Presented at the meetings of the Michigan Academy of Science, Arts and Letters, 1952.

Original: Mich. Acad. Sci., Arts & Letts.
cc: Fish Division
Education-Game
Institute for Fisheries Research
C. T. Yoder
W. R. Crowe

April 10, 1952

Report No. 1327

AN ANALYSIS OF THE FISH POPULATION OF BIG BEAR LAKE, OTSEGO COUNTY, MICHIGAN

by

Walter R. Crowe

Abstract

As part of an investigation of the importance of the white sucker (*Catostomus commersoni*) in the inland lakes of Michigan, population estimates of the more abundant species of fish resident in Big Bear Lake, Otsego County, were made on 8 separate occasions between 1940 and 1946.

All estimates were made by the mark and recovery method which has been described as the Petersen Method (Ricker, 1948), except for the estimate of suckers in the spring of 1943 when the method outlined by DeLury (1947) was used.

All samples were collected with trap nets. The nets were efficient, except for the grave shortcoming of not being able to catch perch in any numbers. Consequently, no estimate of perch abundance was made.

Calculations were originally made through the use of the Schnabel (1938) formula. Calculations by Schnabel's formula are compared with those made by the use of the Schumacher and Eschmeyer (1943) formula,

and that of Chapman (1951). Schnabel's formula is satisfactory, and much easier to use. However, it does not include a method for computing standard error of the estimate.

Estimates, thought to be realistic, were obtained for the sucker, largemouth bass, smallmouth bass, bluegill, pumpkinseed, and rock bass. Prior to its almost complete removal by nets in the spring of 1943, the sucker was by far the dominant species in the lake. Populations of the other species remained more or less static throughout the period. In addition to the 6 more abundant species, estimates of the less abundant bullheads, and bluegill x pumpkinseed hybrids were obtained. Results of all estimates are presented in a table in the report.

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In recent years fisheries workers have increasingly concerned themselves with attempts to assess the magnitude of fish populations. This is evident from the fairly voluminous literature pertaining to estimation techniques which now exists. As the biologist has become aware of the pitfalls which may be encountered in making estimates based on sampling procedures, he has turned to the statistician for help. As a result various refinements in procedure, and more particularly in the handling of the data, have been brought forward by several workers.

When suitable techniques for the estimation of the size of a fish population (i.e. the standing crop) have been developed, then a management program can be put on a sound basis. We will then be able to judge and evaluate the results of different management practices. Recently, certain management programs which might be termed population control have become more prominent. Johnson (1949) mentions the following practices which may be regarded as efforts toward population control with the object of producing the largest possible sustained yield to the fisherman: fish removal and replanting, corrective stocking, alteration of the physical and chemical environment, and restriction of fish movement.

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[*] Contribution from the Institute for Fisheries Research of the Michigan Department of Conservation.

If we are unable to determine the size of the fish population and record the harvest, evaluation of any management program will be rough at best.

The earliest attempts at population control or population analysis were drastic and although much valuable information has resulted from these investigations, complete eradication of fish populations by the use of toxic substances, draining, or synthetic winterkill is neither practical nor useful on large and productive bodies of water. For the most part complete population analyses have come from atypical situations. Benefits resulting from such drastic procedures have frequently been temporary. Johnson (1949) states, "Complete eradication may be achieved by these means, but rough fish invasion almost always occurs and benefits are only temporary. If environmental situations conducive to high rough fish populations remain unchanged new generations are soon produced. This type of complete management is applicable only to drainable reservoirs, or smaller natural waters, and foolproof methods for preventing the re-entry of unwanted species are yet to be devised." As pointed out by Ball (1948) the majority of lakes poisoned in Michigan have become repopulated with undesirable species, and in the future considerable effort will have to be made to prevent the re-entry of unwanted species if the removal of fish is to be a worthwhile undertaking.

Ricker (1948) credits a Danish biologist, C. G. J. Petersen as being the pioneer in 1896 in the practice of using fish marked and released in a body of water to compute the total population. This technique has since been referred to by fisheries biologists as the Petersen Method and the same technique when applied to land animals has been called the Lincoln Index (Adams, 1951). Schaefer (1951) points out that the practice of making estimates through the use of marked individuals in the population is older than this, although Petersen may well have been the first to apply the method to fish populations. The technique was used by the French mathematician Laplace as early as 1783. Schaefer (loc. cit.) also notes that Laplace gave considerable attention to the theoretical problem of the error involved in the use of this method. The problem as stated by Laplace attracted the attention of another famous statistician Karl Pearson, who published an analysis in 1928. Schaefer (loc. cit.) indicates that contemporary zoologists have frequently overlooked Pearson's analysis, and that they have periodically rediscovered the method but have given little attention to the problem of the accuracy of the resulting estimate. Ricker (1942, 1948) has considered the accuracy of estimates obtained by the mark and recover technique. For the sake of convenience we will refer to this technique as the Petersen Method.

Various modifications and refinements of the method have been proposed by different workers but so long as the resulting estimate is based upon the ratio of marked to unmarked all of these modifications can be considered as a single method.

