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

Report No. 1325

April 3, 1952

POPULATION ESTIMATES, AND EXPLOITATION BY ANGLERS, OF FISH IN SUGARLOAF LAKE, WASHTENAW COUNTY, MICHIGAN

By

Gerald P. Cooper

Abstract

Sugarloaf Lake has been the subject of special studies, since 1946, on new fishing regulations. The effects of liberalized fishing regulations are being evaluated by intensive creel census and by fish population estimates. The wide scope of the whole study has meant that many persons have been involved and have made contributions.

The lake is located in Washtenaw County. It has an area of 180 acres, a maximum depth of 20 feet (in a very limited area), an average depth of about 3 feet, moderately heavy fishing intensity, and a population of warm-water fish including the bluegill, pumpkinseed, yellow perch, black crappie, warmouth, rock bass, largemouth bass, pike, bullheads and bowfin.

Trap netting on a systematic pattern of 40 stations over the lake, and on a systematic schedule of dates from May 5 to June 17, gave the data for population estimates in 1951. Using 6-ft. and 3-ft. trap nets, 3,609 fish were collected, 3,524 were marked and liberated at a central release station, and 453 (12.9%) were recaptured. Fish were marked distinctively for each of the 40 stations where first captured.

An analysis of recaptures (by IBM card sorting) showed a moderate tendency for fish to be recaptured in the same half of the lake where first captured: of 453 recaptures, 277 were in the home half, 176 in the opposite half (amounting to a home-half bias of 22%). Continuing the analysis of homing as it applied to the home net sites, for the twenty 6-ft. nets only (because these caught most of the fish), a small excess of fish were recaptured at their home site over and above the number to be expected on a random hypothesis. For use in population estimates, the homing bias is thus roughly corrected by subtracting the 12 bluegills, 5 bullheads, 4 warmouth, etc. (which represent the amount of homing bias), from records of recaptures.

Population estimates for 1951 were made by the Petersen Method, using the formulae of Schumacher and Eschmeyer. The estimate for bluegills was 14,450, for pumpkinseeds 540, black crappie 530, rock bass 600, largemouth bass 470, bullheads 580, warmouth 1,160 and bowfin 280. Totaling gives 100 fish or 40 pounds per acre, and this applies to panfish over 6 inches, bass over 10, and pike and bowfin over 14.

Population data for 1951 were averaged with similar population estimates for 1948, 1949 and 1950 (Cooper, In Press) to give a 4-year average of the standing population for each species. Detailed creel census data provided by Christensen (MS, In Press) were used to compute the total annual removal of fish from the lake for each year 1946 to 1950, inclusive, and to compute the annual average for the five years. For example, the standing crop of bluegills averaged 13,480 while the annual catch averaged 9,977; for pumpkinseeds the crop was 790 but the annual catch was 1,261; for rock bass, 710 and 691; for largemouth bass 770 and 943; and for bullheads, 620 and 199; (and similar data for other species). Exploitation on yellow perch was not determined because perch

were not susceptible to trap nets and no reliable population estimate was possible.

The average standing crop of all game species (excluding perch) over four years (1948-1951) was 18,500 fish, and the average annual creel of all species (excl. perch) for five years (1946-1950) was 14,232 fish.

The above figures apparently show a fairly high rate of exploitation, but it would be easy to misinterpret the data. A more precise determination of the rate of exploitation would require information on the age-composition of the fish population, on which point the data available to date are not adequate. (Available scale samples gave ages which were then averaged in terms of how many years the fish had lived after reaching legal size. For all legal-size fish sampled, this average was 2.2 years, but the figure is regarded as only a rough estimate because bias in sampling is suspected.)

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

Original: Mich. Acad. of Sci., Arts & Letts.
cc: Fish Division
Education-Game
Institute for Fisheries Research
R. S. Marks
G. P. Cooper

April 3, 1952

Report No. 1325

POPULATION ESTIMATES, AND EXPLOITATION BY ANGLERS, OF FISH IN SUGARLOAF LAKE, WASHTENAW COUNTY, MICHIGAN*

by

Gerald P. Cooper

Sugarloaf Lake is one of several lakes on which new fishing regulations are being tested by a creel census of angling returns. On Sugarloaf, fish population estimates are also being made to determine number of fish present and, by a comparison of both sets of data, the rate of exploitation. The only feasible method for estimating the number of fish in this lake is the Petersen Method of mark-and-recapture, in which fish are captured, marked and released; a random redistribution of these marked fish throughout the lake is assumed; and netting operations are continued until an appreciable number of the marked fish have been recaptured, over a period of many days, which gives a basis for estimating the population by a proportion formula. The indirect estimations of relative abundance of fish in lakes, represented by creel census statistics and catch per unit of effort of nets, are much less satisfactory as compared to the direct estimation of the number of fish present.

The assumption of a random redistribution of marked fish and other related assumptions, outlined in detail by Ricker (1948), which are essential to an unbiased estimate of the population, are not always met; in fact, are probably seldom met to the degree of exactness which

---

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

workers hope for or assume. It is essential that the factors which cause bias be understood and that corrections be worked out for the resulting errors, if outstanding progress in research and management of lake fishes is to be made.

Population estimates of lake fishes by other employees of the Institute for Fisheries Research have included the study by Krumholz (1944) on fish in Twin Lake in Oscoda County, the study of fish in Big Bear Lake, Otsego County by Crowe (MS, In Press), and several unpublished studies by W. C. Beckman and associates (I.F.R. typewritten reports). A series of studies started in 1948 by the writer and associates has involved three lakes, and the present study on Sugarloaf Lake in 1951 is a portion of the series. In the present series netting effort is being increased, to obtain a greater catch and to get more extensive coverage of lake area, in order to elucidate and make corrections for the several sources of bias. A study on Sugarloaf Lake during the summers of 1948 to 1950 and of Fife Lake (in Grand Traverse County) in 1950 was summarized by Cooper (In Press, Transactions of the American Fisheries Society). In addition, a study of Pond 24 (a 30-acre pond at the Wolf Lake State Fish Hatchery in Van Buren County) in 1951 promises to be very helpful in understanding many of the problems of population estimates; laboratory analyses of the data are still to be completed.

The problems which are especially pertinent in the Petersen Method of estimating fish populations, problems with which the present study is especially concerned, are as follows: (a) Do marked fish when released at a central station redistribute themselves over the lake at random, or do they show some strong tendency for homing to the site where they were first collected by netting? Is their redistribution to

a large extent non-random because of a combination of ecological differences in the habitat and differences in ecological preferences on the part of the fish? (b) If random redistribution were possible, or even closely approached, only one collecting station per lake would be needed. But actually, the assumption of random redistribution for a variety of species in a lake of one to several hundred acres is quite absurd. The reasons are obvious. For example, some species prefer colder water and thus would be inclined to remain in the deeper parts of a lake. Other forms, preferring shallow water, are more abundant near shore. During spring and early summer, nest-guarding males of centrarchids have different distributions and migratory habits from those of their mates. Some species prefer protective cover more than do others. The examples could be continued at great length. Therefore, although we speak of random redistribution, the assumption is made that it does not exist, and the discrepancy is compensated for by employing several netting stations throughout the lake which, if distributed at random, will compensate for the various inequalities of distribution of marked and unmarked fish--differences due to species, sex, size, and other factors. The key, then, to adequate sampling in the population estimations on a lake is the number and distribution of netting sites and the continuation of netting operations until a large number of fish have been handled. In the present study, an investigation has been made of the adequacy of variable numbers of netting stations, by first employing a large number of stations, and then making secondary population estimates by sub-sampling data for certain stations on a random basis. (c) A tendency for homing by fish which have been marked and released might be in part a matter of returning to the type of habitat within the lake which the fish most prefers, along with some tendency for the fish to return to its own niche. The two problems have different significance

in the population estimation, the first being readily compensated by an extensive pattern of netting stations, but the second would constitute a systematic error which would need to be appraised and corrected by mathematical subtraction. (d) Present population studies have employed a common release station, near the center of the lake, at which all fish are released. This involves a geographical dislocation of the marked fish. The question is then raised as to whether or not these dislocated fish become nomads, or wanderers, with a consequently much higher rate of susceptibility to capture by netting than applies to fish which have not been moved from a particular territory.

