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# PRODUCTION AND THEORETICAL EQUILIBRIUM YIELDS FOR THE BLUEGILL (LEPOMIS MACROCHIRUS) IN TWO MICHIGAN LAKES[1]

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## Abstract

Considerable information on the bluegill populations in two small lakes at the Rifle River Recreation Area was collected between 1957 and 1962. During this time, fishing pressure varied from 70 to 115 hours per acre on Jewett Lake; 10.5 to 53 hours per acre on Lodge Lake. Based on the catches of fish marked each spring, anglers caught between 17 and 24.5% of the bluegills in Jewett Lake; 8 to 26% of the Lodge Lake fish. These same exploitation rates also were obtained by another method of calculation. In only two instances was there a tendency for anglers to catch or keep only the older (larger) fish.

Annual spring inventories in Jewett Lake showed that the bluegill population (fish at least 4.0 inches long) ranged between 5 and 65 pounds of fish per acre; one such census on Lodge Lake indicated there were 21 pounds of bluegills per acre. New growth put on by these fish during the year ranged from 44 to 47% of the weight of these spring populations; 34% for Lodge Lake. By weight, the new growth varied from 2 to 30 pounds per acre for Jewett Lake; 7 pounds per acre in Lodge Lake. For nearly all of these fish, the loss of weight from natural deaths greatly exceeded the weight of fish caught by fishermen.

To determine how much fishing pressure these lakes could take without affecting the populations, a method of calculation was employed that is used mostly by marine biologists for commercial fisheries. This method makes use of information on growth and the rates at which fish die (both natural deaths and fishing deaths). These calculations disclosed that these bluegill populations could have supported increases in fishing pressure ranging from 30 to 90%.

Usually bluegills (and many other species) reproduce so fast that they literally overwhelm their food supply and few can reach a desirable size. They have to be cropped off but usually there is no way of knowing how many must be removed in order to make the best use of the lake. The kind of calculations used in this study can provide the answer if there is enough information at hand.

## Introduction

Few will question the necessity for a sophisticated method of appraisal and management of warmwater fish populations. Careful studies of fish population dynamics, optimum yields, and annual production in natural lakes are needed to obtain this objective. For this study, data suitable for calculations of production and maximum equilibrium yield for the bluegill were gathered from two warmwater Michigan lakes, and I have used these data to examine relationships between production, yield, and standing crop.

A method for computing biological production based on exponential growth and mortality rates was first proposed by Clarke, Edmonson, and Ricker (1946). Ricker (1946) pointed out the applicability of the method to fish production, first applied it to a population of sockeye salmon, *Oncorhynchus nerka* (Ricker and Foerster, 1948), and summarized several methods of computation for production and maximum equilibrium yield (Ricker, 1958). I used his method of calculation which requires data on seasonal rates of growth and mortality plus at least two successive estimates of population size. Such calculations are potentially valuable tools in management but few have used them. This application to field data, available in the present study, may promote their use by other workers.

## Description of lakes

The two lakes are located on the Rifle River Recreation Area in northeastern Michigan. Jewett Lake is a circular, landlocked lake of 12.9 acres. Most of the lake is less than 10 feet deep and the maximum depth is 14 feet. There are stands of pondweeds around the periphery of the lake and the bottom is of fibrous and pulpy peat. Submerged beds of *Chara* cover the deeper parts. The water is relatively soft with a methyl orange alkalinity of 25-30 ppm. The lake does not stratify in midsummer. There are eight species of fish present of which bluegills are most abundant.

Lodge Lake has a surface area of 16.8 acres and a maximum depth of 16 feet. There is no summer stratification. A small, intermittent outlet provided a connection with an adjacent lake at the time of this study and allowed a two-way movement of fish in the spring. There is a considerable amount of natural cover around the shoreline in the form of fallen trees, and the lake has extensive beds of submerged vegetation. During severe winters, oxygen depletion beneath the ice results in moderate kills of fish. Bottom material consists mostly of pulpy peat mixed with marl. The water is moderately hard (methyl orange alkalinity, 92-105 ppm). There are 11 species of fish present of which pumpkinseeds (*Lepomis gibbosus*) and bluegills are most numerous. Forage species are abundant in Lodge Lake but scarce in Jewett Lake.

