2. The lock is located so as not to be attractive to fish. They are attracted to the base of the dam approximately 160 feet upstream from the lower lock opening. In the future, where it might be desirable to pass fish with a lock, it would be more effective as a passing device to locate the lower entrance near the dam base so that fish could find the opening to the lock more easily.

3. There was not enough water to operate the lock for passage of fish upstream during most of the scheduled period. However, during this time there was at least a 4-inch water spillage over the entire crest of the dam. The effectiveness of the lock as an upstream fish passing device would be greatly increased by erecting flash boards on the dam. They would increase the water capacity of the pool above the dam and permit draw-down for fish lockage upstream during times of critical low river flow. Also, with less spillage over the dam, the lower lock entrance would become more attractive to fish.

This experiment offers evidence that anadromous fish can be passed upstream with navigation locks and that a secondary use can be made of the lock to restore the spawning runs above such barrier.

THE ESTIMATION OF CHANNEL CATFISH (Ictalurus Punctatus Rafinesque) POPULATIONS IN FARM PONDS FROM CATCH STATISTICS [1]

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ABSTRACT

The Delury Method was used to estimate the number of channel catfish in three ponds of different years from the catch records of 20,790 anglers at the Farm Pond Project, Auburn, Alabama. The ponds were drained, and the accuracy of the estimates was determined.

Estimates for each pond were made using the average number of channel catfish caught per angler per hour at intervals of: 1 day, 500 angling hours, 800 angling hours, 1,000 angling hours, and one week. The error of these estimates varied between 0.0 and 10.3 percent from the theoretical true number (the total cumulative catch plus the number recovered upon draining). Estimates obtained using the average catch per unit of effort for the different intervals of effort were not significantly different.

The assumptions of the Delury Method were investigated. The assumptions of non-recruitment, the taking of a significant proportion of the population, and constant catchability had to be satisfied to achieve estimates of the above accuracy. The assumption of non-competing units of fishing gear and constant fishing pressure apparently did not have to be fully satisfied to achieve estimates of the above accuracy.

INTRODUCTION

The facilities of the Farm Pond Project of the Auburn University Agricultural Experiment Station offered a unique opportunity for investigation of certain principles of the Delury Method (Delury, 1947), especially in its application to the estimation of populations in which the fish were removed by angling. Experimental channel catfish fishing ponds on the Experiment Station were especially adaptable to a study of the Delury Method since several of the basic assumptions of the method were either met, or the degree of departure from the assumptions could be measured. Complete creel records were available

[1] This paper is a portion of a thesis submitted to the graduate faculty of Auburn University, Auburn, Alabama, in partial fulfillment of the requirements for the degree of Master of Science, August 24, 1962. The research was directed by Dr. E. W. Shell.

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from public fishing experiments in channel catfish ponds.[3] There was little or no recruitment and a minimum of natural mortality. Each pond was drained soon after the pond was closed to public fishing so that the accuracy of each estimated number could be determined.

The purpose of this investigation was to determine: (1) the accuracy of estimates of population size obtained from angler catch records, (2) an interval of effort that would give the most accurate estimate, and (3) the extent to which the assumptions of the method could be violated without significant error in the estimate.

DESCRIPTION AND MANAGEMENT OF THE PONDS

The ponds used in this study, S-1, S-8, and S-14, were built by the personnel of the Farm Ponds Project at Auburn University. Pertinent information pertaining to each pond is as follows:

	Pond S-14	*Pond S-1*	*Pond S-8*
Surface acreage	12.4	22.0	10.7
Number stocked	25,648	44,000	26,108 and 10,700
Year channel catfish stocked	1958	1959	1960 and 1961
Year in which estimate was made	1959	1960	1961

The initially stocked channel catfish were in the 3- to 5-inch group, and were stocked in February or March in each pond. An additional stocking of 10,700 channel catfish was made in Pond S-8 in January 1961. In addition to channel catfish, various combinations of largemouth bass, *Micropterus salmoides* Lacepede, Java tilapia, *Tilapia mossambica* Peters, and fathead minnow, *Pimephales promellas* Rafinesque were also stocked.

Auburn No. 2 pellets (Prather, 1956) were fed to the fish in each pond to increase production. With the exception of the winter months, the pellets were distributed along the pond edges daily from Monday through Saturday at rates of an estimated 2 to 5 percent of their body weight per day.

