AN EVALUATION OF POPULATION ESTIMATE PROCEDURES - H. WESTERS 1963

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AN EVALUATION OF POPULATION ESTIMATE PROCEDURES IN TWO PONDS, CONTAINING ONLY LARGEMOUTH BASS (MICROPTERUS SALMOIDES)

By

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INTRODUCTION

The object of this study was to evaluate procedures of mark-and-recapture estimates of bass populations in two small ponds. Dependable estimates of population size are of great value to fishery workers, both for management practices and for an understanding of the dynamics of natural populations (Eschmeyer, 1938; Cooper and Lagler, 1956; Lagler, 1956; Watt, 1956).

A proposed research project to study production in largemouth bass populations under various rates of mortality initiated this project. Because of the need for both accurate (lack of systematic error) and precise (small sampling error) estimates of population size, special effort was applied to develop a desirable technique of sampling the fish. Because of the small size of the ponds (1.25 and 0.23 acres) it was possible to sample a relatively high proportion of the populations. Certain factors, however, limited the choice of sampling techniques that could be used. A dense bed of *Chara*, which covered almost the entire bottom of the larger pond, made the use of seines impractical.

Because the recapture of the fish (by some method different from that of original capture) may be expected to minimize bias in a mark-and-recapture study (Fredin, 1950; Cooper, 1951; Carlander, 1952; Loeb, 1958; and Waters, 1960), it was decided to use several different methods of catching the fish. The larger pond was sampled by angling and by shocking; the smaller one by angling, by seining, and by shocking. A total of twelve procedures for estimating the population were employed; six different procedures were used in each pond. These different estimates were compared and evaluated.

DESCRIPTION OF THE PONDS

The bass ponds are located in the Botanical Gardens of the University of Michigan, Ann Arbor. This is a tract of land of about 200 acres in Washtenaw County, T 2S, R 6, 7E, Secs. 13, 18, 19, 24 (Fig. 1). Dix Pond, the largest, is 1.25 acres; Rash Pond has a surface area of 0.23 acre. Both are rectangular in shape and are banked on the west side by a gentle sloping ridge about 30 feet high. Along the west and north sides of Dix Pond are several trees (*Populus* spp.) and shrubs (*Salix* spp. and others); the rest of this pond is bordered by a variety of herbs such as milkweeds, composites, grasses, etc. Rash Pond is entirely surrounded by shrubs, mostly *Salix* spp., oftentimes crowding very close to the water's edge. These plants may contribute a considerable amount of organic matter to the pond.

The bottom of Dix Pond is very irregular (Fig. 2) and is almost entirely covered with a dense bed of *Chara*. In the few small areas, where vegetation is lacking the bottom consists of hard clay, sand, or coarse gravel, with little or no organic sediment. A shallow bar, about 150 feet long and a few feet wide, runs north-south through the center of the pond, its ridge is barren of vegetation. This bar is composed of sand, clay, and gravel. Seining in Dix Pond was not practical because of the irregular bottom and dense vegetation. The

Figure 1.--The Botanical Gardens of The University of Michigan showing the location of Dix Pond and Rash Pond.

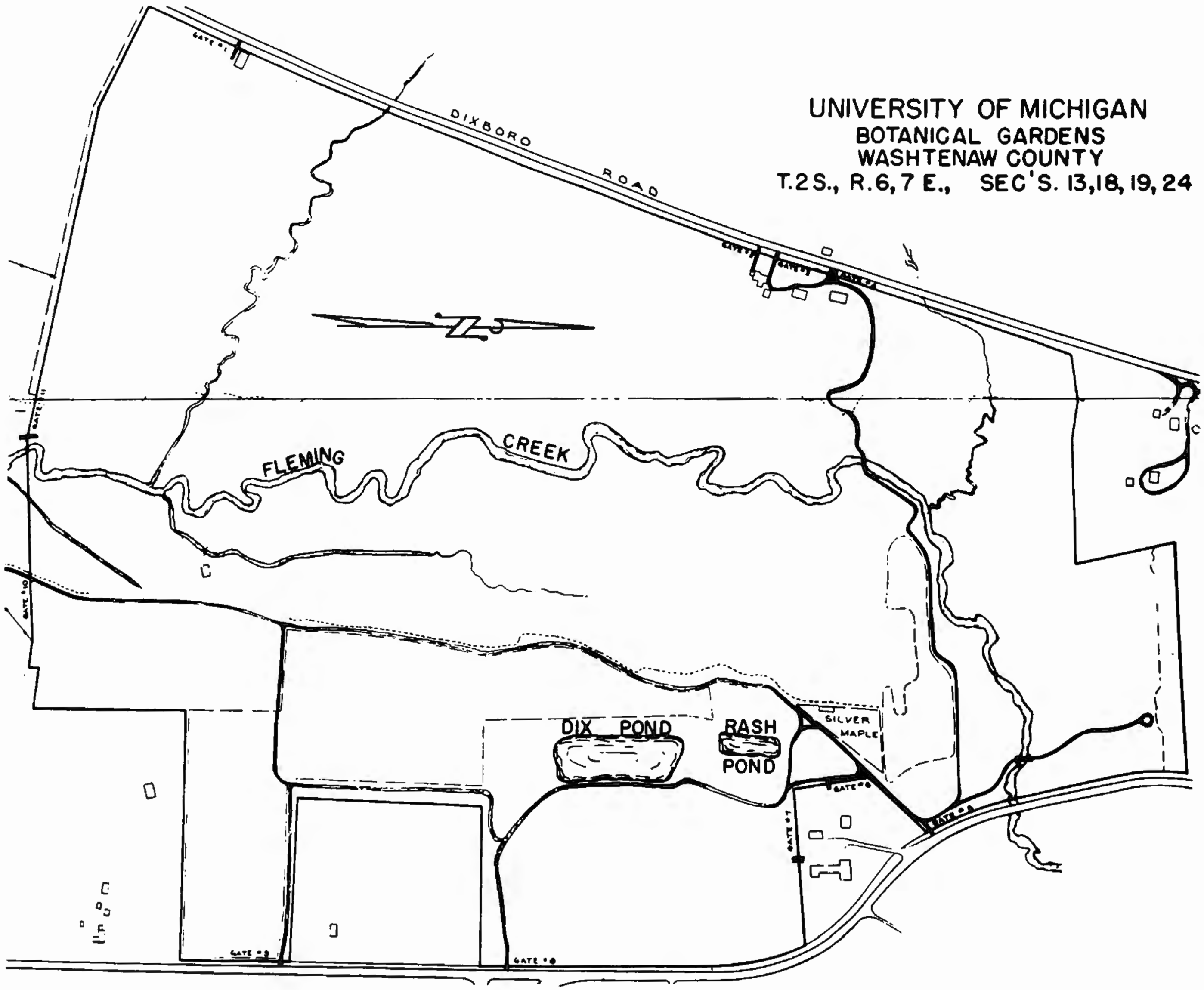

UNIVERSITY OF MICHIGAN
BOTANICAL GARDENS
WASHTENAW COUNTY
T.2S., R.6,7 E., SEC'S. 13,18,19,24
DIXBORO ROAD
FLEMING CREEK
DIX POND
RASH POND
SILVER MAPLE

Figure 1

Figure 2.--Dix Pond (1.23 acres).


DIX POND
AREA 1.25 ACRES
MARGINAL SURVEY AND SOUNDINGS 1962
BOTANICAL GARDENS U OF M
WASHTENAW COUNTY
T. 2S. R. 6 7E. SEC'S 13, 18, 19, 24.
N
0' 20' 40' 60' 80'
SCALE

Figure 2

vegetation provided excellent shelter for the bass and they made good use of it. The water in Dix Pond is very clear and the weed-covered bottom is visible even in the deepest places (10'). Dix Pond was stocked with 6 legal-size bass, 12-16 inches, in August 1955, and with 100 sublegal bass, 5-6 inches, in November 1955.

