ESTIMATION OF THE ABUNDANCE, BIOMASS AND GROWTH OF A NORTHWESTERN ONTARIO POPULATION OF FINESCALE DACE (*PHOXINUS NEOGAEUS*), WITH COMMENTS ON THE SUSTAINABILITY OF LOCAL COMMERCIAL BAITFISH HARVESTS.

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A thesis submitted to the Faculty of Graduate Studies
of the University of Manitoba in partial fulfillment of the requirements
for the degree of Master of Natural Resources Management.

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Estimation of the Abundance, Biomass and Growth of a Northwestern Ontario Population of Finescale Dace (*Phoxinus neogaeus*), with Comments on the Sustainability of Local Commercial Baitfish Harvests

BY

Jeffrey B. Eddy

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree

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ABSTRACT

The abundance, biomass and growth of the adult fish in a population of finescale dace (*Phoxinus neogaeus*) were estimated using both multiple mark-recapture and removal methods in Lake 115, a small (6.5 ha) bog lake in the Experimental Lakes Area, northwestern Ontario. Mark-recapture data were analyzed by Jolly-Seber death-only and open models. Data from removal methods were analyzed by Leslie, Delury, and Moran and Zippin's methods. The best estimates of the population size were 27 244 fish for the death-only model, 22 745 fish for the open-model, 18 468 fish for the Leslie method, 20 135 for the Delury method, and 19 330 for the Moran and Zippin's method. Biomass estimates were based on the death-only abundance estimate. There was an estimated biomass of 52.0 kg for the entire lake, which translates to 8.0 kg • ha^{-1} for fish in the population over the age of 1+. The majority of Lake 115's finescale dace biomass was calculated to be made up of fish in the 52 to 68mm size class, which is probably composed primarily of age 2+ fish. Growth estimated for finescale dace between May 24th and September 14th 1999 indicated that growth rates varied among age classes, with older fish growing less over the course of the season than younger fish.

Information collected from northwestern Ontario commercial baitfish harvesters suggested that baitfish production in lakes can fluctuate and is based on a wide range of factors, including lake size and depth, physical and chemical characteristics, species assemblages, and weather patterns. Commercial harvesters indicated that they used specific strategies to prevent overharvesting in their baitfish lakes. The use of baitfish blocks, which grants exclusive rights to fish in individual lakes, encourages sustainable resource use by creating a limited-access fishery. More information on the biology, population dynamics and productivity of baitfish species could help increase the sustainability of this industry, while ensuring that any regulations that are put into place, such as those restricting baitfish harvest in waters containing gamefish, are based on actual biological responses.

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TABLE OF CONTENTS

List of Figures

List of Tables

GLOSSARY OF TERMS

Cyprinid: Refers to a fish species belonging to the family Cyprinidae. Cyprinids have jaws without teeth, cycloid scales (overlapping disc-like scales with a smooth, spineless margin), and do not have an adipose fin (Boschung *et al.* 1995).

Fork Length: The length of a fish measured from the tip of the snout to the end of the fin rays in the fork of the tail.

Interspecific: Interactions involving or occurring between two separate species.

Intraspecific: Interactions involving or occurring between members of the same species.

Piscivorous: Having a diet that is composed primarily of fish.

Standard Length: The length of a fish measured from the tip of the snout to the margin of the median (middle) rays of the caudal (tail) fin.

Sustainable/Sustainability: Sustainability can be described as "the ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time" (Dunster and Dunster 1996). Baitfish harvest levels within sustainable limits would not compromise the short or long-term sustainability of the water body that is being harvested from.

Winterkill: A lake that is covered by ice and snow is no longer able to acquire oxygen by wind agitation or photosynthesis. In shallow, organically rich lakes that have limited water flow, respiration and decomposition can consume all of the available oxygen. This can lead to partial or complete fish kills due to lack of oxygen (Greenbank 1945).

Young-of-the-year (YOY): Refers to fish that are in their first year of life (age 0+). In this study young-of-the-year fish were fish that were hatched in the spring of 1999. Individual fish are designated as age 0+ until the January 1st after they have hatched, at this time they are designated age 1+.

1. INTRODUCTION

1.1. Context

The sale of baitfish for sport fishing was conservatively estimated to be worth at least US $29 million to Ontario in 1991 and more than US $1 billion annually in Canada and the United States (Litvak and Mandrak 1993). The effects that this industry has on the ecosystems from which these baitfish are harvested can include: (1) population alteration; (2) trophic alteration; and (3) habitat alteration (Litvak and Mandrak 1993). The removal of unsustainably large portions of the biomass of baitfish populations, which leads to reductions in fish abundance, may also have dramatic long-term consequences (Litvak and Mandrak 1993). These impacts may include shifts in ecological communities leading to reductions in primary productivity and increases in the size and abundance of zooplankton (Litvak and Hansell 1990; Litvak and Mandrak 1993).

1.2. Relevance of Research to Society

Reducing the potential damage that the baitfish industry can have on harvested ecosystems requires the development of a more ecologically sustainable management system. However, because this industry is composed primarily of relatively small-scale independent dealers and operators, developing appropriate regulations and determining the levels at which specific waterbodies are affected is extremely difficult (Litvak and Mandrak 1993). To make reliable management decisions, more research needs to be conducted on the effects of baitfish harvesting on aquatic ecosystems, on the basic biology of harvested species, on the trophic roles of forage-fish in their natural habitats, and on the population dynamics of harvested baitfish species (Litvak and Mandrak 1993).

1.3. Research Opportunity

This study was conducted in The Experimental Lakes Area (ELA), which is located 52 km east southeast of Kenora, Ontario (Figure 1.1), at 93°30′-94°00′W, 49°30′-49°45′N (Brunskill and Schindler 1971). The ELA is a unique facility where research on freshwater ecosystems is conducted on lakewide scales.

Lake 115 is a 6.5-hectare first-order lake (no other lakes are upstream from it), with a maximum depth of 1.5 m located in the Experimental Lakes Area. Finescale dace (*Phoxinus neogaeus*), which is a preferred species for a number of local commercial baitfish harvesters, are the dominant fish species present (several pearl dace (*Margariscus margarita*) were captured during this study, but made up less than 0.1% of the total catch). The near absence of other fish competitors or predators makes it possible to more accurately determine the population size, growth and biomass of this species, as this reduces the effects of interspecific resource partitioning and predation (by piscivorous fish) on estimates. The data that have been collected will also provide valuable background information for any future experiments that are conducted in Lake 115 or lakes of similar character. This project fits in well with the ELA objectives of characterizing fish populations in ELA lakes and was greatly facilitated by the expertise available at the ELA in small fish mark-recapture.

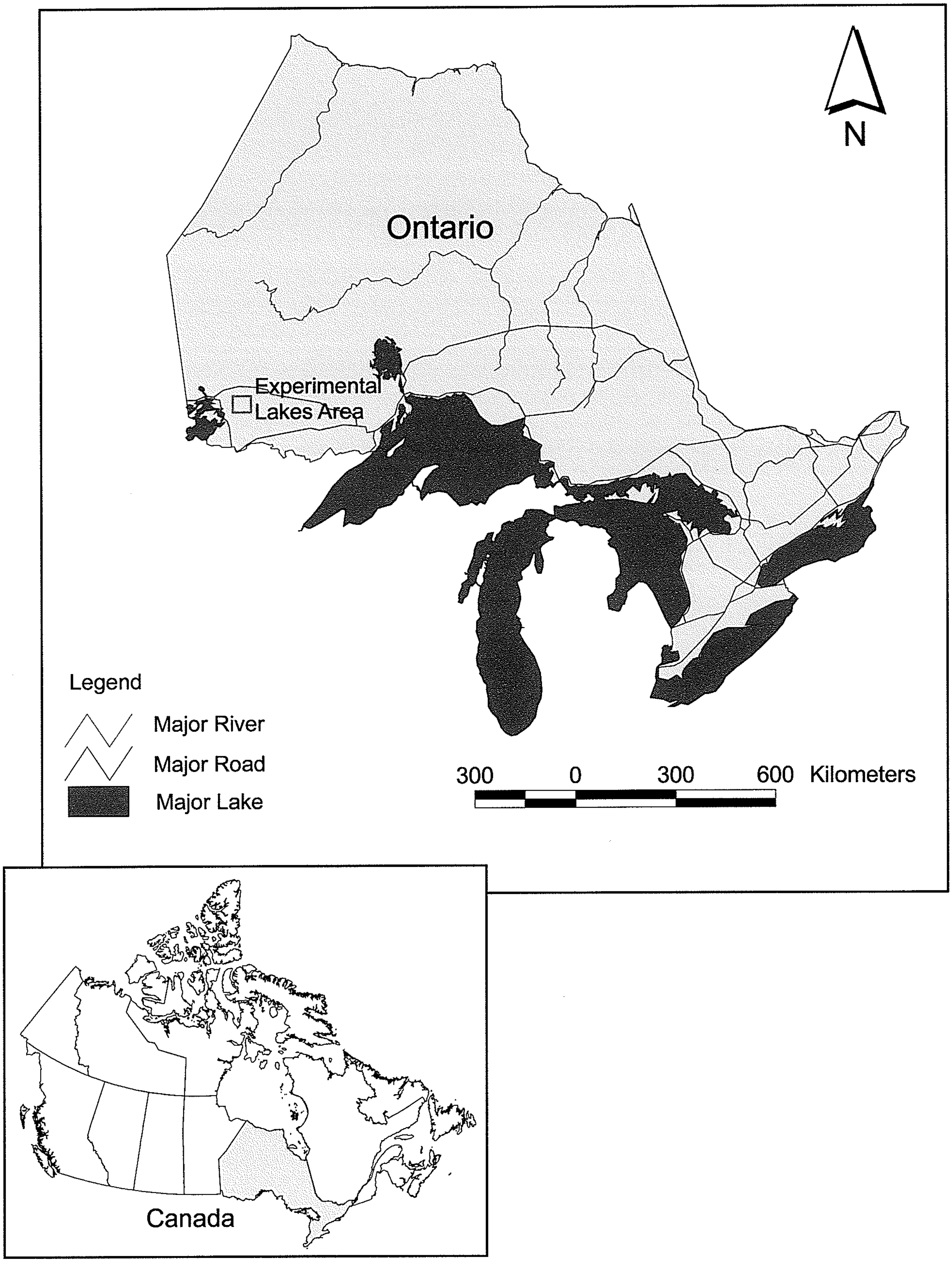

Figure 1.1: Experimental Lakes Area location map.