## Methods

The population estimates used in this paper (Table 1) were derived, with one exception, from the marking (fin clip) and recapture of fish caught in trap and fyke nets during periods of either 4 or 5 weeks in the spring of each year plus one fall estimate for Jewett Lake in 1962. Nets were moved nearly every other day among numbered sites after the site numbers were selected from a table of random numbers. The population estimates and their confidence limits were computed for each inch group using the modified Schumacher and Eschmeyer method recommended by DeLury (1958). Estimates of year-class size were derived by summing the numbers of a particular age class estimated to be in each inch group, as determined from samples that were aged. The exception noted above was the 1959 group of population estimates for Jewett Lake. These estimates were computed from the number of fish captured in two seine hauls on successive days with a 1, 600-foot seine. Bailey's modification of the Petersen formula (see Ricker, 1958) was used to calculate these estimates and their confidence limits.[2] The yearly intervals referred to hereafter are the time spans between successive population estimates.

The two lakes were open to public fishing done under permits issued at the single entrance to the Area. All anglers were required to report the results of their fishing and present their catches for inspection. All fish were measured, weighed, and examined for fin clips. Scales were removed from a large sample of the catch to determine the age composition.

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[2] Immediately after the population size was estimated in 1959, we tried to remove 75% of the bluegills under 6.0 inches to improve the growth rate. As a result, about 53% of the 1955 year class, 75% of the 1954 year class, and 44% of the 1953 year class were removed. Estimates of these year classes were adjusted accordingly for the subsequent calculations for the 1959-1960 interval.

As Ricker (1958) pointed out, seasonal instantaneous rates of mortality and growth are preferable to annual rates because the latter conceal the dynamic changes in growth and mortality which operate during the year. Therefore, seasonal growth and mortality rates were computed after dividing the fishing activity each year into four periods for Jewett Lake and five for Lodge Lake. Three of these periods were nearly identical in each lake. These were: (1) between the date of the spring population estimate and the opening of the bass season in early June; (2) opening date of bass season through Labor Day; and (3) open-water angling after Labor Day. The rest of the year was treated as one period for Jewett Lake but divided into two periods for Lodge Lake. The latter consisted of (1) all ice-fishing activity and (2) open-water angling in the spring prior to the population estimates. The instantaneous fishing mortality $\underline{p}$ for each period was the percentage of the total catch taken during a fishing period multiplied by the annual $\underline{p}$.

The linear body-scale relationship for Jewett Lake bluegills was used for growth computations for both lakes because a larger sample of fish was available for this population than from nearby Lodge Lake. The equation computed by least squares was:

$$L = 0.89 + 0.95\ S$$

where L is total length in inches and S represents the anterior scale radius.

The conversion from length to weight (ounces) for Jewett Lake bluegills was made from a length-weight equation calculated from 371 fish (4.0-10.0 inches long). This equation was:

$$\text{Log}_{10}\ \text{weight} = -2.078 + 3.102\ \text{Log}_{10}\ \text{length}$$

However, for Lodge Lake bluegills, mean empirical weights were used in lieu of a length-weight relationship.

Annual increments of growth in length were determined from scale samples collected while trap netting each year. Seasonal growth by each age group was apportioned on the basis of seasonal rates calculated from a series of scales collected from trap-netted fish between 15 May and 15 October 1962. This series was supplemented by scales collected from anglers' catches. An estimated 25% of the annual growth in length was completed between 20 May and 15 June, 80% by 1 September. Virtually no growth occurred between 1 October and 20 May. The instantaneous growth rate $\underline{g}$ for each year class is the natural log of the fraction: mean weight at end of the growing season/mean weight at the start of the season. It was assumed that changes in weight followed the same seasonal pattern as changes in length, and the above percentages were used to allocate $\underline{g}$ for each period.

Data on the seasonal rates of natural mortality $\underline{q}$ are difficult to obtain and an approximation must be used. Ricker (1946) suggested that a reasonably good assumption might be one in which growth and mortality varied proportionally throughout the year. Four different assumptions were made to determine, by trial and error, this seasonal parameter. These trial assumptions were: (1) a constant weekly _q_; (2) constant weekly _q_ for three-fourths of the year combined with various winter rates; (3) _q_ apportioned as _g_; and (4) _q_ apportioned as _p_. Proof of the effectiveness of these methods of apportionment for these populations was furnished by comparing the known harvest with the computed yield (sum of _p_ times average weight of each year class), similar to Gerking's (1962) method of appraisal.