Another method, different in approach, was advanced by DeLury (1947). In this technique the estimate is derived by plotting the catch per unit of effort and time against the total catch. A regression line is formed and when the direction of this regression line is established the estimate is considered to be equal to that point at which the regression line crosses the abscissa. Total catch is plotted on the abscissa and catch per unit of effort and time is plotted on the ordinate. This method is applicable to a situation where representatives of the population are being removed. It has limitations but has the merit of being independent of the ratio of marked to unmarked individuals. Also, fishing effort must be intensive enough to remove a significant part of the population, so that catch per unit of effort will actually decrease.

Other methods involve poisoning or draining, and counting the population or a portion of it. Because all fish are not always recovered, even these methods are estimation techniques. Other methods involve sampling an area and applying the sample to the whole, as for example, shoreline counts following winterkill, or counting the fish in a blocked section of a stream. Yet another method which may be considered as an estimation technique involves an analysis of the fluctuations of a population above and below a norm. The "normal abundance" has usually been established through the use of an average abundance for a certain period and fluctuations above and below this norm are thought to be indicative of actual changes in the population. The method of computing general abundance of a commercial species has been outlined by Hile (1937). There are doubtless other methods which have been used to estimate fish populations but the above mentioned are those which have been most generally applied.

In its simplest form the Petersen Method assumes that the abundance of the population may be computed by the use of the formula $P = \frac{AB}{C}$ in which P is the total population, B is the number of marked fish released into the body of water, A is the number of fish subsequently captured, and C is the number of marked fish recaptured. In short, the method assumes that the ratio of marked fish in samples taken after the introduction of a known number of marked fish into the population is representative of the true ratio of marked to unmarked fish in the whole population. Ricker (1948) has summarized the conditions which must hold if the above equation is to be valid:

(1) Marked fish must suffer the same natural mortality as the unmarked.

(2) Marked fish must not lose their mark.

(3) Marked fish must be as vulnerable to the fishing being carried on as the unmarked ones.

(4) Marked fish must become randomly mixed with the unmarked; or sampling effort must be proportional to the number of fish present in different parts of the body of water.

(5) All recaptures must be recognized and reported upon recovery.

(6) Recruitment to the population being sampled must be negligible during the sampling period.

(7) As a corollary to (6) above DeLury (1947) states that the population must be closed, or additions by immigration must be balanced byemigration or death.

In this discussion the term recruitment is considered to apply to addition to the population by growth within a closed population.

Before a discussion of the techniques used and estimates obtained, some discussion of the basic conditions which must be met is warrented.

(1) Differential mortality among marked and unmarked fish.

Ricker (1949) points out that mortality resulting from marking may be of two types; instantaneous mortality, resulting at once from loss of blood, infection, etc. and continuing mortality resulting from a disability imposed upon the fish through the loss of a fin. It is with instantaneous mortality that we need to be concerned. If mortality among marked fish is significantly greater than that among unmarked, estimates will be too high. Ricker (1949) states, "In general it appears that removing a fin or fins has no immediately fatal effect upon either large or small fishes of the kinds that have been most used in marking experiments.

(In North America salmonids and centrarchids have been used oftenest.)"

Marking loss can probably be reduced by making population estimates at a suitable time of the year, i.e. during cool weather. The experience of the operator in handling fish should make a difference, as well as the type of gear being used. Mutilation of the fish through the removal of a fin or fins should be kept to a minimum. At Big Bear Lake loss of marked fish through rough handling, or abrasion by the trap nets was not large, and was thought to be of little consequence.

(2) Permanency of marks.

At Big Bear Lake regeneration of clipped fins was found to be of minor importance. Fins were clipped close to the body, and during the period of sampling, regeneration was slight. Actually many clipped fish were easily recognizable even the second or third year after clipping. Here again the experience of the operator is important.

(3) Differential availability of marked and unmarked fish.

We have no reason to suspect that the marked fish were more or less vulnerable to the trap nets used.

(4) Random mixing of marked fish with the unmarked population or proportionate sampling.

To permit further confidence in population estimates based upon marking and recovery technique either one or the other of the conditions described must be met. It will often be more feasible to make the sampling in different parts of the lake random, than it will to assure random mixing of the marked fish with the unmarked population. Every effort towards random sampling and marking should be made. The randomness of the sampling may be tested through a comparison of the rate of recapture at different stations, or by comparing samples taken by different gear.

(5) Recognition and reporting of marked specimens.

This may be important when returns are coming from fishermen, or are not actually seen by the operator, but in this investigation the problem of non-recognition of marks was of little consequence, because all fish were handled by the writer. As has already been mentioned marked fish were usually clearly recognizable even the second or third year after marking.

(6) Recruitment

During the netting periods under consideration recruitment is thought to have been negligible. It can be shown that most of the fish being sampled were of a certain minimum age, and that very few of the younger fish grew into the size range of the older fish during the netting period. Thus, while there was undoubtedly a small amount of recruitment its effects were at least of small magnitude.

(7) Unity or integrity of the population.

The fish population at Big Bear Lake may be considered as closed. The lake is landlocked, and records of any fish stocked during the netting period are available.

In addition to the factors already mentioned which may serve to prevent a uniform recapture rate there are other possibilities which must be mentioned. Marked fish may become net shy, or certain individuals may have a marked affinity for the nets. Certain species are definitely more catchable than others, but the obvious solution to this difficulty is to make estimates for each species separately. All such inconsistencies may produce systematic errors, but on the other hand it is at least possible that errors in one direction may be balanced by those in the other. As Ricker (1948) suggests, recaptures are generally rather few, and the limits of sampling error may be so wide that systematic errors are hard to demonstrate. All methods which have been used for estimation of fish populations have definite limitations, and systematic errors are of common occurrence, but by careful planning some at least of the unknowns may be eliminated, and usable estimates may be obtained. Every effort must be made to make samples representative through the use of adequate gear, and proper sampling of all habitats.