1.4. Research Objectives

There were two goals to this project. The first was to collect and present original data on the abundance and biomass of finescale dace, an important baitfish species, in a boreal lake. The second goal was to place these data in the context of the northwestern Ontario baitfish industry. These goals have been achieved by addressing the following objectives:

1. To estimate the abundance, biomass, and growth of finescale dace in ELA's Lake 115. This information will also provide background data for future experiments in Lake 115 or lakes of similar character.
2. To link abundance and biomass estimates of the finescale dace population of Lake 115 with data gathered from local baitfish harvesters.
3. To examine the fishing practices and harvest strategies of the northwestern Ontario baitfish industry.
4. To discuss the ecological sustainability of the baitfish industry in the context of abundance, biomass and growth estimates, in addition to data collected from local baitfish harvesters.

1.5. Methods

Collection of Biological Data:

Population estimates were determined using both multiple mark-recapture and removal methods. For multiple mark-recapture, fish were captured in 40 unbaited Gee® brand cylindrical minnow traps (22 x 46cm) distributed systematically along the shoreline for five biweekly sampling periods (Table 1.1). Fish were removed from traps and lightly anesthetized with MS-222 (Tricaine Methane Sulfonate) to sedate them for measuring and marking. This reduced fish handling time, and therefore fish stress.

Each fish captured in the minnow traps was marked by means of a fin clip and released. A unique fin clip was used each sampling period, with recaptured fish receiving additional marks (Table 1.1). Fish captured in week five were only examined for marks. However, the fact that each marking period took place over several days made it necessary to mark fish captured prior to the last day of the week five recapture period, by clipping the left pectoral fin, to ensure that no fish were counted more than once.

Removal methods began shortly after the completion of the last mark-recapture sampling period. For this technique the minnow population was trapped for 7 days in 60 baited minnow traps that were set around the shoreline, along with several mid-lake sets to ensure even coverage of the lake. All captured fish were removed from the population and held in holding pens until the end of the sampling period. The number of fish captured in each trap per day was recorded for later statistical analysis.

Eight subsamples of 500 fish were measured to the nearest millimeter for fork length, the distance between the snout and fork in the caudal fin, approximately every two weeks throughout the study period. These lengths were recorded and compared to estimate growth rates throughout the growing season.

Table 1.1: Field Schedule of Sampling Periods.

Sampling Period	Dates (1999)	Mark (fin clipped)
1	May 22, 24-27	upper caudal fin
2	June 7-10	lower caudal fin
3	June 21-24	dorsal fin
4	July 5-8	anal fin
5	July 19-22	no mark
Removal Methods	August 26-September 1	
Final Length Subsample	September 14	

Analysis of Biological Data:

- Mark recapture data were statistically analyzed in a Microsoft Excel worksheet using the Jolly-Seber death-only model and the Jolly-Seber open model (Ricker 1975).
- Fish removal data were analyzed using Leslie's and Delury's (Ricker 1975), as well as Moran and Zippin's methods (Everhart *et al.* 1975).
- Growth rates for each age class of finescale dace were estimated by performing a Cassie (1954) analysis to identify probable mean forklengths for each age class and determining the change in these forklengths that occurred in each age class over the study period.
- Biomass estimates were determined by applying a length-weight regression, calculated for Lake 115's finescale dace population, to each forklength of the May 24th Jolly-Seber death-only model population estimate. This allowed biomass to be calculated for each size class.

Collection of Baitfish Industry Data:

Information on the northwestern Ontario baitfish industry was gathered through informal interviews with northwestern Ontario commercial baitfish harvesters at their September 25th meeting in Vermilion Bay and questionnaires on rates of fishing activities and lake productivity. Focus was given to determining how commercial baitfish harvesters attempt to sustainably manage baitfish populations. Additional information was collected on such topics as the preferred sizes and species of baitfish, desirable baitfish lake characteristics and potential ideas for cooperative research between baitfish harvesters and scientific researchers.

2. LITERATURE REVIEW

2.1. Scope

This chapter is divided into three sections. The first deals with the taxonomy, distribution, and biology of the finescale dace, an important baitfish species in northwestern Ontario. The second section covers the available methods by which fish populations can be estimated, as well as examining the advantages and disadvantages of a range of fish capture techniques. Lastly, the third section examines the baitfish industry focusing on regulations and ecological impacts.

FINESCALE DACE

2.2. Taxonomy and Distribution

Scott and Crossman (1973) describe the finescale dace (Figure 2.1) as a stout fish averaging 76mm in length, with a maximum body depth of 15.4-22.4% of total length occurring midpoint to the tip of the pectoral fin. Obvious sexual dimorphism can be observed during the spawning season when males possess highly modified pectoral fins, rows of breeding tubercles on their ventral region, and display bright red and yellow colouration of the entire ventral surface below the lower margin of the lateral band (Scott and Crossman 1973; Stasiak 1977).

Finescale dace strongly resemble the northern redbelly dace (*Phoxinus eos*), a species with which they are closely related enough to frequently produce fertile hybrids (Scott and Crossman 1973; Cochran *et al.* 1988; Das and Nelson 1989; Das and Nelson

Figure 2.1: Male *Phoxinus neogaeus* displaying breeding colouration (Photo: Konrad P. Schmidt www.nativefish.org/cgi-bin/cgiwrap/nativefishgallery.pl).

1990). Distinguishing characteristics between these two species include intestine length, mouth size and differences in the size and shape of pharyngeal teeth. While the northern redbelly dace has a longer, more coiled, intestine, relatively small mouth and slender pharyngeal teeth, the finescale dace has a short intestine, relatively large mouth and robust, hooked pharyngeal teeth (Stasiak 1977; Cochran *et al.* 1988).

According to Scott and Crossman (1973) finescale dace occur east to New Brunswick, Maine, and New Hampshire, through southern Quebec, northern New York State, north of the lower Great Lakes to Michigan and northwest to the Arctic Circle in the Mackenzie River system. *P. neogaeus* is a headwater species found in cool bogs, creeks and lakes of forested highlands and wetlands (Stasiak 1978; Harbicht *et al.* 1988). Finescale dace associate strongly with the shore and structure, such as the edge of bog mats (Cochran *et al.* 1988). However, diel onshore-offshore migrations by *P. eos* x *P. neogaeus* hybrids have also been observed. These nighttime feeding migrations into the pelagic zone appear to be due to the presence of a littoral zone competitor, pumpkinseed sunfish (*Lepomis gibbosus*), and visually oriented pelagic predators, brook trout

(*Salvelinus fontinalis*) and lake trout (*Salvelinus namaycush*) (Gauthier and Boisclair 1996).

2.3. Breeding

Spawning generally commences in late April or early May and extends into June or July, depending on water temperatures (Stasiak 1978; Das and Nelson 1990). Spawning activity takes place when water temperatures reach 15.0° C and remain less than 19.0° C (Stasiak 1978; Das and Nelson 1990). Reproduction in finescale dace occurs when one or two ripe females leave large schools, followed by several males, and quickly enter cover in the form of fallen trees or brush. Males then use their large, modified pectoral fins to control the female's swimming and hold them against an object, at which point the male's tail curls over the female's tail and the male's anal tubercles are rubbed over the vent of the female. Both fish vibrate in this position for approximately 10 seconds as eggs (between 20 and 30) and milt are released. The female then swims back to the school while the male continues to emit milt for several more seconds. The eggs rapidly sink to the substrate and are abandoned (Stasiak 1978).

Finescale dace generally have a sex ratio of 1.5 males for every 1 female on spawning sites and 1:1 during non-breeding times of the year (Stasiak 1978). The majority of the breeding population is composed of fish in their second and third year of life, although males in their fifth and females in their sixth year have been observed spawning (Stasiak 1978). Eggs average 1.24 to 1.50 mm in diameter (Das and Nelson 1990) and hatch in about six days at 20° C. (Stasiak 1978). Females tend to grow larger and live longer than males and can produce between 784 and 3060 eggs per year.

2.4. Diet

Finescale dace are omnivorous, having a diverse diet composed largely of macroinvertebrates such as larval chironimids and other dipterans, odonate naiads, larval tricopterans, coleopterans, and ephemeropteran naiads. However, green algae, diatoms and zooplankton are also consumed in significant amounts (Cochran *et al.* 1988). In water bodies containing both *P.eos* and *P. neogaeus*, the northern redbelly dace, with its smaller mouth, longer intestine, and fine pharyngeal teeth, have been found to feed more on algae, while the finescale dace, with its larger mouth, shorter intestine and more robust pharyngeal teeth tends to feed more extensively on macroinvertebrates (Cochran *et al* 1988).

2.5. Available Methods

The ability to estimate the abundance and composition of standing stocks of fishes in lakes is important to fisheries managers as it enables them to measure the productivity and carrying capacity of specific water bodies (Fraser 1981). According to Cone *et al.* (1988), the three methods of population estimation most commonly used by fisheries managers are ratio methods (such as mark-recapture), catch-per-unit-effort (CPUE) methods, and direct enumeration. While direct enumeration methods may be the most accurate means available for estimating fish populations, biological, physical, and financial constraints generally restrict their use. As a result, abundance estimates are more commonly made by sub-sampling portions of the population. Mark-recapture and catch-per-unit-effort methods are among the most commonly used methods for field studies.

2.6. Catch-per-unit-effort

Catch-per-unit-effort methods are used to estimate population abundance without marking fish. They are based on the assumption that as the abundance of a population, or cohort of a population, declines by the removal of individuals through fishing and natural mortality, the number of fish that are caught per unit of fishing effort will also decline (Wootton 1990). Because gear used to capture fish for CPUE can be selective for specific sizes or life stages of fish, as well as being affected by fish behaviour, abundance estimates using this method must account for these sources of variability (Gryska *et al.* 1998).

CPUE methods have been used in many fish population studies. Chen and Harvey (1995) used CPUE to estimate the abundance of white suckers (*Catostomus commersoni*) in a number of Ontario lakes using gillnets. This information was used to determine the constraints of population density and food supply on white sucker growth rates. He and Lodge (1990) used CPUE to determine the relative abundance and within-lake distributions of northern redbelly dace, finescale dace, and central mudminnow (*Umbra limi*) using minnow traps in a small bog lake in Michigan. They observed that the CPUE of both dace species declined throughout the eleven-day sampling period as fish were removed. However, mudminnow catches actually climbed from initial low levels and stabilized before declining during the final five days of the removal period. Low mudminnow trapability or activity in the presence of high dace densities suggests that interspecific effects must be taken into consideration when using minnow traps to estimate populations by CPUE (He and Lodge 1990).

Using live traps for CPUE population estimations can be particularly useful in situations in which minimal disruption of habitat or mortality of captured fish is required. Gryska *et al.* (1998) used CPUE to estimate the population density of endangered Kendall Warm Springs dace (*Rhinichthys osculus thermalis*). The endangered status of this species made it necessary to use nonlethal capture methods that were nondestructive to dace habitat. In response to this requirement, live trapping methods were used (Gryska *et al.* 1998).