The first two approaches were not satisfactory. Under the first assumption, harvests estimated from the 1962 Jewett Lake data agreed closely with the known yield but estimated catches for other intervals exceeded the known harvests by as much as 39%. These discrepancies occurred because estimates of the winter mortality rates were needed for these latter intervals but not for 1962. However, the second test, which involved the arbitrary assignment of various winter rates of natural mortality, was effective for only one interval (Jewett Lake, 1957-1958).

Using assumption 3, computed yields were low but close agreements with known yields were obtained for Jewett Lake in 1957 and 1959 (Table 2). When _q_ was apportioned as _p_, however, much closer approximations to the known values were obtained; therefore this distribution for each yearly interval was used in the calculations. There is no biological basis for saying that natural mortality varies as fishing mortality _per se_. However, this _distribution_ of natural mortality for bluegills in these lakes happens to approximate closely what must be the true seasonal occurrence of _q_ for these age groups.

The grestest discrepancy between known and calculated harvests was +10.0%. On the average, the percentage distribution of natural mortality in Jewett Lake was 7, 81, 12, and 0 for the spring, summer, fall, and winter periods, respectively.

The high mortality rate for summer is compatible with the known fact that this species cannot withstand much handling in hot weather. Furthermore, mortality among bluegills captured in trap nets in mid-summer is considerably higher than at other times of the year. Perhaps the physiological stresses imposed by spawning activities at summer water temperatures are the principal causes of this mortality.

Ricker's formula for equilibrium yield ($Y_e$) is:

$$Y_e = \sum_{T = T_r}^{T = T_x} \underline{p}_t \, \overline{W}_t$$

$T$ = successive intervals in the life of a fish

$T_r$ = first period under consideration

$T_x$ = last period under consideration

$\underline{p}_t$ = instantaneous fishing mortality for period

$\overline{W}_t$ = mean weight of year class

Production may be computed from this formula by substituting the instantaneous rate of growth ($\underline{g}_t$) for $\underline{p}_t$.

## Production

Published data on the production of warmwater fish in natural environments are scarce, although Ricker first proposed his method of production computation for fish in 1946 (and Allen independently developed a graphical method in 1949), Gerking's (1962) study of the production of bluegills and their food supply constitutes the only published information of this kind. Two other closely allied papers also have appeared. Saila (1956) computed the minimum size limit required for maximum yield and production of chain pickerel (*Esox niger*) in Rhode Island, using data gathered from several local sources. Cooper, Hidu, and Andersen (1963) calculated the surplus production of young largemouth bass (*Micropterus salmoides*) in a small Pennsylvania pond. There have been several salmonid production studies in both stream and lake environments.

In this paper, the bluegill production values are limited to fish at least 4.0 inches long or longer because neither nets nor anglers caught smaller fish. However, this omission of smaller fish does not affect the discussions to follow since here we are interested in fish that already were recruited into the sport fishery.

The basic data required for the computations are presented in Table 3. The numerical population estimates were converted to total weights and the annual rate parameters were translated into seasonal rates, as previously noted. Total production for each yearly interval was the sum of the average seasonal biomass multiplied by its corresponding instantaneous growth rate for each year class.

Production values for the bluegill populations in these lakes during the designated intervals are presented in Table 4, along with data on standing crop, yield, and natural mortality. The small standing crops in 1959-1960 and 1962 in Jewett Lake were caused largely by three factors: (1) population reduction by seining in 1959, (2) the cumulative mortality of the strong 1952 year class, and (3) the relative weakness of succeeding broods spawned in the presence of the 1952 year class.

Bluegill growth rates were slow in Jewett Lake, with annual increments averaging only slightly over 1.0 inch. Little improvement was accomplished by the thinning operation (30% increase in growth in one year for age-group IV fish; growth of others unaffected). On the other hand, bluegills grew faster in Lodge Lake because of greater fertility of the lake, and because the population was reduced periodically by partial winterkills.

This combination of slow growth and a consideration of only the older segments of the population leads to small production. In most instances, production by 4- and 5-year-old fish exceeded the weight harvested, but thereafter yield outweighed the production among older fish (Table 4). For practically all of these age groups, the loss of weight attributed to natural mortality exceeded that harvested.

The total biomass (in pounds) accumulated in the last few years of the life span of three year classes in Jewett Lake is shown in Table 5, together with total angler harvest and natural mortality. During this period these bluegills were fully vulnerable to removal by anglers, but these data do not include the entire catch for these year classes since about 20% of the total catch for each of the 1952 and 1953 broods were caught as 4-year-olds. Catch data for younger members of the 1951 year class were not available. Biomass lost through natural mortality was more than five times greater than the anglers' catch for the 1951 year class, and more than four times as great as the yield for older fish in the 1953 year class. It exceeded the harvest for the 1952 year class by 30%. However, production did exceed the anglers' harvest for the 1952 and 1953 age groups during this time but not for the weak 1951 year class.