Each pond was open to public fishing for portions of two successive years and then drained. The first year of public fishing for each pond began during September or October of the same year in which the pond was stocked and ended in the early part of December. In the second year fishing began in mid-March and continued until mid-September. The ponds were open to public fishing from 7:00 a. m. to 5:30 p. m., Monday through Saturday.

A complete creel census was made by a creel clerk employed by the Farm Ponds Project and stationed at the entrance of each pond. Each angler was charged $1.00 for a permit to fish for one day. He was allowed to catch a limit of five channel catfish, after which he was charged $0.25 for each additional channel catfish during each first year of fishing and $0.30 during each second year of fishing.

Estimates of the number of channel catfish were made from the catch records of 20,790 anglers who fished 110,515 hours. These catch records were taken only from the second year of public fishing. The number of channel catfish caught during the second year of fishing plus the number recovered upon draining were theoretically the total number of channel catfish present in each pond at the beginning of the second fishing season. These values are given below. The values for Pond S-8 include only the initially stocked channel catfish (those stocked in 1960) since an estimate could be obtained only from this group.

	Pond S-14	*Pond S-1*	*Pond S-8*
Number caught by angling	12,759	20,798	7,712
Number recovered at draining	2,238	2,985	565
Theoretical number at beginning of fishing season	14,997	23,783	8,277

USE OF DELURY METHOD IN ESTIMATING NUMBERS OF CHANNEL CATFISH

Simple regression of catch per unit of effort on cumulative catch is used to estimate the number of fish in a population (Delury, 1947; Rounsefell and

[3] The fishing experiments were under the direction of Mr. E. E. Prather, and the records were made available for statistical analysis through his cooperation.

Everhart, 1953; Ricker, 1958; and von Geldern, 1961). Graphically, the catch per unit of effort (the average number of channel catfish caught per hour during some interval of time or C/F[4]) was plotted on the ordinate or Y-axis, and the cumulative catch was plotted on the abscissas or X-axis. A regression line was begun where the C/F began to decline regularly and ended with the total cumulative catch. The regression line was extrapolated or projected across the X-axis. The point where the extended line intersected the X-axis was the estimate of the number of channel catfish in the pond when it was opened to public fishing earlier in the year. The point where the regression line intersected the X-axis was calculated from the least squares equation, $Y = a + bX$. When Y was set equal to 0, X was estimated to be $-a/b$, the mathematical expression for the estimate.

Confidence limits for the estimate were calculated from the roots of the equation (Ricker, 1958):

$$N^2(b^2 - tp^2s^2C_{22}) - 2N(-ba - tp^2s^2C_{12}) + (a^2 - tp^2s^2C_{11}) = 0$$

where:

N = confidence limits
b = the slope of the regression line
a = the height of the regression line at $X = 0$
$s = \sqrt{Sy^2 - bSxy/\,(n-2)\,Sx^2}$ (S = the sum of:)
$C_{11} = SX^2/\,(nSx^2)$ (n = the number of observations)
$C_{12} = SX/(nSx^2)$
$C_{22} = 1/Sx^2$
tp = the *t* value corresponding to a given probability of p.

This equation was of the general form:

$AZ^2 + BZ + C = 0$ whose roots were: $(-B + B^2 - 4AC)/2A$.

Similarly, the roots (upper and lower confidence limits) of the above equation are:

$$N = \frac{2(-ba - s^2C_{12}tp^2 + \sqrt{2(ba - s^2C_{12}tp^2)^2 - 4(b^2 - s^2C_{22}tp^2)\,a^2 - s^2C_{11}tp)^2}}{2(b^2 - s^2C_{22}tp^2)}$$

The value of X (cumulative catch), to be paired with Y (C/F), was calculated as described by von Geldern (1961). Each value of X included the cumulative catch through the entire previous fishing interval plus one-half the catch of the current interval. For example, if 100 fish were caught on each of the first two days, the value of X for the first day would be 50, and value of X for the second day would be 150. The value of X (cumulative catch) was similarly calculated for each succeeding fishing interval (interval of effort).

Extensive use was made of Auburn University's computer and supplementary machines in processing the data. The IBM 650 computer was used until replaced by the faster IBM 1620, which was used to process most of the data.