Methods

Sugarloaf Lake is located in the northwest corner of Washtenaw County about 25 miles northwest of Ann Arbor. It has an area of 180 acres. The maximum depth is 20 feet, but only a very limited area is over five feet deep. Most of the lake has a considerable amount of aquatic vegetation. Because of the uniform shallowness of the lake, making the entire fish population accessible to small trap nets, the lake is ideal for this type of study. It compares favorably with other lakes of southern Michigan in fish production under moderately heavy fishing intensity. The game and panfishes include a majority of the warm-water species which are common to the southern part of the state--namely the bluegill, largemouth bass, black crappie, warmouth, rock bass, pumpkinseed, yellow perch, northern pike and bullhead (for scientific names, see Table I).

The field work involved the operation of trap nets and the processing of fish during the period of May 6 to June 17, 1951. Two sizes of

Table I

Summary of trap net operations on Sugarloaf Lake, May 6 to June 17, 1951

Species	Number newly captured (u)	Number marked and released (Σ = n)	Number recaptured (m)	Percentage recaptured
Bluegill *Lepomis macrochirus*	2,401	2,349	223	9.5
Yellow bullhead *Ameiurus natalis*	180	180	45	25.0
Brown bullhead *Ameiurus nebulosus*	36	35	8	22.9
Black crappie *Pomoxis nigro-maculatus*	192	186	45	24.2
Largemouth bass *Micropterus salmoides*	80	68	9	13.2
Rock bass *Ambloplites rupestris*	148	147	21	14.3
Pumpkinseed *Lepomis gibbosus*	135	131	22	16.8
Warmouth *Chaenobryttus coronarius*	333	330	63	19.1
Pike *Esox lucius*	13	11	...	...
Bowfin *Amia calva*	87	83	17	20.5
Yellow perch *Perca flavescens*	3	3	...	...
Shortnose gar *Lepisosteus platostomus*	1	1	...	...
Totals	3,609	3,524	453	12.9

trap nets, a 6-ft. net and a 3-ft. net, were used, and the mesh sizes were such that these nets retained game and panfishes of the size usually taken by anglers. The smaller fish were not captured and are not involved in the present study. A detailed description of these nets is given in the earlier publication (Cooper, loc. cit.), and need not be repeated here.

Four of the 6-ft. and four of the 3-ft. trap nets were fished continuously in the lake, at 40 stations, in a pattern systematized as to location on the lake (Fig. 1) and on a schedule systematized as to date (Fig. 2). Furthermore, each half of the lake was fished continuously by two 6-ft. and two 3-ft. nets, and a systematic scheme of locating consecutive net sites over each half of the lake was followed. Each net was left at a particular site for 4 consecutive nights and moved to the next site (in numerical sequence) on the fifth day.

All nets were serviced once a day and all fish were marked before release, using a distinctive mark for each station. A system of punching holes in two or more of the various fins provided a series of identification "numbers" for the 40 stations. All marked fish were liberated at a central release station (Fig. 1). For marked fish which were subsequently recaptured, records were kept of the stations of recapture and of marking. Length and weight data were obtained on individual fish of certain species, based on random samples from the nets. Daily records were kept of netting, marking, recaptures, and mortalities in nets and on the lake, and daily waters temperatures were taken. Water temperatures were cool, so that there was relatively little mortality resulting from the netting. Laboratory analyses of the data were facilitated by use of IBM card sorting and tabulating.

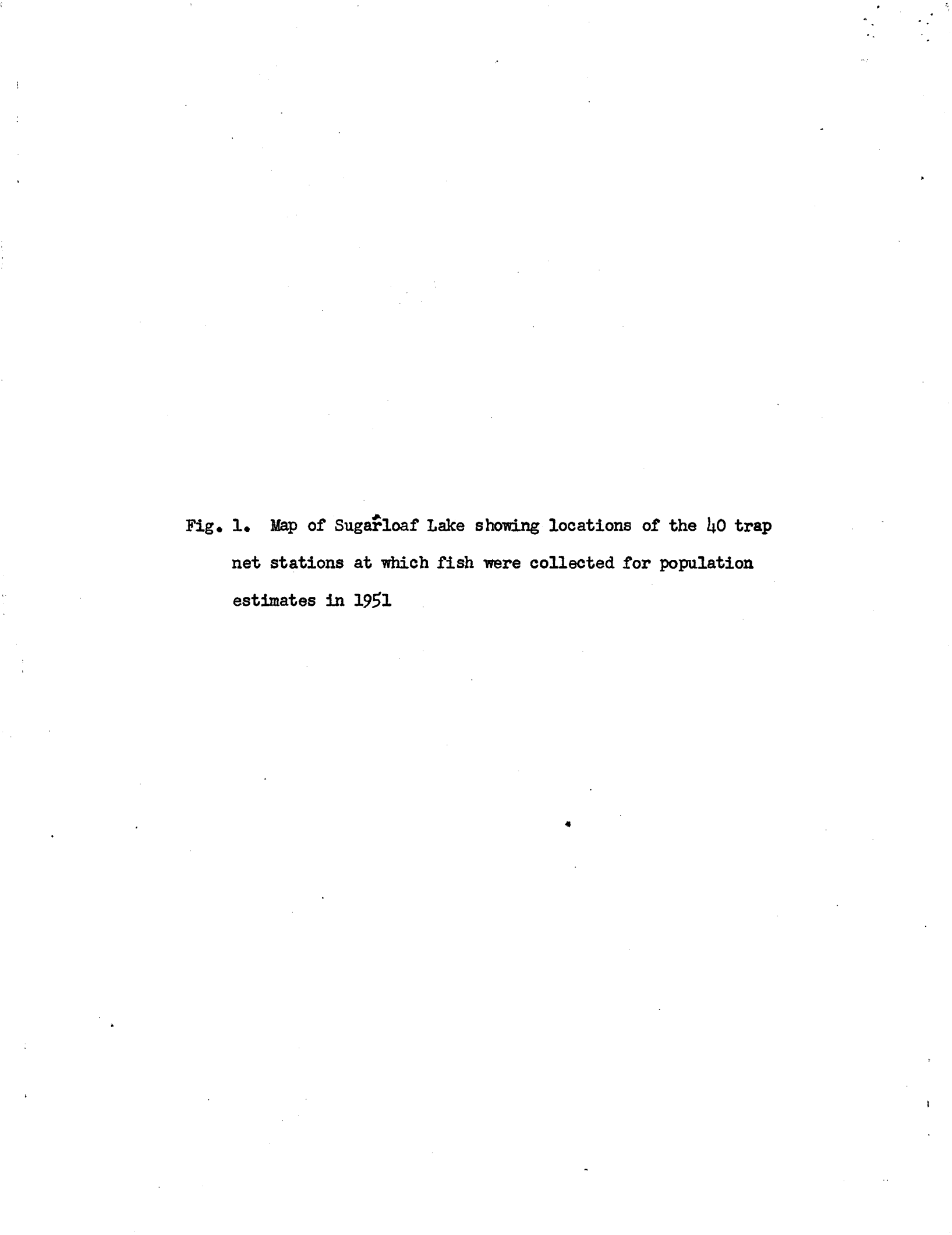


Fig. 1. Map of Sugarloaf Lake showing locations of the 40 trap net stations at which fish were collected for population estimates in 1951