The accuracy of CPUE methods for determining population abundance is dependent on the sampling design. Sufficient time between sampling periods must be allowed for fish to redistribute to avoid unequal catchability. Peterson and Cederholm (1984) found that a recovery time of at least 1 hour between electroshocking removal periods was a critical element in generating reliable CPUE population estimations for juvenile coho salmon (*Oncorhynchus kisutch*) in small streams. However, the authors felt that even when adequate time is allowed for recovery, the problems associated with such field variables as stream width, habitat complexity, and sampling crew experience make mark-recapture methods a better choice than CPUE for estimating fish populations.

2.7. Direct Enumeration

Direct enumeration of fish populations is also dependent on the assumption that all of the fish in a population are recoverable. Pot *et al.* (1984) found that the recovery of fish from a pond following rotenone poisoning was hindered by reduced visibility and siltation caused by disturbing the sediment, and the possible loss of fish that were trapped in the substrate, either inadvertently or due to active burrowing. Similar observations were made by Fraser (1981) who recorded burrowing activity in brook trout (*Salvelinus fontinalis*), brown bullhead (*Ictalurus nebulosus*), and white sucker (*Catostomus commersoni*) following rotenone treatment, as well as difficulties in recovering fish due to heavy shoreline vegetation and poor visibility at lower depths. However, marking and releasing fish prior to lake poisoning can be used to estimate the percentage of the total population that recovered fish represent (Fraser 1981).

2.8. Mark-Recapture

The generation of valid results from a mark-recapture study requires that a number of assumptions are met. Cone *et al.* (1988) listed the following six assumptions: (1) homogeneous probability of capture between marked and unmarked fish; (2) homogeneous probability of capture among previously marked fish; (3) homogeneous probability of survival between marked and unmarked fish; (4) homogeneous probability of survival among marked fish; (5) retention of marks by fish and accurate reporting of marks by field personnel; (6) instantaneous sampling (relative to the duration of the study) and immediate release of fish after each sample. Violation of any of these assumptions can result in biases in population estimations. However, various researchers have developed tests to detect and sometimes compensate for violations of assumptions (Arnason and Mills 1987).

Mark-recapture methods have been widely used by fisheries managers to estimate parameters for fish populations. Cone *et al.* (1988) used a multiple mark-recapture procedure in their study comparing mortality in two wild strains of brook trout (*Salvelinus fontinalis*). They used a combination of pelvic fin clips, caudal fin clips, and freeze brands to identify marked fish. While they found that abundance estimates were upwardly biased due to marking mortality, this could probably have been reduced by a more efficient marking process, as some fish were held for up to six hours before being processed. A large portion of the handling mortality was likely due to handling stress. Similarly, Holland-Bartels *et al.* (1989) found high handling and marking mortality in young-of-the-year centrarchids and cyprinids that were marked with fluorescent pigments, particularly when they were seined in midsummer. This was due to a combination of high water temperatures and stress during removal from the net. These authors suggested that reducing handling stress through the use of minnow traps and avoiding sampling when water temperatures are high could significantly lower mortality of marked fish. Arnason and Mills (1987) also observed temperature related handling mortality in lake whitefish (*Coregonus clupeaformis*) during multiple mark-recapture experiments in the Experimental Lakes Area, northwestern Ontario. To reduce mortality in subsequent sampling periods, the authors used ice to cool the water in fish holding containers to $<10^{o}$C when epilimnetic temperatures were observed to be $\geq 12^{o}$C.

Mark-recapture techniques were used by Raffetto *et al.* (1990) to measure changes in the demography, age-specific sex ratios, and mortality rates of a population of smallmouth bass (*Micropterus dolomieui*) in a 40-ha Wisconsin seepage lake. Savitz (1978) noted that largemouth bass (*Micropterus salmoides*) marked with numbered Floy tags were recaptured significantly less frequently than fish marked by fin clipping. Low survival rates among tagged fish, most likely due to infection, was the suggested cause of differing recapture frequency. Savitz (1978) also detected no significant bias using fish that had been fin-clipped multiple times for the calculation of population parameters.

One solution that has been suggested to increase the potential accuracy of population estimates is to combine the results obtained from mark-recapture and CPUE sampling. Gatz and Loar (1988) used this approach in a study on a population assemblage of stream fishes. The authors stressed the importance of testing the assumptions of both methods and making appropriate adjustments to population estimates if any violations are detected.

2.9. Methods of Marking Fish

An important decision in the design of any mark-recapture study is what type of marking strategy to use. There are a wide variety of marking techniques available and the decision of which method(s) to use is dependent on a number of variables, such as the size and shape of the species being studied, the habitat being sampled, the length of the study period, available budget and the level to which identification will be made (individuals or groups) (Nielsen 1992). Nielsen (1992) lists and describes the following seven different marking styles available to researchers: external tags, external marks, internal tags, natural marks, biotelemetric tags, genetic identifiers and chemical marking. External tags consist of physical devices that are attached to a fishes body. While this technique provides a number of marking options, the presence of the tag and the stresses associated with its application lead to a significant number of disadvantages (Nielsen 1992). Xiao (1994) discusses the disruption in growth that can be caused by tagging and presents a model that allows these effects to be quantified. Arnason and Mills (1987) detected significant tag loss in lake whitefish tagged with Floy gun tags. Savitz (1978) found that the use of numbered Floy anchor tags caused a significant reduction in the recapture of largemouth bass and attributed this to higher mortality levels in tagged fish. However, Raffetto *et al.* (1990) successfully used Floy FD-67C anchor tags to mark male smallmouth bass, with tags apparently not hindering survival or breeding success.

External marks consist of altering the fish's appearance to allow external identification. Among the techniques available for this style of marking are fin clipping, brands, pigments and dyes. These marks are generally among the easiest to apply and are commonly used for short-term and geographically restricted projects (Nielsen 1992).

External marking has been used by a large number of researchers. Pot *et al.* (1984) used pectoral fin removal to estimate the population densities of small fish by mark-recapture. Peterson and Cederholm (1984) identified salmon smolts by clipping the dorsal lobe of the caudal fin, while Gatz and Loar (1988) identified stream fishes by clipping either the upper or lower lobes of the caudal fin. Cone *et al.* (1988) used freeze branding and caudal fin clipping to identify different strains of stocked brook trout. Pigment marking, imbedding an inert coloured material into or just below a fish's dermis (Nielsen 1992), is another method of external marking. Holland-Bartels *et al.* (1989) observed high levels of mortality in young-of-the-year centrarchids and minnow species marked by granular fluorescent pigment applied with a low pressure compressed nitrogen spray gun. They also found that mortality of marked fish tended to increase with higher water temperatures. Warren and Pardew (1998) used injected pigments to batchmark fishes from 21 different species during a study on the effects of different types of road crossings on small-stream fish movement. In several studies fish were anesthetized prior to marking to reduce handling stress (Fraser 1981; Peterson and Cederholm 1984; and Gatz and Loar 1988). Tricaine methanesulfonate (MS-222) was the most commonly used anesthetic.

Internal tags are devices that are implanted in the fish's body. The majority of internal tags used today consist of binary coded wire tags. While recovery of these tags usually requires the fish to be killed, new non-lethal techniques such as biotelemetric tags, are being developed (Nielsen 1992). Biotelemetric tags consist of attached or internal tags that transmit information to a remote observer or sensor. While this technique reduces the need for recapturing and handling the animal, large tag sizes, limited battery life, and high costs have restricted their use. However, this technology is continually improving and becoming more affordable (Nielsen 1992). Genetic marking is based on biochemical tests to identify fish based on their DNA and can be used to identify relationships between individuals or populations (Nielsen 1992). Chemical marking is based on the detection of chemicals that have accumulated in an animal during its lifetime, or purposely introduced to it for marking purposes. This technique is not widely used due to the difficulties involved with its application in the field (Nielsen 1992).

2.10. Capture Techniques

Fisheries researchers use a wide variety of capture gear to obtain fishes for population estimation. Each method has specific advantages and disadvantages and tends to be selective for specific sizes and/or species of fish. Some of the most popular collection methods used in fish population studies are electrofishing, gill nets, a number of different types of enclosure traps, lift nets, seine nets, and passive traps.

Electrofishing is particularly useful for collecting species such as bass (*Micropterus* spp.) that are difficult to capture using other methods, and for fish populations that are found in structurally complex environments, such as streams containing abundant cover. Carpenter *et al.* (1987) used electrofishing methods to estimate largemouth bass populations in lakes in which they had been experimentally introduced to lower primary productivity and reduce eutrophication. Peterson and Cederholm used electrofishing to compare CPUE and mark-recapture abundance estimates of juvenile coho salmon (*Oncorhynchus kisutch*) in small streams.

Electrofishing has also been used to collect small fish species such as blacknose dace (*Rhinichthys atratulus*) (Bain and Finn 1991) and a wide variety of stream dwelling minnows (Cyprinidae), sunfishes (Centrarchidae), topminnows (Fundulidae), and darters (Percidae) (Warren and Pardew 1998). Electrofishing has traditionally been limited to waters that have moderate to good conductivity and is less effective in waterbodies with low conductivity, such as northern bog lakes (He and Lodge 1990). However, as the technology continues to improve so does the range of habitats that can be sampled by electrofishing.

Gill nets can be used to capture fishes of a variety of sizes, and from a variety of water depths. However, because this is a normally a lethal capture technique, it is used almost exclusively in studies in which fish will not be released. Magnan (1991) used multifilament gill nets to sample dace from the offshore zone, while Chen and Harvey (1995) used gill nets to estimate white sucker populations by CPUE. Jackson and Harvey (1997) used gill nets in combination with a wide variety of other gear types to determine the abundance, composition and distribution of fishes in 43 lakes.

Enclosure traps are devices that are used to capture fish by quickly enclosing an area. These may be thrown, dropped from a set frame or set to rise quickly from the bottom. Some of the advantages of enclosure traps are their effectiveness in heavily vegetated areas where seining or electroshocking is difficult (Dewey et al. 1989), and ease of operation, requiring only one or two people to operate many models (Kushlan 1981). Kushlan (1981) found enclosure traps to be effective sampling devices for small fishes in shallow water. A 1-m^2 throw trap was the most effective of three types tested, due to ease of use and short sampling time. Dewey *et al.* (1989) found pop nets to be a useful method of sampling for species that may be difficult to seine, or when minimal disturbance of an area is desired. Pot *et al.* (1984) used a lift net to sample fish from a small pond and found that fish catchability declined rapidly over time. Enclosure traps are not a very effective means to sample certain species (Pot *et al.* 1984; Dewey *et al.* 1989) and sizes of fish, particularly larger specimens that can easily evade these types of capture devices (Kushlan 1981; Carlson and Berry Jr. 1990). This can lead to an underestimation of fish abundance (Carlson and Berry Jr. 1990).

