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Analysis of the Capture-Recapture Method of Determining Fish Population Size in a Pond Community

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Analysis of the Capture-Recapture Method of Determining Fish Population Size in a Pond Community
(TITLE)

BY

Richard E. Hall

THESIS

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Presented by

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A Candidate for the Degree of Master of Science

And Hereby Certify That, In Their Opinion, It Is Acceptable

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INTRODUCTION

The capture, marking and the subsequent recapture of marked animals to obtain information regarding the population dynamics of given species of fish began with Sir Francis Bacon in 1653. Bacon tied ribands on the tails of young salmon and recaptured a portion of the marked individuals six months later upon their return from the sea (Walton 1653). Fraser in 1829 marked salmon by removing the adipose fin (Cormack 1969). Cormack (1969) indicates that Laplace in 1786 was the first to utilize this technique to estimate population size. Laplace computed the population of France by recording the number of births in areas of known population whose names were recorded among the total country. The concept of capture-recapture to determine fish population size was developed by Peterson (1896). Peterson's idea was first put into practice to estimate population size by Dahl (1918). Peterson, although postulating the capture-recapture idea to estimate population size, used marking only for estimating mortality rates. Dahl captured trout by seining, marked them by removing the adipose fin and subsequently recaptured them by seining (Le Cren 1965). The theory behind Dahl's work, commonly known as the Peterson method, involves the marking of animals on a single occasion and the sampling to recapture on a subsequent occasion. This method whose concept is the basis for all other mark-recapture formulas, involves the theory that with a known number of marked individuals in a population, an estimate can be made of the entire population by comparing the ratio of marked to unmarked individuals captured on a subsequent occasion (Cormack 1969). The formula derived by Peterson is

$N=\frac{mc}{r}$, with m being the total number of marked individuals in the population, c the number of fish in the sample, r the number of fish recaptured in the sample and N the population estimate (Lagler 1971). This same method was developed by Lincoln (1930) working with waterfowl populations, without prior knowledge of Peterson's work. The types of animals involved in these separate studies has led to wildlife biologists referring to this single marking method as the Lincoln index and fisheries biologists as the Peterson method (Le Cren 1965; Cormack 1969). Marking experiments since this time have been expanded into many varied statistical methods to obtain not only population sizes but also the rates of exploitation of populations, survival rates of populations from one year to the next, the rate of recruitment into a population, movements, migrations, age and growth determination and behavioral studies (Ricker 1958; Stott 1971).

MARKING AND TAGGING

Marking and tagging are necessary procedures, in capture-recapture studies, which allow a fish to be identified as either an individual or a member of a particular group. Tagging involves the attachment of a foreign object, usually bearing a number, to the outside or inside of the fishes body. Marking involves the mutilation of part of the fishes body to leave an identifiable condition (Stott 1971; Lagler 1956).

Marking, as a rule, is used as a group identifying technique rather than a method of identifying individuals, although a coding system can be used to identify individuals if needed (Stott 1971; Lagler 1956).

The most widely used marking method is that of fin clipping. Fin clipping is accomplished by removing all or a portion of the selected fin or fins. The paired fins, pectoral and particularly the pelvic fins are used most often. The single fins, dorsal, and caudal, are seldom used due to their roles in behavior and mobility in most fish. The adipose fin is often used in salmonids (Stott 1971; Lagler 1956).

Holes punched in the operculum or fins by adapting small pliers to punch various shaped holes allows for many distinguishing marks to be made for identifying many different groups of fish. Fishes with fleshy or brittle opercula cannot be marked by punching in that region. Holes punched in either the operculum or fins regenerate quickly and are not suitable for long term experiments.

Branding is an attractive method of marking in that it allows for the recognition of individuals without tagging but has, to this date, yieled varied results (Stott 1971).

Electrically heated brands and brands heated in boiling water have been tried by many investigators (Buss 1953; Johnson and Fields 1959; Moav et al 1960 a b; Groves and Novotny 1965). Cold branding, using various combinations with dry ice is apparently easier to use in the field than the heating methods although neither method leaves a mark lasting longer that six months (Stott 1971). Owens and Gebhart (1958) developed an electrodesiccating unit for branding that yielded similar results. Mighell (1969) obtained the best results to date using a portable kit containing liquid nitrogen that left a recognizable mark for 14 months on sockeye salmon. This method is best utilized on fish with small scales and is hindered by the risk of fungal infection due to the branding (Stott 1971).

Tattooing by placing inert pigments under the skin to form specific marks by the use of needles operated by hand or electric vibrators have been tried by many investigators with limited success. Dyes and pigments remain visible for up to three months while india ink and typan blue in titanium dioxide remain visible for five months (Chapman 1957 b). The tattooing process is limited in its usefulness by being of only short term effectiveness, being slow to apply and cannot be used on large scaled fish. Tattooing when done properly, however, keeps mortality and behavioral changes low (Stott 1971).

Subcutaneous injections of dyes and latex have also been used with mixed results. Dyes were mostly ineffective, though Kelly (1967 a b) found that National Fast Blue GXM with hydrated chromium oxide produced a mark lasting for at least a year. Hart and Pitcher (1969) has similar results with Alcian Blue 8GX. Working with lampreys, Wigley (1952), obtained good results with carbon and mercuric sulphide. Liquid latex, first used by Davis (1955) has been found effective for three years in catostomids (Green and Northcote 1968), found suitable for small plaice (Riley 1966), had no different effect on the survival of redear sunfish than fin clipping (Gerking 1958) and was unsatisfactory on rainbow trout (Chapman 1957 a).

Vital Stains can be used to mark small fish by either immersing or feeding. Neutral red, Bismark Brown and Acridine Orange have been used by immersing, with Acridine Orange giving the best results (Mathews 1970; Deacon 1961; Bouchard and Matteson 1961). Sudan Black B when applied to cut fins has been found to leave a visible line after regeneration (Eipper and Forney 1965). This dye also results in stained eggs and fry for up to six weeks after the yolk sac is used up by feeding it to female brown trout (Bagenal 1967). Hasler and Faber (1941) developed a life long lasting mark by injecting fingerling rainbow trout interperitoneally with radioactive thorium dioxide in a carbohydrate carrier. The process is limited in its usefulness, however, due to the need of x-ray equipment for detection of the mark.

The use of florescent material injected under the skin can be used successfully for up to six months (Duncan and Donaldson 1968; Phinney et. al. 1967). Weber and Ridgeway (1962, 1967) showed that the feeding of florescent materials leaves marks that are retained for three and one-half years without adverse survival affects. This method, however, is limited in its scope since an ultra violet light source is needed to determine the sites of ossification (Stott 1971).

The ease and quickness of marking, and the minimal amount of equipment involved make the fin clip method of marking the standard practice in fisheries investigations (Ricker 1949; Stott 1971).

Tagging has an advantage over marking in that the tags can be numbered sequentially to allow the identification of individual fishes. Internal tags of brightly colored plastic or metal are used on some fish that are handled at commercial fish cleaning stations (Lindroth 1955). Le Cren (1954) unsuccessfully tried subcutaneous tags on char while Bergman et. al. (1968) showed severe hatchery loss with their use.

External tags are of various shapes, sizes and compounds which are attached by means of a wire loop or an internal anchor. Commonly used wired on tags are the plate tags, hydrostatic tag and the double attachment trailer tag (Stott 1971).

Plate tags involve the use of a small plate or strip of metal or plastic being attached to the anterior portion of the dorsal fin by means of a wire hoop. The hydrostatic tag consists of a transparent plastic cylinder, attached in a variety of ways, plugged at the ends, containing a message or number inside. Peterson tags are made up of two buttons connected by a wire or rod that passes through the body under the dorsal fin or through the operculum. Double attachment trailer tags are links of stainless steel fastened to a cardboard strip contained in celluloid, attached by two wires passing through the interneural bones under the dorsal fin.

Internally anchored tags, such as the Sphyrion, spring anchor, barb-type plactic and Danish roll and anchor, operate by lodging an anchor between the interneurals or behind the body wall with a trailing portion containing a number or message. Spaghetti tags are plastic tubes which run through the musculature in front of the dorsal fin and fasten by a plug. Strap tags, attached to the operculum or jaw, are used on those fish whose pre-opercular or mandibular bones are hard and robust enough to prevent the tag from wearing through. The disadvantage of the jaw tag is that it may affect feeding and therefore growth. Tags for specialized purposes can be made to fit the investigator's needs (Stott 1971).

METHODS OF POPULATION ESTIMATES

The determination of fish population size can be determined by direct and indirect methods. Direct methods involve the actual counting of fish populations. The draining of small bodies of water, the counting of migratory fishes moving up and down streams and fish kills are common methods of direct enumerations of fish populations. Fish kill counts come from natural kills such as the red tide and pollution as well as from the purposeful killing of a population, for management purposes, with rotenone or other chemicals. Additional methods used for direct counts include photography from airplanes, the use of underwater cameras and electric eyes, trapping until there are repeatedly no returns and the use of divers swimming transects, singly or in large teams where the water is sufficiently clear (Lagler 1956).

Indirect enumeration of populations involves the estimation of population size either by capture-recapture techniques based on previously marked fishes in the catch or by the technique of reduction of catch per unit of effort due to a diminishing population size due to sampling. The latter method, derived by Delury (1947) is known as the Delury regression method. This method involves estimating the population by using data on the catch per unit of effort. This method is limited in its scope of application as it requires the decrease of the population, due to sampling, to show a reduction in the catch during subsequent samples per unit of fishing effort. Ideal conditions for this method would allow for reduction to the extent of depletion. Estimation of population size is made by an inspection of the graphed data to fit the expected straight line regression. The catch per unit of effort is the ordinate and total catch, including the latest sample is the abscissa. The regression line is then extrapolated by continuing the line either by eye or formula to where it intercepts the X axis giving the population estimate of the population originally present.