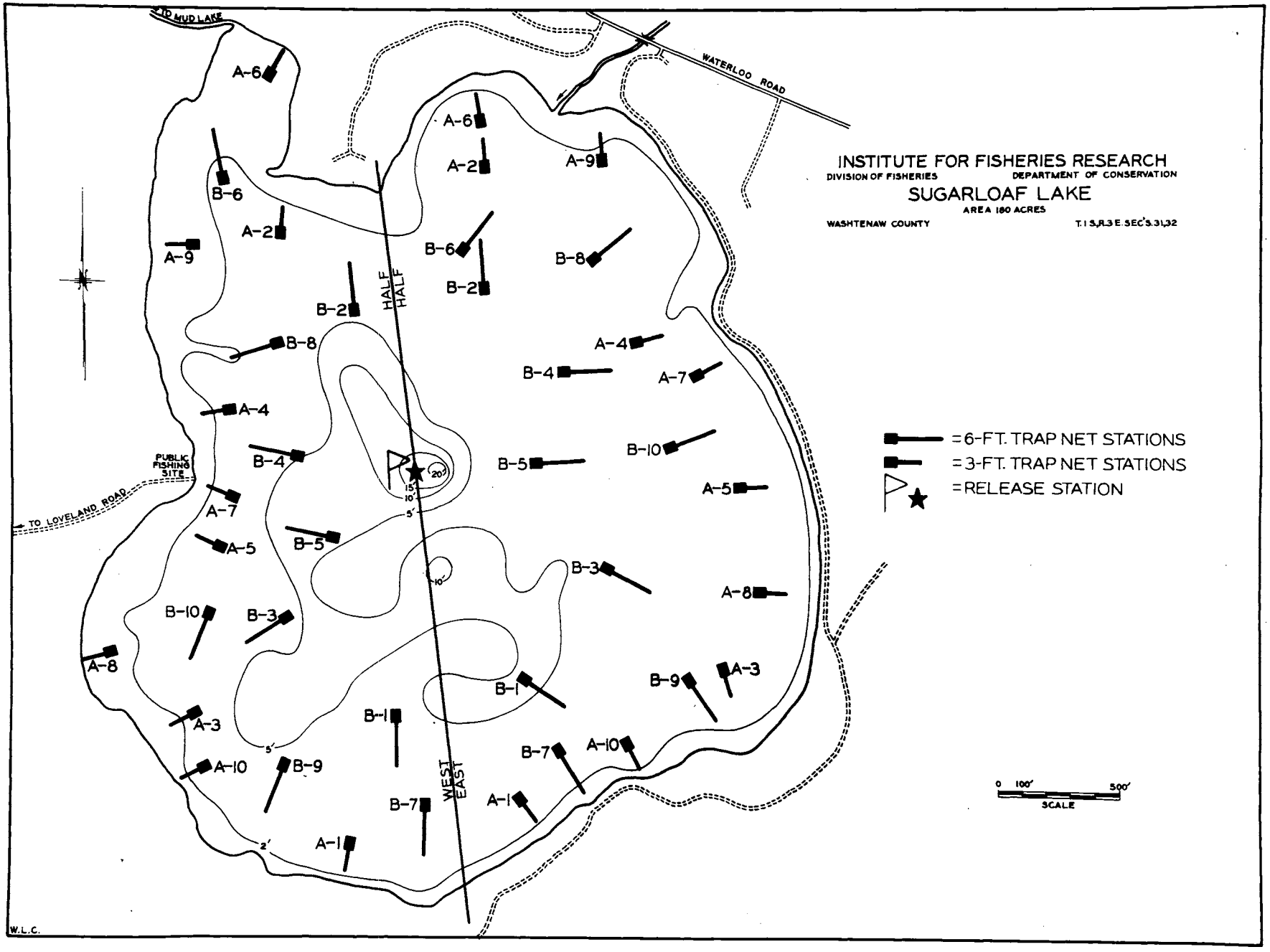
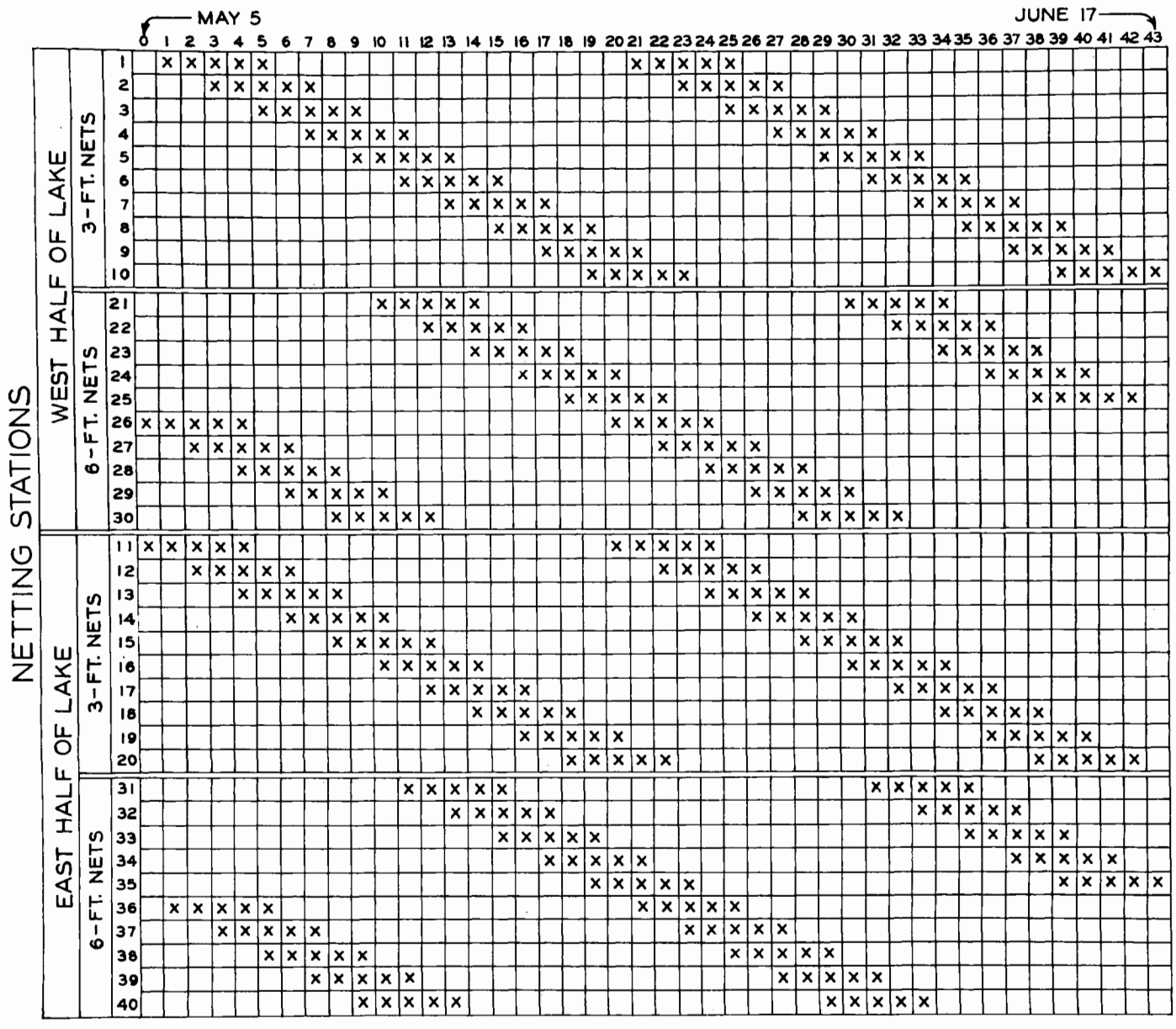