Seining is one of the more common methods used to capture fishes for population estimation or other types of studies. Tallman and Gee (1982) successfully used seining to collect pearl dace of a number of different age classes from the Brokenhead River in southeastern Manitoba, while Gauthier and Boisclair (1996) used seining to sample hybrid dace (*Phoxinus eos* x *P. neogaeus*) during their diel onshore-offshore migrations. Fish collected in the offshore zone were captured using a pelagic seine. Seines are frequently more effective for capturing less abundant taxa than many other types of collection gear (Dewey *et al.* 1989), but can cause high mortality in small fish due to handling stress (Holland-Bartels *et al.* 1989).

Passive trapping includes the use of weirs, trap nets, pound nets, hoop nets, fyke nets, and minnow traps (Backiel and Welcomme 1980). Traps can be very selective in both size and species of fish that are captured (Stott 1970) but can have a number of advantages over other types of sampling gear. They can be used in a wide variety of different habitats and depths, are economical to use, cause little disturbance, can catch fish without causing physical damage, and can be used in the collection of information on fish movements and population densities (Stott 1970; Backiel and Welcomme 1980).

Minnow traps are an effective type of passive gear for the capture of small fish species and are commonly used for abundance estimations in lakes (He and Lodge 1990). Traps may be baited with pet food (Bendell and McNicol 1987; Litvak and Hansell 1988; Gryska *et al.* 1998), bread or rolled oats (Backiel and Welcomme 1980; He and Lodge 1990), although unbaited traps are also successful for capturing fish (Payer and Scalet 1978; Culp and Glozier 1989; He and Lodge 1990; Duffy 1998). However, Litvak and Hansell (1988) found that unbaited traps were unsuccessful over trapping periods of less than one hour. While minnow traps are more commonly used in lentic (lake, pond or bog) environments, modified versions have been used to sample fish populations in lotic (stream or river) environments (Culp and Glozier 1989; Gryska *et al.* 1998).

Litvak and Hansell (1988) used minnow traps to sample cyprinids for gut content analysis, while Bendell and McNicol (1987) sampled cyprinid populations in small northern Ontario lakes with minnow traps. CPUE sampling using minnow traps was conducted by He and Lodge (1990), Jackson and Harvey (1997) and Gryska *et al.* (1998), while mark-recapture studies that utilized minnow traps include Stott (1970), Payer and Scalet (1978) and Magnan (1991).

The effectiveness of sampling with minnow traps to estimate fish abundance depends on the sampling design. He and Lodge (1990) observed that trap location had a significant effect on trapping success. Traps placed at the perimeter of the lake caught 21 to 52 times more fish than traps set at midlake locations. Magnan (1991) noted that unrecognized fish behavior, such as offshore diel migrations, can affect the accuracy of population estimates derived from minnow trap catches alone. He and Lodge (1990) also found that interspecific interactions lead to a low catchability for mudminnows in the presence of high densities of redbelly and finescale dace.

Conditions known as "trap shy" and "trap happy", can affect the accuracy of mark-recapture studies that utilize minnow traps by violating the assumptions of homogeneous probability of capture between marked and unmarked fish and homogeneous probability of capture among previously marked fish (Cone *et al.* 1988). However, these conditions usually are presumed to not occur in fish (Cone *et al.* 1988). Culp and Glozier (1989) found that previous trap experience did not affect the escape times of small fishes, including pearl dace, from minnow traps. In another study, Stott (1970) demonstrated that European perch (*Perca fluviatilis*) displayed no significant tendency to avoid traps as a result of being captured the previous day.

2.11. Biomass of Cyprinid Populations in Small Lakes

There are few estimates of the population sizes of Cyprinid species in small lakes. Knowing the size of standing stocks of baitfish species is important information for the management of these populations because it can act as an indicator of the productivity and potential sustainable harvest (Fraser 1981). Carlson and Berry Jr. (1990) estimated the population sizes of fathead minnows (*Pimephales promelas*) in South Dakota prairie wetlands to average 47 620 fish per hectare. The authors estimated that the wholesale value of these baitfish-producing wetlands averaged US $233 per hectare. Duffy (1998) estimated fathead minnow populations in South Dakota wetlands to range from 52 000 to 431 000 fish per hectare, with a mean biomass of 81.0 to 117.6 kilograms per hectare. However, fathead minnows are a very prolific species. Females may have 16 to 26 spawning events per season and produce 6800 to 10 600 eggs (Duffy 1998). Prairie wetlands also tend to be highly productive water bodies and lower population and biomass estimates should be expected for less prolific species and less productive water bodies.

THE BAIT FISH INDUSTRY

2.12. Economics

Baitfish are widely used in both Canada and the United States for sport fishing. A combination of inconsistent reporting of catches and the fact that the industry is largely made up of individual harvesters (Noel and Hubert 1988; Kircheis 1998) makes determining its wholesale and retail value extremely difficult (Litvak and Mandrak 1993). Litvak and Mandrak (1993) estimated sales of wild and cultured baitfish to be worth at least one billion dollars (US) to Canada and the United States. This value was based on conservative estimates of $367 million (US) for nine US states (Arkansas, Colorado, Kansas, Minnesota, Nebraska, Ohio, Vermont, West Virginia, and Wyoming) and $29 million (US) for one Canadian province (Ontario). According to Litvak and Hansell, (1990) baitfish are worth more per kilogram than all commercially grown trout and had an average wholesale price of $11.42/kg, compared to an average landed value of $1.55/kg received for total commercial fisheries. Other estimations of the economic value of the baitfish industry can be found in Nielsen (1982), Carson and Berry Jr. (1990), Meronek *et al.* (1997) and Kircheis (1998). Despite its economic importance, the baitfish industry has received relatively little attention in comparison to other areas of fisheries research (Carson and Berry Jr. 1990). Many of the studies that have been done on this industry have not been published and therefore much of the information about commercial baitfish harvests remains unavailable (Nielsen 1982).

2.13. Regulations

Regulations governing the baitfish industry vary widely between regions (states and provinces). Differences in bait definitions, licensing, harvestable waters, allowable gear, and laws regarding the transport and importation of bait are common (Meronek *et al.* 1995). These inconsistencies can lead to confusion among anglers, hinder the bait industry, and reduce the credibility of management agencies (Meronek *et al.* 1995). Ontario regulations stipulate that anyone selling baitfish must have a baitfish dealer's license, or a license to culture and sell fish, and only allow the use of specific species as bait (OMNR 2000). The following is a list of fish that may be used as bait in Ontario:

- Mudminnow family (Umbridae)
- Sucker family (Catostomidae)
- Stickleback family (Gasterosteidae)
- Lake herring (*Coregonus artedii*) of the whitefish family (Salmonidae)
- Darter sub-family (Percidae)
- Trout-perch family (Percopsidae)
- Sculpin family (Cottidae)
- Minnow family (Cyprinidae), except for carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*)

The use of live (or dead) baitfish is prohibited in some Ontario regions (Litvak and Mandrak 1993, OMNR 2000) and non-resident anglers are not permitted to capture their own baitfish by any means (OMNR 2000). Release of baitfish into waters other than those from which they were harvested and the importation of baitfish are prohibited in many jurisdictions to prevent the introduction of exotic species (Litvak and Mandrak 1993).

One of the most common problems reported for the industry is that of baitfish shortages (Noel and Hubert 1988; Meronek *et al.* 1997). Bait shortages are largely due to fluctuations in wild stocks and will probably continue to be a problem as long as the industry remains dependent on wild sources of baitfish (Noel and Hubert 1988; Frost and Trial 1993). While the use of cultured baitfish has the potential to meet industry demands (Stone *et al.* 1997), shorter growing seasons in northern states and Canada lead to high production costs (Frost and Trial 1993). Baitfish farming requires a substantial investment, is labour intensive and is highly susceptible to market fluctuations due to poor fishing conditions and competition from wild-caught bait (Stone *et al.* 1997). Overexploitation of wild fish stocks has been suggested in several studies (Litvak and Mandrak 1993; Frost and Trial 1993). In contrast, Brant and Schreck (1975) found that any depletions were likely to be only temporary due to the short life cycles, high reproductive potential and rapid growth rates of most baitfish. It is worth noting, however, that Brant and Schreck's study was limited to short-term manipulations of one stream community. Long-term harvests and harvests from lakes and ponds, which may not be as readily colonized as streams, may have significantly different impacts.

2.14. Commercial Practices

Gear restrictions for commercial and personal baitfish harvest vary among states (Table 2.2) and between provinces. Legal capture methods include seines, drop nets, dip nets, traps, throw nets, and hook and line for larger species (Noel and Hubert 1988; Frost and Trial 1993; Meronek et al. 1995). Noel and Hubert (1988) reported that most of the baitfish harvested from the wild in Wyoming were captured using traps and seines, with traps accounting for approximately 80 percent of the total harvest.

Table 2.2: Restrictions on sizes and uses of commercial gear used for baitfish harvest in the North Central United States (Modified from Meronek *et al.* 1995).

State	Allowable Gear
Illinois	Seine, 20 ft long; minnow trap, 24" long; dip net, 4 ft diameter
Indiana	Seine, no size specified
Iowa	Traps, ≤ 36" long; dip net ≤ 4 ft diameter; seine ≤ 50 ft long ¼ to ≤ ½" bar mesh
Kansas	Traps, ≤ ½" bar mesh, and ≤ 2" opening; seine, ≤ ½" bar mesh, no length specified; lift net, ≤ ½" bar mesh; lift net, ≤ ½" bar mesh; other methods may be approved by Department of Natural Resources.
Michigan	Seine, .125 ft long x 16ft wide; trap, 24" long, opening 1-1½"
Minnesota	Minnows may be trapped or seined; seine ≤ 50 ft long
Missouri	No commercial harvest of baitfish allowed
Nebraska	Minnow seine, ≤ 20 ft long, 4 ft deep, ¼" square mesh; dip net, neither length nor width can exceed 36", ¼" mesh size; traps, 24" long, 16" diameter, opening ≤ 1-1½"
North Dakota	Retailer trap, 30 x 12, 1-1¼" opening, 3/8" square mesh; retailer seine, 25 ft x 6 ft, 3/8" square mesh; wholesaler trap, 5 ft diameter, ½" square mesh, throat < 6"; wholesaler seine, < 250 ft long x 14 ft deep, ½" square mesh
Ohio	Minnow seines: inland, 4 ft x 8 ft, ½" square mesh; Lake Erie, no limit on length, ½" square mesh; minnow dip nets: inland, 4 ft per side, ½" square mesh; Lake Erie, 6 ft per side, ½" square mesh; fish traps are also permitted
South Dakota	Wholesaler trap, can be > 12" x 36", opening not > 1"; angler trap, no larger than 12" x 36", opening 1"; wholesaler seine, 50 ft x 6 ft, 3/8" square mesh; special permit may be issued to wholesaler for larger gear than the following angler restrictions: cast net, 24 ft diameter, ≤ 3/8" square mesh; lift net, 4 ft square, ≤ 3/8" square mesh
Wisconsin	Trap 24" x 16" x 1-1½"; seine, 35 ft long maximum; dip net, 8 ft square or 8 ft long; cast net, 7 ft diameter, ½" stretch mesh; smelt seine, 75 ft x 6 ft; other methods may be approved by the Department of Natural Resources.

