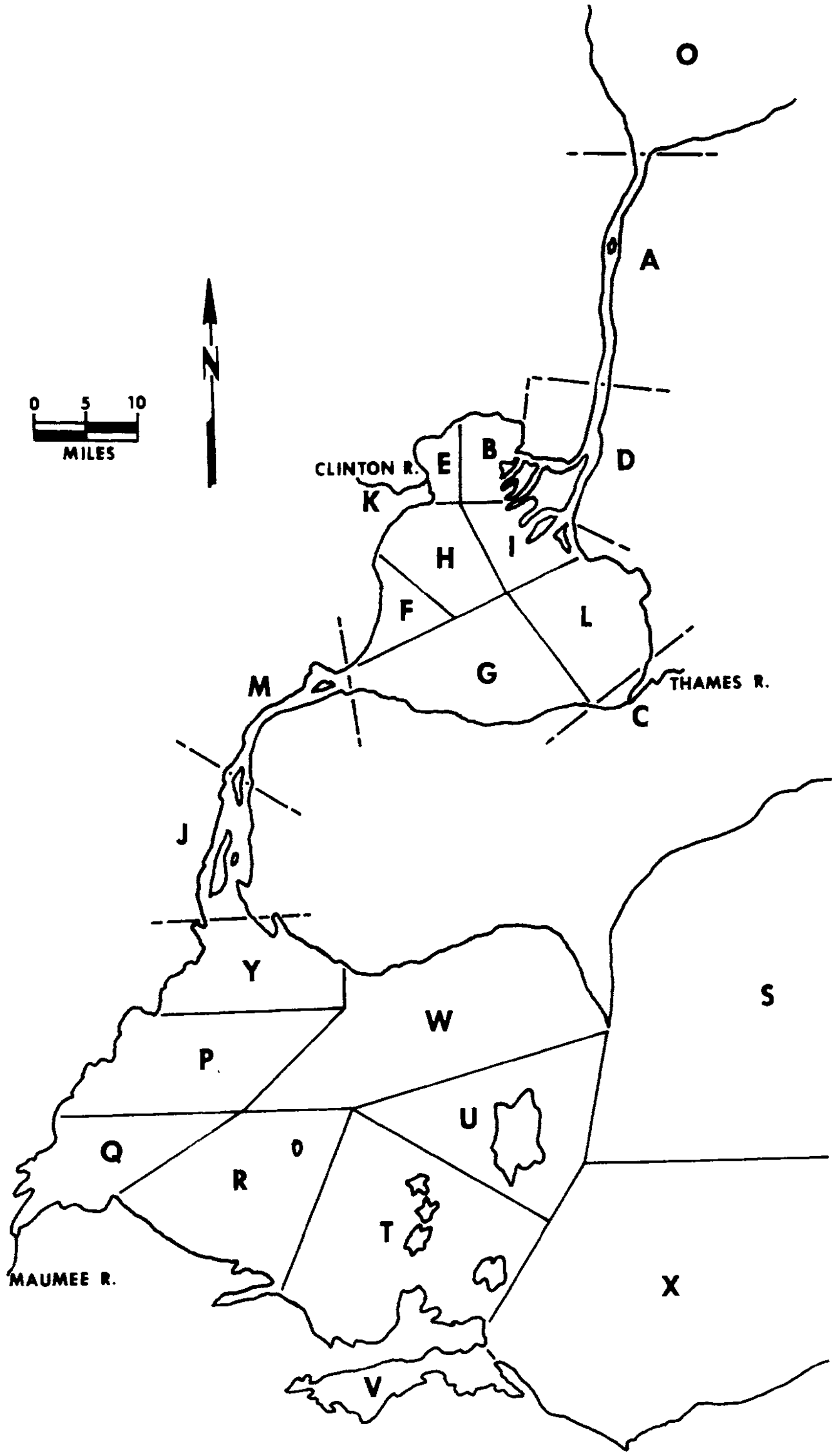

Figure 2. Grids used to locate tag recoveries reported by anglers from Lake St. Clair and connecting waters.