Description of the site

Big Bear Lake is located in Otsego County, Michigan, (T29-30N, R1W, Sec. 1, 2, 36). It lies midway between the towns of Lewiston and Johannesburg, about 8 miles by road from each. The lake is easily reached from either town. The shape of the basin is irregular, and might be described as roughly triangular. The three sides of this rough triangle total 6,800 feet in length. The greatest north-south and east-west diameters are about 1 mile. The lake is undoubtedly of glacial origin, and was probably formed by a melting block of ice at the edge of a moraine. A glacial map of the region shows the lake to lie at the intersection of a morainic region and a sandy outwash plain. The country immediately surrounding the lake is somewhat hilly, and the drainage area is very small. The lake is completely landlocked at present, and whether or not the lake had a connection with the Au Sable River in earlier times is not known, but its isolation from other waters is of some importance in this investigation. Water-levels have fluctuated considerably in relatively recent years as illustrated by the photograph (Plate I).

The lake has a surface area of about 350 acres and a maximum depth of 35 feet. The mean depth is 15.8 feet. Bottom types are sand,

Plate I

Shoreline, Big Bear Lake, Otsego County, Michigan, showing different high water levels.

gravel, and fibrous peat in the shallow water, and pulpy peat and clay in the deeper waters. The water is clear, and by visual test colorless. Secchi disk readings of 12.8 feet were obtained in August of 1940. It may be considered as a temperate lake of the third order in that it does not usually become stratified (Welch, 1935). The water in the lake is alkaline and moderately hard (pH 8.0-8.2, M. O. alkalinity, 45-98 ppm.) There are considerable areas of wind- and wave-swept shoal and also a few protected bays with lush growths of aquatic vegetation. In general the shores are clean. The shoreline shown in the photograph (Plate I) is typical of much of the lake and at only a few isolated localities do the soft bottom and rank growth of vegetation closely approach the shore. Most of the beach is sand and/or gravel, making the lake a very attractive one to swimmers.

Big Bear Lake might be considered as having a more than usually uniform fish habitat. There are no restricted areas and the slope of the basin is moderate. As might be expected the list of species present has remained constant throughout the period of the investigation. These species are:

White sucker - Catostomus commersoni commersoni

Bluntnose minnow - Pimephales notatus

Northern common shiner - Notropis cornutus frontalis

Northern yellow bullhead - Ameiurus natalis natalis

Northern brown bullhead - Ameiurus nebulosus nebulosus

Western mudminnow - Umbra limi

Western banded killifish - Fundulus diaphanus menona

Yellow perch - Perca flavescens

Iowa darter - Etheostoma exile

Northern smallmouth bass - Micropterus dolomieui dolomieui

Largemouth bass - Micropterus salmoides

Pumpkinseed - Lepomis gibbosus

Common bluegill - Lepomis macrochirus macrochirus

Northern rock bass - Ambloplites rupestris rupestris

Northern muddler - Cottus bairdi bairdi

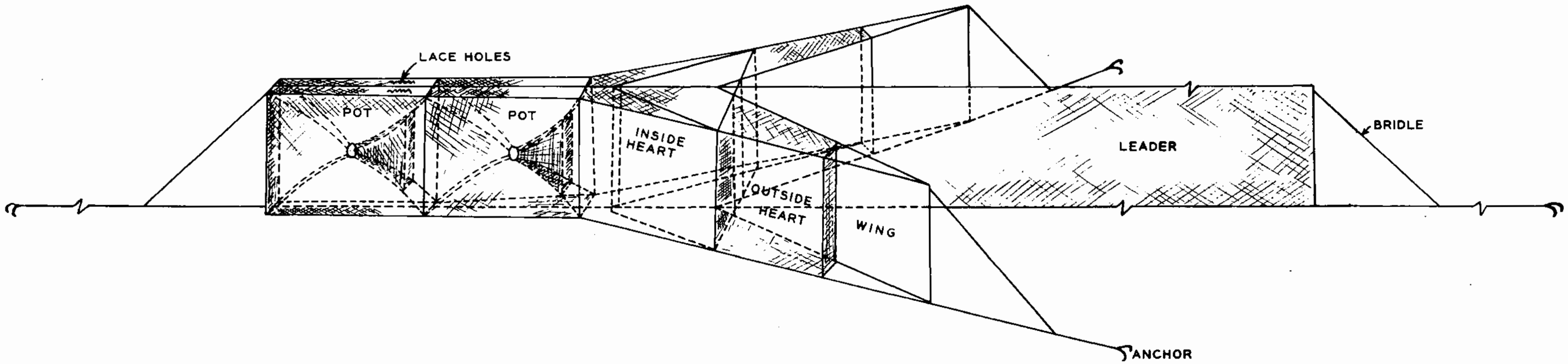
In addition to the above known residents of the lake we have captured two black crappies (Pomoxis nigro-maculatus), and a single specimen of the finescale dace (Chrosomus neogaeus) was captured in a seine in 1949. Emerald shiners (Notropis atherinoides) have been found in numerous perch stomachs, but these unquestionably represent bait minnows, rather than resident minnows. Also a single walleye (Stizostedion vitreum) was reported in the creel census in 1940. This almost certainly represents a mistake, although many walleyes were planted prior to 1940, and a few may have survived, but the species has never become established.