In the Kenora district the Ontario Ministry of Natural Resources regulates commercial baitfish harvest through the use of a baitfish blocks, or Bait Harvest Area's (BHA's) (C. MacDonald pers. comm. Feb. 2000). There are several possible ways by which BHA's become available. A licensee can voluntarily relinquish their BHA, the license may be removed by the OMNR, a licensee can fail to renew their license, or a BHA may never have been licensed (C. MacDonald pers. comm. Feb. 2000).

The allocation of BHA's takes place in the following manner. Individuals that wish to apply for a BHA can do so at any time by completing a Bait Harvest Area Application. Successful applicants are then notified when a BHA becomes available. The applications may then be graded to determine the top applicant. If two or more applicants are tied for top choice, then the Regional Bait Committee may be consulted for their recommendations. The OMNR District Manager then makes the final allocation decision and awards the BHA to the most qualified applicant, with all vacant BHA allocations being made by May 15th of each year (C. MacDonald pers. comm. Feb. 2000).

The type of gear that commercial baitfish harvesters are permitted to use can vary from region to region in the province and appears as a condition of a Commercial Bait License. In the Kenora District, there are no longer any limits on the number of baitfish traps, dip nets or seines allowed for each license, although seine nets must be less than 20 meters in length and 2 meters in depth (C. MacDonald pers. comm. Feb. 2000). Additional restrictions may also be placed other allowable gear, such as the use of gillnets. However, this is not common in northwestern Ontario (C. MacDonald pers. comm. Feb. 2000).

2.15. Ecological Impacts

Litvak and Mandrak (1993) identified a number of ecological problems associated with the bait fish industry and divided them into two major categories: i) impacts on donor ecosystems and ii) impacts on recipient ecosystems. They further divided donor system impacts into three categories: 1) population alteration, 2) trophic alteration, and 3) habitat alteration.

Population alteration consists of the direct impacts that baitfish harvesting can have on the abundance of the harvested species. This can have both short and long-term effects (Litvak and Mandrak 1993). Frost and Trial (1993) suggested that as more efficient methods of capturing and holding baitfish species become available, the potential for population overexploitation increases.

Trophic alteration refers to the changes in an aquatic community that can occur when a substantial portion of the waterbody's forage fish are removed (Litvak and Mandrak 1993). Typical changes that occur following forage fish removal are a decrease in primary production, an increase in zooplankton size and abundance, and species shifts in the plankton community (Henrikson *et al.* 1980; Carpenter *et al.* 1987; Litvak and Hansell 1990).

Habitat alteration consists of the physical and biological impacts that harvesting activities have on the donor ecosystem (Litvak and Mandrak 1993). These impacts can include damage to spawning beds, the uprooting of macrophytes, which are important cover for forage fish and the young of game fish, and incidental damage to non-baitfish species through by-catch.

The primary impact that the baitfish industry has on recipient ecosystems is through the introduction of non-native species. Introduced species can affect recipient ecosystems through habitat alteration, trophic alteration, displacement of native species, gene pool deterioration and the introduction of disease (Litvak and Mandrak 1993). Ludwig Jr. and Leitch (1996) define bait bucket transfer (BBT) as the transfer and release of aquatic biota into non-native environments through sportfishing activities. They found non-bait species in 28.5% of bait samples purchased from 21 retailers in North Dakota and Minnesota and calculated that the probability for the transfer and introduction of species across watershed boundaries (from the Mississippi River basin into the Hudson Bay basin) through BBT is almost certain. Courtenay and Taylor (1986) estimated that as many as 58 species of fish in Canada and the United States had been transplanted outside of their natural ranges through unintentional release from bait buckets.

Litvak and Mandrak (1993) detected six illegal baitfish species in four Toronto bait shops and found that 41% of 34 anglers surveyed released unused baitfish into waters other than those from which they had been caught. Anglers who release their unused baitfish generally see their actions as being humane and often think that they are actually doing something beneficial for ecosystem (Courtenay and Taylor 1986; Litvak and Mandrak 1993). Kircheis (1998) found ten species of fish that were not legal to use as bait in Maine baitshops, although the incidence of illegal baitfish declined rapidly following the establishment of annual inspections. According to Litvak and Mandrak (1993), the development of an appropriate management strategy for the baitfish industry will require more research to be done on baitfish in the areas of basic biology, population and trophic dynamics, the effects of harvesting in donor ecosystems, and the effects of baitfish introductions on recipient ecosystems.

3. Methods

3.1. Location and Species

This study was conducted on Lake 115 in the Experimental Lakes Area (ELA), northwestern Ontario. Lake 115 is a small first order lake that has a surface area of 6.5 hectares and a maximum depth of 1.5 meters (Beamish *et al.* 1976). The lake is generally shallow and is ringed by a sphagnum bog mat that, aside from macrophytes that emerged in late June, provides most of the available cover. The dominant fish species present in Lake 115 is finescale dace (*P. neogaeus*). The only other fish species present, pearl dace (*Margariscus margarita*), make up an extremely small percentage of the total fish population, probably less than 0.1%.

3.2. Multiple Mark-Recapture

The data for the multiple mark-recapture study were gathered biweekly over five sampling periods from mid-may to late July. Finescale dace were captured using 40 unbaited Gee® brand cylindrical wire minnow traps (2.5cm opening), distributed systematically along the perimeter of the lake, set adjacent and parallel to the bog mat (Figure 3.1). Each sample period consisted of three 24 hour sets and of 40 traps. Rather than emptying all of the traps and processing the fish on shore, each trap was emptied into a water-filled tub in the boat. All fish from a trap were then measured for forklength (first 500 in each sampling period), marked, and immediately released before the next trap was emptied. Total handling time for individual fish was typically less than 5 seconds for fish that were not measured for fork length and less than 20 seconds for fish that were measured for fork length. Additional care taken to minimize handling stress

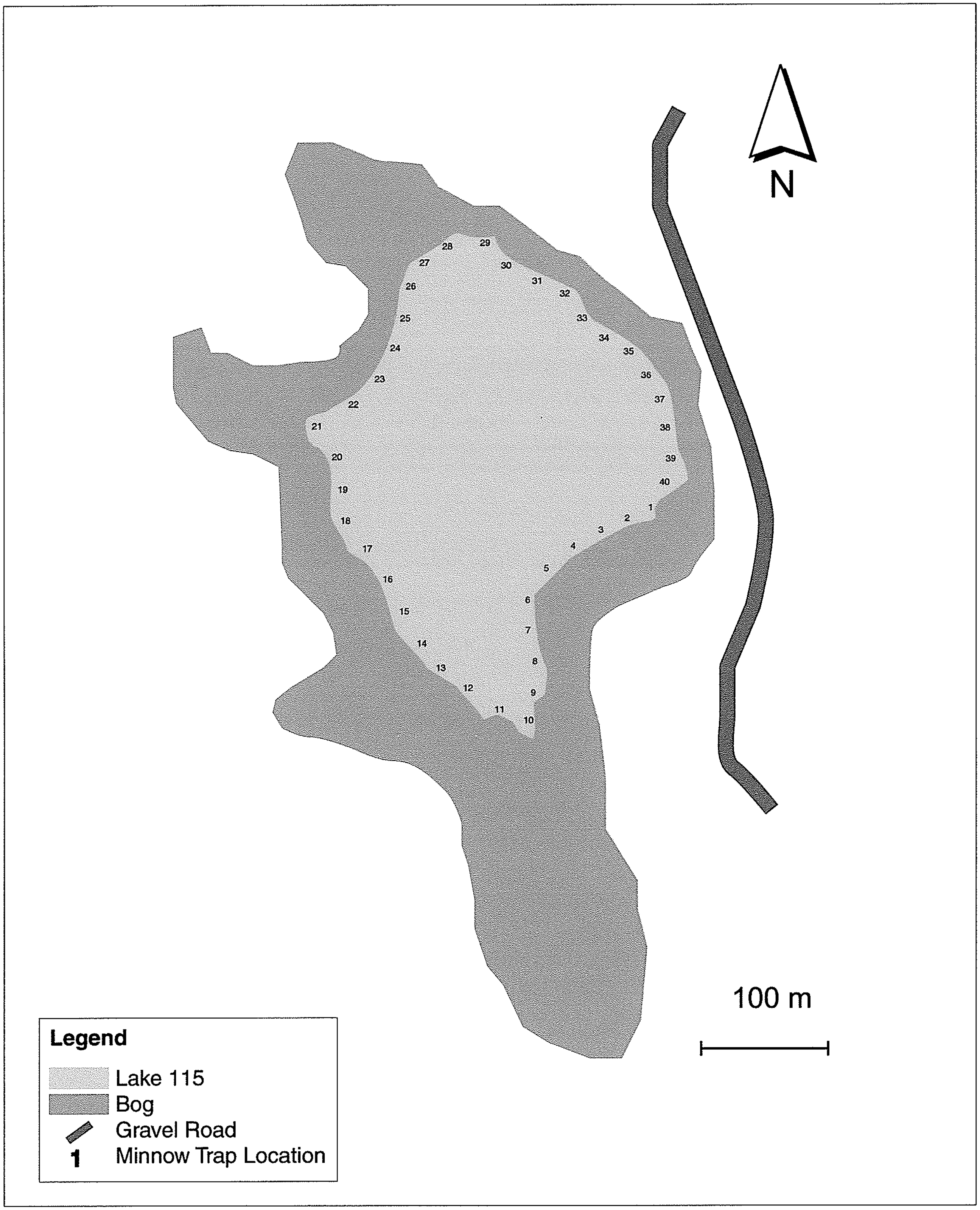

Figure 3.1: ELA Lake 115 showing approximate distribution of minnow traps for multiple mark-recapture study.

was to keep hands wet at all times when handling fish and measuring fork lengths by putting fish in a wet clear plastic bag and measuring with a ruler held up to the bag, rather than using a measuring board. This technique reduced the effects of handling stress and by enabling all processing to be done at the site of capture, allowed the fish to be returned to the lake in a relatively even distribution, rather than releasing them all in one concentrated area of the lake.