Rash Pond has quite a regular basin reaching a depth of about 7 feet (Fig. 3). Much of the bottom is covered with a soft layer of black muck and organic debris. Here and there are patches of *Potamogeton* spp. and in one corner is a small stand of *Typha*. Throughout the summer the water was very turbid, due to the presence of phytoplankton. Plankton blooms, observed during the summer, resulted in layers of scum nearly covering the entire pond. During seining operations many nymphs of Odonata were noticed together with members of the family Naucoridae (water creepers) and Notonectidae (back swimmers). Rash Pond, therefore, seems to be biologically more productive than Dix Pond. Rash Pond was stocked with 15 bass in June 1957. These bass were of the November 1955 planting and were transferred from Dix Pond to Rash Pond. They averaged 11 to 12 inches.

Figure 3.--Rash Pond (0.23 acre).

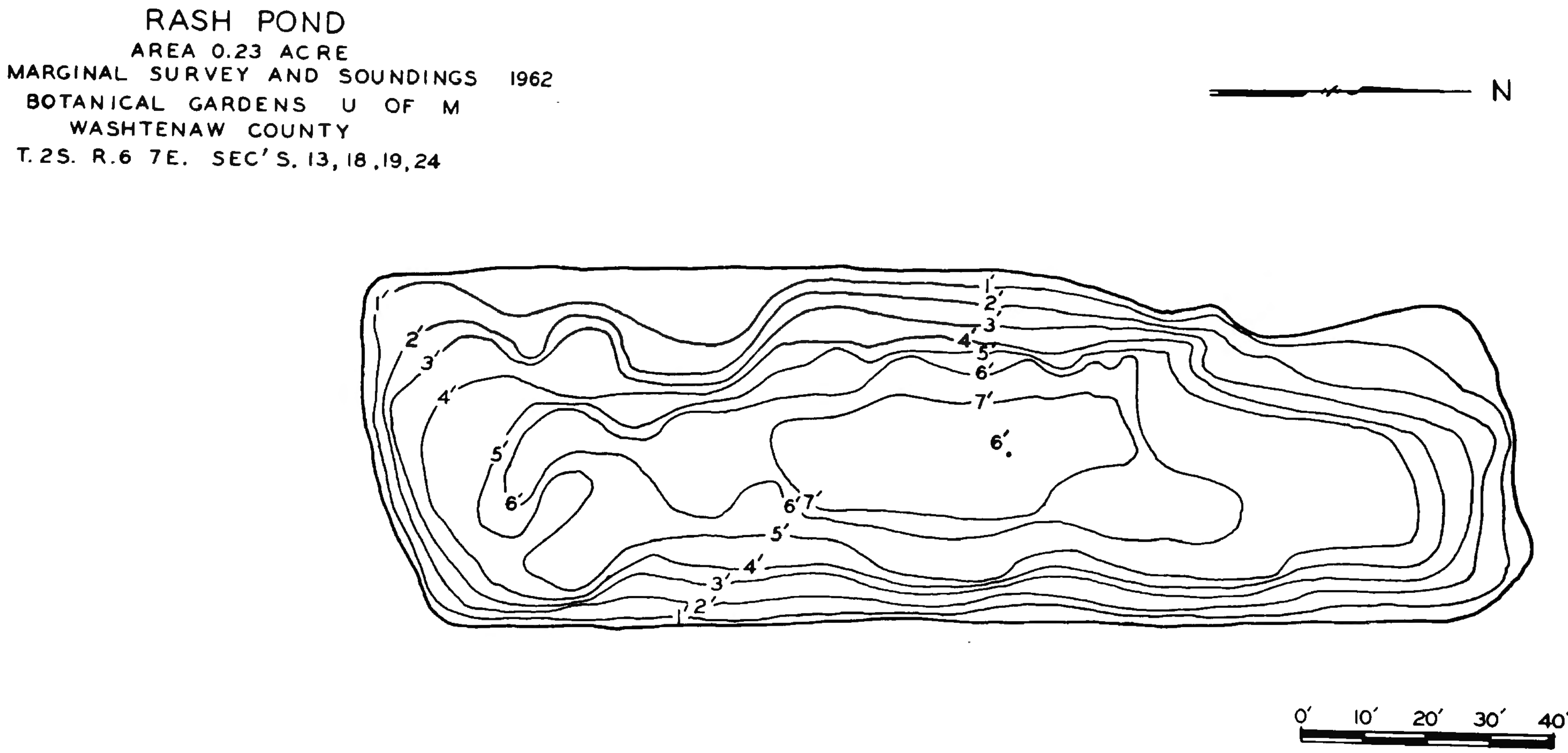

RASH POND
AREA 0.23 ACRE
MARGINAL SURVEY AND SOUNDINGS 1962
BOTANICAL GARDENS U OF M
WASHTENAW COUNTY
T. 2S. R. 6 7E. SEC'S. 13, 18, 19, 24
N
1'
2'
3'
4'
5'
6'
7'
0' 10' 20' 30' 40'

Figure 3

METHODS

Development of efficient sampling methods for mark-and-recapture population estimates is often very difficult, even in small bodies of water. Selectivity of the gear is one of the systematic errors that one almost invariably encounters when dealing with population estimates of this nature. In order to reduce or eliminate this type of error, several investigators (Ricker, 1942; Lawrence, 1952; Cooper, 1952; Cooper and Schafer, 1954; Carlander and Moorman, 1956; Waters, 1961) have suggested recapture of the fish in a different way than they were originally taken, as previously stated. Estimates based on the above principle were termed "mixed" procedures by Waters (1961) in contrast to "pure" procedure for population estimates obtained when employing the same methods for capturing and recapturing the fish. I adopt the above terminology with reference to the respective types of estimates.

Sampling methods used for Dix Pond

The nature of a pond or lake, its location, and the type of its fish population, affect the choice of the gear to be used for sampling the population. Angling and electric shocking were the most efficient in Dix Pond. Seining, for reasons already mentioned, could not be employed. Trap nets, of the type described by Crowe (1950), placed in both ponds for a period of 72 hours, did not catch any bass. On July 31, August 1, 2, 9, and 15 Dix Pond was fished with rod and reel, using mostly spinning equipment, and to a lesser extent fly casting equipment. Anglers fished all areas of the pond, from shore as well as from boat using lures of their choice. The fish which were caught were fin-clipped on the upper part of the dorsal lobe of the caudal fin, measured (total length to the nearest 0.1 inch), and scale sampled. They were then held during the day in a live cage in order to observe hooking mortality, which proved to be very small (less than 3.5 percent). At the end of the day, all bass which showed signs of weakness, were removed from the population while the others were returned to the pond at different places along the entire shore in an attempt to obtain random distribution. Angling was discontinued from August 15 until September 14.

Electric shocking as a sampling method for fish collection was done on August 15, 16, 28, and September 1. A direct-current, 220-volt electric shocker was used. On August 15 an attempt was made to shock during the daytime but it was quite ineffective. Subsequent shocking was done at night, using as a light source two 250-watt light bulbs attached to a framework suspended in the water beneath the bow of the rowboat. Although visibility was very good, few bass were observed. Most bass probably sought shelter in the dense bed of <u>Chara</u> while some may have moved ahead of the boat far enough away to stay out of the field of visibility. The boat was rowed very slowly through the pond while two persons, each with an electrode, systematically probed the vegetation. The bass, when affected by the electric field, followed the electrode fairly well and usually could be drawn out of the vegetation and picked up with long-handled scap nets. The handles of the electrodes were about 6 feet long and therefore the few deeper areas could not be sampled effectively. A longer handle proved to be impractical because of the loss of maneuverability and inability to lead the fish to the scap net. It is felt, therefore, that the deepest areas were sampled less intensively with the shocker than the rest of the pond.

During the shocking operations young-of-the-year bass were encountered for the first time. None had been captured previously during angling or netting operations. These were marked prior to being released by clipping the upper lobe of the caudal fin. The older bass sampled with the shocker were marked by clipping the anal fin in order to distinguish them from the angling-marked fish. Bass caught by both angling and shocking were marked with a caudal clip and an anal clip (Table I).