The change in population densities which occurred in Jewett Lake after the spring of 1959 (Table 1) did not improve the relationship between production and standing crop for these older age groups, reflecting the lack of improvement in growth rates. On the average, total production in Jewett Lake amounted to 47% of the standing crop before reduction, 44% thereafter. Production in Lodge Lake amounted to only 34% of the standing crop of the three oldest age groups (III-V) present in June, 1957.

## Exploitation and theoretical maximum yields

A complete record of angling on these lakes since they were opened to public fishing in 1945 was documented by Patriarche (1960).[3]

[3] In this publication, Lodge Lake is listed as having an area of 17.2 acres (Table 1, p. 11). The lake has since been remapped and the corrected area of 16.8 acres is used in this paper.

Between 1945 and 1956, bluegills comprised 56-75% of the catch annually in Jewett Lake; 29-50% in Lodge Lake (1950-1956). The largest catches occurred in the first year of heavy exploitation (1945 for Jewett; 1950 for Lodge), followed by a considerably lower annual catch thereafter except for Jewett in 1954 when the bluegill catch almost equaled that of 1945.

Data on population size and exploitation of bluegills for the two lakes for most years during the period 1957-1962 are presented in Table 6. Fishing pressure was light on Lodge Lake but moderately heavy on Jewett Lake. No significant relationship ($p < 0.05$) between size of the spring population and fishing quality was evident ($r = 0.32$). Between 62 and 82% of the bluegills caught annually in Jewett Lake and 51-88% of those caught in Lodge Lake were taken by anglers still-fishing with earthworms. When the catch-per-hour data were stratified for this type of fishing the values were somewhat higher but this modification had little effect on the correlation coefficient ($r = 0.38$).

Estimates of exploitation rates were possible because many bluegills over 4.0 inches long were fin-clipped each spring prior to the fishing season. These rates are simply the percentages of the marked fish of specified ages caught by anglers during the year. It was assumed that marked and unmarked fish were randomly mixed and equally vulnerable to angling. These rates of exploitation ranged from 17.2 to 24.6% for Jewett Lake; 8.2-26.1% for Lodge Lake (Table 6). The mean length of the bluegills caught in these lakes ranged from 6.2 to 6.7 inches.

Perhaps a more significant expression of utilization would be the proportion of the population weight available to anglers which was harvested. The total available weight is the weight of the spring standing crop of catchable-size fish plus their increase in biomass (production) during the year. As shown in Table 7, there was good agreement between the above exploitation rates and those based on the proportion of total weight harvested.[4] This similarity indirectly substantiates the assumptions made for the distribution and catchability of the marked fish.

Anglers sometimes are inclined to sort their catches, keeping only the larger fish. If this happened very often, the older age groups would be eliminated. Knowing the age composition of both the population and the catch, this possibility of selection was examined by subjecting the expected age distribution of the catches each year for 7 years (5 for Jewett, 2 for Lodge) to individual Chi-square tests. Significant but inconsistent tendencies were noted for 4 of the 7 years. In 1958 and 1959, anglers on Jewett Lake kept a proportionately greater number of old fish (Chi-squares: 532 and 323, respectively, with 2 and 3 degrees of freedom). In 1957, however, anglers on both lakes kept greater numbers of young fish than expected (Chi-squares: 125 and 14 with 4 and 2 degrees of freedom, respectively). No significant differences were noted between actual and expected catches of the various age groups either in Lodge Lake in 1958 or in Jewett Lake in 1960 and 1962. The poor

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[4] Both sets of values are a little low because neither procedure allows for natural mortality.

fishing success experienced in those years (see Table 6) probably deterred anglers from discarding anything they caught.