All captured fish were marked with a fin clip (tip of selected fin removed) that was unique to the sampling period in which they were captured (Table 3.1). Fish that were recaptured in subsequent sampling periods were marked with the fin clip for the current sampling period in addition to marks that they had acquired in previous sampling periods. The exception to this was fish that were captured in sample period number five. These fish were only examined for marks from previous sampling periods. To prevent fish from being counted in the final sample period more than once, all fish captured in the first two days of the fifth week were given a fin clip (left pectoral fin) to identify them as having been already captured. The number of marks that each fish carried was recorded for later statistical analysis. Although clipped fins were being regenerated during the study, marks were still clearly discernable throughout the entire mark-recapture period.

Table 3.1: Selected marks used in the mark-recapture of finescale dace in ELA Lake 115 (selected from Wydoski and Emery(1983)).

Sampling Period	Mark Location	Mark Description
1	Upper caudal fin	about ½ of the fin removed
2	Lower caudal fin	about ½ of the fin removed
3	Dorsal fin	about ½ of the fin removed
4	Anal fin	about ½ of the fin removed
5	Examined for marks only	left pectoral fin marked to identify previously captured fish (not counted as a mark)

The sub-samples of 500 fish that were measured for fork-length during each mark-recapture period were compared to other 500 fish sub-samples that were collected in August and September. These were used to form length frequency distributions that were used to calculate fish growth rates.

3.3. Statistical Analysis of Multiple Mark-Recapture Data

Mark-recapture data were statistically analyzed with a Microsoft Excel worksheet using the Jolly-Seber death-only and Jolly-Seber open (which takes into account births and immigration) methods (Jolly 1965; Seber 1982). The following estimates were calculated:

A(i) = Catchability (probability of an animal alive a time i being caught in the i^{th} sample),

M(i) = Total number of marked fish in the population at time i,

N(i) = Total number of fish in the population when the i^{th} sample is captured,

S.E.[N(i)] = Standard Error for N(i),

S(i) = Survival rate (probability that an animal alive at the moment of release of the i^{th} sample will survive until the time of the $i+1^{th}$ sample),

S.E.[S(i)] = Standard Error of survival rate,

B(i) = Number of new animals joining the population in the interval between the i and $i+1^{th}$ sample and alive at time i+1, and

S.E.[B(i)] = Standard Error of B(i).

These estimates are calculated from the following statistics:

n(i) = number of fish captured in the i^{th} sample,

m(i) = number of marked fish in the i^{th} sample,

l(i) = number of dead fish during sampling, and

R(i) = number of fish marked in time i that are recaptured in time i+1.

3.4. Catch-per-unit-effort

Catch-per-unit-effort population estimation methods began following the completion of the mark-recapture portion of this study. Fish were captured in 60 stale bread baited minnow traps set systematically along the shoreline. Several mid-lake sets, to ensure that all possible habitat types were being sampled, were also used. However, mid-lake sets generally captured few fish. Traps were set for approximately 24 hours and emptied daily for a period of seven consecutive days. The number of fish captured in each trap per day was recorded and all captured fish were transferred to a large holding pen within the lake until the end of the study.

3.5. Statistical Analysis of Catch-per-unit-effort Data

Catch per-unit-effort data was analyzed using Leslie's and Delury's methods (Ricker 1975), as well as Moran and Zippin's method (Everhart *et al.* 1975).

In Leslie's method the catch-per-unit effort is plotted against cumulative catch over a period of time. The resulting straight line is then used to estimate both the initial population and catchability (Ricker 1975). Leslie's method is based on the following equation (Ricker 1975):

$C_t = qN_o - qK_t$ in which:

C_t = size of catch at time interval t,

q = catchability (the fraction of the population t taken by one unit of fishing effort,

N_o = original population size, and

K_t = cumulative catch to the start of interval t added to half of that taken during the interval.

The catchability (q) and original population size (N_o) are calculated from the regression equation of Kt and Ct. The negative slope (= coefficient m) multiplied by –1 is equal to q and N_o is the fraction of constant (a) and the coefficient (m).

For Delury's method the logarithm of catch-per-unit-effort is plotted against the cumulative effort. A fitted straight line is then used to estimate the initial population and catchability (Ricker 1975). Delury's method is based on the following equation (Ricker 1975):

No = C/1-Sf in which:

No = original popualtion,
C = total removals of fish from the lake,
S = fractional survival of the stock after one unit of effort, and
f = total number of units of effort.

The Moran and Zippin method is appropriate to use when equal units of effort are used for each sample and is based on the following equation (Everhart *et al.* 1975):

$$N = C/1\text{-}(1\text{-}q)^n \text{ and } 1\text{-}q/q - n(1\text{-}q)^n / 1\text{-}(1\text{-}q)^n = \sum_{i=1}^{n} (i=1)C_i / C$$

in which:

in which:	C	= total catch,
	n	= number of samples,
	N	= original population size, and
	q	= catchability.

Confidence intervals were calculated for each method after Ricker (1975).

3.6. Biomass Estimates

Adult finescale dace biomass estimates were obtained by converting the abundance and length-frequency distribution data for the May 24th sample period to biomass data. This required the application of a length-weight relationship formula, which was calculated specifically for Lake 115 finescale dace from the length and weight measurements of a sub-sample of fish, to each forklength class. The estimated biomass of all forklength classes were then added together to estimate the biomass for the entire lake, which was then divided by the lake's area to provide an estimate in kg • ha^{-1}.

3.7. Growth Estimates

Growth of Lake 115's finescale dace during the sampling period was estimated by Cassie (1954) analysis. Length frequency distributions for the May 24th sampling period and the September 14th sampling period were plotted on probability graphs. The resulting inflexion points indicated the probable minimum and maximum forklengths for each age class. The increase in probable mean forklength from the May 24th to the September 14th sample period for each age class was then used to estimate growth for each age class.

3.8. The Baitfish Industry

Information on the northwestern Ontario baitfish industry was collected through informal discussions with northwestern Ontario commercial baitfish operators at their general meeting on September 25, 1999 in Vermilion Bay Ontario. The information covered a number of topics including fishing techniques, sustainable harvest strategies, rates and frequency of fishing activities and fluctuations in lake species makeup and abundance. On the advice of the president of the baitfish association, questionnaires (Appendix 1) on rates of fishing activities, preferred species and sizes of fish, and lake productivity were also given out at this meeting, to supplement the information collected. These data were compared to abundance estimates and baitfish biology in an attempt to determine whether their current harvest is likely to be above, below or near ecologically sustainable levels.

4.1 Mark-Recapture Population Estimates

6989 finescale dace were captured during the five sampling periods of the mark-recapture portion of this study. These data (Table 4.1) were used to calculate population estimates for ELA Lake 115 using the Jolly-Seber death-only model (Table 4.2) and the Jolly-Seber open-models (Table 4.3). The death-only abundance estimate for the first capture period (week of May 24 1999) was 27 244 fish +/- 2532 (95% confidence limits), while the Jolly-Seber open model population estimate for the week of June 8 was 22745 fish +/- 5802.

Table 4.1: Jolly-Seber mark-recapture summary statistics: used for calculations

							Number of fish that were recaptured during subsequent sampling periods						
Date	**i**	**n(i)**	**M(i)**	**N(io)**	**l(i)**	**s(i)**	**2**	**3**	**4**	**5**	**R(i)**	**Z(i)**	**Z(i)'**
Week 1	1	2046	0	2046	0	2046	227	55	53	19	354	0	4370
Week 2	2	2108	227	1881	0	2108		72	29	18	119	127	2616
Week 3	3	887	127	760	0	887			28	9	37	119	1848
Week 4	4	959	110	849	0	959				63	63	46	926
Week 5	5	989	109	880	0	989					0	0	0

i = sample time
n(i) = sample size at time i
m(i) = number of marked fish in n(i) at time i
N(io) = number of unmarked fish in sample i
l(i) = losses on capture
s(i) = number of fish returned to population
R(i) = number of recaptures out of s(i)
Z(i) = number of fish marked before time which are not caught in the i^{th} sample, but are caught subsequently
Z(i)' = number of fish marked before time which are not caught in the i^{th} sample, but are caught subsequently, including fish captured for the first time subsequent to time i

Table 4.2: Jolly-Seber Death-only model estimates (This allows for death)

Output from Analysis:

Date	I	A(i)	M(i)	N(i)	SN(i)	PHI(i)	SPHI(i)
Week 1	1			27244	1266	1.764	0.140
Week 2	2	0.108	2459	48084	4182	0.916	0.170
Week 3	3	0.144	2907	44072	7019	0.336	0.088
Week 4	4	0.115	800	14849	1751		
Week 5	5	0.111					

i = sample time
A(i) = proportion of marked fish in the population
M(i) = estimated number of marks in the population
N(i) = estimated population size at time i
SN(i) = conditional standard error of estimate of population size
PHI(i) = estimate of survival rate between i, i+1
SPHI(i) = standard error of estimate of survival rate

Table 4.3: Jolly-Seber open model estimates (This allows for death and births)

Output from Analysis:

Date	i	A(i)	M(i)	N(i)	SN(i)	PHI(i)	SPHI(i)	B(i)	SB(i)
Week 1	1					1.202	0.135		
Week 2	2	0.108	2459	22745	2901	0.670	0.126	4933.214	2187.503
Week 3	3	0.144	2908	20173	3916	0.218	0.047	2518.914	815.4395
Week 4	4	0.116	800	6919	1262				
Week 5	5	0.111							

i = sample time
A(i) = proportion of marked fish in the population
M(i) = estimated number of marks in the population
N(i) = estimated population size at time i
SN(i) = conditional standard error of estimate of population size
PHI(i) = estimate of survival rate between i and i+1
SPHI(i) = standard error of estimate of survival rate
B(i) = estimate of births entering between i and i+1
SB(i) = standard error of the estimate of births

4.2 Removal Population Estimates

A total of 10 641 fish were captured throughout the 7 day removal experiment. Catches generally declined over the removal period. The catch on the final day was less than half that on the first day (Table 4.4). The Leslie method gave a regression equation of $C_t = 2253.0692K_t - 0.121996$. This resulted in an estimated population size for ELA Lake 115 of 18 468 (+15 159, -5739) fish. The DeLury method indicated a catchability of 10.2% per day, or about 0.17% of the population per trap per day. This led to an estimated population size of 20 135 fish. Moran and Zippin's method estimated an abundance of 19 330 (+/- 1095) fish. Abundance estimates from all five methods are illustrated in Figure 4.1.

Table 4.4: Summary of finescale dace catches in ELA Lake 115 during the 7 day removal sampling period (60 baited traps per day).

