FISHERIES SESSION

FISH POPULATION ESTIMATES IN SMALL PONDS USING THE MARKING AND RECOVERY TECHNIQUE

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Accurate estimation of the fish population in a body of water is extremely important if fishery resources are to be properly managed, and if population dynamics are to be understood. One of the most useful techniques is that of marking a number of fish and estimating the population from the proportion of the marked fish later recovered. This method was first used by C. G. J. Petersen (1896) in Denmark but has been widely used in this country in recent years (Underhill 1949, Ricker 1942, 1945a, Lagler and Ricker 1942, Schumacher and Eschmeyer 1943, Krumholz 1944, Hayes 1947). Statistical treatments of the recovery data to determine the best estimate and the standard errors have been developed by Schnabel (1938), Schumacher and Eschmeyer (1943), and Ricker (1948).

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In the summer of 1948, the fish populations in 19 Iowa ponds were estimated by the marking and recovery technique (Table 1). Theoretically the problems of population estimation should be much simpler in small ponds (the largest was 3 acres) than in large, more complex waters. The condition of the fish population in each pond was first determined by the Swingle method (Anderson 1948). In applying this method a few short hauls were made in the shallow water around the margin of the pond with a common sense seine, 6 to 16 feet long and 4 feet deep. If the fish in the seine consisted of young-of-the-year of both largemouth black bass and bluegills and some 2- to 3-inch yearling bluegills, the pond was classed as being in balance. If no young-of-the-year largemouth bass and very few young-of-the-year bluegills were taken, but the catch was made up almost entirely of the 2- to 3-inch yearling bluegills, the pond was classed as being overpopulated with bluegills. When the samples contained no bass young-of-the-year, a few bluegill

Table 1. Description of ponds in which fish populations estimates were made.

Pond No.	Location	Area (Acres)	Secchi Disc (Inches)	General	Record of Stocking: Date	Record of Stocking: Species	Dates of Estimates	Species not Estimated
GROUP 1. Ponds having a balanced bluegill and bass population.[a]								
2	Lucas Co., Ia., R-20W T-71N, sec 4, SW ¼	0.6	9	Filamentous green algae & pondweed	1944	60 bass 1000 bluegill	6/17-18/48	Green sunfish Fathead minnow
16	Marion Co., Ia., R-18W, T-76N, sec 15, NW ¼	0.6		Very turbid; Willows & cattails			7/19-20/48	Carp, Buffalo, Bass, Black Crappie
17	Marion Co., Ia., R-21W, T-75, sec 11, NW ¼	0.4	9	Plankton bloom	1942 1943	Bullhead Bass & bluegill	7/20-23/48	None
18	Marion Co., Ia., R-21W, T-71N, sec 12, SW ¼	0.2		Heavily silted; Cattails & Bulrushes	1943	60 bass 500 bluegill 100 crappie	7/22-23/48	None
33	Jefferson Co., Ia., R-9W, T-72N, sec 1, NW ¼	0.6	13	Well fertilized	1945	60 bass 600 bluegill	8/11-12/48	None
36	Jefferson Co., Ia., R-8W, T-72N, sec 13 NW ¼	0.2	6	Heavily silted			8/9-10/48	Bullheads, bass, Channel catfish, Common sucker, Bluntnose minnow

Table 1. Continued.

Pond No.	Location	Area (Acres)	Secchi Disc (Inches)	General	Record of Stocking		Dates of Estimates	Species not Estimated
					Date	Species		
				GROUP 2. Ponds overpopulated with bluegills				
3	Wayne Co., Ia., R-20W, T-68N, sec 31, SE ¼	1.5	3	Heavily silted		6/17-18/48		Bluntnose minnow, Golden shiner
4	Lucas Co., Ia., R-22W, T-71N, sec 13, SE ¼	3.0	4	Shallow water Heavily silted	1943	300 bass 200 bluegill	6/16-18/48	Bass
8	Davis Co., Ia., R-12W, T-70N, sec 4, SW ¼	0.1		Very turbid; oil scum on water	1947	100 bass 600 bluegill	6/30/48	Golden shiner, Channel catfish, Perch, Carp
9	Davis Co., Ia., R-15W, T-68N, sec 11, NW ¼	0.75	2½	Cultivated watershed	1946	75 bass 225 bluegill	6/29-30/48	None
15	Marion Co., Ia., R-20W, T-75N, sec 22, NE ¼	0.2	6	Heavily silted	1945	50 bass 750 bluegill	7/20-22/48	None
				GROUP 3. Ponds overpopulated with bass.				
34	Jefferson Co., Ia., R-8W, T-73N, sec 31, SW ¼	0.3		Fertilized Plankton bloom	1945	30 bass 300 bluegill	8/10-11/48	None
35	Jefferson Co., Ia., R-10W, T-71, sec 5, SW ¼	0.2	4	Cattails and sedge present	1946	20 bass 200 bluegill	8/12-13/48	Crappie, Golden shiner

Table 1. Continued.

