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AN APPRAISAL OF METHODS FOR ESTIMATING THE FISH POPULATION OF A LAKE

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The mark-and-recapture method is frequently used to estimate fish populations in lakes. The reliability of these estimates depends upon the degree to which certain basic assumptions are satisfied, and the adequacy of experimental design. The question of how closely such estimates approximate the true number of fish present has been investigated by several workers, mostly on the basis of indirect evidence as to the number of fish present. Evidence from poisoning and counting the population, after making the estimates, was used by Schumacher and Eschmeyer (1943), Krumholz (1944), Carlander and Lewis (1948), Fredin (1950) and Loeb (1958). Waters (1960) made his estimates on known numbers of recently planted hatchery-reared brook trout in lakes. In a theoretical approach, DeLury (1951) and Cooper and Lagler (1956) used known numbers of beans for testing their models.

In the present study, 2,878[1] fish were caught by seine, marked by fin-clipping, and returned to Dollar Lake. After a 10-day "rest" period

[1] A total of 2,945 fish were marked during the seining but 67 were found dead either during the marking period or during the ensuing 3 days (none were observed thereafter). Thus there were assumed to be 2,878 marked, live fish in the lake.

for the fish, estimates of this "known" population of marked fish were made from trap and fyke net catches over a span of 22 days. To test the efficiency of collecting methods and usefulness of the different formulas, the resulting estimates were compared with the "known" population. Also, population estimates for the entire fish population (marked plus unmarked) were made by the various methods and compared.

Description of Dollar Lake

Dollar Lake is a circular, 12.9-acre, landlocked lake on the Rifle River Area in Ogemaw County (Fig. 1). It has a maximum depth of 17 feet; 94 percent of the lake is less than 15 feet deep. The bottom material is soft organic muck. Emergent pond weeds (mostly Potamogeton spp.) are abundant around the periphery of the lake and a mat of Chara covers much of the bottom in the deeper part. Seven species of game and pan fish (Table 1) are present; the bluegill is the most abundant species.

Methods

On April 18-19, 1958, two seine hauls were made with a 1,600-foot by 15-foot seine, with 1-inch mesh (bar measure) in the bag. The fish captured were marked by removal of the left pectoral fin and returned to the lake, thereby establishing a marked population of known size. Each seine haul covered about two-thirds of the lake.

After a 10-day interval, three trap nets and four fyke nets were fished for 22 days (April 29-May 23). This netting was done at 15 established stations, 14 around the edge of the lake and the fifteenth near the center of

Figure 1.--Outline of Dollar Lake, Rifle River Area, showing 5-foot depth contours and locations of 15 netting stations.