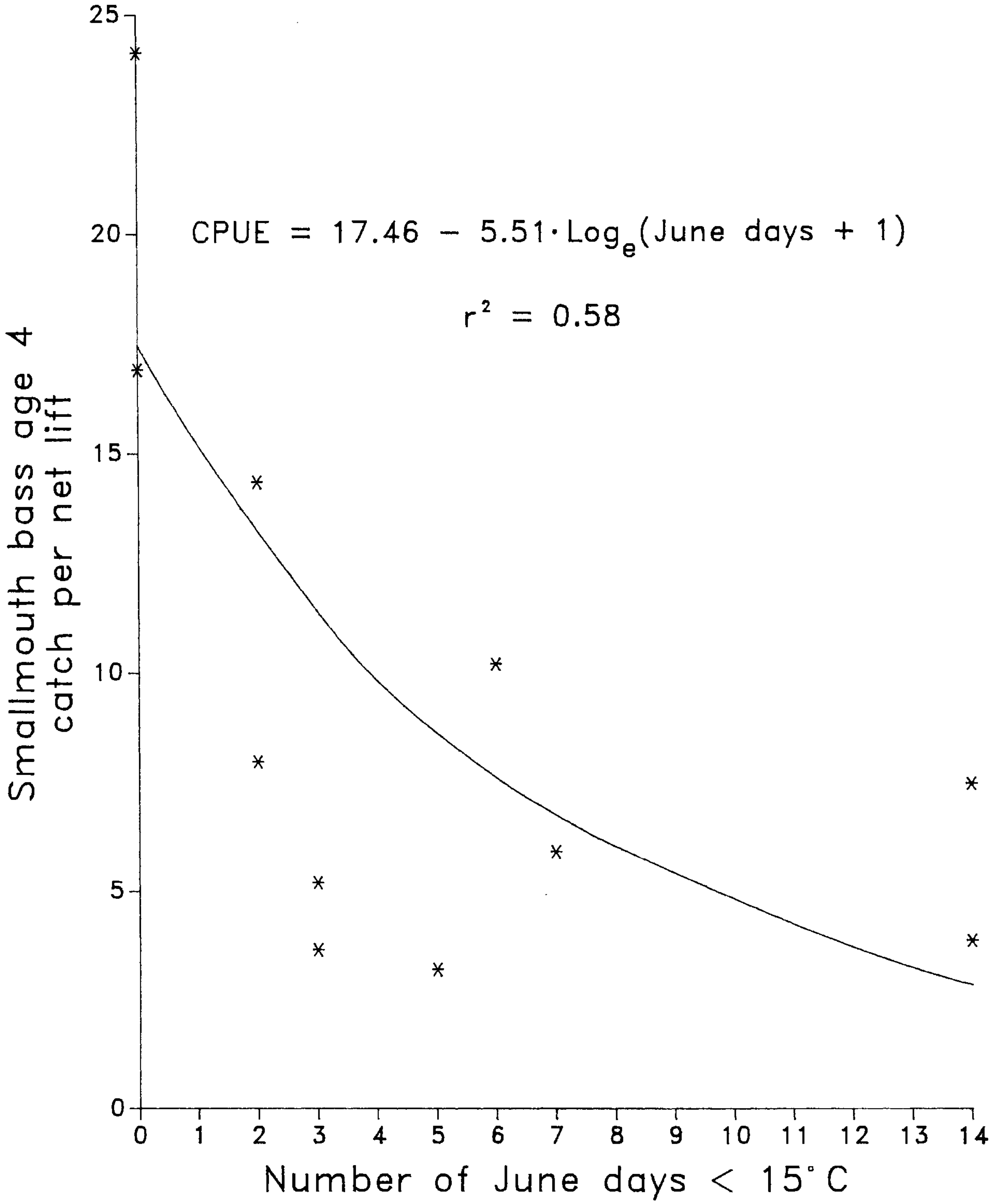

Figure 3. Relationship between catch per net lift (CPUE) of smallmouth bass age 4 and the number of June days with water temperature less than 15 °C.