During the second period of angling (Sept. 14-Oct. 11) no fish were marked. This new angling period was used to test the hypothesis that angling success diminshed during the first days of fishing because the bass developed a "hook resistance." This type of change in the behavior of the largemouth bass (Micropterus salmoides)

Table I.--Methods of sampling and marking the largemouth bass, other than the young-of-the-year, of Dix Pond, and the total number of marked bass present at the end of the marking period

Sampling method	Type of fin clip	Number of marked bass*		
		C	A	C+A
Angling	Upper lobe of caudal fin (C)	139	...	...
Shocking	Anal fin (A)	...	88	...
Both angling and shocking		...	...	24

* C = Caudal marked
A = Anal marked
C+A = Caudal and anal marked

was observed by Bennett (1954) when he studied the relationship between catch rate and fishing pressure in Ridge Lake, Illinois. He noticed that the catch rate dropped within a few hours after the lake was opened to public fishing. At the end of the second day less than 10 percent of the bass had been caught but the rate of catch had dropped from an average of 3.9 hours per bass during the first two days to an average of 13.3 hours per bass during the following three days. This "hook resistance" apparently was acquired not only by the fish which had been hooked but also though to a lesser degree by those that had not been caught at all. In this study bass which were caught were again released in the pond. If they were more resistant to subsequent capture by hook and line than those bass which had not been caught during the marking period, they would not appear in the angling recapture samples in proportion to their abundance in the pond. This differential catchability would result in biased population estimates as will be shown subsequently.

Sampling methods used for Rash Pond

Three different methods of sampling were used in Rash Pond: angling, seining, and shocking. Angling methods were similar to those employed in Dix Pond, and were, in proportion to the population, equally successful on the first two days. As in Dix Pond, however, angling success declined sharply thereafter. The man-hours fished on each pond were about 12 hours the first two days and about 10 hours each on later days. Seining, impractical in Dix Pond, was quite successful in Rash Pond. This pond contained a rather large population of young-of-the-year bass. These fish were seen in schools along the entire shore and it was expected that they could be sampled effectively with a "common-sense" minnow seine. On August 1 and 7 such a seine (10' long with 1/8" mesh) was used and 184 and 181 young-of-the-year bass were caught on the respective dates. The sample of August 1 was marked by clipping the upper lobe of the caudal; those caught on August 7 had the soft dorsal removed. On August 8 a bag seine was used in this pond in an attempt to collect bass other than young-of-the-year. This seine was 50' x 7' x 3/8" bar mesh with a bag 6' wide of 1/4" bar mesh. The length of the seine almost equaled the width of the pond. Two men, working on opposite shores could pull this seine the entire length of the pond. On this first day 219 young-of-the-year and 38 larger bass were caught with the bag seine. The young-of-the-year were not marked because they were considered to form the final recapture sample for a population estimate including this group only. All bass other than young-of-the-year were marked by clipping the soft dorsal fin (Table II). On August 9 and 14 fish were again sampled with the bag seine. On the 9th, 355 young-of-the-year and 12 other bass were caught. On the 14th, 415 young-of-the-year and only 2 other bass were taken. The young-of-the-year taken on August 9 were marked by clipping their anal fin

Table II.--Methods of sampling and marking the largemouth bass, other than young-of-the-year, of Rash Pond, and the total number of marked bass present at the end of the marking period

Sampling method	Type of fin clip	Number of marked bass *						
		C	D	A	C+D	C+A	D+A	C+D+A
Angling	Upper lobe of caudal fin(C)	6	..	..	..	..	..	..
Angling and seining		..	..	..	6	..	..	..
Seining	Soft dorsal fin (D)	..	15	..	..	7	..	4
Seining and shocking		..	..	..	..	..	22	..
Shocking	Anal fin (A)	..	..	20	..	..	..	..

* C = Caudal marked
D = Dorsal marked
A = Anal marked
C+D = Caudal and dorsal marked
C+A = Caudal and anal marked
D+A = Dorsal and anal marked
C+D+A = Caudal, dorsal and anal marked

(Table III), while those taken on August 14 were released without additional marking.

The final method of collecting fish from Rash Pond was electric shocking. This was done on the nights of August 15 and 30. Shocking was more efficient than in Dix Pond because of the smaller area and shallower water in Rash Pond. This was true even though the water was turbid and the fish could usually not be seen until they flashed sideways in the electric field. The fish caught during the first night of shocking were marked by clipping their anal fins.

Because of the three different methods of sampling, each distinguished by its own type of mark, Rash Pond contained fish (not including the young-of-the-year) with seven different markings by the end of the sampling period.

As the fish were caught they were scale sampled and measured (T. L.). The young-of-the-year from Dix Pond ranged in total length from 2.4 to 4.4 inches, and from Rash Pond from 1.6 to 2.9 inches. The young-of-the-year in Dix Pond were collected between August 16 and September 1, whereas the first ones of Rash Pond were collected on August 8 and the last ones on August 30. The ages of all young-of-the-year over 4.0 inches were substantiated by scale samples. Also, several of the middle and smallest size of the young-of-the-year were scale sampled.

Table III.--Dates of sampling and marking the young-of-the-year largemouth bass of Rash Pond, and the total number of marked bass present at the end of the marking period

Sampling date	Type of fin clip	Number of marked bass*						
		C	D	A	C+D	C+A	D+A	C+D+A
8-1	Upper lobe of caudal fin (C)	183	...	...	...	...	...	...
8-7	Soft dorsal fin (D)	159	157	...	24	...	...	...
8-8	None	159	157	...	24	...	...	...
8-9	Anal fin (A)	106	113	240	9	53	44	15
8-14	None	106	113	240	9	53	44	15

* C = Caudal marked
D = Dorsal marked
A = Anal marked
C+D = Caudal and dorsal marked
C+A = Caudal and anal marked
D+A = Dorsal and anal marked
C+D+A = Caudal, dorsal and anal marked

RESULTS

In order to apply mark-and-recapture procedures for estimating animal populations, several assumptions must be made (Ricker, 1958). If one or more of these assumptions cannot be met, appropriate corrections should be applied. The following statements regarding the assumptions underlying population estimation procedures may be made with considerable assurance with respect to the bass ponds: (1) There was no recruitment problem. The ponds contain only bass; reproduction had already taken place and growth was negligible during the sampling period. The time of sampling and recapture was of short enough duration that no reproductive season was involved. (2) The marked and released fish did not lose their marks during the period involved. (3) Recognition of all fin-clip marks would be likely since during the time interval little regeneration took place. (4) Random distribution of the marked fish with the unmarked ones was expected because of the small size of the ponds and the fact that, in Dix Pond the fish were caught from all areas of the pond and released at different places along the shore. (5) The assumption that there was equal mortality between the marked and unmarked fish was not tested. However, the captured fish were kept in a live cage in order to observe mortality due to injuries caused by the collecting gear. Bass showing symptoms of injury were removed from the population as stated previously. Only a total of 6 fish had to be eliminated due to injuries caused by hooking. By removing the few wounded and dying fish, it is felt that this assumption of equal mortality was met in a satisfactory way. (6) The final necessary assumption, that the marked and unmarked fish are equally vulnerable to capture, could not be accepted without considerable caution. Especially with respect to angling, it is felt that the method of capture causes changes in the behavior of the fish thereby affecting their vulnerability. Systematic errors in the estimate, due to the fact that this assumption does not hold true, may be considerable. Ricker (1958) points out that this assumption is extremely difficult to evaluate. Waters (1961), estimating brook trout populations of approximately known sizes, tested the hypothesis that systematic errors, due to differential vulnerability between marked and unmarked fish, could be overcome, partly or completely, by using different methods for the initial capture and recapture of the fish. When comparing the estimates obtained by several different procedures, he found that the ones obtained by using a mixed procedure compared most favorably with the known approximate population of brook trout present. The different methods used for sampling the bass population permitted pure as well as mixed procedures of estimating the populations.

The population estimates of Dix Pond

The bass other than the young-of-the-year

For Dix Pond six different estimates were calculated (Table V), using two pure and four mixed procedures, based on a total of marked fish (Table IV). For calculating the population estimates the method of Schumacher and Eschmeyer (1943) was used. The 95 percent confidence limits were obtained by the method discussed by Ricker (1958) using formulas given by Schumacher and Eschmeyer.