The capture-recapture method of indirect enumeration of fish populations involves the capture and release of a number of marked fish into the population followed by the recapture of some of these marked fish along with some unmarked fish. The basic formula for this method was developed by Peterson (1896), $N=\frac{mc}{r}$, in which there is one marking period followed by a subsequent recapturing period. This basic formula has been expanded upon by a great many authors to allow for more varied sampling techniques. Modifications of the Peterson method have been made by Schnabel (1938), Schumacher and Eschmeyer (1943), Bailey (1951), Jackson (1939), Parker (1955), Chapman (1954), and others (Lagler 1971; Ricker 1958).

The various techniques may be of the single, multiple, or point censusing type. In the single or Peterson type census the fish are marked on only one occasion and subsequently recaptured on a single other occasion. Multiple censusings, those of Schnabel, Schumacher and Eschmeyer, and Chapman, involve marking fish over a long period of time during which time recaptures are also being made. Repeated censusing is used to determine survival rates by making two successive single or multiple censuses successfully. Point censuses, those of Bailey, Jackson, and Parker, are especially useful in studies of recruitment and survival rates. These involve sampling at certain times to mark, others to mark and recapture, and others just to recapture, with each sample having its own identifying mark (Ricker 1958).

These three censusing types may be direct, indirect, modified inverse or sequential in nature. Direct censusing requires that the size of the samples to be taken is fixed in advance or is dictated by sampling success. Indirect censusing involves ending the study when that number is reached. The modified inverse sampling utilizes a pre-determined number of unmarked fish in the sample while sequential censuses are done in stages to determine if a population is greater or lesser than a given size (Ricker 1958).

The formula modifications of the Peterson method most used in fisheries biology are those of Schnabel and Schumacher and Eschmeyer (Ricker 1958). Schnabel (1938) derived her method from the concept of maximum liklihood. A multiple censusing procedure, the Schnabel formula relies on continuous and simultaneous capture and recapture during the sampling. Fish are continually being marked throughout the entire procedure allowing estimates to be made after each sampling period until such time as continued sampling produces little affect on the population estimate. The formula, $N=\Sigma mc/\Sigma r$, is most efficient in large populations where only a small portion of the entire population is marked (Cormack 1969; Houser 1959).

The Schumacher and Eschmeyer (1943) formula, also for multiple censusing, derived from a method of least squares is $N=\Sigma m^2c/\Sigma mr$. Houser (1959) and Cormack (1969) indicate that this formula is superior to the Schnabel formula in small populations where over one-half of the population has been marked.

Chapman (1951) derived the formula $N=\Sigma\frac{(mc)^3}{(r)\ (u)\ (m-r)}/\Sigma\frac{(mc)^2}{u\ (m-r)}$ where u is the number of unmarked fish in the sample. Cormack (1969) indicates that this formula gives an unbiased estimate of the population size.

Bailey (1951) suggested the Triple catch method, a point census, to estimate population size. This method involves sampling fish a total of three times. Sampling on the first and second occasions, the number of fish captured are marked T_1 for the first sampling and T_2 for the second. During the second and third sampling the sizes of the samples, n_2 and n_3 are taken and the number of recaptures taken at these times are m_{12}, m_{13}, and m_{23}. Recaptures on the third sampling are from either the first or second sampling and are distinguished by m_{13} and m_{23} respectively. Estimates made from the data are the proportion of the initial population that survives from the first to the second sampling $P_1=\frac{t_2\ m_{13}}{t_1\ m_{23}}$, the size of the population on the second sampling $N_2=\frac{t_2\ m_2\ m_{13}}{m_{12}\ m_{23}}$, and the proportion of increase between the second and third sampling due to recruitment or immigration $R=\frac{n_3 m_{12}}{n_2 m_{13}}$, (Jones 1966).

Positive and negative methods to determine population size were developed by Jackson in 1936 (Jones 1966). The positive method involves marking the animals once and recapturing them at regular intervals. Assuming that the population remains constant while the number of marked animals decline, an estimate of the survival rate from the declining proportion of marked animals in each sample can be made. Using that, the population size can then be calculated by using the Peterson formula. Jackson's negative method uses recapturing on a single occasion the animals previously marked during a series of regularly spaced intervals. Parker (1955) developed a method similar to Jackson's positive method but assumed a fixed T and an increasing N (Jones 1966).

Jones (1966) indicates that there are three different situations that can be encountered in estimating fish populations. Populations may be so large that only a minute fraction of the fish population can be marked. This occurs in commercial marine fisheries where there is little expectation of obtaining marked fish in a sample taken at a given time. The Peterson method is appropriate here since the investigator must rely on the prolonged activities of the commercial fishermen for recapture.

The second situation is that found in those lakes and streams where the investigator is able to mark a large proportion of the population. The large proportion marked makes it reasonable to expect that marked fish will be obtained at any given time. In this situation, the Schnabel, Jackson positive and negative methods and Bailey's triple catch methods can be employed to obtain good results (Jones 1966).

Situations where a very large segment of the population is marked and marked animals are repeatedly caught are best handled by the Schumacher and Eschmeyer formula (Jones 1966).

ASSUMPTIONS OF INDIRECT ESTIMATING PROCEDURES

The great variations of methodology in indirect population estimation procedures, regardless of the type, can give justifiable results only if certain assumptions can be met. The closer these assumptions are to being true the less biased the results will be, resulting in a more accurate estimation (Lagler 1956; Ricker 1958). The assumptions made for the Delury regression type of procedure are: 1) the population is closed (migration and natural mortality are neglegible), 2) units of effort employed do not compete with one another or are constant during the sampling and 3) the response of the fish to the sampling procedures remains constant during the investigation (Lagler 1956).

Assumptions for capture-recapture estimates are: 1) marked and unmarked members of the population undergo the same mortality, 2) marked individuals do not lose their marks, 3) marked and unmarked members of the population are equally vulnerable to capture, 4) marked individuals must mix randomly with the population or the sampling effort must be proportional to the number of fish present in different portions of the body of water, 5) all recaptures must be recognized and reported and 6) recruitment must be negligible (Ricker 1948).

Differential mortality or marked individuals undergoing more mortality than unmarked individuals is frequent in marking experiments (Ricker 1958). This extra mortality results either directly from the tag or mark or indirectly due to the handling and stress of the marking operation. This mortality can be instantaneous due to the loss of blood, infection or trap shock or it can be continuing mortality due to some sort of disability imposed upon the fish by the tag or loss of a fin. Mortality resulting from the marking procedures, either direct or indirect will result in population estimates that are too high and exploitation rates that are too low since the number of recaptures will be too small to be representative of the number originally marked (Ricker 1948; Crowe 1953). The most common approach utilized to test for differential mortality is the comparison of the returns of individuals marked with different kinds of marks or tags. Marks recaptured with equal frequency indicate that none of the marks produced any significant mortality regardless of the amount of mutilation involved in the marking. The recapturing of fish more frequently with one mark than another indicates that the mortality is more severe with one mark over that of the other but does not indicate that the mark with the better returns has no significant affect on mortality (Ricker 1958). Foerster (1936) found that the removal of the ventral fins of yearling sockeye salmon resulted in marked fish surviving to maturity only 38% as often as unmarked ones. Ricker and Lagler (1942) marked centrarchids by removing the pelvic fins of half the captured fish and used a jaw tag as well as removing the pelvics on the other half. Both marks were recaptured with the same frequency in traps indicating that neither the tag or the mark affected the mortality of the fish. Ricker (1949) indicates that the removal of fins from spiny rayed fishes five inches and longer has so small an affect on the growth and mortality of the fish that it can be ignored. The affect on small bass, however, has a definite unfavorable affect upon their survival. Coble (1971) has shown that the recovery of a fin clipped bass is about one-half to one-third that of the control fish and that survival is better when only one ventral fin is clipped.

The loss of marks or tags can be another source of error in population estimate studies. Tags must be attached reasonably permanently to attain usable results. Tags not attached permanently can at times be detected through close examination of samples where scars from detached tags can be detected. Marking by fin clipping or punching holes in fins must be done with care since many fish have considerable power of fin regeneration. Pectoral fins of adult Pomoxis annularis have been known to regenerate almost perfectly in one year, except for some waviness, when clipped almost at the base (Ricker 1958). Young Micropterus salmoides (Meehan 1940) in Florida regenerate pectoral and pelvic fins within a few weeks while young bass in Indiana exhibit imperfect regeneration (Ricker 1958). Lepomis, various Ictalurus and Perca flavescens do not regenerate pectorals and imperfectly regenerate pelvics when closely cut. All centrarchids regenerate soft dorsal and anal fins perfectly regardless of how closely they are cut. Salmonid fishes regenerate all fins poorly with regeneration best, though imperfect, in the adipose fin (Ricker 1958). Missing fins occur in nature but are rare, especially in freshwater, and are probably of no significance.

A source of error commonly encountered is that of marked or tagged fish being more or less vulnerable to capture than unmarked fish. This occurs most often due to changes in the behavior of the fish resulting from the capture and marking operations. The capture and marking operations impose both physical and probably psychological handicaps upon the fish (Ricker 1948,1958). These handicaps alter the bahavior patterns of the marked individuals for varying lengths of time. Behavioral changes have been shown in centrarchids. Marked individuals when first released swim down and burrow into the weeds. This type of behavior would allow these marked individuals to be more easily caught in traps or hoop nets than unmarked fish. Marked fish may not feed for a time resulting in these fish being less likely to be caught by fishermen. Mobility may be less, due to marking, resulting in these fish being less likely to be caught in stationary gear like hoop or gill nets, but more likely to be caught in seines or trawls. Conversely, marking may result in increased activity resulting in more recaptures than should occur in stationary gear (Ricker 1948, 1958). Jaw tags make fish much less vulnerable to angling while "Peterson disks" allow fish to be more vulnerable to gill nets than untagged fish since the tags get entangled in the twine of the net (Ricker 1958). Ricker (1949) indicates that tagged fish were recaptured much less frequently by anglers than marked ones. The presence of the tag or mark caused no excess mortality but the tag apparently interferred with the feeding of the fish, hence influencing the number recaptured by fishermen.