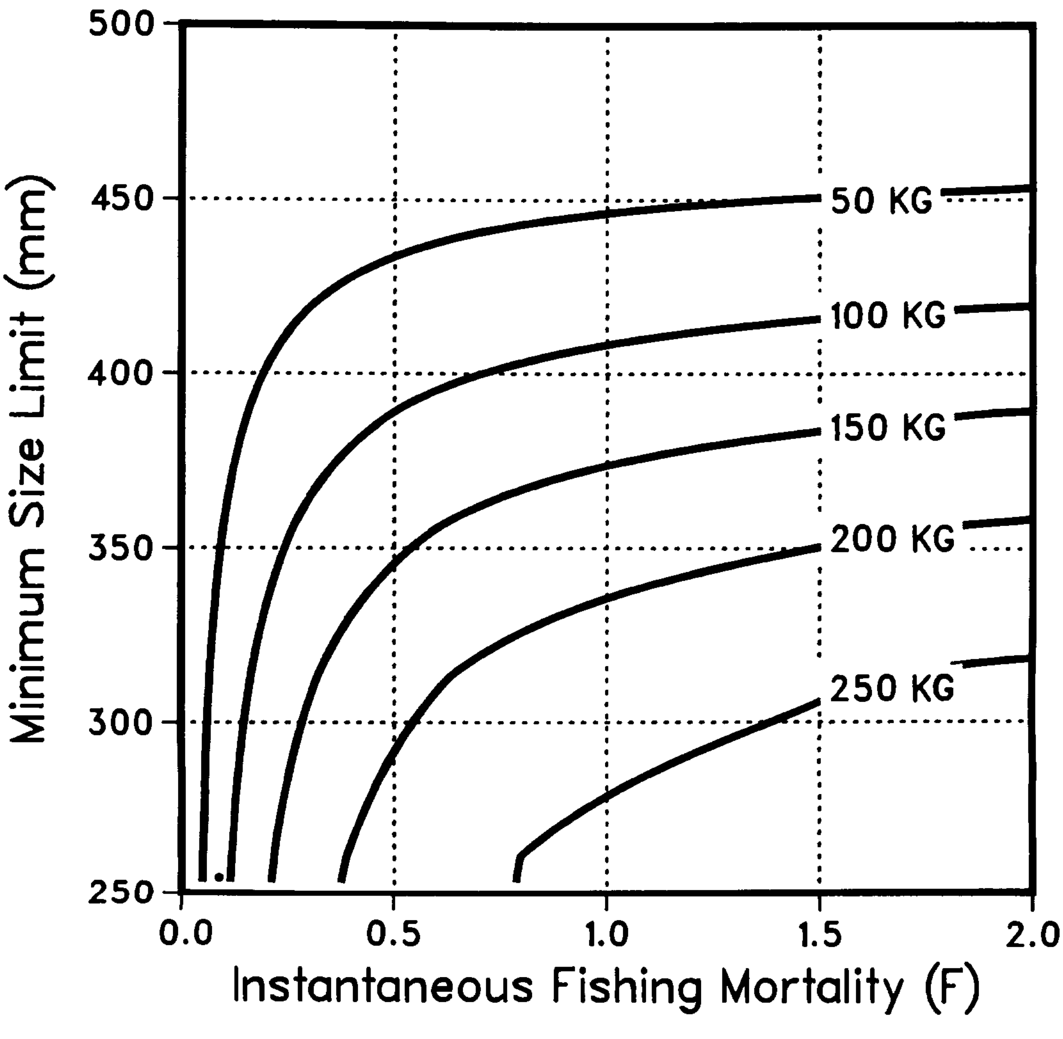

Figure 4. Yield per 1,000 recruits as a function of minimum length and instantaneous fishing mortality rate in the 1972-76 period. Size of entry was 254 mm and estimate of F was 0.103. Point indicates operating level of fishery.