The young-of-the-year

Electric shocking was the only technique which sampled some of the young-of-the year of Dix Pond. Only 5 were sampled the first day of shocking and 7 the second day, of which 2 died. Thus, before the start of the third night of shocking only 10 marked young-of-the-year were present in the population, a rather low number. The third night 32 young-of-the-year were collected, 2 of these were recaptures. Although an estimate of the population of young-of-the-year bass was possible, it could not be very reliable on the basis of such a small sample. By using the direct proportion or Petersen method, the estimated population is 160 young-of-the-year with 95 percent

Table IV.--The number of bass, other than young-of-the-year, sampled, marked, and recaptured in Dix Pond from July 31 to October 11, 1962

Date	Sampling method		Died	Number of bass marked*			Number of marked bass present*			Total number of marked bass	Recaptures*		
	Angling	Shocking		C	A	C+A	C	A	C+A		C	A	C+A
7-31	102	...	3	99	...	...	0	...	...	0	...	...	...
8-1	39	...	1	35	...	...	99	...	...	99	3	...	...
8-2	19	...	2	17	...	...	134	...	...	134	0	...	...
8-9	8	...	...	6	...	...	151	...	...	151	2	...	...
8-15	9	...	...	6	...	...	157	...	...	157	3	...	...
8-15	...	9	...	...	8	1	163	...	...	163	1	...	...
8-16	...	59	...	...	43	16	162	...	1	171	16	...	...
8-28	...	57	...	...	37	7	146	...	17	214	7	10	3
9-1	...	47	...	...	...	...	139	88	24	251	7	6	...
9-14	11	...	...	...	...	...	139	88	24	251	1	6	...
10-4	25	...	...	...	...	...	139	88	24	251	3	8	...
10-11	11	...	...	...	...	...	139	88	24	251	2	1	...

* C = Caudal marked
D = Dorsal marked
A = Anal marked
C+D = Caudal and dorsal marked
C+A = Caudal and anal marked
D+A = Dorsal and anal marked
C+D+A = Caudal, dorsal and anal marked

Table V.--Estimates of the bass population, other than young-of-the-year, of Dix Pond in the summer of 1962, by using various procedures, two "pure" and four "mixed"

Procedures used to estimate the population	Population estimate	95 percent confidence limits	
		Lower limit	Upper limit
Angling and recapture by angling first period only	1,063	488	∞
Angling and recapture by shocking	753	599	1,014
Angling and recapture by angling of the second period	1,165	730	2,893
Angling and recapture by shocking plus angling of the second period	693	568	890
Shocking and recapture by shocking	551	429	770
Shocking and recapture by angling of the second period	447	286	1,031

confidence limits ranging from 50 to 1,000. The 95 percent confidence limits were obtained from a graph developed by Clopper and Pearson (Adams, 1951).

The population estimates of Rash Pond

The bass other than the young-of-the-year

For Rash Pond six different estimates were calculated (Table VII), using two pure and four mixed procedures based on the marked fish (Table VI). Although three different sampling techniques were employed, angling could be used only in a mixed procedure because no recaptures by angling were obtained. Seining was quite effective on the first day only. Apparently, bass soon learn to avoid a seine (Carlander and Moorman, 1956) and in our samples the number of bass taken on successive days declined rapidly to zero.

The young-of-the-year

This segment of the population was the easiest to sample. Several different markings were employed, corresponding with certain dates on which these fish were collected (Table VIII). On August 14, the last day of the recapture period, 56 percent of the sample taken consisted of marked fish. Many investigators feel that samples composed of one-third recaptures provide reasonably accurate

Table VI.--The number of bass, other than young-of-the-year, sampled, marked, and recaptured in Rash Pond from July 31 to August 30, 1962

Date	Sampling method: Angling	Seining	Shocking	Number of bass marked*: C	D	A	C+D	C+A	D+A	C+D+A
7-31	13	..	..	13	...	...	...	...	...	...
8-1	6	..	..	6	...	...	...	...	...	...
8-2	2	..	..	2	...	...	...	...	...	...
8-7	2	..	..	2	...	...	...	...	...	...
8-8	..	38	..	...	31	...	7	...	...	...
8-9	..	12	..	...	5	...	3	...	...	...
8-14	..	2	..	...	1	...	...	...	...	...
8-15	..	..	53	...	...	20	...	7	22	4
8-30	..	..	42	...	...	...	...	...	...	...

Date	Number of marked bass present*: C	D	A	C+D	C+A	D+A	C+D+A	Total number of marked bass
7-31	13	...	...	...	...	...	...	13
8-1	19	...	...	...	...	...	...	19
8-2	21	...	...	...	...	...	...	21
8-7	23	...	...	...	...	...	...	23
8-8	16	31	...	7	...	...	...	54
8-9	13	36	...	10	...	...	...	59
8-14	13	37	...	10	...	...	...	60
8-15	6	15	20	6	7	22	4	80
8-30	6	15	20	6	7	22	4	80

Date	Recaptures*: C	D	A	C+D	C+A	D+A	C+D+A
7-31	...	...	...	...	...	...	...
8-1	...	...	...	...	...	...	...
8-2	...	...	...	...	...	...	...
8-7	...	...	...	...	...	...	...
8-8	7	...	...	...	...	...	...
8-9	3	3	...	1	...	...	...
8-14	...	1	...	...	...	...	...
8-15	7	22	...	4	...	...	...
8-30	2	10	7	2	3	8	3

* C = Caudal marked
D = Dorsal marked
A = Anal marked
C+D = Caudal and dorsal marked
C+A = Caudal and anal marked
D+A = Dorsal and anal marked
C+D+A = Caudal, dorsal and anal marked

Table VII.--Estimates of the bass population, other than young-of-the-year, of Rash Pond in the summer of 1962, using various procedures, two "pure" and four "mixed"

Procedures used to estimate the population	Population estimate	95 percent confidence limits	
		Lower limit	Upper limit
Angling and recapture by seining	109	67	230
Angling and recapture by shocking	104	77	177
Angling and recapture by seining and shocking	105	82	164
Seining and recapture by seining	106	59	292
Seining and recapture by shocking	101	87	130
Shocking and recapture by shocking	106	80	151

Table VIII.--The number of young-of-the-year bass, sampled, marked, and recaptured in Rash Pond from August 1 through August 14, 1962

Date	Sampling method M*	Sampling method B*	Dead	Number of bass marked* C	D	A	C+D	C+A	D+A	C+D+A
8-1	184	...	1	183	...	...	...	...	...	...
8-7	181	...	0	...	157	...	24	...	...	...
8-8	...	219	0	No bass marked						
8-9	...	355	3	...	...	240	...	53	44	15
8-14	...	415	3	No bass marked						

Date	Number of marked bass present* C	D	A	C+D	C+A	D+A	C+D+A	Total number of bass marked
8-1	183	...	...	...	...	...	...	183
8-7	159	157	...	24	...	...	...	340
8-8	159	157	...	24	...	...	...	340
8-9	106	113	240	9	53	44	15	580
8-14	106	112	240	9	53	43	15	578

Date	Recaptures* C	D	A	C+D	C+A	D+A	C+D+A
8-1	...	...	...	...	...	...	...
8-7	24	...	...	...	...	...	...
8-8	27	35	...	7	...	...	...
8-9	53	45	...	15	...	...	...
8-14	27	33	132	2	26	22	9

* M = Common sense minnow seine
B = 50' bag seine
C = Caudal marked
D = Dorsal marked
A = Anal marked
C+D = Caudal and dorsal marked
C+A = Caudal and anal marked
D+A = Dorsal and anal marked
C+D+A = Caudal, dorsal and anal marked

estimates (Carlander and Moorman, 1956; Isaac and Bond, 1963). The population estimate, using the Schumacher and Eschmeyer formula, was 1,000 fish with 95 percent confidence limits ranging from 911 to 1,108.