TO MUD LAKE
WATERLOO ROAD
INSTITUTE FOR FISHERIES RESEARCH
DIVISION OF FISHERIES
DEPARTMENT OF CONSERVATION
SUGARLOAF LAKE
AREA 180 ACRES
WASHTENAW COUNTY
T. 1 S, R. 3 E. SEC'S. 31, 32
HALF
HALF
WEST
EAST
PUBLIC FISHING SITE
TO LOVELAND ROAD
= 6-FT. TRAP NET STATIONS
= 3-FT. TRAP NET STATIONS
= RELEASE STATION
0 100' 500'
SCALE
W.L.C.

Fig. 2. Date schedule followed in the operation of trap nets at 40 stations on Sugarloaf Lake in 1951. X indicates that net was at the station on that day. Fish were processed after each of the 4 overnight sets


DAY OF NETTING
MAY 5
JUNE 17
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43
NETTING STATIONS
WEST HALF OF LAKE
3-FT. NETS
6-FT. NETS
EAST HALF OF LAKE
3-FT. NETS
6-FT. NETS
1 2 3 4 5 6 7 8 9 10
21 22 23 24 25 26 27 28 29 30
11 12 13 14 15 16 17 18 19 20
31 32 33 34 35 36 37 38 39 40

Many individuals contributed much to the present study. The field crew for the population netting included Messrs. D. F. Thomas (leader), F. E. Simonis and C. A. Pfitzmaier. Mr. K. G. Fukano made the card-punch analyses of the population data. Mr. Thomas collected the creel census data in the field, and Messrs. K. E. Christensen and R. N. Schafer did the laboratory analyses of these records. Dr. W. C. Beckman kindly made the age determinations of fishes. Dr. A. S. Hazzard, Director of the Institute, made many helpful suggestions.

Results

During the 43 days of netting at the 40 stations, 3,609 fish were caught, 3,524 of these were marked and released, and 453 marked fish were recaptured, all involving a total of 12 species (Table I). The bluegill was by far the most abundant form, comprising 2/3 of the original catch, and 1/2 of the recaptures. For three species there were no recaptures, presumably reflecting rarity in the case of pike and shortnose gar, and non-susceptibility to capture by trap net in the case of yellow perch.

The fish initially captured (n) are listed by species and net station in Table II and by date of collection in Table VIII. The 6-ft. nets, operating at stations 21-40 inclusive, were far more efficient in catching fish than were the 3-ft. nets which were fished at stations 1-20; the 6-ft. nets took 3,272 fish, while the 3-ft. nets took 323 fish (4 perch and gar not included) in comparable amounts of netting effort. Thus the relative efficiency was approximately 10:1 in favor of the 6-ft. nets, and this difference was reflected in number of recaptures.

Table II

Initial captures (u) of fish by trap net from Sugarloaf Lake, 1951, tabulated by species and net station number

Net station number	Bluegill	Yellow bullhead	Brown bullhead	Black crappie	Large-mouth bass	Rock bass	Pumpkin-seed	Warmouth	Pike	Bow-fin
1								4		
2	2	13				2		1		1
3								2		
4	6	11				2		7		
5	1							1		
6	17	4				3		5		
7	2	1	1				1	2		
8	1	3					1	1		
9	1	1						1		
10		2						5		
11	3	12			1		1	15		
12	6	11	1	1		1		16		1
13		5								
14	50	2				15	3	9		
15	8	1				2		4		1
16	8	2	1			3		3		2
17			1			1				
18	11	2	2			1	1	5		2
19	1						1	1		2
20	5					2	1	1		
21	105	3	2	6	5	2	6	46		1

22	177	2	2	4	2	10	8	10		4
23	186	2	6	13	9		9	20	1	7
24	152	2		14	6	3	16	19		5
25	61	1	4	21	18	1	7	7		6
26	180	21		4	3	6	9	7		5
27	112	11	2	20	8	4	5	20	1	5
28	157	5	2	12	7	5	10	11	1	6
29	101	8	3	8	4	3	8	19	1	8
30	85	1	2	8	2	4	5	6		3
31	12			4	2	1	1	4		
32	286	5	3	7	2	4	6	9	1	6
33	42	1		10	2	3	4	2	3	
34	252	3		9		9	10	4		2
35	14			14	1	1	1	2		4
36	105	20	1	10	3	4	6	10	2	5
37	46	7		10	1	23	4	38	1	1
38	114	16	1	6		7	3	4		8
39	15			4	1	11	2	4		1
40	77	2	2	7	3	15	6	8	2	1
Totals	2,401	180	36	192	80	148	135	333	13	87

Of 453 recaptures, 409 were in 6-ft. nets and 44 were in 3-ft. nets (Table III), with a ratio significantly close to the expected 10:1. Thus the 3-ft. nets made a relatively small contribution to the results of this study.

Since two complete rounds, or cycles, of the 40 stations were made by trap nets, the data make possible an analysis of markings and recaptures on the basis of netting cycles which is of some interest. The first cycle required the period of May 5 to 23, and the second cycle extended from May 20 (i. e., with 4 days overlap with the first cycle) to June 17. The records (Table IV) show, for bluegills as an example, 1,394 fish caught and marked during the first netting cycle, and 955 in the second, while there were 69 recaptures during the first cycle and 154 recaptures during the second. Total catch of all species for cycle 1 was (2,237) about twice that (1,272) of cycle 2, presumably reflecting a seasonal difference in fish movements; by late May and early June many of these fishes are involved in spawning and nest guarding. The greater number of recaptures in cycle 2 was to be expected, and in this case more than counteracted the greater catchability of fish during cycle 1, because so many more marked fish were present in the lake at the beginning of, and during cycle 2. Continuing with the bluegill data for illustration, there were in the lake 0 marked bluegill at the beginning, and 1,394 marked bluegills at the end, of cycle 1; whereas there were 1,394 at the beginning, and 2,349 at the end of cycle 2. By averaging the two pairs of totals, we obtain 697 marked bluegills in the lake on the average during the period of cycle 1, and 1,871 for cycle 2. Since the total

Table III

Summary of data on recaptures, for all species combined, to show the greater efficiency of the 6-foot trap nets and the extent of homing to the half of the lake where first captured

Markings			Recaptures			
			3-foot net		6-foot net	
Stations	Net	Lake half	west half	east half	west half	east half
1-10	3-foot	west	2	2	27	13
11-20	3-foot	east	2	8	28	25
21-30	6-foot	west	7	5	121	58
31-40	6-foot	east	5	13	63	74

Table IV

Analysis of data on markings and recaptures according to the first half (cycle 1) and second half (cycle 2) of the netting period

Species	Marked[1]		Recaptured	
	Cycle 1	Cycle 2	Cycle 1	Cycle 2
Bluegill	1,394	955	69	154
Yellow bullhead	157	23	29	16
Brown bullhead	21	14	3	5
Black crappie	145	41	18	27
Largemouth bass	34	34	2	7
Rock bass	115	32	10	11
Pumpkinseed	73	58	11	11
Warmouth	256	74	35	28
Bowfin	42	41	4	13
All species	2,237	1,272	181	272

[1] Three species, 15 fish, not included, because there were no recaptures.

catches during cycles 1 and 2, with comparable netting effort, were about double in cycle 1, the average numbers of marked fish present are multiplied by their relative catchability to estimate expected number of recaptures. Thus 697 X 2,237/1,272 = 1,250 which is related to 1,871 quite identical to the ratio 181:272, (the total recaptures in cycles 1 and 2). This shows that the rate of recaptures of marked fish in the lake proceded with considerable uniformity in proportion to the abundance of marked fish present and their relative catchability.