Having determined the actual harvest and noting that the exploitation rates were rather low, the next step was to estimate the level of fishing at which the population could have supported a maximum sustained harvest. Equilibrium yields for various multiples of the prevailing instantaneous rates of fishing p were computed for the populations in these lakes to find the maximum yield commensurate with the accompanying production (Table 8). Since, by definition, equilibrium yields are balanced with fishing pressure so that the population is stabilized (recruitment is assumed, a priori, to be constant), all computations were carried through the life of the exploited age groups. Ricker (1958, p. 244) pointed out that the immediate and temporary effect of an increase in fishing mortality is a larger catch than that which results when the population is finally stabilized at the new fishing rate. For example, 82.8 lb. of fish were caught in 1,863 hours of fishing in 1945, the first year of public angling on Jewett Lake. This catch was three times as large as the mean catch for the next 11 years, during which time the annual fishing pressure averaged 1,114 hours.

For Jewett Lake in 1958-1959, a twofold increase in the fishing mortality rate would have produced a maximum sustained yield. At twice p, production and yield virtually were balanced. Likewise, a 50% increase in p would have been desirable for both lakes in 1957-1958. In 1962 the bluegill population in Jewett Lake was much smaller than previously but was cropped at approximately the maximum rate (to be precise, however, there could have been a 25% increase in angling mortality). Angling mortality for Jewett Lake in 1959-1960 could have been nearly doubled.

Translating p into fishing pressure (at the prevailing rates of fishing success), the Jewett Lake population could have sustained estimated increases in fishing pressure of 90% both in 1958 and 1959 but only 40% in 1957. Lodge Lake bluegills could have withstood a 30% increase in fishing pressure in 1957 without affecting the population status quo.

An important assumption for these calculations is that there would be no appreciable change in the growth rate. The estimated optimal yields discussed above would be equivalent to increasing the empirical harvests by amounts ranging from 16 to 33% of the spring standing crops. Reductions of this size would have very little effect on these bluegill growth rates. For the thinning operation of 1959, for example, 53% of the 4-year-old bluegills were removed which resulted in an improvement of only 30% (0.5 inch) in the length increment.

## Management implications

The problem of over-population of many warmwater species continues to plague fish managers. How to adjust the size of a population to the environment to encourage good growth commensurate with satisfactory fishing remains an important question. Many investigators have grappled with this problem. Swingle (1950) pioneered studies on the dynamics of fish populations in farm ponds. Bennett (1954) carried on extensive studies on a small artificial lake containing largemouth bass and bluegills. Ricker (1945), Allen (1954, 1955), and Saila (1957) have discussed ways of estimating size and bag limits that could be imposed on a fishery when needed.

Watt (1956, 1959, 1962) and Carlander (1958) pointed out the advantages of using mathematical models to predict and maximize the yield of a fishery and for interpreting the effects of fishing upon a population, an approach that has been studied extensively for marine fisheries. However, both Burkenroad (1951) and Tester (1952) questioned the utility of certain models. Nevertheless, it seems obvious that a more sophisticated approach than has been used previously must be adopted to solve these management problems.

Computations of production and maximum equilibrium yield can be useful aids once the population size and its recruitment rate compatible with good growth and fishing success are known. The manager can then maintain a stabilized fishery at this level by balancing production with the harvest (angling plus some means of artificial cropping if necessary). Determining the appropriate size of the parent stock can be a perplexing problem but this can be solved with some experimentation. For many species, recruitment usually is fairly consistent although it is well known that occasionally environmental variations can upset the equilibrium temporarily.

Interestingly enough, the ratio of production to standing crop (47%) in Jewett Lake before population reduction was similar to the approximately 50% ratios reported by Gerking (1954) for an Indiana lake, by Mann (1964) for the Thames River population vulnerable to the net, and by Huet (1964) for several other European situations. If this relationship is generally true, production could be estimated readily from population estimates alone.

Benson and Bulkely (1963) computed equilibrium yields and listed a number of restrictive proposals for managing a fishery for cutthroat trout (*Salmo clarki lewisi*) in Yellowstone Lake. Silliman and Gutsell (1958) studied the effects of several rates of exploitation on populations of guppies (*Lebistes reticulatus*) in aquaria. The general effect of increasing the exploitation rate was to reduce the population until the fish virtually were eliminated when the rate reached 75%. Maximum yields occurred at exploitation rates between 30 and 40%.

It has been shown, through exploitation rates and computations of maximum sustained yields, that the bluegill populations in these lakes were underharvested, a typical situation for this species. However, exploitation rates on the order of 30-50% (up to twice the rates in effect) would have produced a maximum sustained yield. The trend shown by the widening gap between production and yield with increased fishing mortality (Table 8) foretells a similar inevitable collapse of these bluegill populations, if, in the unlikely event, fishing mortalities of greater than 2 $\underline{p}$ occurred. However, this collapse might be considerably delayed because of compensatory responses in growth and mortality by the population. Such responses are not incorporated in this model.