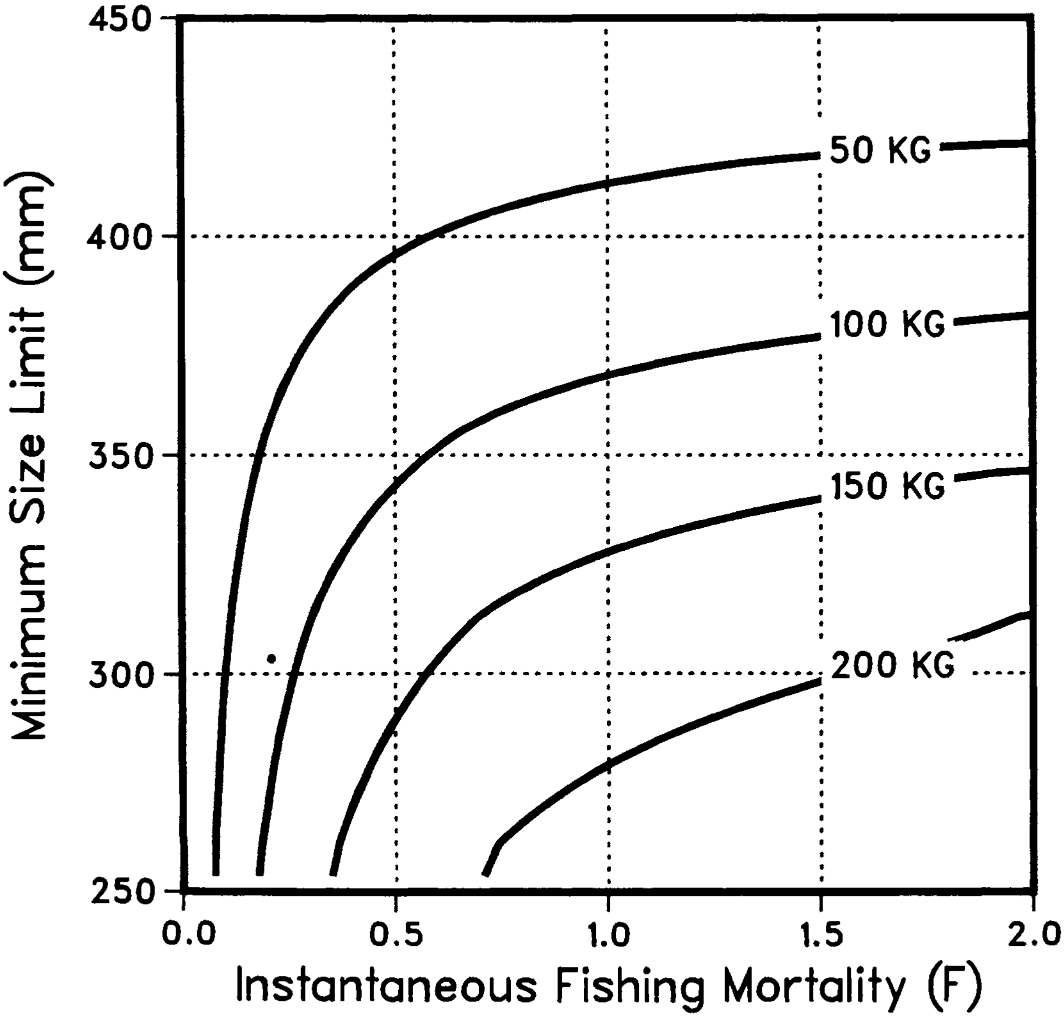

Figure 5. Yield per 1,000 recruits as a function of minimum length and instantaneous fishing mortality rate in the 1978–85 period. Size of entry was 305 mm and estimate of F was 0.195. Point indicates operating level of fishery.

Table 1. Geographical distribution of smallmouth bass tags recovered by anglers 1971–85, after release from A-marker station in western Anchor Bay, Lake St. Clair.