Virtually all fish which were captured were marked and released; the exceptions were 2 pike, 1 pumpkinseed and 4 bluegills taken during the first 40 days of netting and all fish caught during the last 3 days of netting. The netting pattern was such that there were 10 net stations occupied by each of the 2 types of nets in each half of the lake. An analysis was made (Table V) of all markings, and of all recaptures as related to station of marking, for the 2 types of nets and the 2 halves of the lake. For example, for bluegills there were 29 fish marked at stations 1-10 (3-ft. nets in west half of the lake), 90 marked at stations 11-20 (3-ft. nets in the east half), a total of 119 marked at stations 1-20, 1,308 marked at stations 21-30 (6-ft. nets in the west half), etc; and of the 223 bluegills recaptured, 76 were fish which had been marked at stations 1-10 or 21-30 and were recaptured at these same stations, 48 were fish marked at stations 11-20 plus 31-40 and recaptured at stations 1-10 plus 21-30. Correspondingly, for all species, this table gives the basis for an analysis of the extent to which marked fish were recaptured in their home half of the lake vs. recaptured in the half of the lake opposite from where they were first captured and marked. An analysis by Chi-square of the recapture data of Table V, using the Chi-square formula adjusted for small numbers (Snedecor, 1948, Sec. 1.13), shows

Table V

Analysis of records on marking and recapture of fish in Sugarleaf Lake, 1951, by netting stations and thereby according to 2 types of net and 2 halves of the lake (compare with Table III)

Stations	Bluegill	Yellow bullhead	Brown bullhead	Black crappie	Largemouth bass	Rock bass	Pumpkinseed	Warmouth	Bowfin
Markings at:									
1-10	29	35	1	...	...	7	2	28	1
11-20	90	35	5	1	1	25	7	54	8
1-20	119	70	6	1	1	32	9	[illegible]	9
21-30	1,308	56	22	107	53	38	81	163	47
31-40	922	54	7	78	14	77	41	85	27
21-40	2,230	110	29	185	67	115	122	248	74
1-10+21-30	1,337	91	23	107	53	45	83	191	48
11-20+31-40	1,012	89	12	79	15	102	48	139	35
Totals (markings)	2,349	180	35	186	68	147	131	330	83
Recaptures at:									
1-10+21-30 (marked at 1-10+21-30)	76	16	3	16	6	2	12	21	5
1-10+21-30									

(Table VI) a homing tendency which only for certain species (bluegill, yellow bullhead, rock bass and pumpkinseed), is highly significant statistically. This homing tendency, collectively for the 9 species which were recaptured, amounted to 22 per cent:

453 fish recaptured
277 fish recaptured at home-half stations
176 fish recaptured at opposite-half stations
101 excess fish recaptured at home-half stations (=22% of 453)

If fiducial limits are applied to the 277 - 176 = 101 (22%) fish which were the homing increment, with 95 per cent probability, there is 1 chance in 20 that the homing tendency amounted to as little as 18 per cent.

It is shown by an analysis to follow that this pronounced homing consisted mostly of the effect of a home-half phenomenon and only in small part was the effect of a home-station phenomenon. The inference is that the fish redistributed themselves more frequently to a preferred type of habitat within the lake (which might logically be found more commonly in the home half), or that a directional tendency towards the home site or niche was only partly effective. Since that portion of the 22 percentage of homing which is ascribed to a home-half (vs. home-station) phenomenon is not a source of bias in the population estimate, because the extensive pattern of netting stations would compensate for that type of homing, there remains only the small portion of the error which is properly assigned to the home-site phenomenon to be appraised and corrected below.

The analysis of recaptures according to home site versus non-home site is possible, because fish were marked distinctively for each of

Table VI

Analysis of data on recaptures of fish in Sugarleaf Lake according to whether they were recaptured in the same half of the lake (east versus west) as where first captured, and an analysis of ratios by Chi-square testing divergence from a 50:50 hypothesis

Species	Recaptures			Chi-square	P = improbability of significant homing
	Total	At home half	At opposite half		
Bluegill	223	128	95	4.6	0.04
Yellow bullhead	43	33	12	8.9	<0.01
Brown bullhead	8	3	5	0.1	-0.77
Black crappie	45	22	23	0.0	-0.99
Largemouth bass	9	7	2	1.8	0.18
Rock bass	21	18	3	9.3	<0.01
Pumpkinseed	22	19	3	10.2	<0.01
Warmouth	63	37	26	1.6	0.20
Bowfin	17	10	7	0.2	0.64
All species	453	277	176	22.1	<0.01

the 40 stations. The analysis is complicated by the fact that the one type of trap net was 10 times as efficient as the other in catching fish. But the 3-ft. nets recaptured so few fish that their records can be ignored with no important degree of error. Thus the recapture records have been analyzed for homing to the home net site using only fish which were marked in 6-ft. trap nets and recaptured in the same nets. The data in detail are presented for the bluegill in Figure 3, but for other species only in summary form in Table VII. For the 20 net stations involved there were 20 possibilities of fish returning to their home net site while at the same time there were 380 possibilities of fish being recaptured at some net site other than the home site. The hypothesis is set up that the marked fish, after liberation at the common release station (Fig. 1), distributed themselves at random over the lake without respect to the site of their origin. This hypothesis is tested by obtaining the total number of recaptures at home stations versus the total recaptures at non-home stations, and using Chi-square to compare the observed numbers with the expected ratio, 20:380. With the bluegill, for example, 20 recaptures were at home sites while 156 were otherwise. Had these 176 fish been distributed according to expectancy, the numbers would be 8.8 fish at home sites and 167.2 fish at non-home sites. Here Chi-square is 19.9 and the probability that a homing tendency was operating is much higher than 99 per cent. Further, a correction for homing is possible. While 156 bluegills were being recaptured at non-home stations, the expected number for home stations would be 8.2, and this compared to 20 observed home recaptures gives a correction factor for bluegills of 12. Thus if we subtract, by random selection, 12 recaptured bluegills from the accumulated netting data,

Fig. 3. Recaptures of bluegills at stations 21-40 (those where 6-ft. trap nets were fished) and limited to fish which had been marked at stations 21-40, for an analysis of homing

RECAPTURE STATIONS

MARKING STATIONS

		WEST HALF										EAST HALF									
		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
WEST HALF	21	2		3					1		2		1								
	22		2	2	1				1				1		2					1	
	23			7							1		1	1							
	24			1				1					1	1							
	25														1						
	26	1	4	5	2	1			1	1	1		4		1				1		
	27	1		2		1				2	1		2		1						
	28		1	2	2	1		1			1		7		3				1	2	1
	29			3						2			1		1						
	30			1							1		1						1		
EAST HALF	31														1						
	32		1	1	2	2					1		2	1	3	1			1		
	33														1					1	
	34				2	1									4						
	35												1		1						
	36		3	3	3	3	1		1				1		6				1		
	37		1												1				1	2	
	38			2		2				1	1		2	1	4						1
	39										1		1								
	40			2		1							2		2						