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Table 1.--Estimated number of bluegills in Jewett Lake in 1957-1960 and 1962; Lodge Lake in 1957 and 1958. Except where noted, all estimates were made in the spring. Confidence limits (P = 0.05) are shown in parentheses.

| Inch group | Jewett Lake | | | | | | Lodge Lake | |
|---|---|---|---|---|---|---|---|---|
| | 1957 | 1958 | 1959[a] | 1960 | 1962 | 1962 (fall) | 1957 | 1958 |
| 4.0-4.9 | 1,076[b] (696-2,376) | 7,222 (5,694-9,884) | 3,563 (2,836-5,103) | 2,427 (1,128-?) | - | 1,230 (984-2,237) | - | - |
| 5.0-5.9 | 3,155 (2,524-4,205) | 2,442 (2,071-2,973) | 858 (793-940) | 384 (236-1,019) | 297 (181-828) | 323 (249-458) | 1,370 (1,085-1,859) | 135 (79-461) |
| 6.0-6.9 | 1,482 (1,204-1,927) | 1,131 (1,028-1,434) | 465 (439-501) | 118 (76-273) | 218 (159-347) | 341 (305-388) | 1,019 (890-1,192) | 429 (251-1,481) |
| 7.0-7.9 | 94 (54-377) | 143 (120-177) | 62 (53-77) | 19 (13-32) | 44 (26-131) | 75 (58-105) | 190 (152-253) | 158 (85-1,094) |
| 8.0-8.9 | 42 (20-?) | 15 (8-38) | 13 (13-13) | 14 (11-20) | 19 (16-23) | 28 (23-36) | - | - |
| 9.0-9.9 | 18 (12-41) | 5 (3-7) | - | 1 (1-1) | 7 (3-?) | 6 (4-14) | - | - |
| Totals | 5,867 | 10,958 | 4,961 | 2,963 | 585 | 2,003 | 2,579 | 722 |

[a] Population prior to a thinning operation. See text for explanation.

[b] Lower limit of inch group for 1957 was 4.5 inches because no 5-year-old bluegills in 1957 were less than 4.5 inches long.

Table 2.--Actual and estimated yields (in pounds) of bluegills for Jewett and Lodge lakes

| Lake | Year | Anglers' catch | Estimated yield[a] | |
|---|---|---|---|---|
| | | | g | p |
| Jewett | 1957 | 203.6 | 202.3 ( -0.6) | 212.4 (+ 4.2) |
| " | 1958 | 270.2 | 216.4 (-19.9) | 270.6 (+ 0.1) |
| " | 1959 | 109.5 | 108.4 ( -0.9) | 120.4 (+10.0) |
| " | 1962 | 22.2 | 19.2 (-13.5) | 23.9 (+ 7.5) |
| Lodge | 1957 | 106.5 | 99.8 ( -6.3) | 105.8 ( -0.6) |

[a] Yields computed by apportioning seasonal natural mortality as g and p in Ricker's formula. Percentage differences in parentheses.

Table 3.--Annual population estimates, yields, and instantaneous rates of growth (g) and mortality (a, i, p, q) for several year classes of bluegills in Jewett and Lodge lakes for the designated intervals