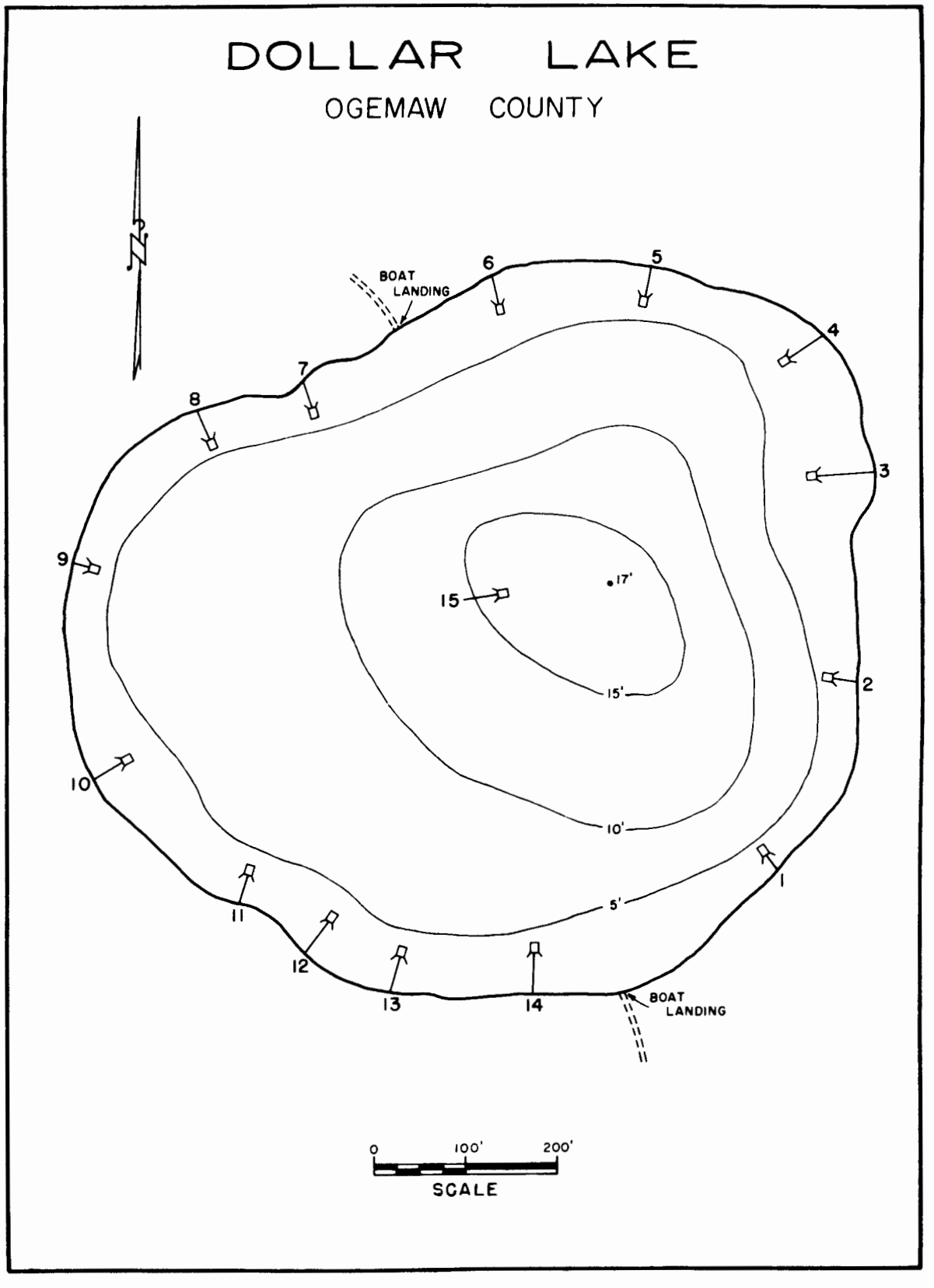
DOLLAR LAKE
OGEMAW COUNTY
BOAT LANDING
BOAT LANDING
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
17'
15'
10'
5'
0
100'
200'
SCALE

Figure 1

Table 1.--Percentage of the estimated total populations of fish in Dollar Lake caught either by seine or by trap nets and fyke nets

Species	Length (inches)	Estimated number in population*	Percentage caught by: Seine	Nets
Bluegill (Lepomis machrochirus)	5.0-10.9	3,736	53.3	28.0
Black crappie (Pomoxis nigromaculatus)	5.0-10.9	941	23.7	38.0
Largemouth bass (Micropterus salmoides)	7.0-21.9	292	77.4	19.2
Yellow perch (Perca flavescens)	6.0-10.9	142	47.2	64.1
Pumpkinseed (Lepomis gibbosus)	5.0- 8.9	106	30.2	31.1
Brown bullhead (Ictalurus nebulosus)	7.0-11.9	40	0.0	100.0
Bluegill x pumpkinseed	5.0- 8.9	31	45.2	64.5
Rock bass (Ambloplites rupestris)	5.0- 9.9	27	7.4	92.3

* Sum of best estimates in Table 5.

the lake (Fig. 1). At Stations 1 to 14 the net leads were directed towards shore; at Station 15 the direction of the net lead was varied. Each time the seven nets were moved, the new stations were chosen at random from the 15 established sites by use of a table of random numbers. The first, third, and fifth selections were reserved for trap nets, and the second, fourth, sixth, and seventh were used for fyke nets. All nets were moved every other day, and each site was used two to five times.

The trap nets were single-pot, 3-foot nets as described by Crowe (1950), fished with 150-foot leads. The fyke nets were double-throated, tapered nets 8 feet long with 6 hoops (diameter of the front hoop, 30 inches). These fyke nets and their 12-foot wings were of 3/4-inch mesh (bar measure), and their 75-foot leads were of 1 1/2-inch mesh.

During the netting period, separate records were kept for the capture of fish from the known segment of the population (left pectoral fin clipped) and for fish not previously marked. The former received a second mark when first caught in a trap or fyke net (upper corner of the caudal fin clipped) so they could be recognized if recaptured a second time in the nets. Fish not previously caught by seine were marked by removing the right pelvic fin. Total length of all captured fish was recorded. All fish captured by trap net or fyke net were released in open water near the center of the same half of the lake in which they were caught, i.e., either in the eastern or western sections of the lake. During both seining and netting operations, daily adjustments were made in the data for observed mortality of marked fish.