Pond No.	Location	Area (Acres)	Secchi Disc (Inches)	General	Record of Stocking		Dates of Estimates	Species not Estimated
					Date	Species		
			GROUP 4. Ponds overpopulated with other species.					
1	Lucas Co., Ia., R-21W, T-71N, sec 12, SE ¼	0.5	7	Heavily silted	1937 1943	Misc fish 50 bass 500 bluegill	6/16-17/48	None
7	Davis Co., Ia., R-14W, T-68N, sec 5, SW ¼	0.4	1½	Much shallow water			7/1-2/48	None
19	Marion Co., Ia., R-20W, T-76N, sec 10, NE ¼	0.6		Turbid	1943	30 bass 25 bullhead 300 bluegill	7/21-22/48	Bass
20	Marion Co., Ia., R-18W, T-76N, sec 25, SW ¼	0.3	9	Poisoned after estimates made	1944	bullhead	7/19-20/48	None
31	Boone Co., Ia., R-28W, T-83N, sec 16, SE ¼	0.8		Vegetated; Heavily silted	1946	80 bass 240 bluegill	8/5-6/48	Golden shiner
32	Jefferson Co., Ia., R-8W, T-72N, sec 30, SW ¼	0.4	7	Heavily silted; Very shallow; Poisoned after estimates made			8/10-11/48	None

[a] Based on check made by the Swingle technique.

young-of-the-year, and no 2- to 3-inch yearling bluegills, an overpopulation of bass was indicated. If there were no young-of-the-year of either bass or bluegills, but the young of yearlings of other species were present, the pond was classed as being overpopulated with other species.

The common and scientific names of the species of fish found in the ponds are listed in Table 2.

Table 2. Common and scientific names of fish found in Iowa ponds.

Common Name	Scientific Name
German Carp	*Cyprinus carpio* (Lacepede)
Goldfish	*Carassius auratus* (Linnaeus)
Fathead minnow	*Pimephales promelas promelas* (Rafinesque)
Golden shiner	*Notemigonus crysoleucas auratus* (Rafinesque)
Bluntnose minnow	*Hyborhynchus notatus* (Rafinesque)
Common Buffalofish	*Megastomatobus cyprinella* (Valenciennes)
Common white sucker	*Catostomus commersonnii commersonii* (Lacepede)
Channel catfish	*Ictalurus lacustris punctatus* (Rafinesque)
Black bullhead	*Ameiurus melas melas* (Rafinesque)
Tadpole madtom	*Schilbeodes mollis* (Hermann)
Largemouth black bass	*Micropterus salmoides* (Lacepede)
Black crappie	*Pomoxis nigro-maculatus* (Le Sueur)
White crappie	*Promoxis annularis* (Rafinesque)
Bluegill	*Lepomis macrochirus* (Rafinesque)
Green sunfish	*Lepomis cyanellus* (Rafinesque)
Orangespot sunfish	*Lepomis humilis* (Girard)
Yellow perch	*Perca flavescens* (Mitchill)

All the sampling was done with a 70- by 10-foot, ⅜-inch mesh seine, or with a 60-foot, ⅜-inch mesh seine with a 12-foot bag. Seines were selected for the study since they took larger samples of the fish population in a short time than most other types of gear. Seines also tend to be less selective as to size and species of fish caught. The fish were marked by clipping the left pectoral fin in all species except the bullhead, in which the left pelvic fin was clipped to avoid removal of the pectoral spine. Sampling to obtain fish for marking was continued until 20 to 50 per cent of the fish caught were marked. In the smaller ponds, 3 seine hauls usually sufficed. The measurements and number of each species of fish in each haul were kept separate, because various species differed in vulnerability to sampling.

After the marking operations were completed, no seining was done for at least one day in order to permit the marked fish to become distributed throughout the entire pond. The same equipment was used to take samples for estimating purposes as was used for marking. Four or five hauls were usually taken for recoveries, varying, of course, with the size of the pond. The measurements and number of marked and unmarked fish of each species were recorded for each haul. From these data the population estimate for each species was calculated.

The Petersen method of population estimation is based on drawing a sample of marked and unmarked individuals from a population containing a known number of marked and an unknown number of unmarked individuals. The ratio of the number of marked fish recaptured to the total number of fish taken is assumed to be equal to the ratio of the total number of marked fish in the pond to the whole population: that is,

$$\frac{m}{m + u} = \frac{n}{N} \quad (1)$$

where *m* is the number of marked fish in the sample, *u* is the number of unmarked fish, *n* is the total number of marked fish in the pond, and *N* is the total population. Since *N* is the only unknown value in this proportion, it can be determined algebraically. An indication of the accuracy of these estimates can be secured by the application of confidence limits for the binomial distribution to the ratio of marked fish to total number of fish taken in the sample (Ricker 1948). The ratio m/(m + u), is obtained from the sample data, and reference to Clopper and Pearson's (1934) chart will give the confidence limits of this ratio. The total population, *N*, can be estimated as follows:

$$N = \frac{n}{R} \quad (2)$$

where *n* is the known number of marked fish in the pond, and *R* is the value of the ratio, m/(m + u). By substituting for *R* the values of its limits, the range of *N* for 95% or 99% confidence can be estimated. Ricker (1942) states that when the ratio of marked to unmarked fish at large is small, less than 0.05, the number of marked fish recovered can be considered a member of a Poisson series. Ricker (1937) has tabulated confidence limits for the Poisson distribution. In this study the ratio of marked fish to unmarked fish was large enough to warrant usage of fiducial limits for the binomial distribution.