The accuracy of the estimates is presented in Table I. The percent error of the estimates from the true numbers of channel catfish was calculated. The percent error of 13 estimates over the three-year period varied from —10.3 to + 6.2 percent. Therefore, it was concluded that reasonably accurate estimates could be obtained from estimates based on catch records from farm ponds and using the Delury Method.

The percent error was at a relatively consistent level of accuracy within each year of estimation. However, there was a shift from underestimation to overestimation from year to year. The average percent error was —9.9, —3.6, and —2.7 in the respective years of 1959, 1960, and 1961.

THE EFFECT OF DIFFERENT INTERVALS OF EFFORT ON THE ESTIMATES

In this study the average number of channel catfish caught per hour of angling, C/F, was determined at daily, 500 angling-hour, 800 angling-hour, 1,000 angling-hour, and weekly intervals of time. The C/F for each of these

[4] C/F was suggested by Holt *et al.* (1959) as a symbol for catch per unit of effort and will be used **in this paper.**

intervals was then used in estimating the population numbers, and the interval giving the most accurate estimates was determined. The accuracy of estimates for each interval of effort was determined by calculating the percent error of the estimate from the true number of channel catfish (the total cumulative catch plus the number recovered at draining).

Table I presents the estimates of the populations using the various intervals of effort. There was no evidence over the three years of estimation of increased or decreased error in estimates obtained from different lengths of intervals of effort. It was concluded, therefore, that estimates obtained from the different intervals of effort of this study were not significantly different.

TABLE I

COMPARISON OF ESTIMATES OF NUMBER OF CHANNEL CATFISH OBTAINED FROM USING THE C/F OF DIFFERENT INTERVALS OF EFFORT

Pond and Year	*Interval of Effort*	*True Number*	*Estimated Number*	*5% Confidence Limits*	*Degrees Freedom*	*Percent Error*
S-14, 1959	Day	14,997	13,552	13,250-13,991	95	− 9.6
	500 hour	14,997	13,446	12,998-14,090	26	−10.3
	1,000 hour	14,997	13,473	12,279-14,220	12	−10.2
	1 week	14,997	13,586	13,161-14,287	14	− 9.4
S-1, 1960	Day	23,783	23,390	22,248-25,330	92	− 1.7
	500 hour	23,783	22,731	21,807-24,075	52	− 4.4
	1,000 hour	23,783	22,593	21,514-24,333	25	− 5.0
	1 week	23,783	22,992	21,793-24,917	14	− 3.3
S-8, 1961*	Day	8,277	8,790	8,184- 9,881	87	+ 6.2
	500 hour	8,277	8,368	7,842- 9,200	44	+ 1.1
	800 hour	8,277	8,472	7,873- 9,498	27	+ 2.4
	1,000 hour	8,277	8,274	7,736- 9,151	22	0.0
	1 week	8,277	8,605	7,988- 9,619	13	+ 4.0

* Only the Channel Catfish stocked in 1960 are included in the estimate.

INVESTIGATIONS OF THE VALIDITY OF THE ASSUMPTIONS OF THE DELURY METHOD

Certain prerequisites theoretically must be fulfilled if the Delury Method is to accurately estimate the numbers of fish in a population. These prerequisites are as follows:

(1) A significant proportion of the population must be taken by the fishermen.

(2) Recruitment and natural mortality are negligible, and the entire population is available to the fishery.

(3) The "catchability" of the fish remains constant during the sampling period.

(4) The units of gear do not compete with each other, or else they are constant during the period involved.

The degrees to which these prerequisites were fulfilled and their effect on the accuracy of the estimates were investigated in this study and will be reported in the following sections.

THE TAKING OF A SIGNIFICANT PROPORTION OF THE POPULATION

No estimate can be made before the C/F begins to decline regularly (Delury, 1947; von Geldern, 1961). Therefore, no estimate could be made in any of the ponds during the first year of fishing. There was no regular decline in C/F until the second year of fishing. The dates at which the C/F began to decline steadily for Ponds S-14, S-1, and S-8 were respectively at or near: May 26, May 31, and June 5.