Because of gear selectivity, arbitrary minimum size limits, below which no fish were marked, were established for each species. These limits were 4.0 inches for bluegills; 5.0 inches for pumpkinseeds, rock bass, black crappies, and hybrid sunfish; 6.0 inches for yellow perch; and 7.0 inches for largemouth bass and brown bullheads.

The plan of the investigation permitted several different estimates of the population (in most instances, with 95 percent confidence limits) as follows: (1) The Schumacher method (Schumacher and Eschmeyer, 1943) was used for estimates of the "known" population from trap and fyke net catches of left-pectoral clipped fish; these estimates were then compared with the known numbers to obtain a measure of the efficiency of the method. (2) Schumacher estimates were made for the entire fish population, from the capture and recapture of all fish by trap and fyke nets. When corrected for gear efficiency (see p.16) these estimates were considered the most reliable. (3) A Petersen-type estimate was made for the entire population from recaptures by seine on the second day, of fish marked after seining on the first day. (4) Petersen estimates for the entire lake population were computed from the total recaptures in trap and fyke nets of fish marked during the seining operation. (5) Recoveries of marked fish by anglers between May 30 and July 6, 1958 provided another basis for Petersen estimates of the population. (6) Estimates of the rock bass and brown bullhead populations were made by the DeLury method (DeLury, 1947).

The modifications of the Schumacher and Petersen formulas proposed by DeLury (1958) and Bailey (1951), respectively, and recommended by Ricker (1958), were used for the estimates and their confidence limits.

Chapman's adjusted Schnabel formula (Ricker, 1958) also was used on the "known" population for comparative purposes. These latter estimates closely approximated the Schumacher values but usually were slightly lower.

A rather subtle source of error, stemming from a difference in behavior of marked and unmarked fish, could bias population estimates (Ricker, 1958; Waters, 1960; and others). In the process of estimating the "known" population, the recaptured fish had to be caught and handled a minimum of three times--once in the seine and twice in the nets. Many of the fish were caught twice in the seine so that some were captured at least four times. If those fish, which originally were caught in the seine and fin clipped, reacted differently towards the trap and fyke nets than the rest of the population, a systematic error would be involved in using net recaptures of seine-marked fish to estimate the total population. Furthermore, differences in catchability would invalidate the use of the correction factors to increase the precision of the Schumacher netting estimates (p. 16). To test this possibility, a t test was applied to a logarithmic transformation of the data on rate of recapture by nets, between fish marked in the seine and fish marked only in the nets. The difference was not significant ($t_{16} = 1.19$; $P = 0.05$), and it was concluded that the handling and marking of the fish in the seine did not affect their subsequent catchability in the nets.

Effectiveness of the gear

The two seine hauls captured 3,534 fish of which 2,945 were marked, 554 were recoveries (marked during the first haul and recaptured during the second), and 35 were not used in the study. The seven trap and fyke nets

were fished for 22 days and caught 3,187 fish, of which 2,316 were marked after capture, 675 were recaptures, and 196 were not used in the study. Both seine and nets were effective for most species, as shown by a comparison of the percentages of the estimated total populations of various species caught by the two types of gear (Table 1). The seine was more effective for bass and bluegills than the nets but ineffective for rock bass and brown bullheads. The trap and fyke nets were highly effective for rock bass and brown bullheads (catching nearly all of these fish believed to be in the lake) and were slightly more effective than the seine in capturing perch, crappies, pumpkinseeds, and hybrid sunfish.[2] As a tool, the seine was more economical than the nets, since it captured more fish in much less time and effort.

Both trap and fyke nets were used in order to get greater diversification in the population sampling. The fyke nets operated more effectively in shallow water than the trap nets and caught more fish of smaller size. The trap nets were more effective in deeper water and took mostly larger fish. The use of two types of nets compensated for any bias introduced by either one, as shown by the similarity of the ratios of marked to unmarked fish in the catches. For trap nets this ratio was 1:3; for fyke nets, 1:2.4. Certain deviations were noted. Most of the marked perch (recaptures) were caught in fyke nets, and a high proportion of the recoveries of rock bass were made in trap nets. Only three largemouth bass were caught in fyke nets. Most of the smaller (shorter than 7.0 inches) perch were caught in fyke nets whereas most of the larger ones were caught in trap nets.