A modification of the Petersen method, which considers each sample as a separate estimate from which a more accurate estimate is secured by the method of minimizing squares of residuals, has been developed by Schumacher and Eschmeyer (1943):

$$N = \frac{S(n^2(m + u))}{S(nm)} \quad (3)$$

where *S* indicates summation.

Ricker (1945*b*) pointed out that the efficiency of (3) is at a maximum when n/N is equal to 0.5. Since, in the population estimates made on the ponds in this study, the proportion of the number of marked fish in the total population was believed to be from 0.2 to 0.5, the Schumacher and Eschmeyer formula was used. Another advantage in using (3) lies in the fact that Schumacher and Eschmeyer have computed formulae for calculating sampling variance and standard error of the estimate, as follows:

$$s^2 = \frac{1}{k - 1} \left[S\left(\frac{m^2}{m + u}\right) - \frac{1}{N} S(nm) \right] \quad (4)$$

where s^2 is the sampling variance of the estimated number of fish in the pond and *k* is the number of samples taken from the pond. It should be pointed out here that a sample was considered to be one drag through the pond with the net used. The standard error of the estimate was calculated by the formula,

$$(N^2)\ \frac{Ns^2}{S(nm)} \qquad (5)$$

Certain basic assumptions must hold true before the marking and recovery method can be used to estimate total populations in ponds (Ricker 1948):

1. The marked fish must become randomly distributed throughout the population.
2. The marked fish are as vulnerable to the sampling methods as are the unmarked.
3. The marked fish suffer no greater mortality than the unmarked fish.
4. The marked fish do not lose their marks.
5. All marks are recognized and reported on recapture.
6. Recruitment to the population is negligible during the time recoveries are being made.

Since the samples were taken with the seine within one or two days after marking operations, the fish could not have lost their marks in that time. Because the sampling was done shortly after marking, and no pond was connected to another body of water, recruitment to the population being estimated was nil. Finally, since all marks were uniform and each sample was thoroughly checked by one of three persons, it was believed that all marked fish were recognized and reported.

The effect of the marking did not appear to be significant. Only a very few dead marked fish were found, and these consisted principally of white crappies. It is possible that some dead marked fish sank to the bottom, but the fact that so few were recovered leads to the assumption that the fin clipping technique caused little harm to the fish. Ricker (1949) demonstrated that fin clipping caused a significant decrease in survival rate in largemouth black bass but not in bluegills. In the present study, the time lapse between marking and recovery was so short as to eliminate errors such as Ricker indicated. Since the ponds were small, since the seine hauls usually covered most of the pond area, and since the fish were given at least overnight to become redistributed before recapture, it is believed that errors due to nonrandom distribution of the marked fish were kept at a minimum. Assumption 2 is the only one on which evidence of validity is not readily available. It will be shown later that in some ponds errors occurred which may have been due to differences in the vulnerability of marked and unmarked fish.

SITUATIONS IN WHICH NO ESTIMATES WERE SECURED

It was not possible to estimate the abundance of certain species either because an insufficient number was marked or no unmarked fish was taken in the recovery samples. For either of these reasons, the following populations could not be estimated in the number of ponds listed: golden shiner, 4; largemouth black bass, 4; bluntnose minnow, 2; carp, 2; channel catfish, 2; fathead minnow, 1; green sunfish, 1; buffalofish, 1; white crappie, 1; black crappie, 1; bullhead, 1; common sucker, 1; and yellow perch, 1.

It should be pointed out that it is hardly possible to obtain an accurate estimate of the very small fish of any species. The small fish cannot be handled and marked without a considerable mortality. Furthermore, a large number of the 1- and 2-inch fish can school in a clump of vegetation where sampling operations are hindered; these small fish do not enter the samples, and no reasonable estimate of their numbers is attainable.

In several cases no estimate could be made of the bass population, and in other ponds the estimates that were secured had excessively high standard errors. The bass over 9 inches in length were often able to avoid capture with the seines, and the numbers marked and recovered were too few to make an accurate estimate.

In addition to the 19 ponds which were studied, observations were made on 15 ponds in which it was considered not feasible to make an estimate. Four ponds had such a growth of aquatic plants and filamentous green algae that it was impossible to sample the populations with the equipment available. The net rolled to such an extent that it was extremely difficult to pull it without damaging the fish. There were trees, posts, and sunken shelters, such as car bodies and brush heaps, in 5 ponds. No attempt was made to estimate the populations in these ponds, since the danger of entangling the net in these obstructions and tearing or destroying it completely was so great. The fish populations had been recently killed by poison in 3 ponds, and 2 other ponds had been stocked only a short time previously; hence there was no purpose in sampling these ponds. The size of one pond made estimating the fish populations unfeasible, because many more samples would have been needed than it was possible to take with the equipment and time available.