Age composition
in Dix Pond

Scale samples taken from 212 bass over 5 inches long were used to determine the ages of these fish. The 212 bass were distributed among age groups as follows: age-group I, 15 bass; age-group II, none; age-group III, 97 bass; age-group IV, 19 bass; and age-group V, 9 bass. It is assumed that all age groups were equally susceptible to the sampling methods employed. Unequal vulnerability among the various age groups was not apparent throughout the study. If the assumption holds, these groups were sampled in proportion to their occurrence and therefore the number of bass of each age group present in the pond can be estimated from the proportion of each age group in the sample. The age groups show little difference in size and almost complete overlap is found in age-groups III, IV, and V (Fig. 4). Use of the estimate of 753, fish of all ages older than age-group 0, which was derived by using angling as the initial capture method and shocking as the recapture method, gives the following estimates of bass present: age-group I, 15/212 x 753 = 53; age-group III, 97/212 x 753 = 345;

Figure 4.--Frequency distribution of age groups I, III, IV and V of the largemouth bass (*Micropterus salmoides*) of Dix Pond, sampled in July and August 1962.

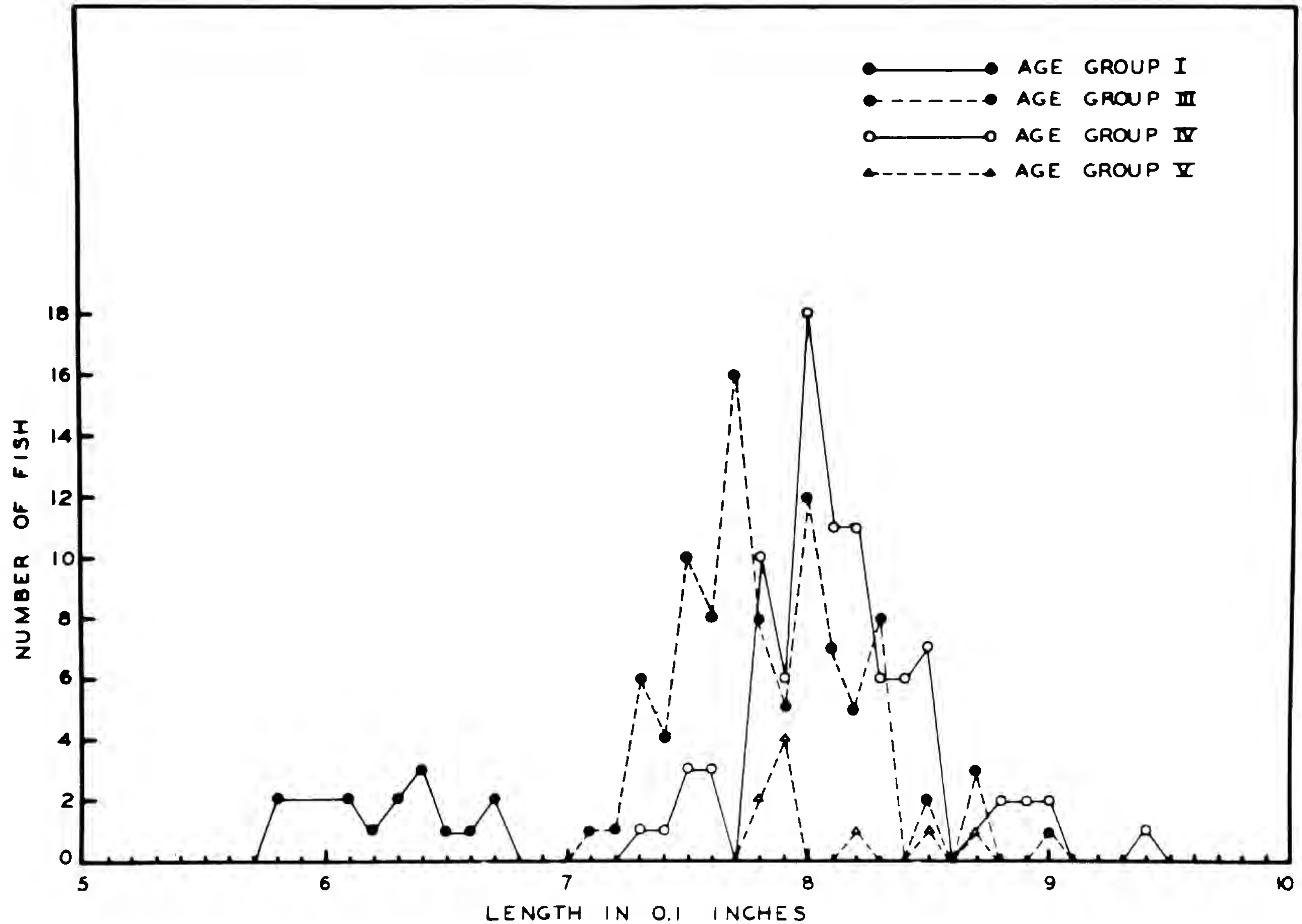

AGE GROUP I
AGE GROUP III
AGE GROUP IV
AGE GROUP V
NUMBER OF FISH
0
2
4
6
8
10
12
14
16
18
5
6
7
8
9
10
LENGTH IN 0.1 INCHES

Figure 4

age-group IV, 91/212 x 753 = 323; age-group V, 9/212 x 753 = 32. As previously stated, no bass of age-group II were found among the scale-sampled fish.

Age composition in Rash Pond

Scale samples were taken from 55 bass with a size range between 5 inches and 10 inches. These fish were all of age-group I. With the exception of the young-of-the-year, only 3 other bass were caught. One individual of age-group IV was 13.0 inches, and 2 bass of age-group V measured 12.9 and 13.4 inches. No fish of the age-groups II or III were found.

DISCUSSION

The estimates of the bass population of Rash Pond

The young-of-the-year

The estimates obtained were consistently around 1, 000 with 95 percent confidence limits of 911 to 1, 108. Seining was the only method of sampling used. The fish, after being marked and recorded, were kept in a live cage until the end of the seining operations and were then returned to the pond either along the entire shore or in the center of the pond. The bass, released in the center, were observed moving shoreward in all directions. Because of these methods of releasing the fish, random distribution of the marked bass among the unmarked ones is expected. The total time involved from the first day of marking to the last day of recapturing was two weeks (August 1-14).

About one month after the termination of the data collecting, few young-of-the-year bass were seen along the shoreline of Rash Pond. Ricker (1949) found that fin clipping causes a significant decrease in the survival rate of largemouth bass. During late October Rash Pond was seined again in an attempt to collect the young-of-the-year, but the results were negative; in addition, no small bass were seen along the shore. It is possible that a high mortality among the fin-clipped bass caused a significant reduction of young and the remainder were heavily preyed upon by the oldest bass. For the young-of-the-year there was very little or no cover for escape from predation. By the end of October this population may have been so reduced that the seine did not collect any. The alternative is that the remaining population moved to deep water where the seine could not reach them.

The bass other than the young-of-the-year

Angling, seining and shocking were the three methods used to sample these fish. A total of 80 bass were marked. This was believed to be a high percentage of the population. As shown in Table VI a very high proportion (83 percent) of the sample taken on August 30 consisted of marked bass. Because of this very high proportion of marked fish, all estimates, independent of the procedure followed, are near 100. Very likely this estimate is accurate as well as precise.

The estimates of the bass population of Dix Pond

The young-of-the-year

As already pointed out, too few young-of-the-year bass were marked to provide a reliable estimate. They were not observed in the open water and probably remained most of the time in the vegetation to avoid predators. The importance of predation was demonstrated by a simple experiment early in my study. A few young-of-the-year bass were seined from Rash Pond and tossed into Dix Pond; immediately after landing in the water they were eaten by the resident bass. Unless the young-of-the-year remain hidden in the vegetation, there seems to be little chance for them to survive as fish under 4 to 5 inches long but, of course a few do survive.

The bass other than the young-of-the-year

The six population estimates varied enough to suggest some bias. On the basis of Waters' (1961) study the estimates obtained by the pure procedure with angling as the sampling method are expected to produce overestimates. Studies conducted with largemouth bass demonstrated that this fish becomes rapidly resistant to angling (Bennett, 1954; Bowers and Martin, 1956), as previously described. After the first day of angling in Dix Pond hooking success declined way out of proportion to the number of fish previously caught. The decline in angling success was so great that only a moderate proportion of the population ultimately was caught, marked, and returned to the pond. Not only did the once-hooked fish become conditioned against angling, but the same happened to fish that were never hooked, at least to a considerable extent. The important question is whether the non-hooked bass displayed "hook resistance" in a greater or lesser degree than did bass which had been caught once and released. If non-hooked bass are less "hook-resistant" than those caught once and released, as might be expected, population estimates will be too high. Table IX suggests that this was the case.