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[2] Bluegills and other species under 5.0 inches were poorly sampled by both methods. Few bluegills shorter than 4.0 inches were caught. The nets caught 8.0 percent of the bluegills 4.0 to 4.9 inches long; the seine took 5.4 percent. The adjusted population estimate for 4-inch bluegills was 7,222 fish.

The tendency for fish to return to their home sites after being displaced has been demonstrated for several species (Cooper, 1953; Gerking, 1959), some of which are present in Dollar Lake. These species include bluegill, pumpkinseed, rock bass, and largemouth bass. Nonrandom movements such as this are a source of bias that may be overcome by random netting effort, releasing fish near the site of capture, and a prolonged period of sampling. A review of the daily net catches showed that they were reasonably consistent throughout the netting period for most species except crappies and perch. Few crappies were caught during the first 10 days of netting, but on May 12 the catch started to increase markedly, reached a peak on May 16, and subsided gradually thereafter. The catch of perch was high on four different days, separated by 5-day periods of small catches. The fluctuation in catches of crappies and perch probably was associated in some way with spawning activity, since many individuals of both species were gravid.

Estimates compared with known numbers

An estimate which repeatedly approaches ±5.0 percent of the true population size in a daily series of estimates is regarded as a "good" one (Cooper and Lagler, 1956). Comparisons between the "known" populations in Dollar Lake and the estimated numbers are presented in Table 2. Differences between the two sets of values were expressed as percentages of the "known" population and subsequently used to correct the estimates for the whole lake population.

The 17 estimates for the various length groups of the different species shown in Table 2 were obtained under nearly ideal conditions and allowances

Table 2.--Known populations of marked fish in Dollar Lake, Schumacher estimates of these populations, and percentage differences

Species	Length (inches)	Number of marked fish in population on April 22, 1958			Percentage difference between known number and estimate
		Known	Estimated	Confidence limits of estimates (P = .05)	
Bluegill	5.0- 5.9	1,078	985	819-1,234	-8.6
"	6.0- 6.9	758	734	566-1,045	-3.2
"	7.0- 7.9	107	104	102- 107	-2.8
"	8.0- 9.9	12	9	6- 16	-25.0
Pumpkinseed	5.0- 5.9	10	...	...	...
"	6.0- 6.9	9	4	2- ?	-55.6
"	7.0- 7.9	6	...	...	...
"	8.0- 8.9	7	7	4- 127	0.0
Bluegill x pumpkinseed	5.0- 8.9	14	17	10- 58	+21.0
Black crappie	5.0- 5.9	10	...	...	...
"	6.0- 6.9	89	66	47- 110	-25.8
"	7.0- 7.9	92	75	64- 91	-18.5
"	8.0- 8.9	24	21	17- 27	-12.5
"	9.0-10.9	8	6	5- 9	-25.0
Largemouth bass	7.0- 9.9	121	...	...	...
"	10.0-11.9	67	...	...	...
"	12.0-12.9	9	4	2- 27	-55.6
"	13.0-13.9	12	10	5- 36	-16.7
"	14.0-21.9	16	21	10- ?	+31.3
Yellow perch	6.0- 6.9	8	...	...	...
"	7.0- 7.9	13	13	5- ?	0.0
"	8.0- 8.9	30	25	21- 33	-16.7
"	9.0- 9.9	13	8	6- 12	-38.5

were made for all known sources of bias. Nearly all of the estimates were low. However, the 95 percent confidence limits encompassed the known values in 12 of the 14 groups for which confidence limits could be established. Nine (53 percent) of the estimates were good ones (within 5 percent of the "known" population or within 3 fish of populations under 50). Among the eight "poor" estimates, one was fairly close (5-inch bluegills) but five were underestimates of 16.7 to 55.6 percent. No explanation can be offered at this time for the preponderance of low estimates. Marked fish may be more susceptible to recapture, although earlier (p.7) it was shown that no significant difference was noted between the behavior of marked fish that were caught and marked either once or several times.

Two groups (bass over 14 inches and hybrid sunfish) were overestimated. Either or both of these high estimates may have occurred by chance because the numbers of fish in the "known" populations (16 and 14) were very small. Possibly some of the hybrids were confused with pumpkinseeds. Also, if significant numbers of marked fish died without being observed and recorded, the populations would be overestimated. Among the dead fish observed there were no 14-inch bass and only a single hybrid sunfish. Observed mortality during and after the netting period included 55 marked (left pectoral) and 23 unmarked fish. Most of the dead fish were bluegills and larger crappies but apparently there was little unobserved mortality of these species because their populations were not overestimated.