Day	1	2	3	4	5	6	7	Total
Number of Fish Caught	2333	1748	1551	1282	1377	1192	1158	10 641

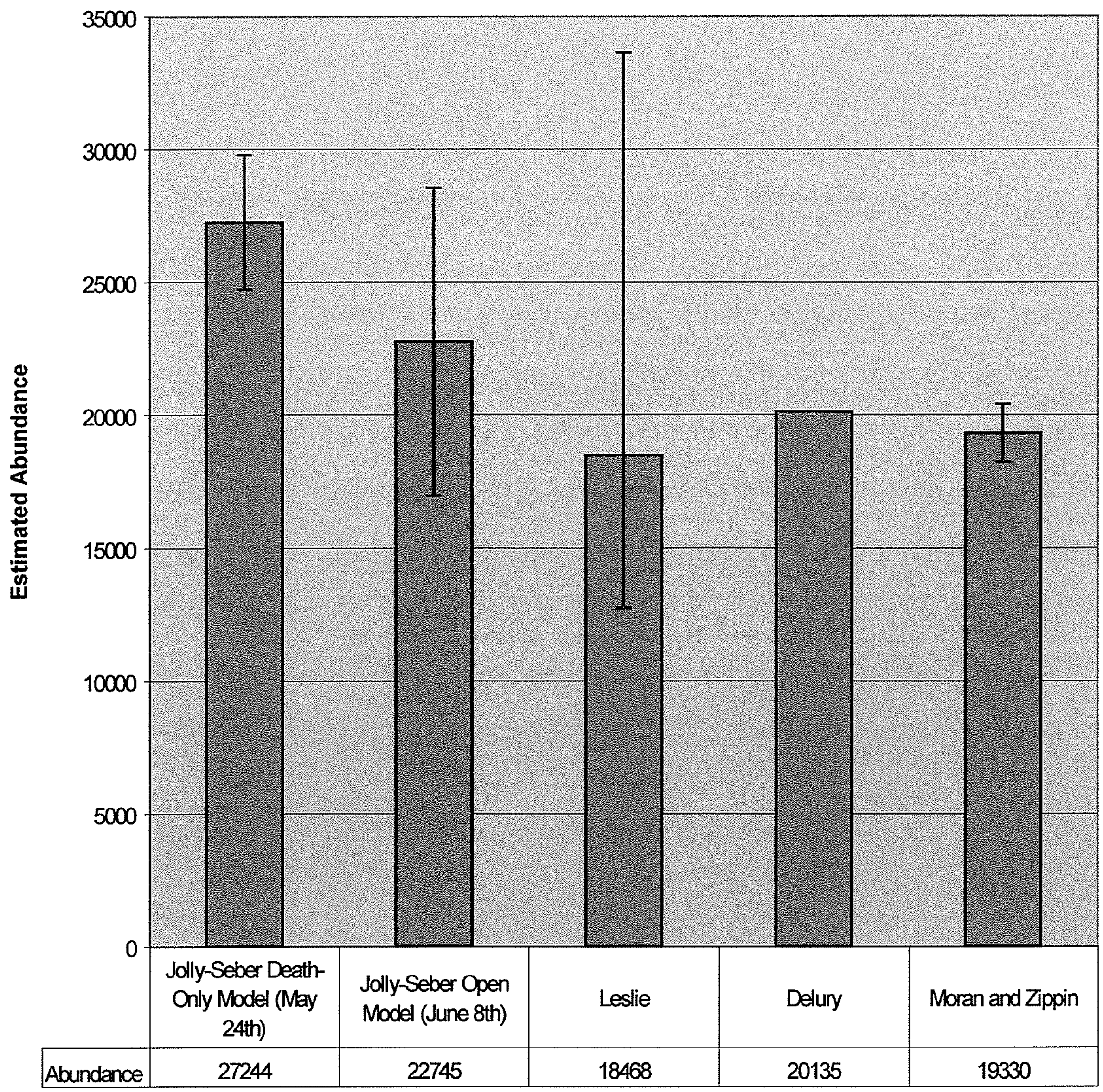

Figure 4.1: Summary of finescale dace abundance estimates for Lake 115.

4.3. Biomass Estimates

Biomass estimates for ELA Lake 115 were obtained by converting the abundance data to biomass data based on the length-frequency distribution of the May 24th sample. The length-weight relationship is:

$$\log \text{weight} = -12.38272 + 3.216144 * \log(\text{forklength})$$

This formula, which was calculated from length and weight measurements obtained from the Lake 115 finescale dace population, was applied to each forklength class of the May 24th length frequency distribution sub-sample. This yielded a biomass estimate of 52.0 kg for the entire lake, which translates to 8.0 kg • ha^{-1} for finescale dace that were large enough to be captured in the minnow traps (forklength greater than about 34mm), based on an abundance estimate of 27 244 fish.

The estimated biomass per length class for the May 24th length frequency distribution was graphed to determine which size classes contributed the greatest proportion to the biomass of the population (Figure 4.2). As Figure 4.2 indicates, the majority of Lake 115's finescale dace biomass at this sample period was centered around a forklength of about 60mm, ranging from approximately 52mm to 68mm. This size class is probably composed primarily of age 2+ fish (Stasiak 1978).

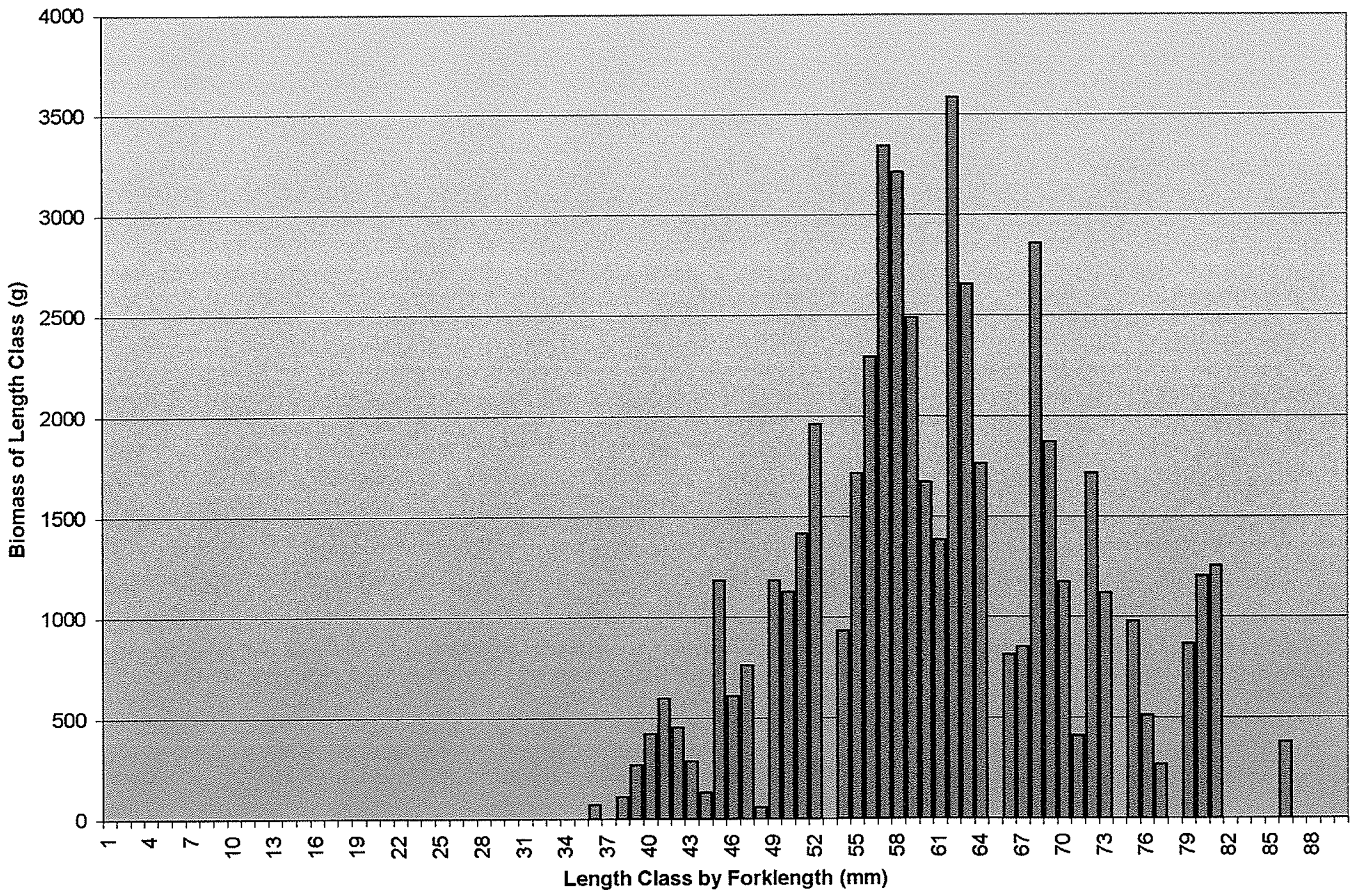

Figure 4.2: Distribution of biomass by forklengths for Lake 115 finescale dace (May 24/99).

4.4. Growth Estimates

Three distinct age classes can be seen in the Cassie analysis of the length frequency distributions taken throughout the 1999 season (Figures 4.3 - 4.4). These classes probably represent age 1+ (fish from the 1998 year class), age 2+ (fish from the 1997 year class), and age 3+ (fish that are from the 1996 year class or older) (Stasiak 1978). The largest fish measured in these sub-samples had a forklength of 87mm, although slightly larger fish were captured during the season. The smallest fish length recorded in these sub-samples was 34mm. This length corresponds with the minimum size of fish that the minnow traps were able to capture. Any fish that had a forklength of less than about 34mm also tended to have a sufficiently small enough girth to enable them to escape through the 5mm X 5mm mesh of the minnow traps. This prevented the capture of any young-of-the-year fish (1999 year class), since these fish did not reach the minimum trappable size during the sampling period. If this had occurred there would have been a noticeable peak at the 34mm mark during the latter sampling dates, rather than the complete absence of fish in the lower size classes.

To calculate the growth of Lake 115's finescale dace population, the mean forklength of each age class (1+, 2+ and 3+) that was estimated by Cassie analysis of the May 24th sample period was subtracted from the mean forklengths of the corresponding age class in the September 14th sample period. The change of mean forklengths for each age class was then used to determine the amount of growth that had occurred over the sampling periods. The results of this analysis indicate that the mean growth of each age class between May 24 and September was 10mm (1+ fish), 9.5mm (2+ fish) and 7mm (3+ fish).