Fish not originally a part of the population, such as hatchery raised fish, whether marked or not, will behave differently, resulting in errors in estimates due to too few or too many being recaptured (Ricker 1958).

Differential vulnerability to capture of marked and unmarked fish is difficult to detect. Recaptures are ordinarily not numerous so determination of errors of this nature are hard to demonstrate. Effects of this nature can be confused with mortality due to tagging and can be studied by comparisons of recaptures by various sampling techniques since vulnerability will vary with the type of gear used (Ricker 1958).

The random mixing of marked individuals into the population or the sampling effort being proportional to the number of fish in different areas of the body of water must occur to obtain an unbiased estimate. Singly, either one of these factors when present will result in an unbiased estimate(Ricker 1948, 1958). Schumacher and Eschmeyer (1943) pointed out that their ratio of unmarked to marked Ictalurus sp., Cyprinum carpio and Ictiobus sp. showed significant differences apparently due to the inability to sample much of the pond with their nets due to the large amount of shallow water. Studying a long narrow pond, Lagler and Ricker (1943) found that there was little mixture between the fish populations at each end of the pond. The lack of random distribution of fish in situations like this necessitates that the fishing effort be random or that the sections of the lake be considered separate populations. Small bodies of water (Carlander and Lewis 1948) allow the random distribution of marked fish quickly whereas equal random mixing is unlikely in large lakes. Rivers, large lakes and oceans provide the most difficult problems in establishing random mixing or sampling due to the size of the bodies of water, local stabilization of populations and the movement of fishes (Ricker 1958). Fredin (1950) expressed concern in obtaining random samples during sampling procedures since all sampling gear is selective and can't be used in certain areas of a body of water. The need for different capturing techniques to eliminate this was suggested.

The incomplete checking of marks can result in significant errors in estimates. The checking of the marks or tags by trained personnel will minimize this bias. In many studies, however, the investigator must rely on commercial, sport fishermen or untrained personnel to return capture data. The more obvious the mark or tag, the more publicity given, the amount of handling required and the amount of reward given all influence the complete checking of marks if trained personnel are not available (Ricker 1948, 1958).

Recruitment by growth and immigration must be negligible if population estimates are to be reliable. When recruitment becomes a factor, population estimates are too high. Recruitment due to immigration in ponds and lakes is practically nonexistent, while in rivers and oceans it must be dealt with (Ricker 1958; Cooper and Lagler 1956). Corrections for recruitment due to growth of fishes can be made in several ways to eliminate error. The population can be divided into age groups which overlap only slightly in length. A boundary can be set up whose position will advance as the season progresses and as the fish grow by choosing the lower limit of size of the fish to be marked at the gap between the two age groups. This will allow a constant proportion of marked to unmarked fish to be obtained as long as the other assumptions hold true. Another method involves determining the rate of growth of the two age classes most near the minimum size of fish being sampled. The rate of growth, determined by annulus formation on the scales, when applied proportionately to the length of time involved, can be used to determine which fish were of the minimum size at the initial date of sampling (Ricker 1948, 1958). Parker (1955) developed a method which avoids the use of age or growth estimates to prevent bias by recruitment. Upon the completion of marking, additional fish are added to the population which decreases the percentage of marked fish in the population with a corresponding reduction in the ratio of marked to unmarked in later samples. The ratio, plotted against time gives a line which at the intercept of X=0 gives an estimate of the ratio of marked to unmarked at the time of marking. This number divided by the number marked yields an estimate of the initial population. The standard deviation, calculated from the line and converted to standard error gives confidence limits that allow for recruitment (Ricker 1948, 1958).

Sources of systematic error other than the six basic assumptions are those of differential vulnerability to capture of different sizes and species of fish. Lawrence (1952) discovered that larger bluegills are more vulnerable to trap recapture than smaller bluegills. Since most sampling methods are selective, but in different ways, error due to selectivity can be lessened when one method is used in marking and another to recapture (Lawrence 1952; Fredin 1950; Fessler 1950; Westers 1963). The detection of differential vulnerability of different sized fish can be accomplished by comparing the rate of recaptures of marked individuals of different sizes with a large enough number to minimize sampling error. Differential vulnerability of different size fish can be hard to separate from differential mortality or differential behavioral changes if they affect one size more than another. This varied vulnerability of different sized fishes, though common, can be minimized by excluding those fish near the limits of vulnerability of the sampling technique by using less selective sampling or by dividing the population into size groups (Ricker 1948, 1958).

Differential vulnerability among different species, even closely related species can be great. Lepomis microlophus is about ten times more vulnerable to trapping as Lepomis macrolophus. Trapping data in a mixed population of these two species would yield twice as many redears being captured than bluegills with twenty times as meny redears being recaptured. Combining the species together would yield a population estimate 64% lower than the sum of the two species considered separately (Ricker 1958). Krumholz (1944) also found this to be true in a population of Micropterus and Lepomis gibbosus where, when calculated separately, the total population was 19,080, but when lumped together and calculated, it was 9,700. These errors can be prevented by estimating each species separately regardless of how closely they are related (Ricker 1958).

SAMPLING

Knowledge of taxonomy, population size, growth rate, mortality rate, recruitment and sex and year class composition in fisheries biology are derived from the capture of fishes. Capturing is necessary due to the aquatic environment itself which generally prevents the direct observation of fish populations. Capture methods usually sample only a small amount of the fishes present in a population and are selective with respect to species, size, and often sex. Among the more common methods of capturing fish and the ones used in this study are electrofishing, seining, hoop netting and gill netting (Lagler 1971).

ELECTROSHOCKING

The use of electric current to capture fish was first used in Europe in the 1920's (Schiemenz and Schonfelder 1927; Hager 1934). Electrofishing has the advantage over many sampling methods in that it is one of the least selective active fishing methods (Lagler 1971; Sullivan 1956). Early use of electrofishing principally involved population studies of streams (Larimore et. al. 1950). Stream shocking has been done with both A.C. and D.C. generators and battery powered back pack units. The A.C. units involve the use of two electrodes five meters apart immobilizing fish so they can be netted. D.C. units are operated by two electrodes, the cathode (ground) and the anode. The anode is moved by a pole to lead fish to a dip net for recovery. Stream shockers are frequently used in conjunction with nets blocking areas of the stream to prevent fish from escaping (Lagler 1971).

Electrofishing gear for lakes and river use are mounted in small motor boats. The electrodes made of metal rods or chains are suspended from booms in front of the boat. The boat is then slowly driven through shallows and along weed beds with the stunned fish being netted from the water. Gear for lake shocking may be A.C., D.C., or D.C. equipped with an adjustable electronic pulsator.

Electric seines have also been developed that operate on an A.C. power source with one electrode running along the lead line and the other along the float line of the seine. These seines are limited to water two meters deep and are ineffective in reducing the avoidance behavior of fishes to a conventional seine (Lagler 1971).

The reactions of fish to electric current are of three types. The first reaction type is the "frightening effect". The second is electrotaxis which results in either an attraction or repulsion to the electric current. Electronarcosis or galvanonarcosis, the third type of reaction, is the complete immobilization of the fish, if at this time there is a sufficient increase in power, the fish dies by electrocution. This series of responses ending in electronarcosis is due to increased levels of voltage (Vibert 1967; Adams et. al. 1972).

The effectiveness of electrofishing depends on electrical parameters, biological parameters and physio-chemical parameters. The electrical parameters of impulse current, shape of the impulse and length of the impulse all influence fish behavior to the current. Fish reactions involving the impulse of the current depend on the shape of the current, impulse rate, and mean flow of the current. The shape of the impulse needed to capture fish is that of a steep increase with a slow decrease. This drop in voltage, due to the conductivity of the fishes flesh and the conductivity of the water is important in causing electronarcosis. Length of the impulse that is effective varies with species, size and shape (Vibert 1967; Adams et. al. 1972).

The biological parameters that affect electrofishing are the species, metabolic rate, length of the fish and the degree of sexual maturation or exhaustion at the time. The optimum rate varies depending on the species. A rate of 7-20 impulses per second is effective for tuna, 45-50 for carp and 60-65 for trout. Fish with higher metabolic rates are more prone to capture, like the trout, than those with a low metabolic rate like the carp. Fish that are long in length are more prone to capture than short fish who are less prone to capture at the same potential. Fish that are sick, exhausted, or at the stage of sexual maturity do not react well to electric current and are more easily captured than healthy fish (Vibert 1967).

The physio-chemical parameters involved in electrofishing efficiency are the chemical composition of the water and water temperature. Water that has a high concentration of K^+ increases the metabolism and excitability of fish. This apparently causes induction at lower densities of current and electronarcosis at higher densities of current than water containing high concentrations of Ca^+, which decreases the metabolism and excitability of fish. Temperature affects fish by making them more easily stimulated in warmer water temperatures due to an increased metabolic rate (Vibert 1967).

Vibert (1967), Pratt (1951) and Taylor et. al. (1957) indicate that direct current is superior to alternating current not only for effectively capturing fish but also superior in safety to the fish. Pulsed direct current when compared to the other two has the greatest neurophysiological effect on the fish, allowing more captures and at the same time has the least damaging effects.