No estimates could be made for six groups because of lack of recoveries. A more prolonged netting period might have improved some of the "poor" estimates. However, it is suspected that in a small lake the problem of net avoidance by the fish might be a limiting factor.

Latta (1959) pointed out a source of error in population estimates which is introduced because of size selectivity by trap nets. In Dollar Lake, the average lengths of recaptured bluegills, rock bass, crappies, perch, and pumpkinseeds were 0.5 to 0.8 inch greater than those of unmarked fish caught in the trap and fyke nets. For bass, however, the mean lengths were nearly the same (14.7 inches for unmarked fish; 14.5 inches for recoveries). Both Latta (1959) and Cooper and Lagler (1956) advised that, whenever possible, population estimates should be made by size groups. They based their recommendations on examples which involved comparatively large numbers of fish.

Estimates of the "known" population in Dollar Lake were computed both for separate inch groups and for grouped data (Table 3). Accuracy of the population estimate was improved considerably by stratifying the data into inch groups for the large population of bluegills, but for the smaller populations the two methods gave similar estimates.

Number of netting days required

The fisheries biologist, attempting to determine population size, needs to know, with reasonable assurance, how many trials (net days) are necessary to secure satisfactory estimates. From their bean models, Cooper and Lagler (1956) arrived at a curvilinear relationship between the number of days required for a good estimate and the proportion of the population captured each day. They indicated that, theoretically, about 20 days of netting is required when about 2 percent of the population is caught daily, whereas 80 days is necessary if only 0.1 percent of the population is caught each day.

Table 3.--Estimates of the "known" population of fish of different species in Dollar Lake, computed as a single estimate and as a sum of the estimates for different inch groups*

Species	Length (inches)	Known number in population	Population estimate	
			All length groups combined	Sum of estimates for different inch groups
Bluegill	5.0- 9.9	1,955	1,589	1,832
Black crappie	6.0-10.9	213	165	168
Yellow perch	7.0-10.9	56	46	46
Largemouth bass	12.0-21.9	37	31	35
Rock bass	5.0- 9.9	...	28	27
Brown bullhead	7.0-11.9	...	44	41

* The rock bass and bullhead estimates are estimates of the whole lake population and are presented here as further evidence that stratification by size groups has little effect on estimates for small populations.

A minimum of 1.7 percent of the "known" population in each size group was caught daily (on the average) in Dollar Lake, except for 5-inch bluegills. Good estimates were obtained for 9 of the 17 groups (Table 2) in 20 days of netting.[3] An average of 1.3 percent of the 5-inch bluegill population was caught daily, from which a final estimate within 8.6 percent of the true value was obtained. Apparently, in actual practice a "good" estimate in 20 days by 2 percent sampling does not necessarily hold true. Furthermore, I was unable to detect a relationship between goodness of estimate and any of the following: (1) percentage of population marked, (2) mean percentage of recoveries in daily catch, (3) percentage of total number of marked fish recaptured, (4) mean number of fish caught per day, (5) percentage of total net days in which recaptures were made, and (6) consistency of daily estimates.

Fredin (1950) presented mathematical formulas whereby the sample size needed for estimates at various levels of accuracy could be computed. Several attempts were made to apply the formulas to these data (where it was known how many trials were needed) but apparently these formulas were not applicable to these data.

Estimates as good as, or better than, the final ones were obtained by chance for most groups within 9 to 17 days (Table 4). However, the confidence limits of these 9- to 17-day estimates were wider than for the 20-day estimates. Under these nearly ideal conditions, a minimum of 20 trials was required for good estimates of 53 percent of the length groups in this 12.9-acre lake; even then, some of the confidence limits were uncomfortably wide.

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[3] The nets were not examined on the weekend of May 10-11. Therefore the nets were lifted 20 times during the 22 netting days. From the standpoint of sampling, this amounted to 20 days of netting.

Table 4.--A comparison of the "nearest" estimates of "known" populations of certain species of fish with the "final" estimates (after 22 days of netting) in Dollar Lake, 1958

Species	Length group (inches)	"Known" number of fish in lake	Nearest estimate			Final estimate	
			Number of days required for estimate	Number of fish	Confidence limits	Number of fish	Confidence limits
Bluegill	5.0- 5.9	1,078	15	1,066	769-1,741	985	819-1,234
"	6.0- 6.9	758	17	753	538-1,256	734	566-1,045
"	7.0- 7.9	107	17	106	74- 185	104	102- 107
"	8.0- 9.9	12	9	9	5- ?	9	6- 16
Black crappie	6.0- 6.9	89	17	77	50- 170	66	47- 110
"	7.0- 7.9	92	13	83	66- 112	75	64- 91
"	8.0- 8.9	24	14	24	18- 37	21	17- 27
"	9.0-10.9	8	11	8	4- 27	6	5- 9
Yellow perch	8.0- 8.9	30	14	29	18- 75	25	21- 33
"	9.0- 9.9	13	10	8	5- 18	8	6- 12
Largemouth bass	12.0-21.9	37	15	38	22- 151	31	21- 57