Table VII

Analysis of recaptures of Sugarloaf Lake fish, both marked and recaptured in 6-ft. trap nets, according to whether recapture was at the same net station where marked or at one of the 19 other 6-ft. net stations, and analysis by Chi-square testing divergence of observed ratios from the expected 20:380

Species	Recaptures			Chi-square[+]	P = improbability of significant homing	Correction for homing bias
	Total	At home station	At non-home station			
Bluegill	176	20	156	19.9	<0.01	12
Yellow bullhead	17	6	11	28.9	<0.01	5
Brown bullhead	6	1	5	1.1	0.29	1
Black crappie	36	3	33	0.29	0.60	1
Largemouth bass	8	1	7	0.03	0.87	1
Rock bass	11	1	10	0.0	0.99	1
Pumpkinseed	17	1	16	0.0	0.99	0
Warmouth	34	6	28	8.9	<0.01	4
Bowfin	11	2	9	2.1	0.15	1
All species	316	41	275	36.6	<0.01	26

[+] In a summation Chi-square with d.f. = 9, X^2 = 61.2 and P <0.01.

a population estimate can be made which is corrected for the bias of homing. Like the bluegill, the yellow bullhead and the warmouth showed a pronounced homing tendency, although the number of fish involved was low. For all species collectively, the homing tendency was highly significant statistically but of relatively low magnitude. Up to this point continuous emphasis has been put on the evidence that the fact of homing was established and some bias was inherent among the data. A partial reorientation in point of view at this time is probably in order, since it is shown that the significant homing bias is small and can be corrected.

Population estimates were made by applying the formulae of Schumacher and Eschmeyer (1943) to the marking and recapture data (Table VIII), treating each species separately. Only fish of legal size are involved: bass over 10 inches and panfish over 6 inches. The number of unmarked fish caught each day (u) and the daily recaptures (m) are recorded. As u fish are marked and released, they accumulate in daily totals (n); and since n is the running total number of marked fish known to be present on any given date, the observed daily mortalities of marked fish (either in the nets, in creels, or elsewhere) must be subtracted in arriving at this total. The population estimates are based on summaries for k number of days in the netting period, of daily functions of u, n and m, in the following formulae:

$$P \text{ (population)} = \frac{\Sigma[n^2(m+u)]}{\Sigma(nm)}$$

$$\text{Variance of } P = s^2 = \frac{1}{k-1}\left[\Sigma\left(\frac{m^2}{m+u}\right) - \frac{1}{P}\Sigma(nm)\right]$$

$$\text{Standard error of } P = \sigma_e = P\sqrt{\frac{Ps^2}{\Sigma(nm)}}$$

Table VIII

Initial captures (u) of fish in Sugarloaf Lake, practically all of which were marked and released (exceptions, see text), and recaptures (m), by species and netting day

Day (May 6-June 17)	Bluegill		Yellow Bullhead		Brown Bullhead		Black crappie		Large-mouth bass		Rock bass		Pumpkin-seed		Warmouth		Pike		Bowfin	
	u	m	u	m	u	m	u	m	u	m	u	m	u	m	u	m	u	m	u	m
1	63		10				1		1				2		5				1	
2	43		22				2		1		3		2		5				4	
3	77		12	2			9		2		3		5		11	1	1			
4	116	1	25	2			11		1		11		6		32	1	1		2	
5	87	1	17	3			14	1	2		3		4		18	1	1		3	
6	88	1	10	2	2		10				14	1	4		17		2		2	
7	58	2	8		1	1	2		1		4		2		12		1		2	
8	78	3	20	4	1		3	1			16		7	1	10	1			1	
9	53	1	8	2	2		9		1		6		4		9	2			2	
10	40	1	7	3			3		1		6	2	4	2	13	3	1		1	
11	46		1	2			8		1		3				16	7	1		1	
12	54	1	2		2		2		2		7	2	1		10	2				
13	60	1	2		1		5	1	6		15	1		1	15	2			1	
14	126	12			3		2	5			4		4		21	1			3	
15	143	17	1	2	3		2	1	1		4	3	3		15	2	2		4	1
16	66	7	2		1	1	1		2		1	1	8		7	2			4	1
17	49	5	3	4			10	2	3		2		3		19	6	1		2	
18	73	7	1	1	5	1	10		1	1	3		3	3	4	1			3	1
19	46	2	2	2			15	5	2	1	1		5		2	1	1		2	
20	16	3	3				17	2	3		3		5	1	9	1				1
21	20	2	2				4				7		2	1	6	1			2	
22	9	2	1		1		5		4		1		3	1	3	1			1	
23	5	2			2	1	3	1	1			1		1	1				2	
24	10	1	2			1		2		1	1				5				3	
25	13			1			1	1	3	1	2	1	1		8	2			2	
26	39	5	3		1	1	2	3	7	1	3			1	5	4			4	1
27	64	3		1	1		2	1	5		1	1	2		2	2			7	
28	28	1		1			1	2			4	1	3	1	6				4	1
29	29	6		1				1			2		2		3	1			2	
30	39	11		1	1		3	2	1		6	1	4	2	4				2	
31	36	5			1		4	2	1	1	1	1	4	1	5	1			2	
32	36	4	2	3			3	1			1	1	7	1	2	1				1
33	19	2	1		1		2		2		1	2			11	2			1	1
34	48	3	1	1	2		4	1			2		1		2	2			2	1
35	65	17	3	1			4	1	1		1	1	3	1	1				2	
36	57	9	1		1		3	1	2		2		4		3	2			1	2
37	92	18	3	2			1	1	2				6		2	2			2	1
38	133	22					2	2	2	2	2		4		6	1			1	3
39	151	16	4	1			1		4		1		9	1	3	3	1		3	2
40	78	18	1		3		5		2	1			5	1	2	2			2	
41	39	8		1			3	4	3		1	1	2	2	2	2			2	
42	8	3		2	1	2	3	1	8				1		1				2	
43	1								1											
Totals (u)	2,401		180		36		192		80		148		135		333		13		87	
Totals (m)		223		45		8		45		9		21		22		63		0		17

The population estimates, using data for all stations and corrected for homing bias, are given in Table IX. The general range of the 95 per cent confidence limits for the estimates varies approximately from ± 15 per cent for bluegills to ± 50 per cent for largemouth bass. (The following estimates based on sub-sampled data are not corrected for home-station bias; the differences resulting from such corrections would be quite insignificant.) Estimates based on only the records for 6-ft. trap nets (Stations 21-40) agreed quite closely with the estimates based on all records (Table IX), which was to be expected since the 6-ft. nets caught most of the fish; the differences which did develop were well within the computed limits of error. For the three species for which there were adequate data, the estimates based on odd stations only, and on even stations only (Table IX), are somewhat too variable to come within the computed error of difference. For example, the difference between the two bluegill estimates (14,180 and 7,410) is about 4 times its standard error. For the black crappie and warmouth the differences were not so great but were statistically suggestive. The estimates which were based on odd stations only (same for even stations) were necessarily limited to fewer (theoretically one-fourth) of the recapture records than the records available for the primary estimates, as illustrated by the following summation of recapture records for 3 species:

	All stations	Odd stations	Even stations
Bluegill	211	37	103
Black crappie	44	18	6
Warmouth	59	21	17

(As a reminder, the recaptures listed for odd stations are here limited to fish marked at odd stations, and correspondingly for the even stations.) The lower numbers of recapture records used in these sub-sample estimates must be the reason for the variable nature of the results. Two conclusions

Table IX

Estimations of fish populations (Pop. est.), and standard errors of estimates (Err.), in Sugarloaf Lake, 1951 by the formula of Schumacher and Eschmeyer (1943), using marking-recapture data for all stations, for stations 21-40 only, for odd-numbered stations only, and even-numbered stations only, as different bases for estimates.