| Year class | $\hat{P}$ on date | | Anglers' catch[a] | g | a | i | p | q |
|---|---|---|---|---|---|---|---|---|
| JEWETT LAKE | | | | | | | | |
| | 4/30/57 | 4/29/58 | | | | | | |
| 1952 | 4,509 | 1,924 | 1,215 | .61 | .57 | .84 | .39 | .45 |
| 1951 | 549 | 55 | 14 | .26 | .90 | 2.31 | .26 | 2.05 |
| 1950 | 7 | 1 | 1 | .17 | .86 | 1.95 | .33 | 1.62 |
| 1949 | 44 | 3 | 7 | .14 | .89 | 2.22 | .38 | 1.84 |
| 1945-1948 | 13 | 3 | 2 | .10 | .77 | 1.46 | .29 | 1.17 |
| | 4/29/58[b] | 5/13/59 | | | | | | |
| 1953 | 7,390 | 650 | 954 | .83 | .91 | 2.43 | .34 | 2.09 |
| 1952 | 1,924 | 136 | 713 | .49 | .93 | 2.66 | 1.06 | 1.60 |
| 1951 | 55 | 1 | 25 | .14 | .98 | 3.91 | 1.80 | 2.11 |
| | 5/13/59 | 5/4/60 | | | | | | |
| 1955 | 1,627 | 59 | 241 | 1.12 | .964 | 3.33 | .51 | 2.82 |
| 1954 | 98 | 33 | 65 | .96 | .663 | 1.09 | 1.09 | 0.00 |
| 1953 | 367 | 17 | 224 | .66 | .954 | 3.08 | 1.97 | 1.11 |
| 1952 | 136 | 1 | 59 | .64 | .993 | 4.96 | 2.17 | 2.79 |
| | 5/1/62[c] | 10/1/62 | | | | | | |
| 1958 | 142 | 22 | 43 | .75 | .845 | 1.86 | .65 | 1.21 |
| 1957 | 258 | 25 | 58 | .55 | .903 | 2.33 | .58 | 1.75 |
| 1956 | 6 | 1 | 2 | .46 | .833 | 1.79 | .72 | 1.07 |
| LODGE LAKE | | | | | | | | |
| | 5/22/57 | 6/3/58 | | | | | | |
| 1954 | 1,197 | 267 | 320 | .65 | .78 | 1.50 | .52 | .98 |
| 1953 | 513 | 142 | 109 | .48 | .72 | 1.28 | .37 | .91 |
| 1952 | 472 | 6 | 81 | .18 | .99 | 4.60 | .76 | 3.84 |

[a] Number caught during interval between population estimates.

[b] Seven older bluegills (ages VIII-XIV) were estimated to be present, but were not included. None were caught by anglers.

[c] Six additional bluegills (1955 year class) were omitted. None were caught by anglers.

Table 4.--Estimated standing crop, production, yield, and natural mortality of bluegills (pounds) by year and year class in Jewett and Lodge lakes

| Year class | Age group | Spring standing crop | Production | Yield | Natural mortality |
|---|---|---|---|---|---|
| JEWETT LAKE | | | 1957-1958 | | |
| 1952 | V | 535.6 | 307.3 | 195.0 | 225.4 |
| 1951 | VI | 87.1 | 13.7 | 12.6 | 99.0 |
| 1950 | VII | 1.8 | 0.2 | 0.4 | 1.7 |
| 1949 | VIII | 16.1 | 1.4 | 3.3 | 16.1 |
| 1945-1948 | IX-XII | 6.2 | 0.4 | 1.1 | 4.4 |
| Totals | | 646.8 | 323.0 | 212.4 | 346.6 |
| Pounds per acre | | 50.1 | 25.0 | 16.5 | 26.9 |
| | | | 1958-1959 | | |
| 1953 | V | 581.5 | 315.4 | 122.9 | 763.3 |
| 1952 | VI | 246.3 | 68.1 | 139.2 | 212.8 |
| 1951 | VII | 10.9 | 0.8 | 8.3 | 9.7 |
| Totals | | 838.7 | 384.3 | 270.4 | 985.8 |
| Pounds per acre | | 65.0 | 29.8 | 20.9 | 76.4 |
| | | | 1959-1960 | | |
| 1955 | IV | 102.7 | 55.3 | 26.4 | 146.4 |
| 1954 | V | 14.9 | 13.2 | 15.1 | 0.0 |
| 1953 | VI | 60.1 | 18.4 | 56.7 | 32.0 |
| 1952 | VII | 26.9 | 6.0 | 20.8 | 26.7 |
| Totals | | 204.6 | 92.9 | 119.0 | 205.1 |
| Pounds per acre | | 15.8 | 7.2 | 9.2 | 15.9 |
| | | | 1962 | | |
| 1958 | IV | 19.9 | 12.0 | 9.1 | 16.9 |
| 1957 | V | 45.8 | 16.0 | 14.2 | 43.2 |
| 1956 | VI | 1.6 | 0.5 | 0.7 | 1.1 |
| Totals | | 67.3 | 28.5 | 24.0 | 61.2 |
| Pounds per acre | | 5.2 | 2.2 | 1.8 | 4.7 |
| LODGE LAKE | | | 1957-1958 | | |
| 1954 | III | 166.9 | 79.1 | 60.8 | 115.0 |
| 1953 | IV | 99.3 | 38.8 | 26.1 | 64.6 |
| 1952 | V | 92.1 | 5.5 | 18.9 | 96.3 |
| Totals | | 358.3 | 123.4 | 105.8 | 275.9 |
| Pounds per acre | | 21.3 | 7.3 | 6.3 | 16.4 |