Recovery location	Grid	Distance from tag site (miles)	Distance from tag site (km)	Number of returns	Number of total
Southern Lake Huron	0	44.3	71.3	1	0.1
Upper St. Clair River	A	32.0	51.5	32	2.0
Lower St. Clair River	D	16.0	25.7	158	9.9
East Anchor Bay	B	4.5	7.2	430	26.9
Western Anchor Bay	E	—	—	674	42.2
Clinton River	K	9.4	15.1	4	0.2
Northern Lake St. Clair	H	9.1	14.6	141	8.8
St. Clair River Delta	I	9.3	15.0	57	3.6
Eastern Lake St. Clair	L	19.3	31.1	4	0.2
Southern Lake St. Clair	G	17.4	28.0	1	0.1
Western Lake St. Clair	F	13.7	22.0	55	3.4
Upper Detroit River	M	28.5	45.9	15	0.9
Lower Detroit River	J	43.3	69.7	11	0.7
Detroit River Mouth	Y	47.0	75.6	3	0.2
Northwestern Lake Erie	W	65.4	105.2	2	0.1
Unknown location	—	—	—	11	0.7
Total	—	—	—	1,599	100.0

Table 2. A summary of reward and non-reward tagged smallmouth bass recovered during the 1981–85 period.

Tag value	Year tagged	Number tagged	Year recovered 1981	1982	1983	1984	1985	Total recoveries	Percent recoveries
$2	1981	88	6	4	2	1	0	13	14.77
$4		93	8	9	2	1	0	20	21.51
$6		88	13	2	4	0	0	19	21.59
$8		85	8	4	2	1	0	15	17.65
Non-reward		644	43	38	13	1	2	97	15.06
Total		998	78	57	23	4	2	164	16.43
$2	1982	43	—	5	2	1	0	8	18.60
$4		44	—	11	4	2	0	17	38.64
$6		39	—	3	7	1	0	11	28.21
$8		44	—	4	3	0	0	7	15.91
Non-reward		214	—	30	10	4	1	45	21.03
Total		384	—	53	26	8	1	88	22.92
$2	1983	54	—	—	12	3	1	16	29.63
$4		52	—	—	17	6	1	24	46.15
$6		53	—	—	14	2	1	17	32.08
$8		55	—	—	16	5	0	21	38.18
Non-reward		727	—	—	102	41	13	156	21.46
Total		941	—	—	161	57	16	234	24.87

Table 3. Smallmouth bass catch per lift (CPUE) by year class in trap nets set in the spring, Anchor Bay, Lake St. Clair, 1972–85.

Year class	Sample year[1]											
	1972	1973	1974	1975	1977	1978	1979	1980	1981	1983	1984	1985
1962	0.09	—	—	—	—	—	—	—	—	—	—	—
1963	0.05	—	—	—	—	—	—	—	—	—	—	—
1964	0.17	—	—	0.02	—	—	—	—	—	—	—	—
1965	0.22	0.04	0.02	0.03	—	—	—	—	—	—	—	—
1966	0.56	0.43	0.06	0.07	—	—	—	—	—	—	—	—
1967	2.26	0.61	0.36	0.08	0.03	—	—	—	—	—	—	—
1968	2.89	2.20	0.81	0.42	0.13	—	—	—	—	—	—	—
1969	1.97	3.86	2.64	0.90	0.19	—	0.02	—	—	—	—	—
1970	0.05	1.66	3.66	2.43	0.99	0.24	0.18	0.11	—	—	—	—
1971	—	—	1.62	3.21	1.85	0.59	0.26	0.11	—	—	—	—
1972	—	—	—	0.16	1.31	0.94	0.49	0.97	0.10	—	0.01	—
1973	—	—	—	0.01	7.96	12.76	3.12	2.12	0.37	0.01	0.00	—
1974	—	—	—	—	0.48	7.44	2.11	1.71	0.34	0.07	0.08	—
1975	—	—	—	—	0.07	3.09	5.89	5.20	1.53	0.02	0.11	0.11
1976	—	—	—	—	—	0.09	4.55	14.34	6.80	0.68	0.19	0.18
1977	—	—	—	—	—	—	0.05	20.64	24.12	3.60	1.67	0.59
1978	—	—	—	—	—	—	—	—	2.87	2.19	2.00	0.81
1979	—	—	—	—	—	—	—	—	0.07	5.19	4.35	2.21
1980	—	—	—	—	—	—	—	—	—	3.12	10.19	6.33
1981	—	—	—	—	—	—	—	—	—	0.04	8.16	16.91
1982	—	—	—	—	—	—	—	—	—	—	0.15	2.93
1983	—	—	—	—	—	—	—	—	—	—	—	0.07
Total CPUE	8.26	8.80	9.17	7.33	13.01	25.15	16.67	45.20	36.20	14.92	26.91	30.14
Mean age	4.41	4.36	4.44	4.86	4.69	4.56	4.43	4.02	4.27	4.58	4.24	4.47