Comparison of population estimates for Dollar Lake

Five separate estimates of the total fish population in Dollar Lake (plus DeLury estimates for rock bass and bullheads) are listed in Table 5. The best estimates are marked with an asterisk. The modified Petersen formula was used for three of the estimates, and estimates from trap and fyke net catches were computed by the modified Schumacher formula. The Schumacher estimates were adjusted for efficiency of the gear by a correction factor. This factor was the proportion of the "known" population that was estimated. For example, the estimated number of marked 5-inch bluegills was 985 (Table 2) or 91.4 percent of the true number (1,078). Assuming that the same error was present in the estimate for all 5-inch bluegills in the lake, the estimate of 2,232 was divided by 0.914 to obtain the adjusted estimate of 2,442 in the right hand column of Table 5.

The best estimates for each size group were selected as follows: (1) Adjusted Schumacher values were used wherever available (17 size groups) and were considered the most accurate. No correction was needed for 8-inch pumpkinseeds and 7-inch perch. (2) The Schumacher estimates computed from trap and fyke net catches were used for all length groups of rock bass and bullheads plus four length groups of other species, because either too few or none were caught by seine or hook and line. (3) Petersen estimates, based on seine catches only, were used for the three length groups of bass under 12 inches, either because it was the only estimate available (7.0- to 9.9-inch group) or because more recaptures were made with this gear.

Table 5.--Four kinds of population estimates for Dollar Lake and adjusted Schumacher estimates[1]

[P = population estimate; CL = confidence limits. Best estimates are marked with an asterisk]

Species	Length (inches)	Methods of estimation and of recapture								
		Petersen						Schumacher		Adjusted Schumacher
		Seine[2]		Nets[3]		Creel[4]		Nets[5]		
		P	CL	P	CL	P	CL	P	CL	P
Bluegill	5.0- 5.9	2,242	1,974-2,538	2,829	2,567-3,171	3,544	2,904-4,590	2,232	1,893-2,717	2,442*
"	6.0- 6.9	1,121	1,023-1,240	1,261	1,166-1,378	1,636	1,453-1,896	1,095	995-1,388	1,131*
"	7.0- 7.9	124	...	162	145- 184	235	...	139	117- 172	143*
"	8.0-10.9	...	...	21	...	16	...	15	11- 22	20*
Black crappie	5.0- 5.9	...	...	...	...	...	...	364*	269- 563	...
	6.0- 6.9	256	...	327	270- 424	...	...	297	256- 353	400*
"	7.0- 7.9	146	109- 253	143	...	...	...	113	99- 133	139*
"	8.0- 8.9	28	...	26	...	...	...	26	21- 35	30*
"	9.0-10.9	8	...	8	...	...	...	6	5- 9	8*
"	7.0-10.9	180	142- 256	172	157- 191	187	...	...	...	...
Pumpkin-seed	5.0- 5.9	16	...	37	...	...	...	33*	17- 436	...
	6.0- 6.9	11	...	22	...	...	...	23	11- ?	52*
"	7.0- 7.9	6	...	12	...	...	...	8*	5- 63	...
"	8.0- 8.9	8	...	14	...	...	...	13	9- 19	13*
"	5.0- 8.9	40	...	80	60- 128	172	...	...	...	...
Yellow perch	6.0- 6.9	...	...	67	...	...	...	69*	53- 98	...
	7.0- 7.9	16	...	22	...	68	...	21	13- 57	21*
"	8.0- 8.9	32	...	32	...	38	...	29	23- 39	35*
"	9.0-10.9	16	...	22	...	21	...	11	9- 12	17*
"	7.0-10.9	67	54- 91	75	67- 83	170	125- 276	...	...	...
Hybrid sunfish	5.0- 8.9	24	...	25	...	66	...	37	26- 68	31*
Largemouth bass	7.0- 9.9	156*	132- 198	...	...	...	...	...	...	...
	10.0-10.9	66*	...	93	...	...	...	...	...	...
"	11.0-11.9	11*	...	11	...	...	...	...	...	...
"	12.0-12.9	9	...	11	...	...	...	5	3- 21	11*
"	13.0-13.9	14	...	16	...	...	...	15	13- 19	18*
"	14.0-21.9	29	...	41	...	...	...	39	26- 78	30*
"	10.0-21.9	128	...	172	155- 254	197	...	...	...	...
Rock bass	5.0- 5.9	...	...	...	...	...	...	5*	...	...
"	6.0- 6.9	...	...	...	...	...	...	6*	4- 24	...
"	7.0- 7.9	...	...	...	...	...	...	14*	11- 18	...
"	8.0- 9.9	...	...	...	...	...	...	2*	2- 2	...
"	5.0- 9.9	...	...	...	...	54	...	27	...	...
Brown bullhead	7.0- 7.9	...	...	...	...	...	...	6*	5- 8	...
	8.0- 8.9	...	...	...	...	...	...	13*	11- 15	...
"	9.0- 9.9	...	...	...	...	...	...	10*	9- 11	...
"	10.0-10.9	...	...	...	...	...	...	9*	8- 10	...
"	11.0-11.9	...	...	...	...	...	...	2*	2- 3	...