An investigation was made to determine to what extent the populations had to be depleted before there was a steady decrease in the C/F. The average percent of channel catfish removed since stocking and the average number remaining per acre (calculated from estimates at each interval of effort) when the C/F began to decrease steadily were as follows:

	Pond S-14	Pond S-1	Pond S-8 [5]
Number stocked	25,648	44,000	26,108
Total removed	19,751	33,099	21,466
Percent removed	77.0	75.2	82.2
Number remaining/acre	476	495	434

[5] Includes only those channel catfish stocked in 1960.

Except for the high percentage removed from Pond S-8 prior to the decrease in fishing success, the relative closeness of percentages of previously removed fish and of the remaining fish in the different ponds indicated that the channel catfish had to be reduced to rather definite levels before there was a regular decline in fishing success. A possible explanation for the high percentage removed from Pond S-8 is that some of the channel catfish stocked in January, 1961 were likely mistaken for those stocked in February, 1960.

A further significant proportion of the population had to be removed after the C/F started to decrease steadily because the method of estimation depended upon the ability to estimate the slope of the regression of C/F on cumulative catch. Further depletion of the population resulted in the probability of an increased accuracy of the estimate since slight variation in the C/F of a shorter range of data upon which the regression line was based altered the slope and often made an appreciable difference in the point at which the extrapolated regression line cut the X-axis.

It was concluded that the assumption of taking a significant proportion of the population had to be satisfied to achieve accurate results. However, the required removal of 75 to 82 percent of the population before an estimate could be made may give this method a serious disadvantage in the practical estimation of fish populations in farm ponds.

NEGLIGIBLE AMOUNTS OF RECRUITMENT AND NATURAL MORTALITY

The assumption of non-recruitment was tested with the catch data of Pond S-8, 1961. In S-8, 26,108 channel catfish were stocked in February, 1960, and 10,700 channel catfish were stocked in January, 1961. Fish of the 1961 stocking did not become a significant part of the fishery until the C/F from the 1960-stocked channel catfish began to decrease. As the fishing season progressed, the fish stocked in 1961 were recruited in increasing numbers into the fishery to such an extent that the regression line between C/F and cumulative catch actually had a slightly positive rather than a negative slope.

Since the estimate of the number of channel catfish depended on where the projected regression line cut the X-axis, no estimate was possible when the recruited fish were included in the estimate. This emphasized the necessity of not more than a negligible amount of recruitment for achieving accurate estimates of population size. Very close estimates were achieved for Pond S-8, 1961, when only the fish stocked in 1960 were included in the estimate (Table I).

The natural mortality appeared to be at a minimum during the period of estimation. It was likely that much of it occurred with initial stocking, during the first year of fishing, and by poaching, especially when the ponds were not open to public fishing. There was likelihood of more natural mortality during the first year of public fishing than during the second year since the fish were relatively easy to catch at that time, and limits of five channel catfish were easily taken. This induced the anglers to throw back the smaller-sized fish at the time of capture or after catching larger ones. Many of these small channel catfish probably died since they were usually deeply hooked and/or had been on the stringer for some time. Poaching by means of wire baskets was discovered when the ponds were not open to public fishing and in the form of night anglers. Many channel catfish were probably also slipped out by anglers, especially when the limits were easily taken. No accurate estimation of natural mortality could therefore be made for the periods of estimation. However, it was concluded from the above observations that mortality caused either by poaching or fish returned to the water and dying was probably a minor factor during the time in which the estimate was made.

A CONSTANT CATCHABILITY

Delury (1947) stated that the assumption of constant catchability is not essential to the application of the method. Ricker (1958) stated that inconstant catchability is perhaps the greatest potential source of error in applying methods of estimation based upon secular change in C/F because either catchability varies with seasonal changes or because fish vary in vulnerability so that the more vulnerable fish are caught first. Ricker also suggested that day to day variation is less serious but of widespread occurrence and merely increases the scatter of points about the regression line.

In this study the assumption of constant catchability could not be adequately investigated with the data available, but inconstant catchabiliy was a potential source of error (especially during periods in which water temperature fluctuated widely). However, the regression estimates were not made until the water temperature had stabilized so that it had little apparent effect on the C/F. No direct measurements of catchability were made during periods of estimation, but relatively accurate estimates of population size were achieved each year anyway. If there was inconstant catchability of the channel catfish because of seasonal effects, changes in food availability, changes in the physiology of the fish, and removal of the more vulnerable fish; the effect of these factors was masked by the effect of cumulative catch on the C/F. There was day to day or short-term variation in C/F, but this merely increased the scatter of points about the regression line and had little over-all effect on the estimate.