POPULATION ESTIMATES AND ERRORS ASSOCIATED WITH ESTIMATES

Table 3 gives the population estimates obtained by the two methods used, the Schumacher and Eschmeyer method of minimizing squares of residuals, and the Petersen ratio estimate. Standard errors of estimate and confidence limits are given for the respective methods of population estimation. Other pertinent data concerning the numbers of fish marked, marked and unmarked fish captured, and samples taken are presented. During the course of this study, each pond was numbered in the order in which it was surveyed, and these numbers are used throughout the paper for identifying the ponds. In general, both methods of population estimation give very similar results. The range of the 95 per cent confidence limits is approximately equal to plus or minus two standard errors. Using the Schumacher and Eschmeyer method of population estimation, one can have only about 67 per cent confidence that the true population lies in the interval of the estimate plus or minus one standard error which sometimes may be as much as or greater than 75 per cent of the estimate.

The large sampling errors which accompanied many of the population estimates in this study make these estimates insufficiently reliable to serve as a basis for certain management practices, particularly without the supporting evidence of the Swingle method check. The results of the poisoning operations more forcefully emphasize the fact that the estimates are not as accurate as desired (Table 4).

It was the purpose of this study to investigate the errors which may appear in estimating fish populations. There were two sources of error in this study, one caused by the sampling techniques and the other by characteristics of the fish populations.

Table 3. Fish population estimates.

Pond No.	Species	No. of Samples	Schumacher & Eschmeyer Formula: n[a]	S(m)[b]	S(m + u)[c,d]	Estimate	Standard Error	Petersen Ratio Method: Estimate	95% Confidence Limits
GROUP 1. Ponds having a balanced bluegill and bass population.									
2	Bluegill	5	324	10	121	3917	1583	4050	2160 - 8100
	Bass	5	2	1	2	4	1	4	1 - 5
16	Bluegill	3	61	22	88	244	28	244	174 - 359
	Bullhead	3	40	34	80	94	13	93	75 - 121
	Green Sunfish	3	8	2	8	32	24	32	23 - 47
	Orangespot Sunfish	3	7	2	26	91	31	91	80 - 100
17	Bass	3	17	11	35	54	6	55	41 - 77
	Bluegill	3	106	50	151	323	35	321	247 - 442
18	Bass	3	5	2	2	5	0	5	
	Bluegill	3	78	34	71	163	6	163	134 - 205
33	Bass	4	8	4	14	29	4	28	21 - 40
	Bluegill	4	64	8	35	281	69	278	200 - 427
36	Bluegill	4	55	50	80	88	5	87	76 - 104
	Carp	4	3	1	2	7	2	6	5 - 8
	Green Sunfish	4	41	38	122	126	10	132	100 - 186

Table 3. Continued.

Pond No.	Species	No. of Samples	n[a]	S(m)[b]	S(m + u)[c,d]	Schumacher & Eschmeyer Formula: Estimate	Schumacher & Eschmeyer Formula: Standard Error	Petersen Ratio Method: Estimate	Petersen Ratio Method: 95% Confidence Limits
					GROUP 2. Ponds overpopulated with bluegills.				
3	Bass	3	4	1	2	8	6	8	7 - 10
	Bluegill	3	78	18	75	325	142	325	236 - 486
	Bullhead	3	39	4	44	429	178	433	244 - 975
	Green Sunfish	3	92	24	58	221	51	224	180 - 297
4	Bluegill	4	43	9	47	155	19	226	154 - 358
	Bullhead	4	74	7	49	593	445	529	336 - 925
	Green Sunfish	4	21	4	24	124	43	124	81 - 210
8	Bluegill	2	141	73	174	336	60	336	271 - 441
	Bullhead	2	517	340	556	845	113	848	728 - 1014
9	Bass	5	43	18	41	95	52	95	78 - 124
	Bluegill	5	133	121	211	219	10	233	199 - 283
15	Bass	3	9	7	9	12	1	12	10 - 13
	Bluegill	3	200	143	251	351	26	351	299 - 426
	Golden Shiner	3	6	2	9	22	7	27	20 - 43
					GROUP 3. Ponds overpopulated with bass.				
34	Bass	3	12	8	12	17	3	18	16 - 21
	Bluegill	3	130	90	142	218	7	206	181 - 245
35	Bass	5	3	1	7	21	12	21	14 - 38
	Bluegill	5	28	18	50	78	21	78	61 - 104

Table 3. Continued.

Pond No.	Species	No. of Samples	n[a]	S(m)[b]	S(m + u)[c,d]	Schumacher & Eschmeyer Formula Estimate	Schumacher & Eschmeyer Formula Standard Error	Petersen Ratio Method Estimate	Petersen Ratio Method 95% Confidence Limits
	GROUP 4. Ponds overpopulated with other species.								
1	Bass	3	4	2	11	22	15	22	15 - 36
	Bluegill	3	140	42	191	637	58	636	451 - 1000
	Bullhead	3	30	8	63	236	87	231	142 - 428
	Goldfish	3	6	1	13	84	80	75	40 - 150
7	Bluegill	3	24	10	30	72	10	72	56 - 100
	Bullhead	3	14	6	18	42	9	42	33 - 58
	Crappie	3	14	9	11	17	3	17	16 - 19
	Golden Shiner	3	21	6	8	28	5	28	25 - 32
19	Bluegill	3	163	73	159	355	21	354	291 - 453
	Bullhead	3	29	15	58	114	5	112	81 - 161
	Crappie	3	102	43	91	216	11	217	179 - 276
	Orangespot Sunfish	3	5	3	6	10	5	10	8 - 13
20	Bullhead	4	216	48	175	796	114	800	584 - 1137
31	Bullhead	4	606	125	257	1249	170	1237	1027 - 1554
	Crappie	4	46	21	55	120	35	121	96 - 164
	Green Sunfish	4	31	8	94	364	360	344	194 - 775
32	Bullhead	9	191	82	185	435	30	434	354 - 562
	Goldfish	9	146	36	140	558	65	562	406 - 811

[a] n = number of marked fish in pond.
[b] m = number of marked fish recaptured.
[c] u = number of unmarked fish captured.
[d] S indicates summation.