Methods

Population estimates at Big Bear Lake were made on 8 separate occasions. All samples were collected with trap nets. The trap nets used were the so called "small subs" frequently used in the Great Lakes. The general appearance of the nets is shown in the accompanying sketch (Figure 1). The trap nets used were of the double pot type, with each pot being 6 feet wide, 4 feet deep, and 10 feet long, making the whole trap 20 feet in length. The leads were 300 feet in length and 4 feet deep. Mesh in the back trap was 2 1/2 inch stretch, that in the second trap was 3 inch stretch, 3 1/2 inch in the hearts, and 4 inch in the leads. The nets are weighted so as to fish on the bottom and all fish are

Figure 1.

Diagram of trap nets used in making population estimates at Big Bear Lake, Otsego County, Michigan.


LACE HOLES
POT
POT
INSIDE HEART
OUTSIDE HEART
WING
LEADER
BRIDLE
ANCHOR

impounded in the nets. Nets of this type are efficient fish catchers although possibly more cumbersome than necessary. In our northern lakes we have not been able to capture fish in large numbers with the use of lighter and less complicated gear. Leads on the nets appear to be needed. The gear used had the great weakness that perch and small fish were not captured.

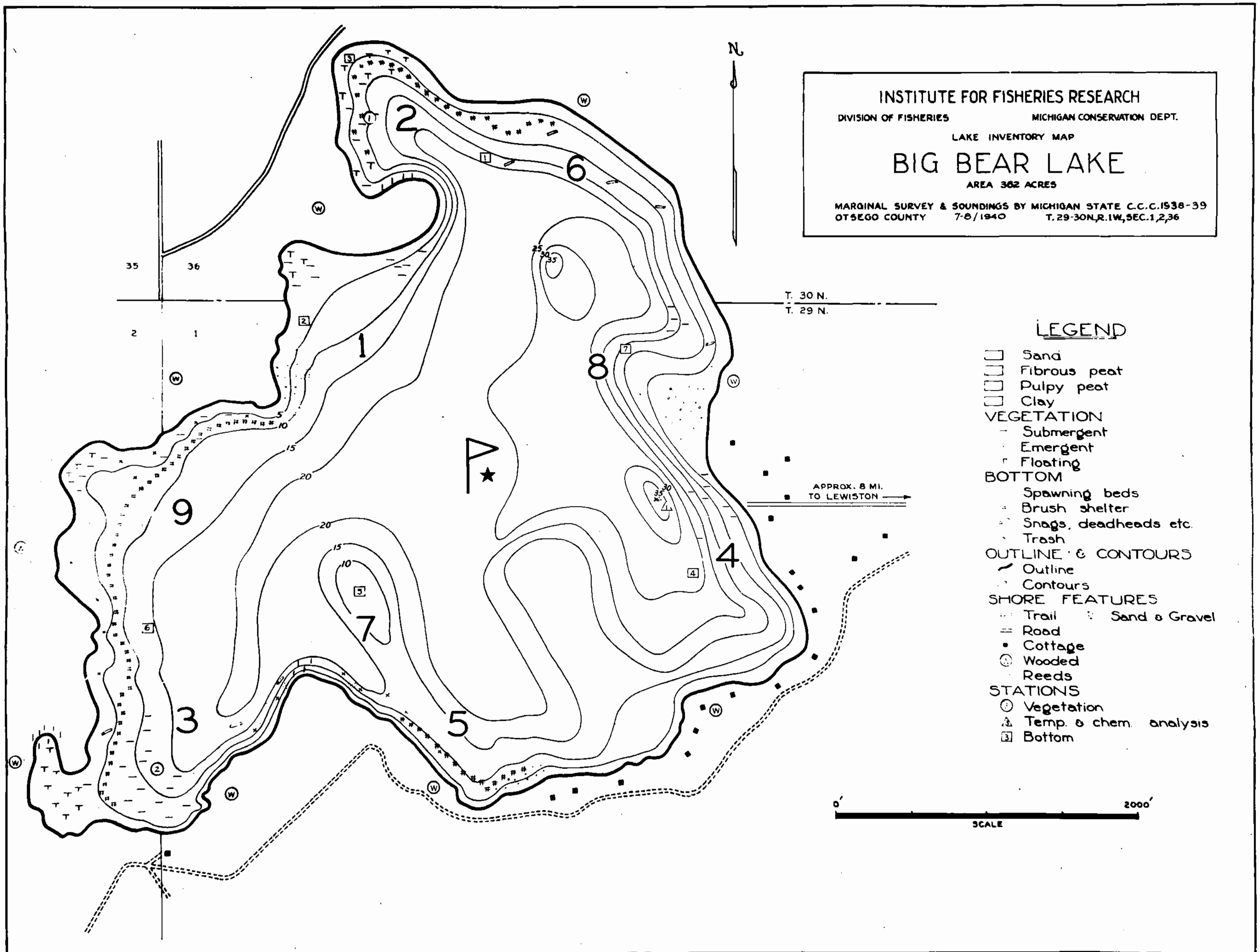
The general procedure might be outlined briefly here. Nets were lifted at 24-hour intervals. Fish were removed from the nets and placed in washtubs in the bottom of the boat. Prior to release each fish was measured, weighed, and examined for marks. If unmarked, it would be marked with the appropriate mark before being released. In 1940 all fish were released in the vicinity of the net where they were captured. In later years they were released at a central point near the middle of the lake. The map of the lake (Figure 2) shows the general location of netting stations used throughout the 8 netting periods. Usually 4 or 5 nets were operated simultaneously. Nets would become fouled after some days in the water, necessitating removal for cleaning and drying. Upon being reset a net would be placed near one or another of the indicated stations. Records were kept of the number of each species caught at each net, and of recaptures. If any dead marked fish were observed, the number of marked fish present in the lake would be reduced accordingly. Fish were handled carefully and loss is thought to have been small.