The limited efficiency of the electric shocker in the deeper areas (>8') and the tendency of largemouth bass to select a home station (Bennett, 1962; Gerking, 1959; Parker and Hasler, 1959; Hasler and Wilsby, 1958) causes the estimates acquired by the pure procedure using shocking as the sampling method to be too low.

The estimates obtained by mixed procedures, with angling and shocking as sampling methods, are expected to provide the most reliable figures. Because angling was effective in all areas of the pond regardless of depth, it is believed that caudal marked fish (those caught by angling) were randomly mixed with unmarked fish. The electric shocker, although not equally efficient at all depths, should sample caudal marked and unmarked fish in proportion to their occurrence throughout the pond, thus providing unbiased estimates. This is in agreement with suggestions and findings of other workers as previously described.

The hypergeometric probability distribution and fish population estimates

When dealing with large populations, usually a relatively small fraction of the fish becomes marked. In such instances the

Table IX.--Number of recaptures for N = 800 and N = 1,000 at the 95 percent level using the hypergeometric distribution. Column 5 represents the true number of recaptures encountered for the values of M (number marked) and C (sample size) and with the specific sampling methods of bass in Dix Pond

M	C	N = 800 95 percent confidence limits Recaptures		N = 1,000 95 percent confidence limits Recaptures		True number of recaptures	Sampling methods
		Upper	Lower	Upper	Lower		
157	75	7	18	6	17	8	Angling (1st period only)
112	104	8	20	6	16	19	Shocking only
163	47	4	15	2	12	6	Angling (1st and 2nd periods)

binomial or Poisson distribution can be used to obtain appropriate confidence limits for the proportion of marked fish in the population. It is customary to divide the number of marked fish at large by the lower and upper limits on the estimate of proportion of marked fish in the population in order to obtain upper and lower confidence limits on the estimate of population size. When working with small populations, it is often quite possible to mark a large fraction of the population. As the number of marked fish becomes a larger and larger part of the population, the binomial approximation becomes poorer and poorer, reaching the worst possible case when M (the number of marked fish) = 1/2 N (N is the total population) (Lieberman and Owen, 1961). For relatively small populations in which a high proportion of the fish can be sampled the hypergeometric distribution gives more realistic confidence limits than the binomial, but the hypergeometric distribution is so difficult to handle computationally that its use in obtaining confidence limits is impractical. However, tables of the hypergeometric probability distribution have become available in recent years, and, for a population of given size, these tables can be used to derive control limits within which estimates of population size can be expected to fall with stated probability.

Control limits, selected of a particular spread, can serve as an indication of the sample size (C) and the number of marked fish (M) needed for a desired level of precision. It might be well to emphasize that M and C are interchangeable when considering the hypergeometric distribution. Such control limits, when set in advance, can serve as an indication of the population's behavior with respect to sampling.

Table IX presents the 95 percent control limits on the number of marked fish in populations of 800 and 1,000 fish. The number of marked fish (M) and the sample size (C) are the same as encountered during the experiments at the pond. For comparison the true number of recaptures are shown also. Although the true number of recaptures are within the 95 percent probability range (except for shocking when N = 1,000), it is nevertheless a significant fact that, in the case of angling, they are at the borderline of the upper limit, whereas in shocking they are at the borderline of the lower limit. The values of N, 800 and 1,000, are chosen on the basis of the estimates already obtained (Table V). If the population is assumed to be lower than 800, the "hook resistance" hypothesis would receive even more support. A population much higher than 1,000 is unlikely because of the extremely high proportion of marked fish collected with shocking and because of all estimates obtained only two are above 1,000 (1,063 and 1,165), while all others are considerably lower than 1,000. Thus, further support is provided that the best estimate obtainable with the data is the one that combines the two sampling methods, angling and shocking.

Planning population estimates using tables of the hypergeometric probability distribution

There are many instances in fishery management and research where estimates are desired for relatively small populations of fish. When confronted with populations not larger than about 10,000 fish, a population estimate program might be set up using the hypergeometric probability distribution. For finite populations and with sampling without replacement, this type of distribution produces more realistic limits of confidence than does the binomial, Poisson or other type of probability distribution. When N (the size of the population) approaches infinity, successive samples taken approach independence, since each withdrawal has such a small effect on the composition of the remaining population. In these instances, the binomial distribution, which assumes that successive samples taken are independent, provides close enough approximations. Roughly, the binomial distribution can be considered a close enough approximation to the hypergeometric when $C/N<0.1$, i.e., when the sample size is less than 10 percent of the population size (Brownlee, 1960).

Confidence limits for N values of 500, 2,500, and 10,000 are compiled in graphs by Chung and DeLury (1950). Through interpolation all possible values of N up to 10,000 can be obtained. Confidence limits are given for the 90, 95 and 99 percent levels and for sampling rates of 5 percent and of 10 to 90 percent with 10 percent intervals. Other sampling rates can be obtained by interpolation (Chung and DeLury, 1950).

When planning a population estimate program using the hypergeometric probability distribution, the experimenter first of all guesses the size of the population he feels is nearest reality. This guess might be based upon numerous criteria such as (1) observations of the fish, (2) preliminary seining or other sampling operations, (3) a knowledge of the history of plantings, (4) a knowledge of the pounds per acre and the average size and weight of the fish, or (5) simply by experience.

After the population is judged to be at a particular level, control limits of the desired probability level, using the hypergeometric probability distribution, can be graphed for all values of M (the number of marked fish) and C (the sampling rate). Such graphs, for populations of 500, 1,000, and 2,500 are presented in figures 5, 6 and 7. The abscissa represents either M or C, these being interchangeable as previously stated. It immediately becomes apparent that the limits are very asymmetrical where they are widespread. As an example we can take a population of 500 (Fig. 5). Here the upper 95 percent control limit, for M = 50 and C = 50, is infinitely large while the lower limit is 355. For M = 50 and C = 62, the upper limit is 3,150,

Figure 5.--95 percent control limits according to the hypergeometric probability distribution for a population of 500.