NON-COMPETING UNITS OF EFFORT AND/OR CONSTANT FISHING PRESSURE

The assumption of "no competition between units of fishing gear" was investigated by von Geldern (1961) in a theoretical example. He concluded that alternate days of high and low fishing pressure caused no serious error in the estimate but that errors created by steadily increasing or decreasing fishing pressure may be extremely large. In this study fishing pressure over long periods of time was generally a function of the C/F during each time interval. After the ponds were opened to public fishing in March, fishing pressure generally increased until late May or early June, decreased greatly by late June, and was subject to no great variation thereafter. However, there was a gradual increase in fishing pressure for Pond S-8, 1961 during the last part o fthe fishing season, when the 1961-stocked channel catfish were being recruited into the catchable population.

According to von Geldern's theoretical example, a great decrease in fishing pressure, as was evident in this study, would result in a convex curve between the steadily declining C/F and cumulative catch, which would yield a high estimate of population size. In this study the relationship between C/F and cumulative catch showed little or no convex curvature (Fig. 1), and the only

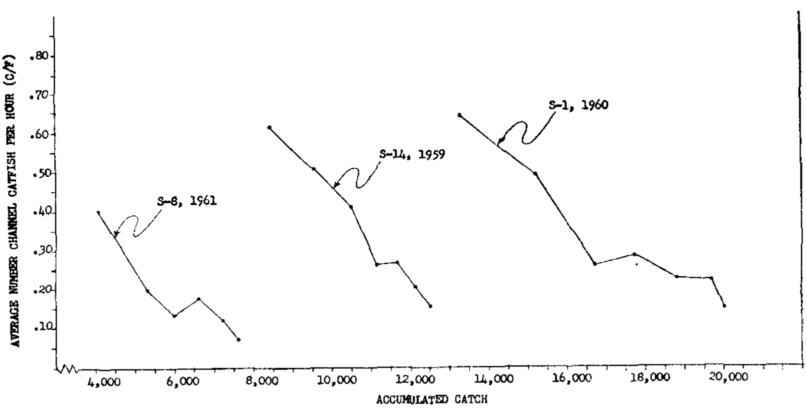

Figure 1 Graphs showing the relationship between average catch per hour (C/F) and accumulated catch. Intervals of effort for Ponds S-8, 1961; S-14, 1959, and S-1, 1960 were respectively 4,000, 4,000, and 1,000 angling hours.

over-estimations of population size were those for the number of 1960-stocked cannel catfish in Pond S-8. These slight over-estimations probably resulted from designating some of the 1961-stocked channel catfish as those stocked in 1960 (Fig. 1). This mistaken designation apparently occurred during the latter part of the 1961 fishing season, when recruitment of the young channel catfish was greatest and when there was a probable overlap in the sizes of the channel catfish from each stocking. It was therefore concluded that the assumption of either constant fishing pressure and/or no competition between units of fishing gear did not have to be fully satisfied in this study during the period from which the data was taken to obtain a regression line to achieve accurate estimates of population size.

CONCLUSIONS

It was concluded that the Delury Method may be used with reasonable accuracy to estimate the number of channel catfish in farm ponds providing the following assumptions are met:

(1) A significant proportion of the population must be taken by the anglers before an estimate is initiated.
(2) Recruitment and natural mortality must be negligible, and the entire population must be available to the fishery.
(3) The "catchability" of the fish must remain relatively constant during the sampling period.

The assumption of non-competing units of fishing gear and constant fishing pressure appears to influence estimation of size of channel catfish populations to a lesser degree than do the above assumptions.

It was concluded that estimates based upon the different intervals of effort of this study did not give significantly different estimates.

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THE COOPERATIVE FISHERY UNITS

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ABSTRACT

The purpose of the cooperative fishery and wildlife units, as stated by Congress, is "to facilitate cooperation between the Federal Government, colleges and universities, the States, and private organizations for cooperative unit programs of research and education relating to fish and wildlife and for other purposes." This paper describes only the fishery phase of the program which is now getting underway. The training of fishery biologists for professional employment is considered the primary objective at this stage. The conduct of research is also recongized as