Table 4. Comparison of population estimates in two ponds with the numbers of fish recovered after poisoning.

Pond and Species	Schumacher and Eschymeyer Estimate	Schumacher and Eschymeyer Standard Error	Petersen Estimate	Petersen Fiducial Limits	No. Recovered after Poisoning	Estimated Population by Poisoning
Pond 20						
Bullhead	769	114	800	584 - 1137	1786	1964
Pond 32						
Bullhead	432	30	434	354 - 562	311	586
Goldfish	558	65	562	406 - 811	674	906

In some of the ponds the populations of certain species were too low to obtain estimates at all. In most of such cases there were probably less than a half dozen fish of each species in a pond. Usually 2 or 3 of each species were marked, and no additional unmarked fish were taken in the recovery samples. These low populations were of little concern in regard as to how they affected the estimation techniques or the general pond dynamics.

The bass populations, although small in many of the ponds, provided a difficult problem. It was necessary to obtain a reasonably accurate estimate in order to determine what management practices should be applied. In only a few ponds, however, was it possible to secure a reliable estimate. It has been pointed out that bass over 9 inches in length were frequently able to swim around the ends of the seine or leap over the float line. Bass were observed to leap over the float line many times, especially while the seine was in deep water where the float line could not be held out of the water. As the seine was pulled onto shore, the float line was held about two feet above the water, and bass unsuccessfully attempted to leap over it. There was little that could be done to make netting of bass more efficient with the equipment used, because the seines could not be pulled rapidly enough to encircle the bass and prevent them from escaping. The presence of a drainpipe in most of the ponds hindered sampling to some extent, and it might help to explain the poor success in capturing bass. Vegetation along the shore made landing the net difficult in some ponds, and some fish, including bass, could have escaped. For any one of the foregoing reasons, or a combination of them, the bass estimates were usually poor.

Low population estimates were obtained for the species of fish in the two ponds poisoned with rotenone (Table 4). The low bullhead estimates were ascribed to the fact that a group of bullheads remained on the bottom during the time the samples were taken and did not enter the population being sampled. This group could be considered as constituting a separate population inasmuch as none of the group was included in the samples taken for the estimate. For the same reason, if a group of fish were concentrated in a bay where it was not subject to any sampling, the population estimate would not include the fish in the bay and would be an underestimate of the real population. Poisoning would bear this out if recovery were nearly complete.

The bluegill population estimates are believed to be fairly accurate, primarily because the nets used sampled this species more representatively than any other species. Bluegills appeared to be as accessible to sampling one day as the next, and no group of fish of this species was selected more readily than another, as was the case with bullheads and bass.

It is very likely that a fish taken in the marking samples is perhaps more likely to be taken in the recovery samples than an unmarked fish. Fish able to escape the net once are able to escape it again, whereas, for some reason or another, such as physical condition, other fish are vulnerable to netting time after time. In such a case the effect of marking could probably make the latter even more vulnerable. The estimate obtained would be low, because a proportionately larger number of marked fish than unmarked fish would be taken in the recovery samples. It is difficult to detect, or to correct for, such errors.

A group of fish may be accessible to capture one day and not the next. The fish may stay on the bottom where they are not susceptible to sampling one day, and they may be active in the upper strata of the pond the following day. In larger ponds the fish may be concentrated in one corner of the pond one day and in another part of the pond the next day. In either of these cases the chance for a sizable error of estimate is large when the marking and recovery sampling are done over a period of only one or two days. To correct for the fact that a certain group of fish is vulnerable to sampling one day and not necessarily the next, either because of the habits of the fish or some difference in sampling technique, marking and recovery operations should be carried on over a longer period of time with more samples taken.

A sampling design which may help to obtain a more accurate estimate of a fish population in a larger body of water is stratification. When it is known that a species is found only in certain locations in a large pond or lake, strata could be formed and sampling done accordingly.

Another source of error was the manner in which the nets were removed from the water. It was not always possible to keep the lead line on the bottom, and fish sometimes escaped by swimming under the net. This was especially true in the case of the goldfish in Pond 32 and serves as a possible explanation for the underestimate (Table 4).

A large standard error accompanied many of the estimates primarily because the proportion of marked fish was too small. More marking samples should be taken over a longer period of time to correct for this.

With the net used in this study relatively large numbers of fish could be sampled in a short time, thus making it possible to survey many ponds with a minimum of equipment. However, there are definite limitations as to the effectiveness of the bag net and 70 by 10 feet seine. They are selective in that they sample certain species of fish more efficiently than others. They cannot be used to sample areas around obstructions, such as drainpipes, trees, and sunken scrap. They are difficult to land along a vegetated shoreline. The need for different techniques of capture is readily seen.