[1]1976 and 1982 survey data were collected during summer and are not comparable.

Table 4. Mean total length (mm) at age of Anchor Bay smallmouth bass compared to a northern, southern, and average population. Sample size is in parentheses.

Sample year	Age 2	3	4	5	6	7	8	9	10
1972	241	273	320	359	390	425	443	442	480
	(1)	(39)	(66)	(50)	(12)	(5)	(3)	(1)	(1)
1973	—	258	286	333	376	411	420	—	—
	—	(71)	(165)	(94)	(27)	(19)	(2)	—	—
1974	—	258	298	328	375	395	437	485	—
	—	(113)	(252)	(179)	(51)	(22)	(4)	(1)	—
1975	239	251	290	332	371	406	437	471	479
	(1)	(8)	(187)	(138)	(51)	(24)	(4)	(5)	(2)
1976	223	255	292	322	370	403	462	419	—
	(4)	(65)	(13)	(18)	(26)	(8)	(2)	(1)	—
1977	211	260	301	326	362	394	426	391	478
	(2)	(13)	(160)	(29)	(48)	(29)	(7)	(3)	(1)
1978	241	276	314	345	373	402	422	—	—
	(1)	(35)	(87)	(158)	(11)	(6)	(2)	—	—
1979	236	267	309	342	377	411	415	438	450
	(2)	(171)	(208)	(74)	(116)	(19)	(10)	(7)	(1)
1980	—	264	301	341	379	393	413	394	419
	—	(154)	(123)	(48)	(16)	(20)	(9)	(1)	(1)
1981	212	264	302	333	373	419	418	434	—
	(2)	(83)	(678)	(193)	(44)	(10)	(11)	(3)	—
1982	243	271	315	346	376	408	431	—	486
	(10)	(100)	(81)	(179)	(45)	(10)	(9)	—	(1)
1983	245	267	309	342	371	399	416	431	483
	(3)	(194)	(315)	(154)	(231)	(43)	(1)	(4)	(1)
1984	251	275	321	356	392	415	434	458	463
	(12)	(637)	(774)	(326)	(142)	(116)	(13)	(6)	(5)
1985	229	267	310	352	384	413	428	453	473
	(4)	(132)	(943)	(394)	(136)	(48)	(35)	(11)	(7)
Anchor Bay, A-marker	239	268	308	344	377	408	427	444	469
Northern (Waugoshance Pt., Lake Michigan)	160	205	246	292	335	371	401	427	442
Southern (Norris Reservoir, Tennessee)	259	358	411	444	457	472	—	—	—
Average (North American compilation)	170	234	279	323	358	381	404	429	—

Table 5. Estimated number of fish harvested by boat anglers in Lake St. Clair from April 1983 to March 1984. (Two standard errors in parentheses.)