Sullivan (1956) using a direct current shocker to make population estimates determined that species found in areas of dense cover such as centrarchids and bullheads are more difficult to capture than species inhabiting areas with little cover such as suckers. Sullivan noted as others have that larger fish are more easily obtained than smaller fishes. This he contributes to the fact that the larger fish are more easily seen than the small fish.

Loeb (1958) estimating populations in New York lakes discovered that after three weeks too many marked fish were being captured. Explanations for this were that marked fish were more susceptible to shocking than unmarked fish, the marked fish may have been weakened by the original capturing process or that the marked fish returned to the shoreline where they were originally captured instead of randomly mixing with the population.

Electrofishing was deemed impractical (Larimore et. al. 1950) in soft water, since the efficiency of the electrical field was greatly reduced, and in turbid waters where shocked fish were difficult to see. Larimore et. al. also noted that some species tend to move ahead of the boat and are not shocked unless cornered.

The density of the population, floatation rate of various species and the depth distribution of the fish all influence the collection of fishes by electrofishing (Vibert 1967).

Cross and Stott (1975) using the Delury regression method by marking fish instead of removing them found that even though the population was not physically reduced the total number of fish caught on each sampling period decreased. Using a pulsed direct current shocker it was determined that the decrease in catch was due to unmarked fish being caught more readily. The decrease in availability of unmarked fish to capture occured during the first or second exposure to electrofishing.

This decrease in availability results in a small population actually being sampled.

Electrofishing is a practical method of sampling fish populations since it does not kill, effect spawning, or impede the growth of fishes (Vibert 1967).

SEINING

The use of seines to capture fish may be done parallel to the shore or from offshore to onshore. The most common seines used are the trailering bag seine, straight seine and minnow seine. Trailering bag seines are generally thirty feet long, six feet deep with 0.5 inch square mesh forming the wings of the seine with a bag eight feet long of 0.25 inch square mesh trailing behind in the middle. This seine, like all seines, has a buoyant float line on top to prevent the top of the seine from becoming submerged and a weighted bottom line so the bottom of the net will remain on the bottom of the body of water.

Straight seines are generally ten feet long, six feet deep with 0.25 inch square mesh. Minnow seines have small mesh, 0.125 inch, and are six to twenty feet long and four feet deep. Seines are usually operated by two or more men pulling the seine through the water by poles attached parallel to the mesh at the ends. Seining results are best when the water used is no deeper than two thirds the height of the net since this prevents fish swimming under or over the net (Lagler 1956, 1971).

The efficiency of seining can be increased by choosing the proper habitat, seining after dusk, seining with the current in sluggish streams and by adding an apron to the weighted line to prevent fish from moving out of the net at the bottom (Lagler 1971).

Carlander and Moorman (1956) indicated that seines were not effective for making population estimates of bass populations since the seine is not an effective device for capturing bass and once captured they are difficult to recapture.

Krumholtz (1951) found that minnow seines often do not reveal all the kinds of young fish present in a pond while Carlander and Lewis (1948) indicate that seining is relatively free from selectivity of certain species of fishes.

The usefulness of seines for capturing fish (Fredin 1950) is that they take larger samples of fish in a shorter period of time than most sampling gear and they are less selective as to species and size of fish caught. Fredin (1950) and Fessler (1950) also indicated that bass were difficult to capture since they would jump over the seine if it wasn't kept high out of the water.

Buck and Thoits (1965) indicated, like Fredin, that seining offers a less time consuming method of sampling fish than other methods despite its inadequacies. In their studies on ponds, they found that perch estimates were too high due to the tendancy of the perch to avoid recapture. Smallmouth bass, largemough bass, brown bullhead and bluegill population estimates were too low due to a disproportionately high number of recaptures. Because of the inadequacies of seining in obtaining unbiased results, they conclude that the seine should not be used for capture-recapture population estimates.

Studying carp, Beukema and DeVos (1974) found that seines were not selective for different sizes of carp. Throughout the study, the catch per seine haul decreased rapidly and marked individuals were more prone to capture than unmarked individuals. This resulted, as is the usual case with this capturing method, in population estimates that were too low.

HOOP NETS

Hoop nets are made of exterior webbing that is tied, in the shape of a cone to the inside of five hoops. The hoops, made of wood or metal vary in size with the first hoop being the largest, the last the smallest with the others of intermediate sizes. The hoops are spaced equally apart at a distance of about one meter each. Two funnel shaped throats are attached to the interior of the net. The first throat is attached peripherally at the front hoop and posteriorly at the third while the second throat is attached to the third and fifth hoops. The size of the hoops and mesh are variable, depending on the size of fish being captured (Lagler 1971).

Hoop nets can be extremely effecient or selective depending on the species involved. Efficiency depends on the species and whether the nets are set parallel or perpendicular to the shore. These nets are generally set in water about equal in height to the diameter of the first hoop. When set in deeper water the nets are baited to attract fish. Baiting or fishing during spawning seasons increase the efficiency of hoop nets (Lagler 1971). Barnickol and Starrett (1951) indicate that hoop net efficiency decreases during the warm months of the year.

Fish are caught in hoop nets due to their own movements. This may be due to the net being in the exact path of movement of the fish, the fish may be captured when they try to get by the wings of the net or certain fish may be attracted to the enclosure just as they are attracted to hollow logs, bank holes or submerged brush. Fish entering the front compartment move about until they either escape or pass through the second funnel. Fish passing into the rear portion of the net are less likely to escape due to the smaller diameter of the rear hoops and the throat camouflaging the hoops (Hansen 1944).

Fish escaping from hoop nets have been described by Waters (1960) who noted that small fish were sometimes gilled in the mesh of the net and were observed at times to escape. Hansen (1944) testing the rate of escape of fish from hoop nets found that bluegills and largemouth bass escape from hoop nets often and with great ease. Turbid conditions apparently have no affect on how successfully a fish escapes from a hoop net though Hansen postulated that there is some turbidity threshold that would limit the number of escapes.

Schumacher and Eschmeyer (1943) found hoop nets to be highly selective to species, location and time of day. Certain species of fish abundant in the pond were captured infrequently while others not abundant were captured frequently. Crappies, bullheads and common suckers were easily captured while carp, buffalo and shad even though they were abundant were not captured easily. Those fish most readily captured were the same ones most readily recaptured. This resulted in errors in indicating the relative abundance of each species in the pond. The possibility of determining the extent of selectivity was expressed and would allow accurate estimates of relative abundance. The locations of nets were selective in that even though all species were present throughout the lake they tended to concentrate in general areas, resulting in certain nets capturing more of a certain species than others. The time of day influenced the efficiency of the nets in regards to various species. Bluegills, bass and redhorse were captured more frequently during the day while crappies, buffalo and bullheads were captured more frequently at night.

Lagler and Ricker (1943) indicate similar selectivity of the hoop net which led to an inaccurate estimate of the relative abundance of fishes in a pond.

Krumholz (1951), realizing the selectivity of hoop nets, used nets of four different mesh sizes. Indicating that fish may react negatively to darkness and therefore avoid nets darkened by small mesh, his use of different mesh sizes, each catching different sizes and species of fish, would allow for a more reliable estimate. Krumholz also indicated that fish less than 45 mm in length could pass through the mesh and could not be captured.

Studying carp capture, Beukema and DeVos (1974) found that certain carp were hoop net shy and others were prone to capture in hoop nets. This variation to capture was related to size, with the smaller carp being more prone to capture than larger carp. Conversely, Latta (1959) has shown that these nets are selective for larger fish, not smaller fish, above the minimum size imposed by the physical dimension of the net. This selectivity was attributed to the behavior of the fish.

Waters (1960), using hoop nets, obtained capture-recapture estimates that were too low. This was due to marked individuals being recaptured too frequently. This was attributed to some individuals being more susceptible to trapping than others. He concluded that capture-recapture estimates are not valid when used with hoop nets because the estimates produced are too low.

GILL NETTING

Gill nets are composed of nylon mesh and twine to form a single wall of fabric. The net, with floats on the top line and weights on the bottom, is hung loosely in the water so that the mesh openings are of a vertically elongated diamond shape rather than square. Typical nets consist of various different mesh sizes and may be set on the bottom or at various other depths (Lagler 1956, 1971).

Fish may become captured in a gill net by becoming wedged, gilled or tangled. A fish becomes wedged when it becomes held tightly by a mesh around the body. A gilled fish cannot escape because it cannot back out of the net due to being caught behind the gill covers. Tangling results when a fish is held by the teeth, maxillaries or other projections without having penetrated the mesh. Wedging and gilling are related to mesh size while tangling is not. Small fish can swim through the mesh while large fish do not penetrate far enough to be gilled. This indicates that the smallest fish caught have maximum girth while the largest captured have their head girth equal to that of the mesh perimeter. Fish of intermediate sizes are held due to the presence of the net not allowing them to back out and to their inability to swim with enough force backwards. The methods of capture by gill net indicate the importance of mesh size on gill net selectivity (Hamley 1975).

Net visibility also plays an important role in gill net selectivity (Hamley 1975). The visibility of the nets is related to the thickness of the twine and the color of the net. Fish generally avoid nets due to visual cues although lateral line detection may also play a role (Hamley 1975).

Jester (1973) indicates that white nets catch more fish than colored nets. Colored nets are selective with regards to species and can be used to select the species or group of fishes the investigator wants to collect. Brown nets catch more smallmouth, buffalo, carp, and river carpsucker along with fewer gizzard shad, channel catfish and white bass than any other colored net. Orange nets are most efficient in capturing small sunfish while large largemough bass were taken most often with yellow nets.