POISONING

As a check on the population estimates, all of the fish were eliminated with rotenone from two ponds immediately after the estimates were made. The small ponds afforded an excellent opportunity to make a check, because it was believed that recovery of the poisoned fish was not hindered by depth or expanse. In Pond 32, the water was shallow enough to permit wading and picking poisoned fish off the bottom. In Pond 20, the seine was dragged across the pond to remove poisoned fish near the bottom. Neither pond was connected to any other body of water; the estimates were for an isolated population, and all fish recovered after poisoning represented this same population.

Of 232 bullheads marked in Pond 20, 211, or 91% were recovered after poisoning. In Pond 32, 90% of the 153 marked goldifsh and 86% of the 226 marked bullheads were recovered after the poisoning operations. These results indicate higher recovery than has been secured in similar poisoning experiments conducted elsewhere. Ball (1945) recovered 59% of the marked bluegills and 45% of the marked trout after poisoning a lake in Ostego County, Michigan, with rotenone. Carlander and Lewis (1948) poisoned a small pond in Marion County, Iowa, and recovered the following percentages of marked fish: bluegills, 38%; white crappies, 14%; largemouth black bass, 33%; black bullheads, 80%; and golden shiners, 91%. In recent years, numerous fish populations in ponds and lakes have been poisoned with rotenone, but in only a very few cases were any fish marked before poisoning. It is recommended that a number of fish be marked prior to poisoning in order to obtain information concerning the percentages of dead fish recovered.

Since a high percentage of marked fish was recovered after poisoning in both Ponds 20 and 32, it was believed that most of the unmarked fish were recovered also. The actual number of poisoned fish removed from Pond 20 was far greater than the estimated population (Table 3). The same was true for the goldfish and bullhead populations in Pond 32; however, the estimates for the latter were not quite as much in error as in Pond 20.

In a pond poisoned a year earlier, the bullhead population has been similarly underestimated (Carlander and Lewis 1948). At that time it was suggested that many of the bullheads were in the bottom mud and not susceptible to capture with the seine. For this reason sampling was done in Pond 20 both in the daytime and after dark in the hope that these fish would be more readily caught at night. Forty bullheads were marked in the daytime and 192 at night, and all recovery sampling was done at night. Despite these precautions, the population was underestimated It would appear that a sizable group of bullheads in these ponds was not vulnerable to capture by seining and regularly eluded capture by burrowing into the mud or in some other manner. Another possible explanation is that once marked the bullheads were more susceptible to capture than the unmarked bullheads.

In seining it was noted that the goldfish reversed directions as the net approached shore and by diving into the loose muck swam under the net. Most of the goldfish that escaped were apparently unmarked fish, thus giving a high ratio of marked fish in the recoveries and a low estimate of the population.

It is believed that the estimates of the bluegills and other species which are more easily seined are relatively accurate, but further studies on poisoned ponds containing these species are needed. The estimates on bluegills, crappies, and golden shiners in the pond reported by Carlander and Lewis (1948) compared quite closely with the populations secured by poisoning.

DETERMINATION OF SAMPLE SIZE

The data collected in this study may be used to give some indication of the number of samples needed to estimate a fish population within certain degrees of accuracy.

The total population of a species of fish can be represented by T_y. The estimate, $\hat{T}_y$, of the population total can be obtained as follows, (Horvitz 1948):

$$\hat{T}_y = \frac{S(Y)}{S(X)} \quad T_x \tag{6}$$

where X is the number of the marked fish recaptured in each sample, Y is the total number of fish taken in each recovery sample, and T_x is the number of marked fish in the pond at the time the recovery samples are taken. It is desirable to know what sample size is necessary for

$$(\hat{T}_y - T_y) \leq d, \tag{7}$$

with a certain confidence level, such as 95%, where d is the difference between the estimated total population and the true total population. The value of d is determined by the experimenter, depending upon the degree of accuracy wanted.

$(\hat{T}_y - T_y)$ is assumed to be approximately normally distributed with mean zero and variance, $V(\hat{T}_y)$. Horvitz (1949) gives the estimated variance of the ratio estimate as:

$$\hat{V}(\hat{T}_y) = \frac{(\hat{T}_y)^2}{n} \left[\frac{sx^2}{\bar{x}^2} + \frac{sy^2}{\bar{y}^2} - \frac{2sy.x}{\bar{x}\,\bar{y}} \right] \qquad (8)$$

The finite population correction term $(N - n)/N$, is ignored, because n, the sample size, is small relative to N, the number of sampling units; that is, $(N - n)$ is approximately equal to N. The number of sampling units, N, approaches infinity when sampling with replacement, as was the case in nearly all of the ponds in this study. In (9) sx^2 and sy^2 are the sample variances, and sy.x is the sample covariance. All of these values can be determined from pre-sample data.