Results

Numerous methods have been used for estimating fish populations in lakes and streams. Some of these techniques have been mainly concerned with estimating stream populations and others have usually been applied

Figure 2.

Map of Big Bear Lake, Otsego County, Michigan, showing netting stations and central release point.



BIG BEAR LAKE Otsego Co. T.29-30N., R.1W., SEC.1,2,36 to lakes, while still others have often been concerned with commercial fisheries. All methods used for estimating the size of biological populations have certain limitations. Some of these may be applicable to all methods, while others may be peculiar to a certain technique.

Estimates at Big Bear Lake were made on 8 separate occasions as follows:

1940	July 6 to August 31	1943	September 25 to October 15
1941	July 1 to August 24	1944	May 17 to June 20
1942	August 19 to September 17	1946	May 22 to June 28
1943	May 18 to June 21	1946	September 5 to September 28

Identical gear was used in all periods, and all samples were secured with this gear. All estimates were originally made by the method of maximum likelihood (Schnabel, 1938) and all data were tabulated so as to be fitted into Schnabel's formula $P = \frac{\Sigma AB}{\Sigma C}$ in which P is the estimated population, A is the number of fish captured on any day, B is the number of marked fish present in the lake on that date, and C represents the number of recaptures. This method has probably been used as frequently as any other. The use of this formula is convenient when it is impossible to catch a large number of fish for marking in a short space of time, and it is possible to conduct the experiment so that marking and recoveries extend over a period of some weeks duration. This procedure was adopted independently in the 1930's by David Thompson and Chancey Juday. The problem of finding the best estimate from all days was turned over to Schnabel who developed a method of combining these daily estimates into a single weighted mean (Ricker 1945, 1948). Schumacher and Eschmeyer (1943) approached the same problem by a slightly different method, that of minimizing the squares of the residuals and used the following formula $P = \frac{(\Sigma AB^2)}{\Sigma BC}$. Their method has the additional advantage of including a formula for computing the sampling variance of P by $s^2 = \frac{1}{k-1}\left(\Sigma \frac{C^2}{A} - \frac{\Sigma BC}{P}\right)$ and hence the standard error of the estimate $P\sqrt{\frac{Ps^2}{BC}}$. In the above formula k is equal to the number of successful lifts. Ricker (1945, 1948) compares the efficiency of the two formulas by stating that Schnabel's is at its maximum efficiency when $B/P \rightarrow 0$, whereas Schumacher and Eschmeyer's is most efficient when $B/P = .5$. They are of equal efficiency when $B/P = .25$. He also points out that B/P will seldom exceed .25. A third method is given by Chapman (1951) in which the estimate P is derived by the formula

$$P = \frac{\Sigma\left(\frac{AB}{C}\right)\left(\frac{AB}{A-C}\right)\left(\frac{AB}{B-C}\right)}{\Sigma\left(\frac{AB}{A-C}\right)\left(\frac{AB}{B-C}\right)}$$

$$A.\ V.\ (P) = \frac{P}{\Sigma\left(\frac{A}{P-A}\right)\left(\frac{B}{P-B}\right)}$$

whence we can derive the standard error.

Chapman's method is based upon a hypergeometric distribution while previous methods have been based upon Poisson and binomial approximations to a hypergeometric distribution. Criteria given in Chapman (1948) indicate that the best method for finding the confidence interval estimate for P is from the normal approximation or preferably from the normal-hypergeometric. Consequently, we have made estimates through the use of two or three of these formulas i.e., Schnabel, Chapman, and Schumacher and Eschmeyer. If B/P exceeds .25 the estimate by the latter formula is included. In a single instance we have been able to apply DeLury's regression line. In the following table (Table I) results for all 8 netting periods are summarized.

For the purpose of clarity estimates of each species will be treated separately.

Table I

Summary of netting results at Big Bear Lake, Otsego County, Michigan, during 8 sampling periods, 1940-1946

For each species the upper figures represents the total catch (A), the middle figure is the total number marked (B), and the lower figure is the total number of recaptures (C).