Thinner gill nets catch more fish than thicker ones. The thinner the net is, the more flexible, stretchable and less visible it is to the fish. The more flexible and stretchable the net, the larger amounts and sizes of fish will be caught as long as the twine does not break. Visibility has a size threshold below which all sizes of twine are equally invisible to fish (Hamley 1975). The twine, whether it is monofilament, nylon or cotton, has no real affect on the overall efficiency of the nets (Hogman 1973).

The selectivity of gill nets to select smaller fish is apparently due to the fact that visual sensitivity and acuity improves as fish grow due to the density of cones in their eyes declining less rapidly than the image area increases (Hamley 1975).

Net selectivity and efficiency can also result from where the net is placed since certain species and sizes of fish inhabit different areas. Net saturation effects efficiency in that as more fish are captured the efficiency rate decreases. Mesh size affects efficiency since smaller mesh sizes, being less efficient must have their surface areas correspondingly larger to have the same efficiency as larger mesh nets.

Moyle (1949) and Carlander and Cleary (1948) indicate that sampling with a gill net is not random because the catch is influenced by the movements of the fish, shape of the fish and the groupings of the fish. Along with this Carlander (1953) shows that certain species of fish are more susceptible to capture than others. Largemouth bass, crappies and sunfishes all avoid gill nets. In addition the visual ability of different species is variable so some fish will be more apt to be captured during the day rather than at night when the nets become less visible (Carlander and Cleary 1949).

Carlander (1953) indicates that probably gill nets do not give a measure that will indicate the realtive abundance of different species.

INTRODUCTION

Successful fisheries management requires the accurate determination of the community structure within a body of water. Population estimates of the species size classes are fundamental in this determination. Capture-recapture procedures, commonly used to estimate fish population sizes, have been developed by Peterson (1896), Schnabel (1938), Schumacher and Eschmeyer (1943) and Chapman (1954). These procedures are based on mathematical models which assume entirely random unbiased sampling. Assumptions necessary for recapture procedures to be valid have been discussed by Ricker (1948, 1958). The consistent inaccuracy of these procedures is due to the inability of these assumptions to function in field situations. This failure arises primarily due to the heterogeneity to capture among different individuals in the population. Heterogeneity to capture is found in marked individuals, different sized individuals and different species.

The capture of marked fish in numbers not proportional to their true abundance is the most common source of bias (Ricker 1958; Beukema and DeVos 1974). Disproportional numbers of recaptures result from behavioral or physical limitations brought about by previous capture or from the disproportional sampling of areas within the body of water. Fredin (1950), Beukema and DeVos (1974) and Westers (1963) have indicated that double method procedures which involve recapturing with a different sampling method than originally used, diminish the bias of disproportionate recapture of marked fish.

The differential vulnerability to capture of species and size groups also results in estimation errors since sampling procedures are selective for different species and sizes.

This study involved the estimation of fish populations based on a series of sampling procedures. Hoop nets, gill nets, seining and electroshocking were utilized in single and multiple evaluation procedures. Elimination of estimation errors due to differential vulnerability and disproportionate recapture of marked individuals was accomplished with multiple evaluation procedures.

MATERIALS AND METHODS

The study took place between March 17 and May 3, 1976 at Lincoln Log Cabin Pond (fig 1). The pond, located at Lincoln Log Cabin State Park, eight miles south of Charleston, Illinois in Coles County, is 0.24 hectares (0.6 acres) in size with an average depth of 1.8 meters and a maximum depth of 3.7 meters. The pond is bordered on the west by willows, Salix sp., the east by the dam, overgrown with multiflora rose, Rose multiflora, and to the north and south by cleared picnic areas. The predominate aquatic vegitation is composed of Elodea and Spirogyra, with Spirogyra being dense enough at times to make seining difficult. Fish were captured by seining, electroshocking, gill netting and hoop netting. Captured fish were marked, measured and released at the end of the pier (fig. 1).

Shocking took place three times a week for a total of 14 sampling trips during the study. Shocking was accomplished with a 220 volt alternating current generator with three copper electrodes mounted on a 14-foot john boat propelled by a seven horsepower motor. Individual sampling periods consisted of slowly driving the boat along the edge of the pond and weed beds for a 45 minute period. Two workers in the front as well as the driver were equipped with dip nets to capture the stunned fish. Fish captured by electroshocking were marked by clipping off the left pectoral fin.

Seining was done three times a week for a total of 13 sampling trips. Seining was done with a 6.1 by 1.2 meter (20 by 4 foot) minnow seine with 0.64cm (0.25 inch) mesh. Individual sampling periods consisted of six seine hauls which sampled the entire shoreling except for the east side (dam) which was unseineable due to the depth and the many fallen trees in the water there. Fish captured by seining were marked by clipping off the right pectoral fin.

Hoop net sampling occurred on 36 occasions. Two 0.9 meter (3 foot) diameter, 2.54 cm (1 inch) mesh hoop nets were used in conjunction with two 4.5 by 1.2 meter (15 by 4 foot) leads placed directly at the middle of and parallel to the front hoops. The nets were checked every 24 hours and were placed randomly in all but the deepest portions of the pond where the leads could not be anchored to the bottom. Fish captured in hoop nets were marked by removing the left pelvic fin.

Gill netting occured on 36 occasions and was accomplished by using a 100 foot (30.5 meter) gill net consisting of four 25 foot (7.6 meter) panels of 1, 2, 3, and 4 inch (2.5, 5.1, 7.6, and 10.1 cm) mesh. The net was placed randomly in the pond and tied to trees at the shoreline. The net was long enough to cover the entire width of the pond at most spots and was checked every 24 hours. Fish captured in this net were marked by removing the right pelvic fin.

Population estimates were made using the Schnabel (1938) and Schumacher and Eschmeyer (1943) formulas. Confidence intervals used were those of Robson and Regier (1971) and Schumacher-Eschmeyer (1943). Estimates were made for each species for the size groups 5-10.1 cm

(2-4 inches), 10.1-15.2 cm (4-6 inches) and 15.2 cm (6 inches) or larger. Fish under 5 cm (2 inches) were not included. Estimates were made by single method procedures for each sampling method and for multiple methods. The multiple methods involved the capture and recapture of fish by two or more methods simultaneously. Multiple methods used were hoop and gill net; hoop net and shocking; hoop net and seining; gill net and seining; seining and shocking; hoop net, gill net, and seining; hoop net, seining, and shocking; hoop net gill net, and shocking; gill net, seining and shocking and all four methods.

The total population was determined by draining the pond to the one meter level and then seined with a 21 meter (70 foot) trailing bag seine. The seine covered most of the drained pond and was used until only 2-3 small fish were being consistently captured indicating that only a few fish were not counted. The fish were held in holding tanks until they could be measured and counted. Micropterus salmoides and Lepomis microlophus were returned to the pond, while the other species were not, as a management procedure.

Physical parameters measured were temperature, turbidity, dissolved oxygen and hardness. Temperature and dissolved oxygen measurements were taken each sampling period with a portable YSI dissolved oxygen meter. Turbidity and hardness were measured using the Hach Model DR-EL/2 Direct Reading Engineers Laboratory.

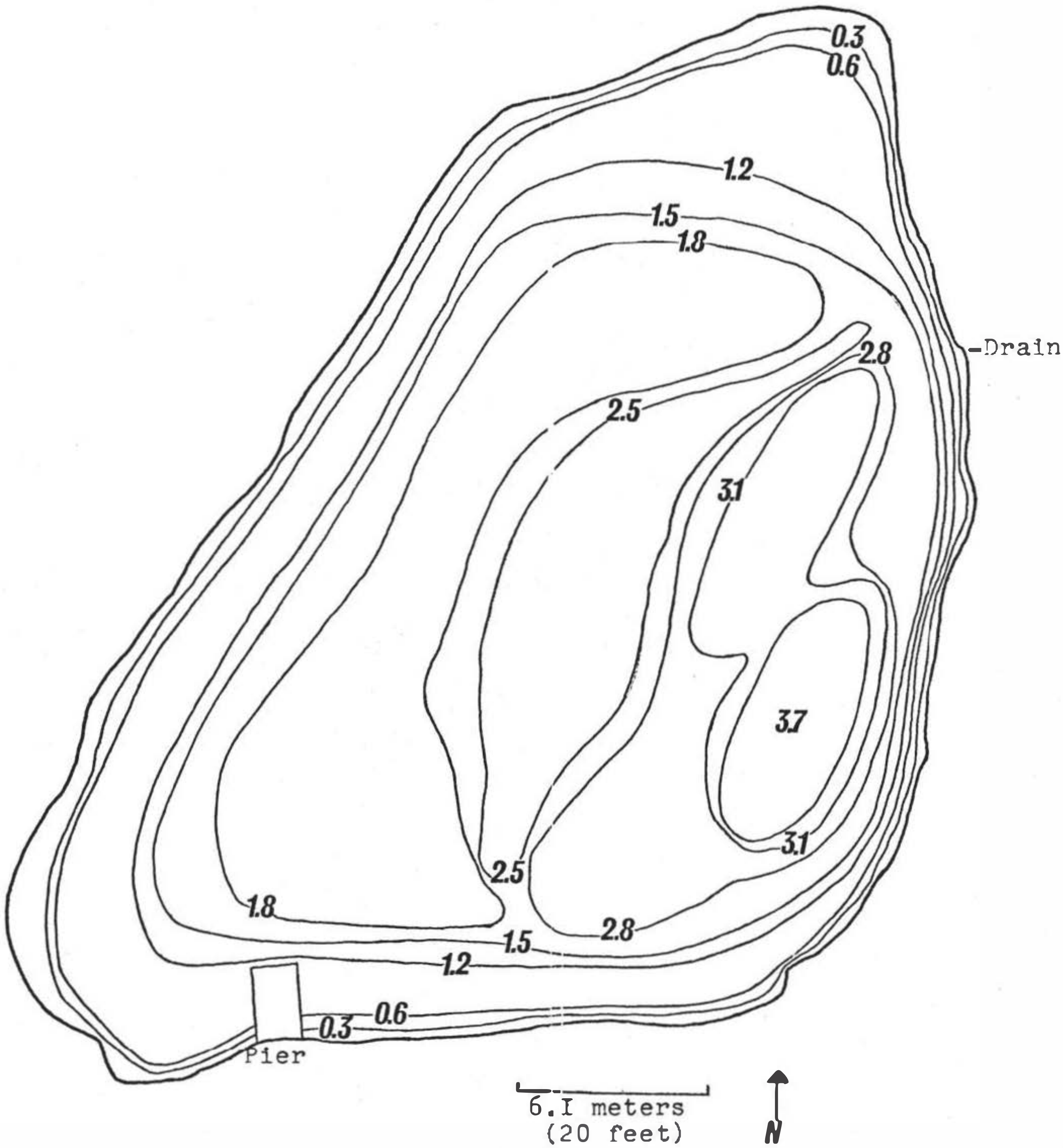

Fig. I. Map of Lincoln Log Cabin Pond, May I976
NE I/4, SW I/4, Sec. 2I, TIIN, R9E Coles County, Illinois
Contour lines in meters