Table 5.--Accumulated biomass, yield, and natural mortality (in pounds) for three year classes of bluegills in Jewett Lake during the years of exposure to angling

| Year class | Age span | Production | Yield | Natural mortality |
|---|---|---|---|---|
| 1951 | VI + VII | 14.5 | 20.9 | 108.7 |
| 1952 | V - VII | 381.4 | 355.0 | 464.9 |
| 1953 | V + VI | 333.8 | 179.6 | 795.3 |

Table 6.--Fishing pressure, angler exploitation and estimated spring populations of bluegills of specified ages in Jewett and Lodge lakes, 1957-1962

| Lake and year | Hours of fishing per acre | Bluegill catch per hour | Population[a] | Minimum age | Number of marked fish[b] | Percentage of marked fish caught |
|---|---|---|---|---|---|---|
| Jewett | | | | | | |
| 1957 | 85.8 | 1.40 | 397 | V | 1,018 | 20.7 |
| 1958 | 115.0 | 1.26 | 727 | V | 3,293 | 24.6 |
| 1959 | 89.6 | 0.56 | 173 | IV | - | - |
| 1960 | 84.8 | 0.15 | 112 | IV | 291 | 17.2 |
| 1962 | 70.5 | 0.42 | 32 | IV | 206 | 22.3 |
| Lodge | | | | | | |
| 1957 | 52.9 | 0.95 | 130 | III | 641 | 26.1 |
| 1958 | 49.1 | 0.36 | 43 | III | 465 | 8.2 |
| 1960 | 10.5 | 0.29 | 54 | III | 177 | 14.7 |

[a] Estimated number per acre prior to fishing season.

[b] No bluegills under 4.0 inches were marked.

Table 7.--The spring standing crop, production, and yield of bluegills in Jewett and Lodge lakes in pounds per acre plus exploitation rates by weight and number

| Item | Jewett 1957-1958 | Jewett 1958-1959 | Jewett 1962 | Lodge 1957-1958 |
|---|---|---|---|---|
| Minimum age | V | V | IV | III |
| Minimum length (inches) | 4.5 | 4.0 | 5.0 | 5.0 |
| Spring standing crop | 50.1 | 65.0 | 5.2 | 21.3 |
| Production | 25.0 | 29.8 | 2.2 | 7.3 |
| Production + crop | 75.1 | 94.8 | 7.4 | 28.6 |
| Anglers' catch | 15.7 | 20.9 | 1.8 | 6.3 |
| Exploitation (% weight) | 20.9 | 22.0 | 24.3 | 22.0 |
| Exploitation (% number) | 20.7 | 24.6 | 22.3 | 26.1 |

Table 8.--Theoretical effects of various multiples of fishing mortality p on equilibrium yield and production of older bluegills at the observed recruitment rates in Jewett and Lodge lakes.[1] Values rounded off to nearest 0.5 lb.

| Item | Minimum age group | 1/2 p | p | 1 1/2 p | 2 p | 3 p |
|---|---|---|---|---|---|---|
| | | | Pounds per acre | | | |
| JEWETT LAKE: | | | | | | |
| 1957-1958 | V | | | | | |
| Yield | | 12.0 | 21.0 | 28.0 | 33.0 | 42.0 |
| Production | | 33.0 | 29.5 | 26.5 | 24.5 | 21.0 |
| 1958-1959 | V | | | | | |
| Yield | | 9.5 | 15.5 | 20.5 | 24.5 | 32.0 |
| Production | | 28.5 | 27.0 | 25.5 | 25.0 | 23.0 |
| 1959-1960 | IV | | | | | |
| Yield | | 3.0 | 3.5 | 4.0 | 4.5 | 6.0 |
| Production | | 6.5 | 5.0 | 4.5 | 4.0 | 3.5 |
| 1962 | IV | | | | | |
| Yield | | 0.5 | 1.0 | 1.0 | 1.5 | 1.5 |
| Production | | 1.5 | 1.0 | 1.0 | 1.0 | 0.5 |
| LODGE LAKE: | | | | | | |
| 1957-1958 | III | | | | | |
| Yield | | 4.5 | 7.0 | 8.5 | 10.0 | 11.5 |
| Production | | 11.0 | 10.0 | 8.5 | 7.0 | 5.5 |

[1] Computations carried through the life span of all affected generations (Ricker, 1958, p. 226).