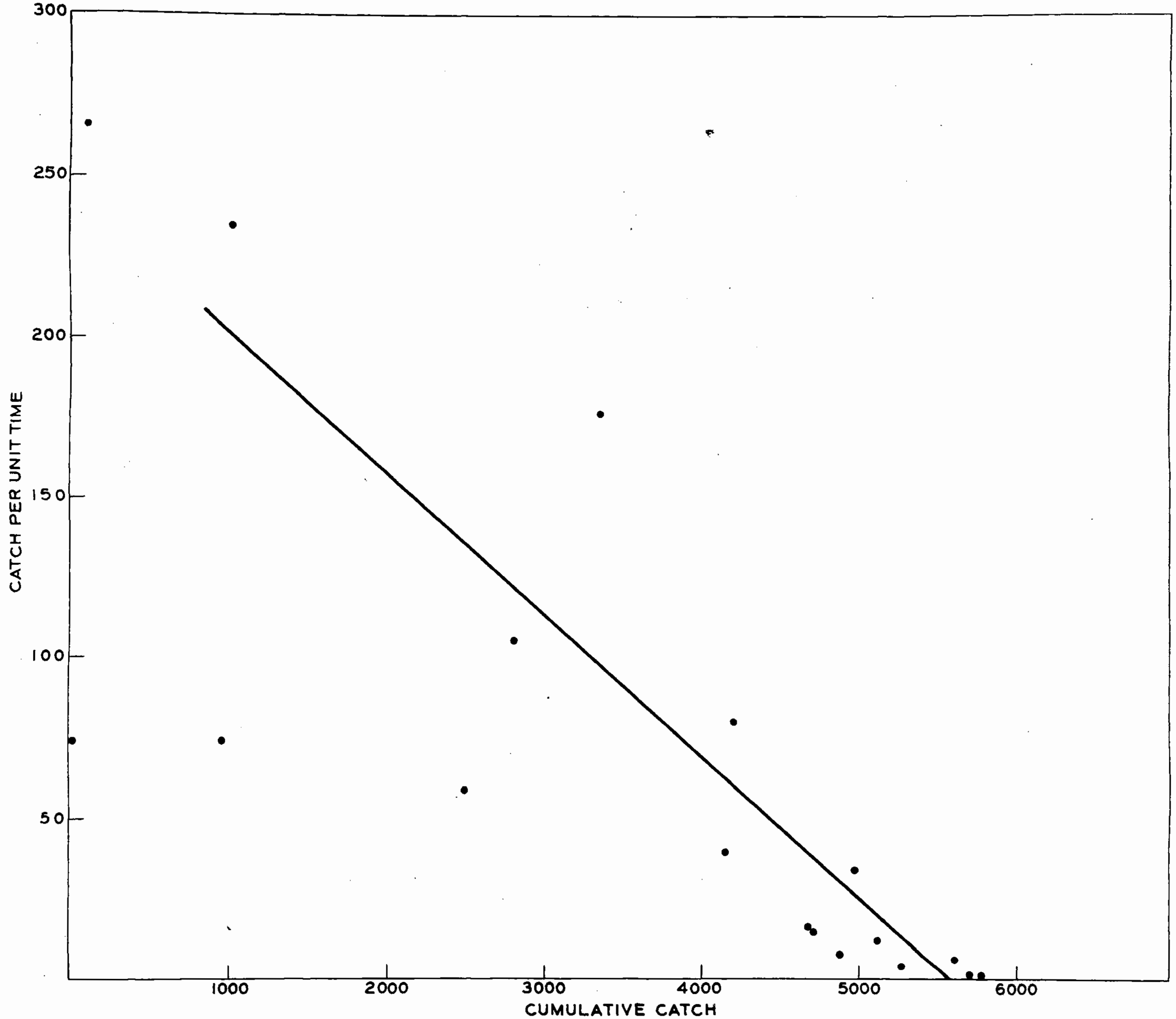
Species	1940 7/6-8/31	1941 7/1-8/24	1942 8/19-9/17	1943 5/18-6/21	1943 9/25-10/15	1944 5/17-6/20	1946 5/22-6/28	1946 9/5-9/28
Suckers	2,665 1,098 212	4,141 1,970 450	2,801 2,056 313	5,778	301 113 79	80 59 2	79 58 11	325 104 75
Large-mouth bass	1,627 479 217	2,261 1,213 768	395 297 56	710 529 104	668 443 67	887 604 131	567 392 83	341 234 21
Small-mouth bass	1,566 406 407	2,903 898 1,752	372 205 154	178 107 46	488 290 146	467 257 111	469 264 165	862 455 281
Bluegill	687 258 41	2,368 994 596	831 607 112	275 224 26	457 298 43	190 133 11	250 142 49	189 98 19
Pumpkinseed	1,502 260 265	2,436 1,339 556	1,021 758 177	868 560 193	836 471 148	743 502 142	717 429 186	566 396 44
Rock bass	327 110 14	535 285 134	173 124 38	84 73 11	1,274 706 320	355 263 31	720 531 102	2,140 1,460 469
Bullheads	28 8 16	65 14 37	19 9 10	6 4 2	19 8 8	1 1 ...	1 1 ...	102 64 21
Bluegill x pumpkinseed	17	27 17 8	12 9 2	2 2 ...	50 30 9	18 15 ...	60 34 26	21 7 1
Others	3 2 ...	... ...	1 1 ...	... ...	8 4 1	13 9 ...	2 2 ...	36 33 ...
All species	8,422 2,640 1,168	14,736 6,730 4,301	5,624 4,071 862	2,123 1,500 383	4,110 2,367 826	2,754 1,843 428	2,865 1,853 622	4,582 2,852 931