RESULTS

The mean water temperature during the study was 14.2^{o}C with a low temperature of 10.8^{o}C and a high of 21.0^{o}C. Dissolved oxygen concentrations ranged from 6.0 to 12.9 ppm with an average of 9.6 ppm. Turbidity ranged from 3.0 to 40.0 J. T. U. with a mean of 17.6. The total hardness was 150 mg/L.

The species composition of the pond, determined by the pond drainage, consisted of Lepomis microlophus, Lepomis cyanellus, Micropterus salmoides, Pomoxis nigromaculatus, Notemigonus crysoleucas and Semotilus atromaculatus. Individuals of all these species were captured during the sampling period with the exception of Notemigonus crysoleucas and Semotilus atromaculatus which were represented in the population by single individuals. The predominate species in the pond were L. microlophus, L. cyanellus and M. salmoides. The P. nigromaculatus population consisted of six large individuals that were consistently sampled by the hoop nets (Table 10).

Lepomis microlophus were sampled most effectively by hoop nets and electroshocking (Tables 2, 3). Small L. microlophus were captured by electroshocking and seining only, with no recaptures occurring (Table 1). The larger L. microlophus (Tables 2, 3) were captured by all methods. The largest individuals were sampled most frequently by hoop nets with the most accurate population estimates coming from the multiple sampling with hoop nets and electroshocking (Table 3). Intermediate sized L. microlophus were captured most effectively with hoop nets and electroshocking (Table 2). The effectiveness of these methods resulted in the most accurate estimates for this population occurring from the single method procedures involving the two techniques, and the multiple method of using both electroshocking and hoop netting together (Table 2).

Micropterus salmoides were captured primarily by electroshocking and seining. Only two specimens were captured with the gill net and none were captured with the hoop nets (Tables 4, 5, 6). Small bass (Table 4) were captured extensively by seining and electroshocking with the most accurate population estimates arising from the multiple methods of seining and electroshocking as well as gill net, seine and electroshocking. The large bass were most effectively sampled and estimated by electroshocking (Table 6) while the intermediate sized bass were not recaptured successfully as is indicated by the single recapture resulting from the multiple method of seining and electroshocking (Table 5).

Lepomis cyanellus were not captured frequently by the gill net and only the small *L. cyanellus* were captured effectively by seining (Tables 7, 8, 9). Electroshocking proved to be the most generally effective sampling method for capturing all the size groups (Tables 7, 8, 9). Hoop netting was the only effective sampling technique for the larger specimens (Table 9). The sampling of small *L. cyanellus* resulted in erroneous estimates and few recaptures with any of the capture procedures (Table 7). Intermediate sized *L. cyanellus* were sampled by all capture techniques with both multiple and single procedures yielding similar results (Table 8).

Fish were captured regularly throughout the sampling period with the exception of *L. microlophus* which were not captured by seining or shocking after April 10, 1976. *L. microlophus* was taken, however, regularly by hoop netting throughout the sampling period. All other species were taken throughout the sampling period with those procedures effective to the particular species.

Capture-recapture procedures are based upon six assumptions discussed by Ricker (1948, 1958): (1) The assumption that both marked and unmarked individuals undergo the same mortality is difficult to determine. It is believed that this assumption held true since no dead or injured fish were found during the sampling and released fish swam away showing no ill effects. This observation is substantiated by Ricker (1949) who indicated that spiny rayed fish over 5 inches long were not unfavorably effected by fin clipping. (2) Loss of marks did not occur since the duration of the sampling was not long enough for regeneration of the fins to occur to prevent mark recognition. (3) All recaptures were reported since the clipped fins were easily recognizable and all fish were examined by the same investigator throughout the sampling period. (4) Recruitment of new individuals was negligible due to the lack of any spring associated with the pond and a minimum amount of fishing pressure during the sampling period. (5) Random mixing of marked and unmarked fish in the population apparently held true. The small size of the pond and the centralized release point allowed for the random mixing of marked and unmarked fishes. (6) The assumption that marked and unmarked fish are equally vulnerable to capture is difficult to detect. Electroshocking registered few recaptures compared to the number captured, with the exception of large M. salmoides (Table 6). Apparently marked individuals were less vulnerable to capture by electroshocking than unmarked fish. Small L. microlophus (Table 1), L. cyanellus (Table 7) and intermediate M. salmoides (Table 5) were not recaptured frequently. Multiple methods and hoop nets provided good numbers of recaptures (Tables 2, 3, 5, 8, 9, 10) with the exception of small M. salmoides (Table 4) indicating that marked and unmarked individuals were equally vulnerable to capture.

TABLE 1. POPULATION ESTIMATES FOR <u>Lepomis microlophus</u> 5-10.1 cm. in length.

Lincoln Log Cabin Pond, Coles County, Illinois. Spring 1976.

Actual population size 88.

SAMPLING PROCEDURE	NUMBER MARKED	NUMBER RECAPTURED	SCHUMACHER ESCHMEYER POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE	SCHNABEL POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE
ELECTROSHOCKING	11	0	-	-	-	-
HOOP NET	0	0	-	-	-	-
GILL NET	0	0	-	-	-	-
SEINING	15	0	-	-	-	-

TABLE 2. POPULATION ESTIMATES FOR _Lepomis microlophus_ 10.1-15.2 cm in length.

Lincoln Log Cabin Pond, Coles County, Illinois. Spring 1976.

ACTUAL POPULATION SIZE 94.

SAMPLING PROCEDURE	NUMBER MARKED	NUMBER RECAPTURED	SCHUMACHER ESCHMEYER POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE	SCHNABEL POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE
ELECTROSHOCKING	23	2	86±58	8.5	135±191	43.6
HOOP NET	51	14	88±24	6.4	121±65	28.7
GILL NET	1	0	-	-	-	-
SEINING	5	0	-	-	-	-
HOOP AND SHOCK	69	24	96±18	2.1	119±48	26.6
HOOP AND GILL	49	14	90±18	4.2	109±58	16.0
HOOP AND SEINE	52	17	80±16	14.9	109±53	16.0
GILL AND SEINE	6	0	-	-	-	-
GILL AND SHOCK	23	2	86±30	8.5	134±190	42.6
SEINE AND SHOCK	31	3	112±57	19.1	135±156	43.6
HOOP, GILL, SEINE	53	17	83±13	11.7	114±55	21.2
HOOP, SEINE, SHOCK	65	35	65±4	30.8	90±30	6.4
HOOP, GILL, SHOCK	69	24	93±13	1.06	132±54	40.4
GILL, SEINE, SHOCK	32	3	125±48	33.0	187±216	99.0
ALL FOUR METHODS	66	35	67±3	28.7	94±32	0

TABLE 3. POPULATION ESTIMATES FOR Lepomis microlophus 15.w cm or longer in length. Lincoln Log Cabin Pond, Coles County, Illinois. Spring 1976. ACTUAL POPULATION SIZE 66.

SAMPLING PROCEDURE	NUMBER MARKED	NUMBER RECAPTURED	SCHUMACHER ESCHMEYER POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE	SCHNABEL POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE
ELECTROSHOCKING	7	0	-	-	-	-
HOOP NET	21	7	36±9	45.4	46±35	30.3
GILL NET	1	0	-	-	-	-
SEINING	0	0	-	-	-	-
HOOP AND SHOCK	26	9	40±32	39.4	58±39	12.1
HOOP AND GILL	21	7	36±9	45.4	46±35	30.3
GILL AND SHOCK	8	1	15±8	77.3	22±44	66.7
HOOP, GILL, SHOCK	27	9	43±6	34.8	57±38	13.6

TABLE 4. POPULATION ESTIMATES FOR *Micropterus salmoides* 5-10.1 cm in length.

Lincoln Log Cabin Pond, Coles County, Illinois. Spring 1976.

ACTUAL POPULATION SIZE 117.

SAMPLING PROCEDURE	NUMBER MARKED	NUMBER RECAPTURED	SCHUMACHER ESCHMEYER POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE	SCHNABEL POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE
ELECTROSHOCKING	24	1	168±93	43.6	252±504	115.4
HOOP NET	0	0	-	-	-	-
GILL NET	1	0	-	-	-	-
SEINING	34	7	74±20	55.6	97±73	38.5
GILL AND SEINE	34	0	-	-	-	-
GILL AND SHOCK	24	2	94±43	18.5	157±222	34.2
SEINE AND SHOCK	52	8	124±51	6	176±124	50.4
GILL, SEINE, SHOCK	53	9	120±25	2.6	178±119	52.1

TABLE 5. POPULATION ESTIMATES FOR *Micropterus salmoides* 10.1-15.2 cm in length.