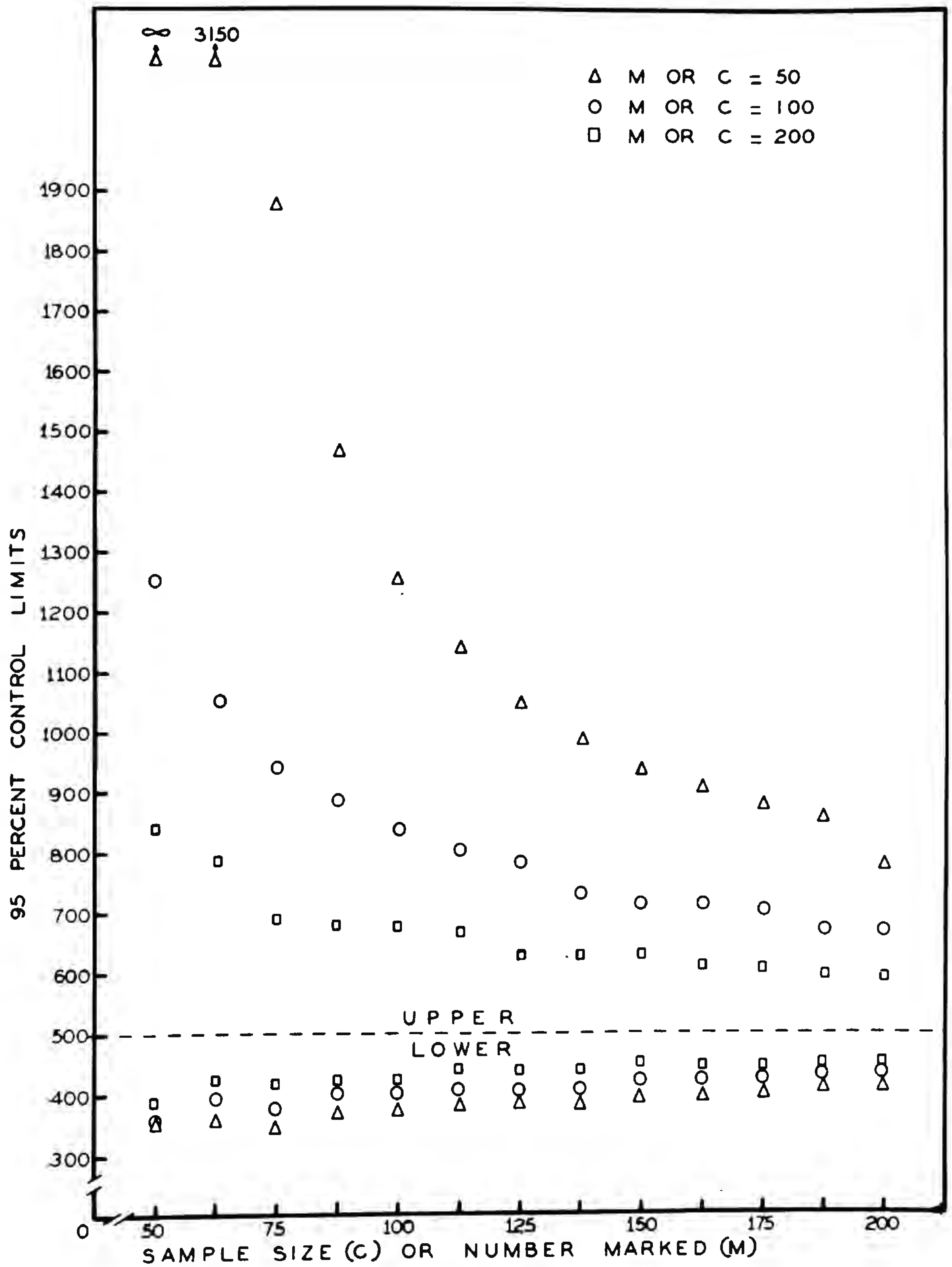

∞
3150
Δ M OR C = 50
O M OR C = 100
□ M OR C = 200
95 PERCENT CONTROL LIMITS
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
0
UPPER
LOWER
50
75
100
125
150
175
200
SAMPLE SIZE (C) OR NUMBER MARKED (M)

Figure 5

Figure 6.--95 percent control limits according to the hypergeometric probability distribution for a population of 1,000.

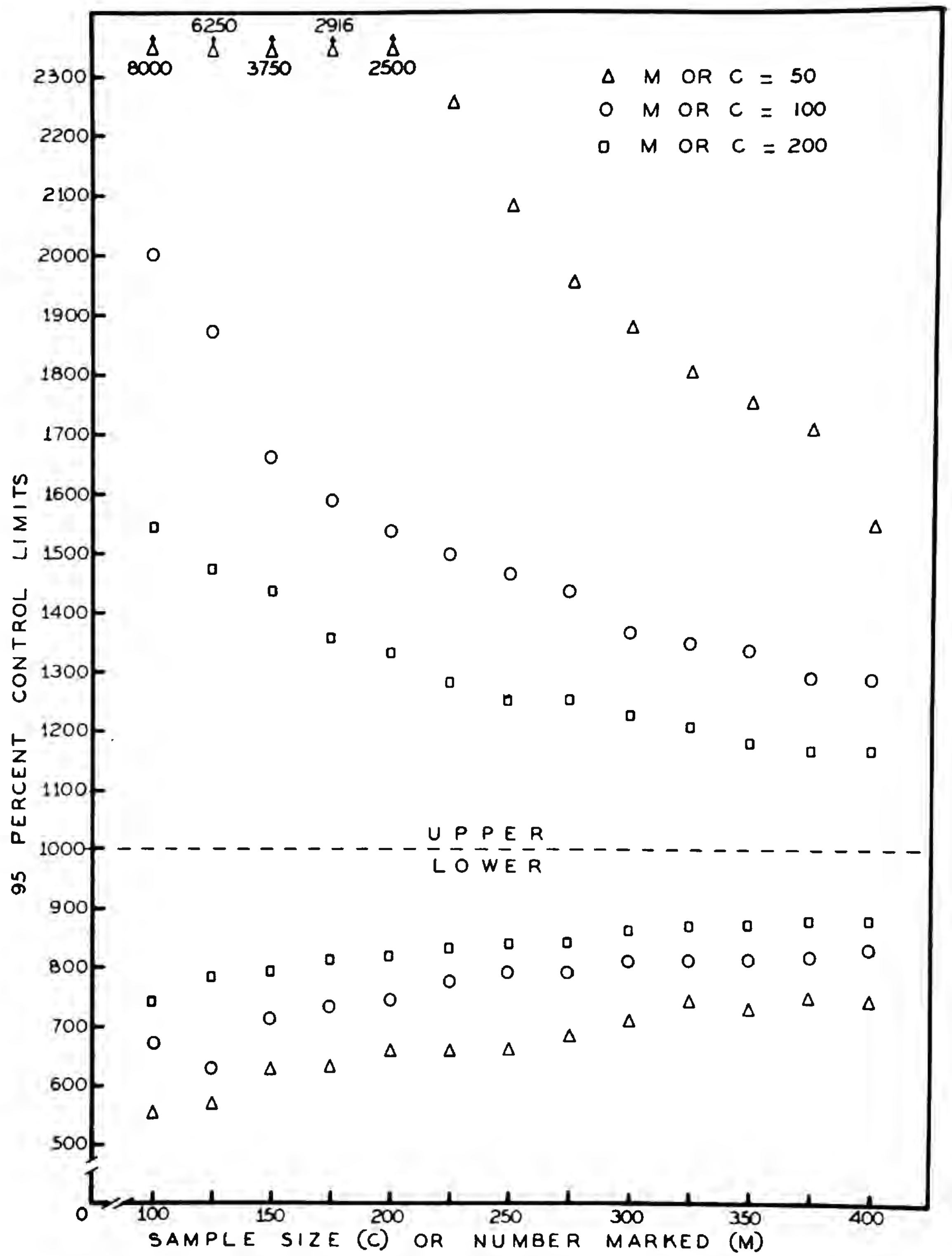
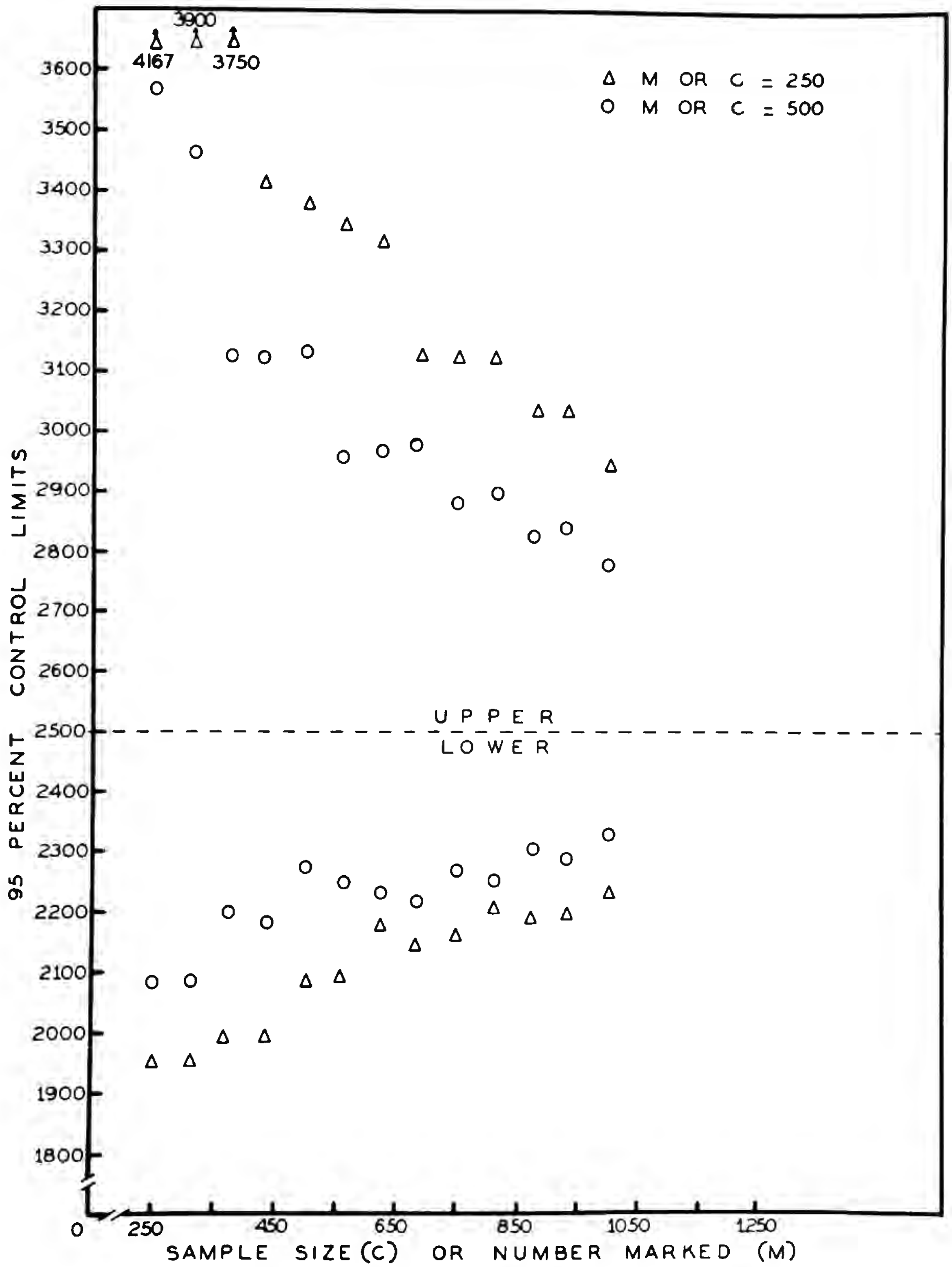