	All stations		Stations 21-40		Odd stations		Even stations	
Species	Pop. est.	Err.	Pop. est.	Err.	Pop. est.	Err.	Pop. est.	Err.
Bluegill	14,450	920	15,700	1,140	7,410	1,330	14,180	1,050
Black crappie	530	74	600	75	370	73	540	163
Warmouth	1,160	120	1,120	157	1,030	160	660	139
Yellow bullhead	460	52	370	55	...	...	...	...
Rock bass	600	111	640	153	...	...	...	...
Pumpkinseed	540	111	580	142	...	...	...	...
Brown bullhead	120	26	...	...	...	...	...	...
Largemouth bass	470	143	...	...	...	...	...	...
Bowfin	280	50	...	...	...	...	...	...

are suggested at this point. (1) There is no basis for employing fewer than the 20, effective, 60ft. net stations (in a 180-acre lake) if estimates with no more error than ± 25 per cent are needed. (2) The fact that there were differences between estimates based on sub-samples, greater than computed errors of difference, merely serves to emphasize the fact that the standard errors computed with population estimates have no relation to the adequacy of netting coverage over the lake. Thus the study of population estimates should be continued on Sugarloaf Lake to explore further the adequacy of the trap net pattern on this 180-acre lake. Another important question, completely unsolved as yet, is that of the possible dislocation of marked fish turning them into nomads.

Reference was made above to the subtraction of 12 recaptured bluegills from the netting records, as a correction for homing bias, in computing the bluegill population. Confidence limits (95%) assigned to this correction factor of 12 give a range of 7 to 20. Corrected estimates of the bluegill population were correspondingly 14,230--14,450--14,930. The uncorrected bluegill estimate was 13,860, and the correction for homing bias thus amounted to about 5 per cent in terms of the estimate.

Fish weighed and measured at random during the netting gave the following average total lengths in inches and average weights in ounces (numbers of fish in parentheses): bluegills 7.4 inches (598) and 4.8 ounces (461), black crappie 9.3 inches (23) and 8.0 ounces (22), warmouth 7.5 inches (24) and 6.0 ounces (21), largemouth bass 14.8 inches (29) and 33.1 ounces (18), bowfin 21.2 inches (8) and 49.5 ounces (8), yellow bullhead 12.0 ounces (2), and pike 25.7 inches (8) and

57.0 ounces (8). The population estimates (Table X) by summation give a total population of "legal-size" game and panfish for Sugarloaf Lake in 1951 of 18,610 fish or 100 fish per acre. Applying the above average weights by species, supplemented where necessary by average weights obtained in 1950, the total weight of the 18,610 fish is computed as 7,570 pounds or an average of 42 pounds per acre, virtually all of which are food and game species.

Exploitation

In addition to the population estimates of 1951, similar data on Sugarloaf Lake are available for the fall of 1948, spring of 1949 and spring of 1950 (Cooper, loc. cit.). These earlier estimates are based on trap netting procedure quite similar to that of 1951, and the data presumably are comparable. A high degree of uniformity in the estimates, from year to year (Table X), gives confidence in their accuracy, i.e., within rather broad limits.

Data on anglers total catch from the lake for 1946 to 1950 have been summarized generally by Cooper and Christensen (1951) and in detail by Christensen (In Press). During this period the lake had a special fishing season open to bluegills and sunfish throughout the year. The census was a highly intensive study involving contact with a large percentage of all anglers, and periodic counts of all anglers, as a basis of computing total fishing returns. Christensen's data on species composition of the catch by percentage have been converted to numbers of fish for use here. The data on total catch (year-around, including winter) for the five years are given as the annual averages in Table X. The annual catch statistics are compared with the averages of the four population estimates in Figure 4.

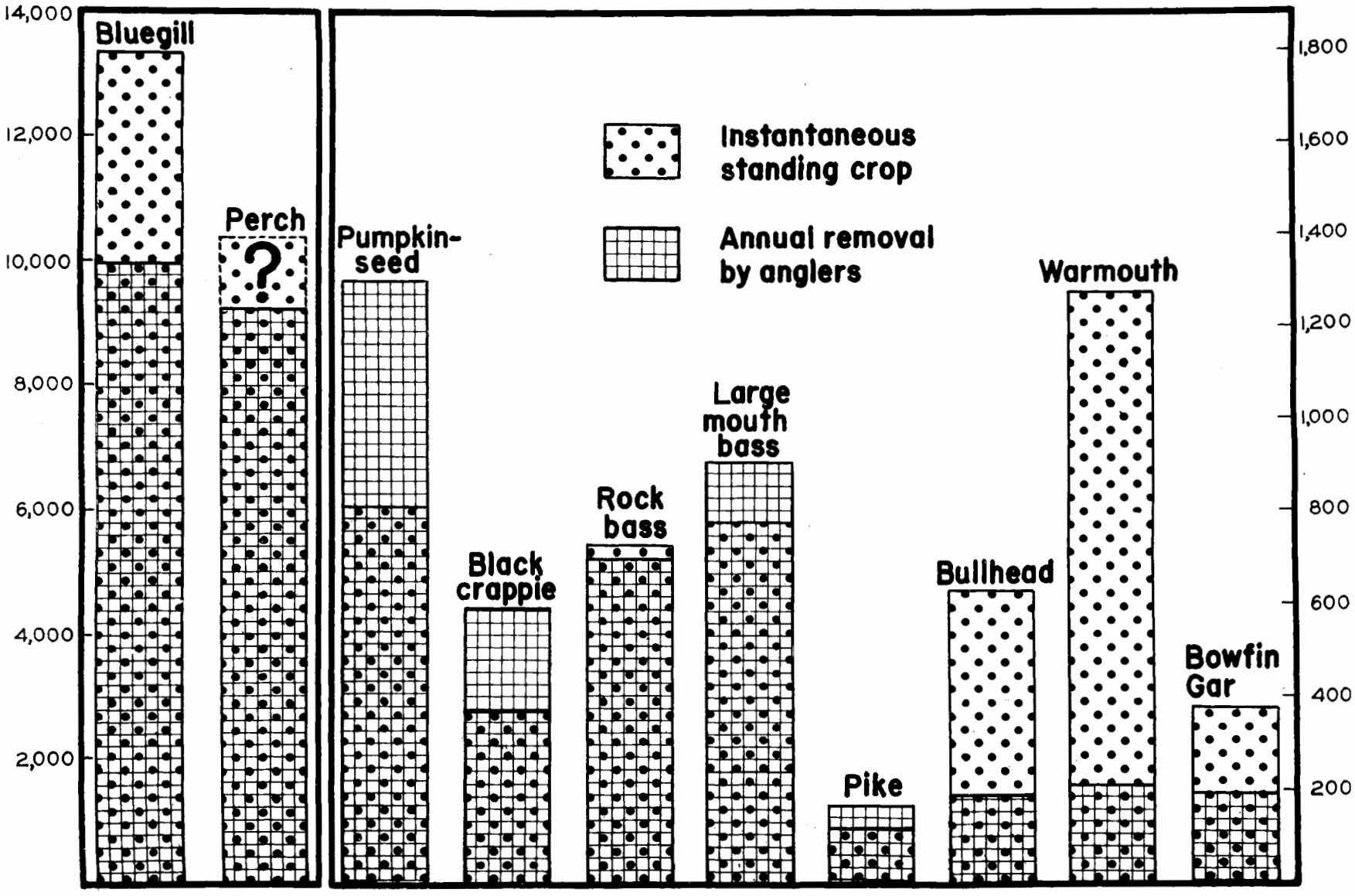
Much speculation could be employed in interpreting Figure 4. The general summary is that the annual removal by anglers closely approximates the crop that is present at any one time, except for the least desirable species (warmouth, bullhead, bowfin). The standing crop of perch is an unknown quantity because this species was not readily caught in the trap nets and perch estimation was impossible in three of the population studies and unreliable in the fourth. For the bluegill (over 6 inches) the average of 4 population estimates was 13,480 fish, while the average annual catch