Squaring both sides and dividing by $\hat{V}(\hat{T}_y)$, formula (7) becomes

$$\frac{(\hat{T}_y - T_y)^2}{\hat{V}(\hat{T}_y)} \leq \frac{d^2}{\hat{V}(\hat{T}_y)} \qquad (9)$$

Assuming that $(T_y - T_y/\sqrt{\hat{V}(\hat{T}_y)}$ is approximately distributed as "Student's" "t" formula (Student 1908), (9) can be written as follows:

$$t^2 \leq \frac{d^2}{\hat{V}(\hat{T}_y)} \qquad (10)$$

Substituting the expression for $\hat{V}(\hat{T}_y)$ in (10), it can be seen that

$$\frac{(\hat{T}_y)^2}{n} \left[\frac{sx^2}{\bar{x}^2} + \frac{sy^2}{\bar{y}^2} - \frac{2sy.x}{\bar{x}\,\bar{y}} \right] \leq \frac{d^2}{t^2} \qquad (11)$$

and $$n \geq (\hat{T}_y)^2 \left[\frac{sx^2}{\bar{x}^2} + \frac{sy^2}{\bar{y}^2} - \frac{2sy.x}{\bar{x}\,\bar{y}} \right] \frac{t^2}{d^2} \qquad (12)$$

The value for t is based on the number of degrees of freedom in the presample at the desired confidence level and can be obtained from a table presented by Fisher (1936). The sample size, n, is the number of samples required to obtain an estimate of the total population within the limits of d fish with a confidence coefficient equal to the confidence level of t.

As an example, the calculations necessary to determine the number of samples to estimate the goldfish population within 100 fish with 95% confidence are given below:

	Sample Number										
	1	2	3	4	5	6	7	8	9	Total	Mean
Marked Fish Recaptured, X	2	0	2	1	2	1	3	11	14	36	4.00
Total Fish in Sample, Y	8	2	11	5	14	6	14	37	43	140	15.55

Number of marked goldfish, $T_x = 146$

$s_x^2 = S(x^2)/(n - 1) = 196/8 = 24.5$

$s_y^2 = S(y^2)/(n - 1) = 1682.2225/8 = 210.28$

$s_{y.x} = S(xy)/(n - 1) = 568/8 = 71$

$\hat{T}_y = \frac{S(Y)}{S(X)} T_x = \frac{140}{36}(146) = 562$

$t_{.95}$, 8 degrees of freedom = 2.306

$$n \geq (562)^2 \left[\frac{24.5}{(4)^2} + \frac{210.28}{(15.55)^2} - \frac{2(71)}{(4)(15.55)}\right] \frac{(2.306)^2}{(100)^2}$$

≥ 20

These results show that less than one-half the necessary number of samples was taken. This method of determining sample size gives reasonable assurance that the population will fall in the designated limits.

The number of samples needed varies greatly in the various ponds and with the different species of fish (Table 5). Part of this variability may be due to not taking sufficient samples to estimate the variance accurately enough for the determination of the number of samples needed. The formula for the variance of the ratio estimate is only an approximation of the true variance, and its degrees of accuracy depends greatly upon the number of samples taken. The variance of the ratio estimate is generally an overestimate when too few samples are taken.

Table 5. Number of samples required to estimate fish populations with less than 10% error with 95% confidence in ponds included in this study.

Pond	Species				
Number	Bass	Bluegill	Bullhead	Crappie	Green Sunfish
1	2356	50	78		
2		408			
3	2676	393	818		260
4		102	408		124
7		134	170	137	
8		989	523		
9		20	257		
15		132	24		
16		76	82		
17	70	41			
18		7			
19		13	5	11	
20			93		
31			88	51	2196
32			13		
33	228	168			
34	164	49			
35	2601	164			
36		38			74
Median	1292	89	90	51	192

It is obviously impractical to try to secure an estimate within 10% of the true population in many of the ponds using the methods of this study. As the degree of accuracy required is decreased, however, the number of samples needed is decreased in geometric proportion. (Fig. 1 and Table 6).