6250
2916
8000
3750
2500
Δ M OR C = 50
O M OR C = 100
□ M OR C = 200
95 PERCENT CONTROL LIMITS
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
0
UPPER
LOWER
100
150
200
250
300
350
400
SAMPLE SIZE (C) OR NUMBER MARKED (M)

Figure 6

Figure 7.--95 percent control limits according to the hypergeometric probability distribution for a population of 2, 500.



4167
3900
3750
Δ M OR C = 250
O M OR C = 500
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
95 PERCENT CONTROL LIMITS
UPPER
LOWER
0
250
450
650
850
1050
1250
SAMPLE SIZE (C) OR NUMBER MARKED (M)

Figure 7

the lower still near 355. A relatively small change in sample size produces quite a drastic change in the value of the upper limit, hardly any at all in the lower limit. Another fact that stands out clearly is the advantage of a relatively high proportion of marked fish in the population. Although this can be said of the sample size, because M and C are interchangeable, it is more practical to apply this to the number of marked fish.

After control limits for a particular population and several values of M and C are drawn, a goal can be set with respect to the number of marked fish wanted in the population. Take as an example a population of 1, 000 fish (Fig. 6) and the number of fish to be marked is 100 (or 10 percent of N). Assuming that for a particular study the 95 percent confidence limits between 1, 400 and 800 are considered sufficient, a sample of 325 fish must be taken (or, when 325 marked fish are in the population, a sample of 100 is needed). If the number of marked fish in the sample of 325 falls outside the control limits, a number of reasons could be responsible: (1) sampling error (the confidence limits were set at 95 percent, permitting an average of 5 percent of the samples to fall outside these limits); (2) the necessary assumptions for mark-and-recapture population estimates may not have been met; (3) the preliminary guess of 1, 000 may be either too high (too few marked fish in the sample) or too low (too many marked fish in the sample).

Sampling error is very unlikely, and can for practical purposes be disregarded when in a second independent trial similar results are obtained ($P = .05 \times .05 = .0025$).

It is important to review the assumptions very critically. The nature of the confidence limits, i.e., too narrow or too widespread with respect to the control limits, makes it possible to disregard certain assumptions, considering the others with extra suspicion. If no systematic errors can be held responsible, a new guess of the population, now supported with the data already collected, should be made and a new set of control limits constructed. However, when the population of 1,000 is too low a guess, sampling must be continued.

The fact that certain systematic errors are extremely difficult to evaluate (Ricker, 1958) does emphasize the need for very critical investigation when the number of marked fish taken in the sample falls at the borderline or outside the confidence limits.

Thus control limits, set before the actual field work is started, may help point out possible systematic errors and by indicating the size of the sample needed for a specific level of accuracy, can prevent the collecting of unnecessary samples.

SUMMARY AND CONCLUSION

During the months of August and September, 1962, population estimates of pure largemouth bass (Micropterus salmoides) populations were conducted in two small ponds.

A proposed research project to study the dynamics of such monospecific populations requires population estimates to be conducted twice a year. However, because only limited resources (monetary as well as labor) are available for this study, the field operations should not take more than four persons for one week for each estimate in order to make the project feasible. Although successful estimates were obtained during this study, the procedures were not always satisfactorily efficient. The bass of Dix Pond (1.25 acres) were sampled with rod and reel and an electric shocker, those of Rash Pond (0.23 acre) were sampled with rod and reel, a 50-foot bag seine, and an electric shocker. All bass sampled were marked with a distinctive fin-clip indicative of the gear with which they were sampled. These differential markings made it possible to obtain estimates of the populations by "pure" as well as "mixed" procedures.

In my opinion, the data needed for an accurate population estimate of the bass in Rash Pond can be collected in two days.

Fifty percent or more of the population can probably be marked if the bass are sampled with a bag-seine of the right dimensions, which I recommend to be 50' x 10' x 3/8" bar mesh and a bag 6' wide and 1/4" bar mesh. After seining the pond should be left untouched for two or three days. The water becomes quite turbid during seining operations and because the electric shocker is recommended as recapturing device the pond should be allowed to clear up as much as possible. Four to six hours of shocking should provide a large enough sample to guarantee a reliable estimate of the bass population of Rash Pond, while a sufficient number of young-of-the-year can be recaptured with a few hauls of the seine to obtain its estimate. The population estimates of the bass of Rash Pond, acquired during this study, were in close agreement, independent of the type of estimate procedure followed ("pure" or "mixed"). The several population estimates of the bass of Dix Pond display enough difference to suggest bias.

The estimates of the population of bass in Dix Pond obtained by "pure" procedures are demonstrated to be too high with capture by angling (due to hook resistance developed in the bass) and too low with capture by shocking (due to the inability of the shocker to sample the areas over 8 feet deep, and the tendency of the bass to "home"). The population estimate arrived at by using a "mixed" procedure is thought to be free of bias because no systematic errors could be demonstrated.

The data collecting, to obtain a satisfactory estimate of the bass population of Dix Pond in 1962 and reported in this thesis, was too elaborate to be practical for the afore-mentioned study of population dynamics. However, it is possible that a population estimate of the desired accuracy can be obtained with considerably less time and effort. I would recommend the establishment of a marked population in Dix Pond with angling. If conducted intensively during two successive days with four persons fishing, one might expect that, on the basis of the results obtained during this study, 100 to 150 bass could be marked. Neither angling nor shocking, for reasons already mentioned, are practical as a recapturing method. Depending on the size of the marked population, which is expected to range from 100 to 150 bass, the recapture sample should be of a magnitude ranging from 300 to 200 fish respectively. Such sample sizes provide 95 percent confidence limits within the range of 800 to 1, 400, assuming the real population is not larger than 1, 000. To obtain a sample size of 200 would involve four nights of shocking with at least three men participating. I therefore propose to seine Dix Pond with a large bag seine, 150 or 200 feet long and 10 or 15 feet deep. The seine, which would stretch from shore to shore, could be hauled either half or the entire length of the pond whichever proves to be most practical. It does not seem to be improbable that a large enough sample can be collected this way before the bass become conditioned to seining.

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