[1] DeLury estimates for rock bass and brown bullheads are not included in the table. They were 28 and 43 fish, respectively.

[2] Fish marked and recaptured while seining.

[3] Fish caught and marked during seining operation but recaptured in trap and fyke nets.

[4] Marked fish recovered by anglers.

[5] Fish marked and recaptured while netting with trap and fyke nets.

Since all of the 17 adjusted estimates (right hand column of Table 5) were considered to be better than other comparable estimates, these adjusted values were used as the standard for judging the quality of the other estimates. Most of the Petersen estimates based on recoveries in the seine and the unadjusted Schumacher estimates from trap and fyke net recoveries were below the adjusted estimates, while Petersen estimates based on recovery in nets of fish marked while seining tended to be high. Eight of both Petersen estimates based on recoveries in the seine and on recoveries in nets were good estimates (within 5 percent or 3 fish of the adjusted values), while six of the Schumacher estimates were classified as good estimates. Since rock bass and bullheads were readily captured in the trap and fyke nets, the estimates for these species may also be good estimates.

With one exception, Petersen estimates based on recaptures by anglers were higher than the best estimates; only the estimates for crappies, large bluegills, and the larger perch were reasonably close to the adjusted Schumacher estimates. This predominance of high estimates is probably associated not only with few recoveries but also with effects of natural mortality among marked fish operating over the longer span of time (38 days) plus recruitment into the population by younger fish. Christensen (1960, unpubl.) also reported high estimates based on recoveries of marked fish by anglers.[4] This recovery method was the least reliable among those tested in Dollar Lake.

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[4] Christensen, Kenneth E., Estimates of the populations of six species of fish in Fife Lake, Grand Traverse and Kalkaska counties, I. F. R. Report No. 1609.

The rock bass and bullhead populations were estimated by the DeLury method of calculating the regression between accumulated catch and catch per unit of effort of unmarked fish (Fig. 2). This method was applicable because the nets caught most of the rock bass and bullheads in the lake during the 20 days of the netting period. The DeLury estimates of 28 rock bass and 43 bullheads agree closely with, and serve to substantiate, the Schumacher estimates. DeLury estimates also were computed for pumpkinseeds, perch, and hybrid sunfish but all were considerably below the best estimates.

On the basis of the sum of the best estimates, Dollar Lake contained a population of 5, 315 fish within the various size ranges shown in Table 5. Bluegills comprised 70.3 percent of the population. By weight, the standing crop of these larger fish on May 30 was 787 pounds or 61 pounds per acre.

It has been recommended by various workers that different methods of capture and recapture be utilized for population estimates. In the work on Dollar Lake, this technique produced estimates that tended to be too high (especially for bluegills), but several estimates based on recaptures in nets of fish marked from a seine were as good or better than those made by other methods. Rock bass, bullheads, and 5-inch crappies could not be estimated, although estimates probably could have been obtained for the rock bass and bullhead populations if some other method of capture (such as electric shocking) had been employed instead of seining.

Because of the general effectiveness of trap and fyke nets (as compared to the seine), mark-and-recapture by nets alone was deemed the best for

Figure 2.--Regression lines computed for DeLury population estimates for rock bass (5.0 inches plus) and brown bullheads (7.0 inches plus) in Dollar Lake, 1958.