Species[1]	Month												Total
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	
White perch	—	—	283	872	281	143	60	—	—	—	—	—	1,639
	—	—	(487)	(934)	(363)	(270)	(89)	—	—	—	—	—	(1,150)
White bass	—	—	10,400	15,050	1,808	19	—	—	—	—	—	—	27,277
	—	—	(12,302)	(24,338)	(1,721)	(40)	—	—	—	—	—	—	(27,324)
Freshwater drum	—	269	5,691	5,229	6,735	2,692	268	—	—	—	—	—	20,884
	—	(571)	(3,916)	(2,568)	(4,432)	(1,674)	(402)	—	—	—	—	—	(6,698)
Rock bass	—	1,032	24,882	11,842	19,053	3,695	1,209	—	—	—	—	—	61,713
	—	(1,935)	(13,446)	(8,486)	(13,114)	(2,298)	(896)	—	—	—	—	—	(20,847)
Pumpkinseed	—	2,436	8,384	2,390	2,531	3,758	585	—	—	—	25	—	20,109
	—	(2,879)	(6,163)	(2,294)	(1,414)	(3,067)	(757)	—	—	—	(50)	—	(7,970)
Smallmouth bass	—	—	15,180	2,567	3,094	2,951	252	29	—	—	—	—	24,073
	—	—	(13,415)	(1,651)	(1,682)	(1,736)	(261)	(57)	—	—	—	—	(13,733)
Yellow perch	—	4,886	45,280	160,854	129,881	95,445	77,600	6,158	—	—	638	68	520,810
	—	(5,094)	(21,930)	(51,221)	(41,290)	(31,365)	(28,429)	(4,757)	—	—	(1,029)	(112)	(81,554)
Walleye	—	1,122	46,178	37,117	38,310	4,936	3,332	504	30	—	—	—	131,529
	—	(1,847)	(21,145)	(12,848)	(9,527)	(2,223)	(2,781)	(615)	(30)	—	—	—	(26,822)
Other	—	999	3,426	7,407	5,071	3,684	842	17	—	—	233	—	21,679
	—	(1,542)	(2,384)	(7,998)	(3,646)	(3,255)	(1,173)	(36)	—	—	(465)	—	(9,875)
Total	—	10,744	159,704	243,328	206,764	117,323	84,148	6,708	30	—	896	68	829,713
	—	(6,641)	(38,722)	(59,434)	(44,816)	(31,936)	(28,617)	(4,797)	(30)	—	(1,130)	(112)	(94,591)

[1]Species not identified in the text are freshwater drum *Aplodinotus grunniens* and pumpkinseed *Lepomis gibbosus*.

Table 6. Estimated number of fish harvested by boat anglers in Lake St. Clair from April 1984 to March 1985. (Two standard errors in parentheses.)

Species[1]	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
	Month												
White perch	—	52	835	760	151	71	72	—	—	—	—	—	1,941
	—	(105)	(1,284)	(1,119)	(311)	(148)	(148)	—	—	—	—	—	(1,747)
White bass	—	301	71,932	508	482	580	101	73	—	—	—	—	73,977
	—	(483)	(113,525)	(353)	(764)	(963)	(205)	(155)	—	—	—	—	(113,533)
Freshwater drum	—	91	4,980	8,259	1,295	607	542	24	—	—	—	—	15,798
	—	(134)	(4,894)	(4,843)	(1,393)	(523)	(935)	(52)	—	—	—	—	(7,107)
Rock bass	73	340	15,510	9,141	6,984	2,491	1,474	97	—	—	—	—	36,110
	(95)	(585)	(7,521)	(3,634)	(2,906)	(1,748)	(1,202)	(207)	—	—	—	—	(9,116)
Pumpkinseed	—	70	4,902	1,038	3,049	1,191	1,383	—	—	—	—	—	11,633
	—	(144)	(7,541)	(756)	(2,487)	(1,136)	(2,250)	—	—	—	—	—	(8,366)
Smallmouth bass	—	107	5,281	6,562	2,267	881	851	87	—	—	—	—	16,036
	—	(221)	(3,146)	(2,653)	(1,284)	(634)	(927)	(127)	—	—	—	—	(4,462)
Yellow perch	511	7,254	25,045	72,425	41,988	91,307	102,628	2,930	—	—	—	124	344,212
	(502)	(11,913)	(10,944)	(28,637)	(19,474)	(30,644)	(67,354)	(2,323)	—	—	—	(260)	(83,320)
Walleye	517	15,789	57,212	30,219	7,156	5,146	12,129	3,040	305	708	—	—	132,221
	(553)	(5,459)	(15,213)	(7,748)	(2,632)	(3,147)	(7,243)	(1,688)	(237)	(868)	—	—	(19,863)
Other	1,214	1,219	3,628	1,488	3,262	2,861	850	—	—	—	—	—	14,522
	(734)	(1,138)	(1,858)	(755)	(2,887)	(2,653)	(644)	—	—	—	—	—	(4,653)
Total	2,315	25,223	189,325	130,400	66,634	105,135	120,030	6,251	305	708	—	124	646,450
	(1,051)	(13,179)	(115,722)	(30,436)	(20,332)	(31,016)	(67,807)	(2,886)	(237)	(868)	—	(260)	(143,090)