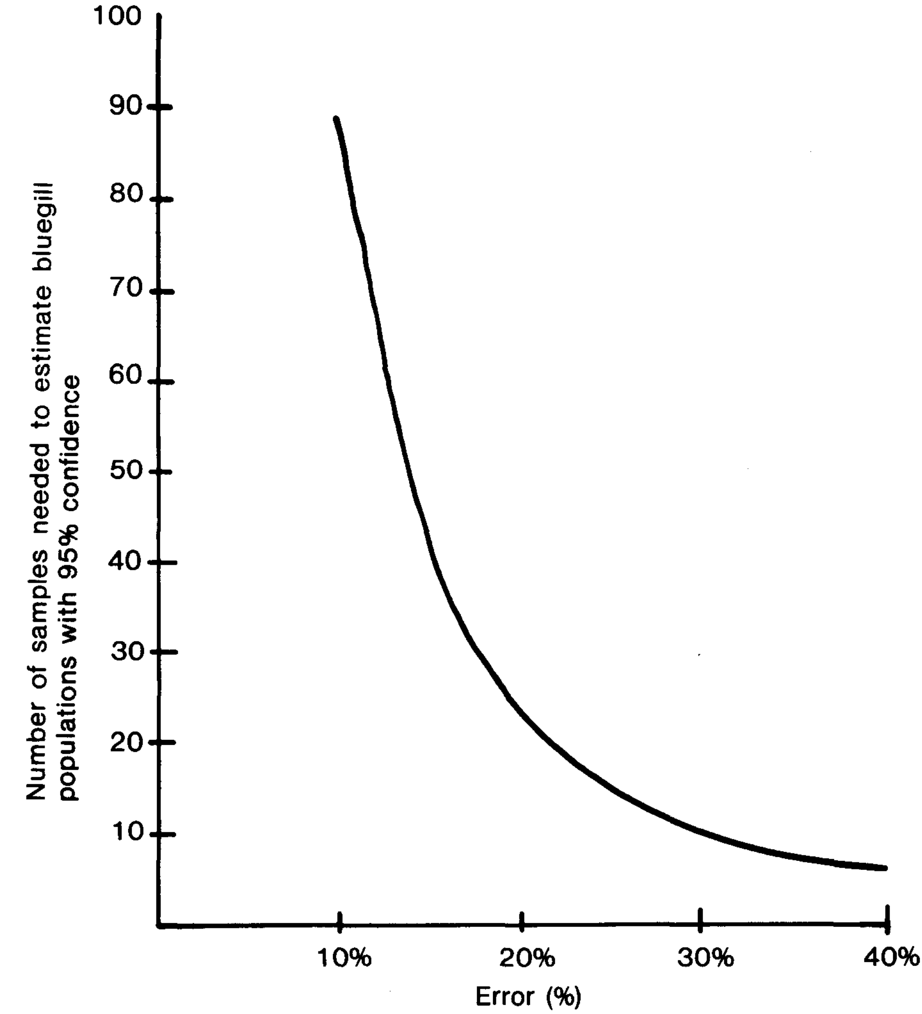

Fig. 1. Relationship between sample size needed and degree of accuracy desired in estimating fish populations.

Table 6. Number of samples required to estimate fish population included in this study with 95% confidence.

Error	Species				
Permitted (%)	Bass	Bluegill	Bullhead	Crappie	Green Sunfish
10	1292	89	90	51	192
20	323	22	22	13	48
30	145	10	10	6	21
40	81	6	6	3	12

When any other method of population estimation, such as that developed by Schumacher and Eschmeyer, is used to evalute the number of fish in a body of water, the variance of the estimate can be used to determine the sample size necessary to obtain an accurate estimate. For example, Schumacher and Eschmeyer's standard error can be used to determine sample size, *k*, where $\hat{N}$ is the estimate of the total population N. It is desirable to know how many samples are needed so that

$$(\hat{N} - N) \leq d \tag{13}$$

where *d* is a chosen interval and $(\hat{N} + N)$ is assumed to be normally distributed with mean zero and variance $V(\hat{N})$. The estimated variance is as follows

$$\hat{V}(\hat{N}) = \sqrt{\hat{N}^2 \frac{\hat{N}_s{}^2}{S(nm)}} \tag{14}$$

where s^2 is as given in (4).

After squaring both sides of (13) and dividing through by $\hat{V}(\hat{N})$, and assuming that $(\hat{N} - N)/\sqrt{\hat{V}(\hat{N})}$ is approximately distributed as "Student's" "t," (13) can be written as follows:

$$t^2 \leq \frac{d^2}{\hat{V}(\hat{N})} \tag{15}$$

Substituting the expression for $\hat{V}(\hat{N})$ in (15), it is seen that

$$\hat{N}\sqrt{\frac{\hat{N}\left(\frac{1}{k-1}\right)\left[S\left(\frac{M^2}{m+u}\right) - \frac{S(nm)}{\hat{N}}\right]}{S(nm)}} \leq \frac{d^2}{t^2} \tag{16}$$

Clearing the radical in (16) and transposing, the sample size, k, is shown to be

$$k = \frac{\hat{N}^3\left[S\left(\frac{m^2}{m+u}\right) - \frac{S(nm)}{\hat{N}}\right]}{\left(\frac{d^2}{t^2}{}^2\right) S(nm)} + 1 \tag{17}$$

Sample sizes using formula (17) have not been worked out for all of the ponds included in this study, but for the one or two cases for which *k* has been determined, the number of samples required for a population estimate with 10% error and 95% confidence were less than that already taken. It should be pointed out that whenever the estimated variance of any population estimate is inaccurate or biased, the resulting value arrived at for the necessary sample size will be misleading.

Of course, all of these calculations are based on the assumption that the fish are being randomly sampled. If the sample is biased (e.g. if it is selecting from one group of fish, with another group of fish avoiding capture), increasing the number of samples may not result in a more accurate estimate of the population.

SUGGESTIONS FOR ESTIMATING FISH POPULATIONS IN SMALL PONDS

*The most serious problem encountered in the estimation of the fish popula*tions in these ponds was the difficulty of getting random samples of the fish. In several cases there were indications that some of the fish were more susceptible to capture than others, and since these were the fish most apt to be marked and recovered, the population estimate tended to be low. It is recommended that several methods be used to capture the fish (e.g. seines, hoopnets, gillnets, and angling) so that the effect of the selectivity of each type of gear be minimized. A measure of the relative efficiency of each type of sampling gear can be obtained at the same time. It is also suggested that the marking and recovery operations be extended over several days, probably up to about 2 weeks, so that if certain groups of fish remain in limited areas for a period of time there will be more opportunity for random distribution of the marked fish. As the period of operations is extended, however, errors due to differential mortality of marked fish and to recruitment increase.

After several samples have been taken from a pond, the data should be analyzed after the fashion previously described to determine the number of samples needed to secure the required accuracy.

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