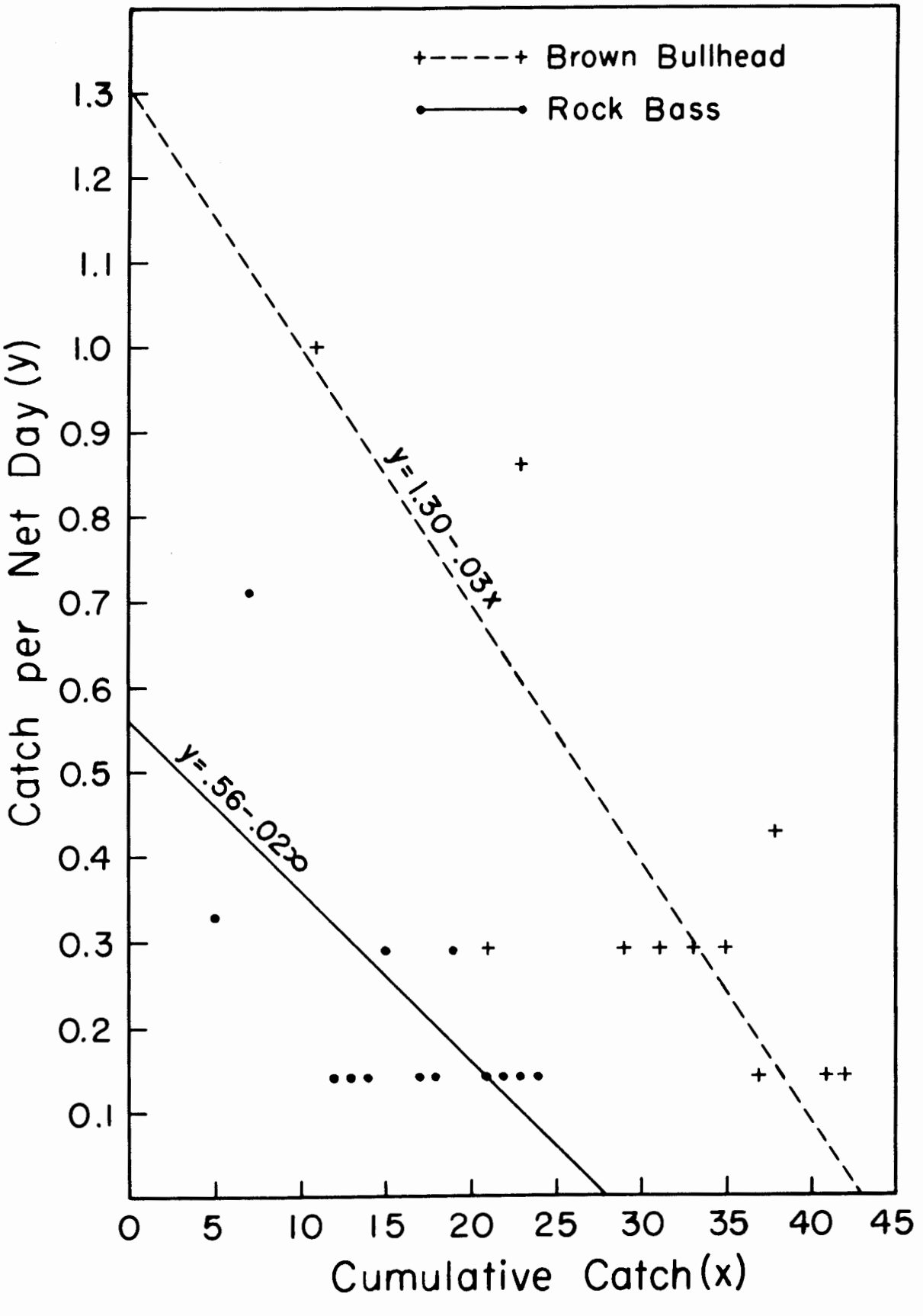
Brown Bullhead
Rock Bass
y=1.30-.03x
y=.56-.02x
Catch per Net Day (y)
Cumulative Catch (x)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
10
15
20
25
30
35
40
45

Figure 2

population estimation (using Schumacher formulas) in this lake with a diversified population.

For making satisfactory estimates in small lakes it is recommended that the investigator make provisions to adjust final estimates to allow for the efficiency of the gear. The work in Dollar Lake demonstrated the need for this added precaution to increase the precision of the estimates. On large lakes, it may not be practical or possible to mark enough fish to compute corrections for gear efficiency although it would be desirable. As Cooper and Lagler (1956) pointed out, "... almost any carefully propounded correction will be better than none."

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