Table X

Fish population estimates and catch by anglers, Sugarloaf Lake, 1946-1951

Species	Population estimates					Average annual catch, 1946-50, legal-size fish
	Spring 1951	Spring 1950	Spring 1949	Fall 1948	Annual average	
Bluegill	14,450	14,012	12,949	12,494	13,480	9,977
Yellow perch	...	1,615 (?)	...	...	...	9,327
Pumpkinseed	540	825	1,013	775	790	1,261
Black crappie	530	126	302	511	370	578
Rock bass	600	997	277	972	710	691
Largemouth bass	470	518	367	1,718	770	943
Pike	...	271	119	80	120	170
Bullheads	580	992	374	543	620	199
Warmouth	1,160	2,389	1,570	...	1,280	210
Bowfin and Gar	280	433	183	555	360	203
Totals	18,610	22,178	17,154	17,648	18,500	23,559

Fig. 4. The average standing crop of fish (based on four annual population estimates) and the average annual catch by anglers (based on five years, all fishing) in Sugarloaf Lake. Data from Table X


14,000
12,000
10,000
8,000
6,000
4,000
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
Bluegill
Perch
?
Instantaneous standing crop
Annual removal by anglers
Pumpkin-seed
Black crappie
Rock bass
Large mouth bass
Pike
Bullhead
Warmouth
Bowfin Gar

over the 5 years was 9,977 fish. There is special interest in the fact that the catch of pumpkinseeds far exceeded the population, and this was also true to a smaller extent for the largemouth bass, crappie and pike. Theoretically this greater cropping is quite possible, and means that fish are recruiting by growth into the catchable size group at an annual rate exceeding the standing crop of catchable fish.

Data on age composition of the legal-size fish in the lake are available (Table XI) from scale samples collected during the spring, summer and fall of 1946 to 1949. One large series was collected by gill net and bag seine; the others were caught by hook and line. Most of the fish which were under legal size were taken by nets, whereas the legal-size fish correspond in size to anglers catches and to the population estimates. These age and growth data may be used to determine for each species the average age at which it recruits into the legal-size class, and the average age of the population in excess of the number of years taken to reach "legal size." These ages-in-excess-of-age-at-legal-size for all species may then be combined to give an average "age in excess" for the entire population. For the 936 fish on which age determinations were made (Table XI), the average "age in excess" was 2.2 years. An average age for each species could also be calculated readily from the data in Table XI. The average "age in excess" for all species, or the average for each species separately, is a key to the rate of turnover of the population of "legal-size" fish in the lake; a population which is equivalent to the amount of anglers' catches plus natural mortalities must be replaced at the rate of every 2.2 years.

The population figures, converted to pounds of "legal-size" fish per acre by the use of average weights obtained during the 1951 trap

Table XI

Age analysis of fish samples from Sugarleaf Lake,

March to September, 1946 to 1949

Age-group given in Roman numerals, L is average total length in inches, R is range in length, N is number of specimens.

Age		Bluegill	Perch	Rock bass	Warmouth	Black crappie	Largemouth bass	Pumpkinseed
0	L						1.8	
	R						1.4-2.3	
	N						18	
I	L	2.1					4.4	
	R	1.4-2.4					4.4	
	N	31					1	
II	L	3.6	6.4			7.3	7.0	4.1
	R	3.5-4.5	5.3-7.6			6.9-7.7	6.5-7.4	3.6-5.2
	N	41	10			4	3	13
III	L	5.1	7.4	5.3	4.6	8.6	10.0	5.2
	R	3.8-6.5	6.4-8.9	4.6-6.2	3.9-5.1	7.8-9.1	7.6-12.6	3.6-6.7
	N	108	47	4	3	10	11	88
IV	L	6.2	7.5	6.8	5.8	10.0	10.8	6.3
	R	4.5-8.5	6.4-8.6	6.2-7.5	4.5-6.4	8.8-11.2	6.5-12.3	5.4-7.3
	N	220	6	8	4	3	22	78
V	L	7.0	10.6	7.2	6.8		12.5	7.1
	R	6.1-8.7	10.6	7.0-7.4	6.1-7.3		9.0-17.0	6.2-8.3
	N	221	1	3	9		24	13
VI	L	7.6		8.1	8.2		14.1	8.2
	R	6.3-9.1		7.4-8.7	8.2		11.8-16.7	7.0-9.0
	N	101		4	1		20	7
VII	L	8.4		8.3			15.6	9.4
	R	7.5-9.5		8.3			14.1-17.5	9.4-9.5
	N	45		1			9	2
VIII	L	8.5					17.4	
	R	6.9-9.7					16.4-18.2	
	N	30					7	
IX	L	9.0					19.0	
	R	8.6-9.2					18.2-19.8	
	N	9					5	
X	L	9.5					20.0	
	R	9.5					19.2-21.3	
	N	1					5	

netting, were computed to be: standing crop (four-year average), 41 pounds, and annual harvest by anglers (five-year average), 52 pounds.

The annual creel of 23,560 fish was the result of an average angling pressure of 19,400 angler hours a year (data from Christensen, 1952).

Literature Cited

Christensen, Kenneth E. In Press. Fishing in several Michigan lakes under experimental regulation. Pap. Mich. Acad. Sci., Arts and Letters. In Press.

Cooper, Gerald P., and Christensen, Kenneth E. 1951. Testing new fishing regulations. Michigan Conservation, 20 (3) : 15, 18-20.

Cooper, Gerald P. In Press. Estimating fish populations in Michigan lakes. Trans. Amer. Fish. Soc., Vol. 81. In Press.

Crowe, Walter R. In Press. An Analysis of the fish population of Big Bear Lake, Otsego County, Michigan. Pap. Mich. Acad. Sci., Arts and Letters. In Press.

Krumholz, Louis A. 1944. A check on the fin-clipping method for estimating fish populations. Pap. Mich. Acad. Sci., Arts and Letters, 29 (1943) : 281-291.

Ricker, William E. 1948. Methods of estimating vital statistics of fish populations. Indiana Univ. Publ., Science Series No. 15, pp. 1-101.

Schumacher, F. X., and Eschmeyer, R. W. 1943. The estimate of fish population in lakes or ponds. Jour. Tenn. Acad. Sci., 18 (3) : 228-249.

Snedecor, George W. 1948. Statistical methods. The Iowa State College Press, Ames. 4ed., 485 pp.

INSTITUTE FOR FISHERIES RESEARCH

Gerald P. Cooper

Approved by: A. S. Hazzard

Typed by M. C. Tait