Sucker population

Of the six species of fish whose populations were estimated, the sucker was by far the most abundant until its numbers were drastically reduced in the spring of 1943. Fluctuations in the estimated sucker population are presented in Table II. In the spring of 1943 we attempted to catch and remove all of the suckers of catchable size. A total of 5,778 suckers was removed. This netting operation has been plotted in Figure 3, according to the method outlined by DeLury (1947) and illustrated for inland lake fishes by Omand (1951). From the 1942 estimate (Table II) there should theoretically have been 10,000 to 11,000 suckers available. In Figure 3 it will be noted that the regression line intersects the abscissa at 5,600. This estimate of about 6,000 suckers appears reasonable and the 1942 estimate was either high, or there was a heavy mortality of suckers between September of 1942 and the spring of 1943 when the suckers were removed. The very small catch of suckers after the removal (Table I) as compared with the catch before removal substantiates the belief that the 5,800 suckers removed in 1943 represented a very large portion of the sucker population as existing at that time. The belief is further substantiated by the estimates of about 350 obtained in the fall of 1943 and the spring and fall of 1946. The estimate of 1,400 in 1944 was probably high. As will be noted (Table I) there were only two recaptures during the 1944 netting period. It is also of interest to note that the large sucker population existing in 1943 had not been replaced by 1949. Apparently the spawning population was reduced to such a low point that reproduction was negligible during this period. For the first time since 1943 suckers again appeared to be fairly numerous as indicated by the results of a few gill net sets in 1950. Most of the suckers collected in 1950 were yearlings or two-year-olds.

Figure 3.

Sucker population, as estimated from catch records, spring, 1943, Big Bear Lake, Otsego County, Michigan.



300
250
200
150
100
50
CATCH PER UNIT TIME
1000
2000
3000
4000
5000
6000
CUMULATIVE CATCH

Largemouth bass population

The largemouth bass is the most abundant game fish in the lake. The estimates for all 8 periods are thought to be realistic. The population reached a low point in 1942 (Table II) but has remained at a more or less constant level since that time. The species reproduces successfully in the lake, and numerous year classes are represented in scale sample collections made each year.

Smallmouth bass

The smallmouth bass is the only other game fish present. It is less abundant than the largemouth, but is well established and reproducing successfully in the lake. Numerous year classes are represented in scale sample collections. The population increased after reaching a low point in the spring of 1943.

Bluegill

Of the 6 species whose numbers have been estimated, only the bluegill seems to occupy a somewhat questionable position as a component of the fish population of the lake. Very nearly all of the bluegills collected since 1941 belong to the 1938 year class, as determined from scale sample examinations. Subsequent year classes are so poorly represented as to be almost lacking. Young (small bluegills from 6 to 7 inches long) never appeared in trap net catches after 1941 in any appreciable numbers. The species makes excellent growth in the lake and year classes deposited after 1938 should certainly have appeared in trap net catches by 1946. Young-of-the-year bluegills were very poorly represented in seine collections made in September 1949. Survival from reproduction by the species has been almost negligible since 1938 and the ability of the species to maintain its numbers is open to question.

Pumpkinseed

The pumpkinseed (with the perch) is the most important pan fish in the lake, although up to 1944 the bluegill was as abundant. The pumpkinseed, in contrast to the bluegill, is well established in the lake, and numerous year classes are represented in the collections of scale samples made during the period 1940-1946.

Rock bass

Estimates of rock bass populations at Big Bear Lake are probably unrealistic, although the number of recaptures was consistently high. During the period of the investigation it was quite apparent that the rock bass were concentrated in the vicinity of the brush piles and they were not properly represented in the catch except in the fall of 1943 and 1946 when they were moving about the lake more freely. All estimates probably are at a minimal level.

Perch

As pointed out earlier perch were not represented in the trap net catches and estimates have not been made. Perch are unquestionably the most numerous pan fish in the lake, and they form the bulk of the fishermen's catch numerically. This dominance of perch in the fishermen's catch has been particularly pronounced since 1944.

Bullheads

From Table I it can be seen that a few bullheads were captured. Estimates of bullhead populations have not been included in Table II because so few were caught. Estimates, probably creditable, were obtained by the use of Schnabel's formula as follows: 11 in 1940, 17 in 1941, 9 in 1942, 6 and 13 in 1943, no estimate in 1944, no estimate in the spring of 1943, and 209 in the fall of 1946. This great (and genuine) increase in the bullhead population results from the appearance of a new, and previously unmarked, bullhead population in the autumn of 1946. Prior to the fall of 1946 probably not more than 20-30 different bullheads were marked. For example, those marked in 1941 included bullheads which had already been marked in 1940, and fish marked in 1942 might have been marked previously in 1940 and 1941. The few bullheads caught from 1940 to the fall of 1946 included both brown bullheads, and a few yellow bullheads. All but 5 of the 102 bullheads caught in September of 1946 were small brown bullheads.

Hybrids: Bluegill x pumpkinseed

In addition to the bullheads, estimates of the hybrid sunfish population were made by the use of Schnabel's formula. As indicated in summary of the catch (Table I) hybrids were caught in fair numbers and recaptures were sufficiently numerous to permit the estimates which follow: 1940 - no estimate, 1941 - 35, 1942 - 31, spring 1943 - no estimate, fall 1943 - 110, 1944 - no estimate, spring 1946 - 50, fall 1946 - 110.