Lincoln Log Cabin Pond, Coles County, Illinois. Spring 1976.

ACTUAL POPULATION SIZE 57.

SAMPLING PROCEDURE	NUMBER MARKED	NUMBER RECAPTURED	SCHUMACHER ESCHMEYER POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE	SCHNABEL POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE
ELECTROSHOCKING	19	0	-	-	-	-
HOOP NET	0	0	-	-	-	-
GILL NET	0	0	-	-	-	-
SEINING	5	0	-	-	-	-
SEINE AND SHOCK	24	1	171 ± 22	140	248 ± 496	289.5

TABLE 6. POPULATION ESTIMATES FOR *Micropterus salmoides* 15.2 cm or longer in length.

Lincoln Log Cabin Pond, Coles County, Illinois. Spring 1976.

ACTUAL POPULATION SIZE 48.

SAMPLING PROCEDURE	NUMBER MARKED	NUMBER RECAPTURED	SCHUMACHER ESCHMEYER POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE	SCHNABEL POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE
ELECTROSHOCKING	19	4	42±23	12.5	55±55	14.6
HOOP NET	0	0	-	-	-	-
GILL NET	1	0	-	-	-	-
SEINING	1	0	-	-	-	-
GILL AND SEINE	2	0	-	-	-	-
GILL AND SHOCK	19	4	38±4	20.8	50±50	4.2
SEINE AND SHOCK	20	4	137±58	185.4	60±60	25.0
GILL, SEINE, SHOCK	19	5	41±7	14.6	55±49	14.6

TABLE 7. POPULATION ESTIMATES FOR *Lepomis cyanellus* 5-10.1 cm long.

Lincoln Log Cabin Pond, Coles County, Illinois. Spring 1976.

ACTUAL POPULATION SIZE 463.

SAMPLING PROCEDURE	NUMBER MARKED	NUMBER RECAPTURED	SCHUMACHER ESCHMEYER POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE	SCHNABEL POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE
ELECTROSHOCKING	18	1	92±64	80.1	148±296	68.0
HOOP NET	5	0	-	-	-	-
GILL NET	0	0	-	-	-	-
SEINING	43	3	199±180	57.0	256±296	44.7
HOOP AND SHOCK	20	1	103±18	77.8	168±336	63.7
HOOP AND SEINE	48	3	220±99	52.5	327±378	29.4
SEINE AND SHOCK	60	6	196±122	59.7	298±243	39.6
HOOP, SEINE, SHOCK	62	6	206±56	55.5	313±256	32±4

ACTUAL POPULATION SIZE 294.

SAMPLING PROCEDURE	NUMBER MARKED	NUMBER RECAPTURED	SCHUMACHER ESCHMEYER POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE	SCHNABEL POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE
ELECTROSHOCKING	8	1	20±7	93.2	30±60	89.5
HOOP NET	26	6	58±22	80.3	67±55	77.2
GILL NET	2	0	-	-	-	-
SEINING	4	0	-	-	-	-
HOOP AND SHOCK	32	10	45±8	84.6	68±43	76.9
HOOP AND GILL	28	6	50±26	83.0	79±64	73.1
HOOP AND SEINE	29	7	50±11	83.0	72±54	75.5
GILL AND SEINE	6	0	-	-	-	-
GILL AND SHOCK	9	2	14±2	95.2	20±28	93.2
SEINE AND SHOCK	12	1	48±20	83.6	70±140	76.2
HOOP, GILL, SEINE	29	8	41±6	86.0	64±45	78.2
HOOP, SEINE, SHOCK	34	11	46±8	84.3	69±42	76.5
HOOP, GILL, SHOCK	35	6	81±18	72.4	125±102	57.5
GILL, SEINE, SHOCK	15	2	40±10	86.4	52±74	82.3
ALL FOUR METHODS	36	13	43±4	85.4	66±37	77.6

TABLE 9. POPULATION ESTIMATES FOR *Lepomis cyanellus* 15.2 cm or longer in length.

Lincoln Log Cabin Pond, Coles County, Illinois. Spring 1976.

ACTUAL POPULATION SIZE 26.

SAMPLING PROCEDURE	NUMBER MARKED	NUMBER RECAPTURED	SCHUMACHER ESCHMEYER POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE	SCHNABEL POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE
ELECTROSHOCKING	7	0	-	-	-	-
HOOP NET	17	5	22 ± 4	15.4	34 ± 30	30.7
GILL NET	0	0	-	-	-	-
SEINING	0	0	-	-	-	-
HOOP AND SHOCK	20	8	32 ± 5	23.1	36 ± 25	38.5

TABLE 10. POPULATION ESTIMATES FOR *Pomoxis nigromaculatus* 15.2 cm or longer in length. Lincoln Log Cabin Pond, Coles County, Illinois. Spring 1976. ACTUAL POPULATION SIZE 5.

SAMPLING PROCEDURE	NUMBER MARKED	NUMBER RECAPTURED	SCHUMACHER ESCHMEYER POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE	SCHNABEL POPULATION ESTIMATE	PERCENTAGE ERROR OF SCHUMACHER ESCHMEYER ESTIMATE
ELECTROSHOCKING	0	0	-	-	-	-
HOOP NET	6	12	4.7 ± 0.42	6.0	6.0 ± 3.5	20.0
GILL NET	0	0	-	-	-	-
SEINING	0	0	-	-	-	-

DISCUSSION

The differential vulnerability of individuals to capture can take many forms, all of which lead to inaccuracies in capture-recapture procedures. Different individuals and size classes as well as species are heterogenious to sampling methods. Capturing methods are themselves selective as to the species and sizes they sample. This, combined with the differential recapture of marked individuals, leads to consistent inaccuracies in population estimates. Differential numbers of recaptures result when marked fish become more or less vulnerable to a particular sampling method. This results from behavioral or physical changes resulting from a previous capture of from the capturing procedure sampling only certain areas of a body of water resulting in the individuals within that area being consistently subjected to sampling pressure. Double method procedures proposed by Fredin (1950), Westers (1963) and Beukema and DeVos (1974) are effective in eliminating the bias of marked individuals being differentially vulnerable to capture. They fail, however, to take into account the heterogeniety to capture of different sizes and species of fish to the particular sampling methods as well as the problem of sampling only those sections of the body of water that those particular sampling methods can adequately sample. Should the two methods involved sample similar areas, there is the distinct possibility that only a particular segment of the population will be sampled. Should the methods be different enough to sample different segments of the population the result may be too few recaptures obtained.

The basic premise behind the multiple method procedure, presented here, involves the simultaneous sampling of all areas of a body of water with several different sampling methods to allow for the capture of most sizes and species of fish. This procedure allows for the recapture of individuals by the same procedure as they were originally sampled, should that method be effective, as well as allowing for the recapturing of those marked individuals which would ordinarily not be recaptured or which would be recaptured in disproportionate numbers by a single method.

In this procedure hoop nets were used to sample those fish having an affinity for the bottom or deeper areas of the pond as well as those which seek deeper water cover. Seining was used to sample those fish in shallow water that were not mobile enough to avoid the seine including many of the smaller individuals of the species present. Electroshocking sampled the shallow water areas as well but also sampled those areas inaccessable to seining and those fish capable of escaping the seine, primarily the larger fish (Fredin 1950; Cooper and Lagler 1956). Larger fish are also more readily shocked than smaller fish (Vibert 1963). Gill nets were used to sample those fish that actively move about from the shallows to deeper water and vice versa. This combination of methods allowed for most areas of the pond and most sizes and species of fish to be sampled.

The multiple method procedures in this study met with mixed success. Single and multiple methods gave both accurate and inaccurate estimates.

Intermediate sized L. microlophus were accurately estimated by hoop nets, electroshocking and many multiple procedures primarily with the use of the Schumacher and Eschmeyer formula, although the Schnabel estimate involving all four methods was exactly correct (Table 2). The efficiency of the Schumacher and Eschmeyer estimates lies in the fact that much of the population was sampled. Table 2 shows this clearly, especially in the multiple procedure of electroshocking and hoop netting. This combination sampled two thirds of the population and recaptured many more individuals than either of the procedures singly. The totally different nature of the sampling techniques and the sampling of entirely different areas of the pond indicates that this population was mobile, moving between deep and shallow water. This movement, and the apparent lower liklihood of recapture by the original capturing method, resulted in more unbiased sampling with the multiple procedures and consequently yielded more accurate results.

The large L. microlophus population was not sampled as effectively as the intermediate sized population so the Schnabel estimate was the more reliable in this situation. Hoop netting and electroshocking were the only effective methods for sampling the population. Electroshocking had a negative influence on recaptures (Table 3). Hoop netting effectively recaptured individuals and the multiple method of hoop netting with electroshocking yielded the most accurate results. This indicates that while hoop nets alone can apparently accurately estimate the population size, the multiple method involving electroshocking increases the efficiency by increasing the sampling of those individuals inhabiting areas with a lot of structure or cover which prevents adequate sampling by hoop nets. The increased numbers allow more potential recaptures by hoop netting, and perhaps in other situations by electroshocking, thus increasing the accruacy of the estimate.

The advantages of multiple methods are clearly shown in the small M. salmoides population (Table 4). Electroshocking and seining both effectively sampled the population but ineffectively estimated the population size while the multiple estimate combining these two capturing techniques was very accurate using the Schumacher-Eschmeyer formula. Since some individuals were sampled by both methods and recaptures were minimal, especially by electroshocking, the indication is that marked individuals were less likely to be captured again with the same apparatus while recapture by the other methods was not affected. This, combined with an increased sample size, led to a better estimate.