[1]Species not identified in the text are freshwater drum *Aplodinotus grunniens* and pumpkinseed *Lepomis gibbosus*.

Table 7. Lake St. Clair mean air and water temperature comparisons, June-October.

Month	Mean temperature (°C) Water 13 years	Mean temperature (°C) Air 30 years	Temperature deviation (C) (water - air)
June	16.6	19.8	-3.2
July	20.9	22.4	-1.5
August	22.4	21.5	+0.9
September	19.5	17.2	+2.3
October	12.8	11.5	+1.3

Table 8. Estimated annual tag recovery and survival rates, with 95% confidence limits in parentheses, for Anchor Bay smallmouth bass from tags applied and recovered during the period 1978–85.

Year	Tag recovery rate in percent	Survival rate in percent
1978	9.3 (7.1–11.4)	37.9 (23.3–52.5)
1979	7.1 (5.6–8.6)	51.9 (36.1–67.7)
1980	4.3 (3.5–5.2)	30.3 (22.2–38.4)
1981	7.0 (5.4–8.6)	33.2 (21.7–44.7)
1982	13.6 (9.7–17.5)	33.3 (21.2–45.4)
1983	14.3 (11.9–16.7)	45.9 (34.6–57.1)
1984	11.5 (10.2–12.8)	58.3 (46.3–70.2)
1985	6.7 (5.8–7.7)	— —

Table 9. Estimated annual tag recovery and survival rates, with 95% confidence limits in parentheses, for Anchor Bay smallmouth bass from tags applied and recovered during the period 1972–76.

Year	Tag recovery rate in percent	Survival rate in percent
1972	6.1 (3.5–8.8)	23.2 (4.8–41.7)
1973	3.0 (1.4–4.6)	54.6 (31.6–77.6)
1974	5.4 (3.8–7.0)	43.6 (28.7–58.5)
1975	7.5 (5.6–9.5)	82.9 (34.0–131.7)
1976	3.3 (1.4–5.2)	— —

Table 10. Estimated annual total, fishing, and natural mortality rates (%) for smallmouth bass in nine populations. Data are from Marinac-Sanders and Coble (1981) except for the Lake St. Clair population.

Location	Total	Fishing	Natural
Lake St. Clair, Michigan (1978–1985)	0.58	0.13	0.52
Clear Lake, Wisconsin	0.78	0.56	0.49
Merle Collins Reservoir, California	0.84	0.76	0.32
Lake Opeongo, Ontario	0.53	0.38	0.25
Waugoshance Point, Lake Michigan	0.58	0.28	0.41
South Bay, Lake Huron	0.51	0.35	0.24
Baie du Dore, Lake Huron	0.57	0.22	0.44
Oneida Lake, New York	0.43	0.35	0.12
Red Cedar, Wisconsin	0.55	0.34	0.31

Table 11. Parameter estimates used in the yield-per-recruit analyses. An asterisk indicates rates used and 95% confidence limits for the growth parameters are in parentheses.

Period	L_∞	K (in mm)	T_0	a	b	M	F	Z
1972–76	553	0.1939	–0.1517	–17.864*	2.979*	0.569*	0.103*	0.672*
	(61)	(0.0533)	(0.3499)	—	—	—	—	—
1977–85[1]	515	0.2297	–0.1413	–18.953*	3.158*	0.683*	0.195*	0.873*
	(48)	(0.0606)	(0.3509)	—	—	—	—	—
1972–85	534*	0.2121*	–0.1670*	–18.968	3.162	—	—	—

[1]Mortality estimates were calculated from 1978–85 data.

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