Acknowledgments

I wish to thank Dr. A. S. Hazzard, director of the Institute for Fisheries Research for assistance in planning this study, and for critically reading the manuscript. Dr. G. P. Cooper of the Institute for Fisheries Research also offered valuable criticisms and help in the preparation of the paper. I am indebted to Mr. George F. Lunger of the U. S. Fish and

Wildlife Service, and to Mr. R. N. Schafer of the Institute for Fisheries Research for assistance with the mathematical applications of the data.

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Table II

Populations of 6 species of fish in Big Bear Lake, Otsego County, Michigan, as estimated by 3 different formulas.

	B/P	Schnabel	Chapman			Schumacher and Eschmeyer		
			Minimum (95%)	Estimate	Maximum	Minimum (68%)	Estimate	Maximum
Sucker								
1940	11.3%	9,699	10,035	11,692 ± 1,657	13,349			
1941	12.7	15,423	12,710	14,305 ± 1,595	15,900			
1942	19.6	10,480	9,955	11,122 ± 1,167	12,289			
1943 (1)								
(2)	30.9	366	302	367 ± 65	432	306	346 ± 40	386
1944	4.2	1,412	...	...	...			
1946 (1)	24.7	235	83	212 ± 129	341	175	206 ± 31	237
(2)	26.7	390	358	453 ± 95	548	354	396 ± 42	438
Largemouth bass								
1940	16.0	2,987	2,847	3,227 ± 380	3,607			
1941	50.9	2,383	2,258	2,409 ± 151	2,560	2,184	2,293 ± 99	2,382
1942	24.9	1,194	897	1,188 ± 291	1,479	978	1,054 ± 76	1,130
1943 (1)	25.4	2,080	2,001	2,485 ± 484	2,969	1,714	1,844 ± 130	1,974
(2)	16.2	2,726	2,536	3,386 ± 850	4,236			
1944	23.9	2,529	2,436	2,937 ± 501	3,438			
1946 (1)	23.5	1,670	1,436	1,827 ± 391	2,218			
(2)	11.0	2,128	1,251	2,286 ± 1,035	3,321			
Smallmouth bass	30.5	1,333	1,335	1,461 ± 126	1,587	1,231	1,268 ± 37	1,305
1940	30.5	1,333	1,335	1,461 ± 126	1,587	1,231	1,268 ± 37	1,305
1941	82.1	1,097	1,057	1,081 ± 24	1,105	1,072	1,091 ± 19	1,110
1942	67.4	304	260	289 ± 29	318	273	297 ± 16	313
1943 (1)	43.9	244	199	265 ± 66	331	234	271 ± 37	308
(2)	49.0	592	520	592 ± 72	664	521	573 ± 52	625
1944	35.7	720	642	765 ± 123	888	651	712 ± 61	773
1946 (1)	54.1	488	417	466 ± 49	515	432	455 ± 23	478
(2)	49.4	921	864	947 ± 83	1,030	839	891 ± 52	943

Bluegills								
1940	18.3	1,940	1,494	2,369 ± 875	3,244			
1941	33.5	2,978	2,858	3,067 ± 209	3,276	2,817	2,923 ± 106	3,029
1942	23.4	2,593	2,216	[illegible]	[illegible]			
1943 (1)	17.6	1,277	[illegible]	[illegible]	[illegible]			
(2)	15.3	1,952	1,514	[illegible] ± 716	2,946			
1944	9.6	1,389	274	[illegible] ± 537	1,348			
1946 (1)	31.4	452	397	546 ± 149	695	397	482 ± 85	567
(2)	15.8	620	270	467 ± 195	662			
Pumpkinseed								
1940	19.6	1,325	1,382	1,458 ± 166	1,714			
1941	34.2	3,926	3,822	4,118 ± 296	4,414	3,747	3,842 ± 95	3,937
1942	30.5	2,486	2,342	2,699 ± 357	3,056	2,181	2,336 ± 155	2,491
1943 (1)	37.2	1,507	1,427	1,627 ± 200	1,827	1,514	1,628 ± 114	1,742
(2)	26.6	1,773	1,665	1,958 ± 293	2,251	1,558	1,702 ± 144	1,846
1944	32.8	1,531	1,469	1,720 ± 251	1,971	1,516	1,636 ± 120	1,756
1946 (1)	40.9	1,049	962	1,093 ± 131	1,224	963	1,026 ± 63	1,089
(2)	13.5	2,941	1,907	2,689 ± 782	3,471			
Rock bass								
1940	8.4	1,307	287	728 ± 441	1,169			
1941	37.3	764	736	870 ± 134	1,004	724	771 ± 47	818
1942	37.8	328	212	294 ± 82	376	247	275 ± 28	303
1943 (1)	27.4	266	96	193 ± 97	290	135	185 ± 50	235
(2)	38.9	1,813	1,695	1,862 ± 167	2,029	1,757	1,848 ± 91	1,939
1944	14.9	1,761	1,032	1,658 ± 626	2,284			
1946 (1)	24.7	2,148	2,064	2,575 ± 511	3,086	1,952	2,154 ± 202	2,356
(2)	38.5	3,791	3,614	3,911 ± 297	4,208	3,504	3,731 ± 227	3,958

(1) = Spring estimate

(2) = Fall estimate

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