Larger M. salmoides (Table 6) was one of the few groups that were accurately estimated by single method procedures. Electroshocking proved to be the only method that could adequately sample these fish. This is apparently due to their size, which makes them more vulnerable to electroshocking, and their habits of being around fallen trees and thick vegetation associated with shorelines (McCann and Carlander 1970; Vibert 1963). The habitat preferences prevent other methods from effectively sampling these areas. Fessler (1950) and Fredin (1950) have shown that seining is ineffective in sampling large M. salmoides while Jester (1973) has indicated the same for gill nets.

Large L. cyanellus (Table 9) were captured only by electroshocking and hoop netting. Hoop netting alone and the multiple procedure of hoop netting and electroshocking yielded accurate estimates. The multiple method, though not as accurate in this study, has merit, primarily due to the increased number of recaptures. This indicates that although electroshocking adversely affected recapture by that method, it did not affect recapture by hoop nets. This theoretically leads to a more varied and larger sample resulting in more accurate estimates.

The small population of P. nigromaculatus was sampled entirely (Table 10). The descrepency in the table resulted from one to the individuals being caught by a fisherman during the study. All individuals were captured at least once and some several times as the larger number of recaptures indicates. Hoop netting provided the only means of sampling these individuals. The marked individuals were obviously not less vulnerable than unmarked fish (if there would have been any) and were possibly more susceptable to capture than unmarked. P. nigromaculatus was apparently captured frequently due to its habits of utilizing brushy areas in deeper water for cover (Huish 1953). The lack of this type of natural cover in the pond made the hoop nets ideal shelter areas for these individuals.

The population of small L. microlophus (Table 1) and L. cyanellus (Table 7) were not successfully estimated. Their small size prohibited them from being captured in the gill net and only the largest individuals in the size group could be captured in the hoop nets. Few recaptures occurred with either single or multiple methods with L. cyanellus and none with L. microlophus. Capture by electroshocking was limited by the small size. Seining, the most efficient capturing procedure, was also ineffective in recapturing. Apparently the small size of these individuals made marking a greater physical handicap than for larger fish allowing excess mortality in the form of predation or disease or, at least had an adverse affect on catchability.

The occurrence of just a single recapture by multiple sampling (electroshocking and seining) indicates why intermediate sized M. salmoides (Table 5) were not accurately estimated. Electroshocking had an adverse affect on catchability. Seining was not highly effective due to the size and mobility of these fish. The need for multiple sampling procedures seems evident by the fact that captured individuals are not proportionately recaptured by single methods and indicates that although ineffective in this study, some system of multiple methods is required to estimate this population.

Intermediate sized *L. cyanellus*, although sampled by all procedures, were inaccurately estimated. Few individuals were captured indicating the Schnabel estimates to be more accurate for the circumstances. Hoop nets proved the most efficient capturing means while the inefficiency of seining and electroshocking are related to size. Apparently these fish were not large enough to be shocked effectively and too large and mobile to be seined effectively. The inaccuracy of the estimate itself arises from too many recaptures for the number of marked fish. Since hoop nets were the only truly effective capturing method, the population was not sampled uniformly. The result was that either those individuals originally captured were more susceptable to the sampling procedure and hence were recaptured too frequently, or, more likely, the non-uniform sampling resulted in only a certain sub-population being effectively sampled. Although all areas were sampled in the pond, the ineffectiveness of most of the capturing procedures accounted for the non-uniform sampling. Multiple methods, however, did substantially increase the number of recaptures indicating that these procedures may have potential for this population.

The success of multiple method procedures lies directly with the role played by the various types of sampling gear. The role played by the sampling gear is in turn influenced by the physical parameters of the water and the habits of the fish species involved.

Electroshocking conditions, with a total hardness of 150 mg/L and the warm water temperatures, were satisfactory for efficient shocking. Any failure of electroshocking to effectively sample the shallow and brushy areas was therefore due to the habits or habitats of the fish with the exception of the smaller ones where size limits their susceptability to capture. The only other fishes not effectively sampled were large L. microlophus (Table 3) and P. nigromaculatus (Table 10). This is due to their affinity to deep water. This affinity to deep water, however, allowed these fish to be easily sampled by hoop nets.

Conditions for passive netting (hoop and gill netting) allow for ample visibility of the nets. The turbidity mean of 17.6 J. T. U. is low enough to indicate there was sufficient clarity for the fish to see the nets. The low turbidity undoubtedly played a role in the effectiveness of the gill netting operation. Centrarchids, being predaceous fish depending on visual cues for obtaining food, have good eyesight (Bennett 1971). This eyesight enables them to effectively avoid capture in gill nets (Jester 1973). Hansen (1944) indicated that low turbidity does not enhance escape from hoop nets but theorizes that there is some limit where escape would be hindered. Though escape evidently occurred from the hoop nets, their efficiency in sampling the intermediate and large L. cyanellus, L. microlophus and P. nigromaculatus was good. Smaller individuals escaped through the mesh, while M. salmoides, having a high association with the shoreline, were not sampled at all.

Physical parameters were apparently conducive to successful seining. Small individuals of all species were sampled most effectively by this method due to their habitat preferences of shallow, weedy water, less developed swimming ability and less accurate eyesight (Hamley 1975).

The obvious advantages of multiple sampling are apparent in this study. The limitations, besides those of the sampling gear themselves, are not so apparent. The most important limitation is the possible effect of one capturing method on a fishes catchability with other methods. The possibility exists that capture by one method may make a fish more or less vulnerable to capture by other methods as well as the original capturing method. Should this occur, the bias of differential vulnerability to capture of marked and unmarked individuals would still be present. The accuracy of the multiple estimates, however, indicates that the methodology is sound, although work is needed to determine the influence of one capturing method on the others.

Multiple as well as single method procedures are limited in that certain individuals, regardless of size or species, are more prone to capture than others. This bias cannot be eliminated but, in this multiple procedure method, its bias can be reduced. This reduction occurs as a result of larger samples being taken by using more methods, and more recaptures occurring due to the removal of recapturing biases. This bias is, therefore diluted and kept to a minimum.

To guarantee uniform sampling of all areas it appears necessary to utilize the different sampling gear in a way to allow for proportional amounts of fishing effort. Whether or not this occurred in this study is unknown. Since the estimates were reasonable accurate it can be assumed that proportional sampling occurred.

The mesh size of the hoop nets can affect the size, kinds and number of fish captured. Different sized meshes need to be tested to determine their effectiveness for different fishes.

The multiple method proposed here has, on the whole, provided accurate and apparently unbiased estimates of the various species in a pond. These estimates have proven the validity of this type of procedure. The sampling of all areas of a body of water by varied procedures allows for all species and sizes of the various sub-populations in the body of water to be sampled. This procedure, effective in this small pond should be of great benefit in larger bodies of water containing larger species combinations and sub-populations. In a situation involving many species, such as a reservoir, the merits for multiple sampling are obvious. The need to determine the population size of the various species rather than one species necessitates sampling with several capturing methods. Large bodies of water include many sub-populations within different species. Those species whose sub-populations are found in similar areas of the body of water could possibly be sampled by single method sampling. Those, however, that inhabit different depths or different habitat types cannot be sampled effectively by single method procedures. The result would be that certain sub-populations would be consistently sampled while others would not be sampled at all. This biased sampling would consequently lead to error. Multiple sampling, however, would allow all species and sub-populations to be adequately sampled while at the same time removing the bias of differential vulnerability to capture.

Multiple methods should be computed using at least two different formulas. This allows for greater accuracy by applying the appropriate formula to the population, based on numbers marked. In this project the Schnabel and Schumacher and Eschmeyer formulas were selected since some populations were sampled better than others. Those populations where 25 to 50% of the population is marked are best estimated by the Schumacher and Eschmeyer formula while the Schnabel estimations are most efficient when only a small portion is marked. They have equal efficiency when 25% are marked (Ricker 1942). In this study the Schumacher and Eschmeyer formula was accurate most often due to the small population sizes. In larger bodies of water the Schnabel formula would probably be most useful but several methods should be used to insure the most accurate estimate for the number of marked individuals obtained.

The use of the four sampling methods in this study indicates that all except the gill net are useful in sampling populations. Carlander (1953) indicated that gill nets probably do not give a measure of the relative abundance of different species. This, along with that fact that centrarchids are poorly captured by gill nets (Carlander 1953), indicates that the gill net should not be used in these procedures. The hardships on the fish being caught in these nets undoubtedly affects recapture as well. Since centrarchids are so common in the sport fishery of the area, gill nets are not useful. Multiple procedures should therefore be carried out using just the three other methods used here or replaced by other devices such as trammel nets where applicable. An improvement in gill net usage for this study would have been to use a yellow instead of a white gill net. This color more effectively captures centrarchids (Jester 1973). Should the species composition of a given body of water be known before sampling (such was not the case in this project) then the best two or more devices can be picked to best sample the species and areas of the body of water.

Improvements that could be made with the procedure used would be the use of a trailing bag seine to more effectively seine the seineable areas and the use of a pulsed direct current electroshocker instead of the alternating current shocker used. This type of shocker is more efficient and has a lesser physiological effect on the fish. This would enable more efficient shocking and perhaps have less of an adverse affect on recapturing susceptibility.

In this study the effectiveness of the different sampling devices singly and in multiple procedures is evident with the exception of the smaller fish. The difficulty in effectively sampling and recapturing these young fish is evident in the data. The need to know the population sizes of these fish is necessary to determine reproductive success and survival within a lake. More work is needed to develop techniques to estimate these fish populations.

Eberhardt (1969) indicated that the equal probability to capture assumption is not fulfilled by usual sampling methods. The multiple method presented here allows the equal vulnerability to capture assumption to become a more realistic assumption.

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