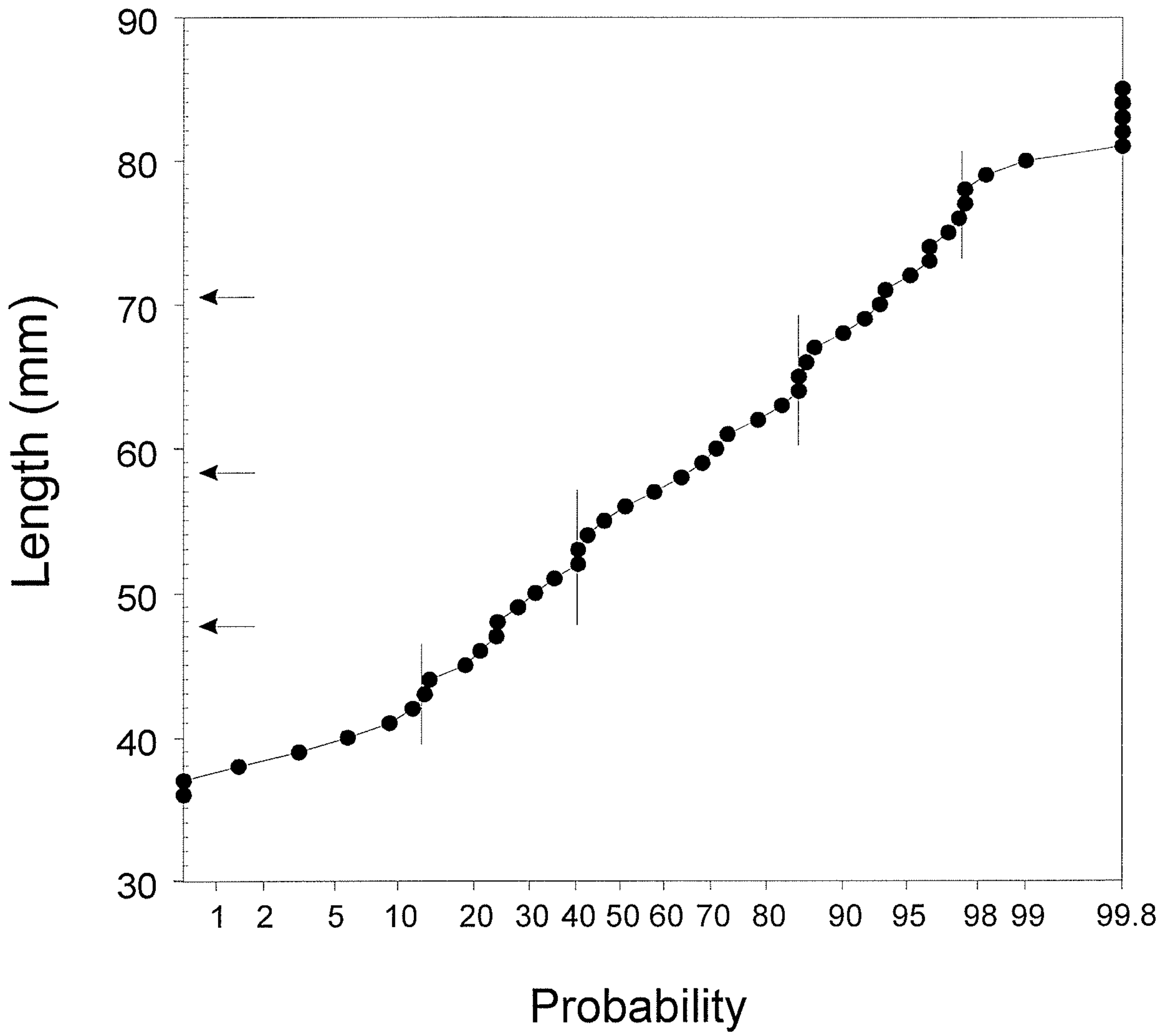

Figure 4.3: Cassie (1954) analysis of Lake 115 finescale dace length frequency distribution for May 24, 1999 sample period. Inflexion points represent the minimum and maximum forklengths of age groups. Arrows represent the mean length of each age class.

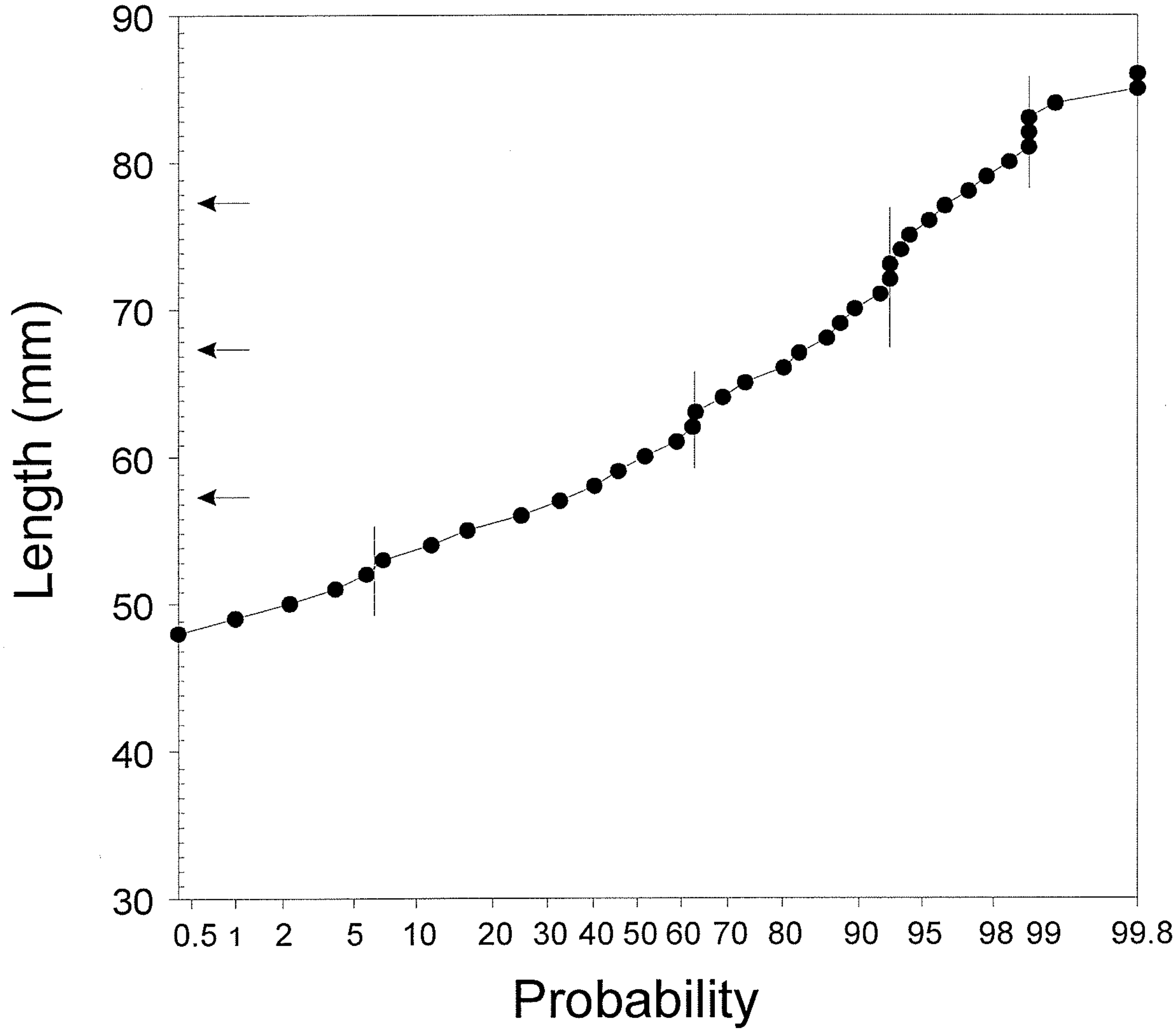

Figure 4.4: Cassie (1954) analysis of Lake 115 finescale dace length frequency distribution for September 14, 1999 sample period. Inflexion points represent the minimum and maximum forklengths of age groups. Arrows represent the mean length of each age class.

4.5. Baitfish Harvester Input

Information obtained from both questionnaires (6 out of 12 returned) and the Baitfish Association of Ontario meeting (12 members in attendance) indicated that most baitfish harvesters have been active in the industry for many years. Fishermen (all local harvesters contacted were male) who returned questionnaires had been in the business at least 20 years, with one person who has been a commercial baitfish harvester for 47 years.

When asked what qualities were common in good baitfish lakes, most fishermen responded that each lake was unique and that predicting which lakes would be good minnow producers was difficult. This is supported by the observation that lakes that appear to be very similar in terms of size, depth, and physical characteristics are often very different in their baitfish productivity. However, there are a number of specific lake characteristics that are common to many good baitfish lakes. For rocky-bottomed lakes, a minimum depth of about 3m with broken rock structure around the lakeshore was preferred. Good minnow producing bog lakes tend to have a minimum depth of about 1.8m, with a consistent depth throughout and dense aquatic plant growth. Lake 115 closely matched these preferred bog lake characteristics and, although it is a rather small lake, it is still larger than other finescale dace lakes that are utilized by commercial harvesters.

Another important quality that fishermen value in good minnow lakes is high dissolved oxygen levels throughout the year. This is necessary to prevent winterkill, which can drastically reduce a lake's baitfish population. In shallow bog lakes, a minimum amount of water flow through the lake during the ice-covered season is an important element in reducing or preventing winterkill conditions from occurring.

Other desired lake characteristics involve species assemblages. In general, lakes that have few fish species are more productive than lakes that have many species. However, lakes that have a number of desirable baitfish species can also be very productive. The absence of competitor or predatory species is important. Generally, the presence of predatory fishes such as northern pike (*Esox lucius*) or lake trout (*Salvelinus namaycush*) is thought to have a detrimental effect on baitfish harvests. While many bait fishermen will not even bother fishing lakes that contain northern pike, there are exceptions. Several fishermen indicated that some of their top producing lakes contained lake trout and even, less commonly, northern pike. The presence of yellow perch (*Perca flavescens*), which can act as both a competitor and a predator of baitfish species, is almost universally thought to reduce the baitfish productivity of a lake.

Another factor that makes characterizing a good baitfish lake difficult is the variability of annual harvest from individual lakes. A wide range of factors can affect the productivity of baitfish lakes: including weather, trophic-level effects, and species assemblages. Fishermen indicated that minnow catches can decrease or increase quite rapidly in some lakes due to changes in weather, food availability (which affects the attractiveness of baited traps), or other factors. Baitfish harvesters noted that baitfish production was often cyclical in some lakes, with specific baitfish species dominant and easily catchable in one period and while other species are dominant in the next, and that these cycles can be anywhere from weeks to years apart. These cycles were thought to be triggered by changes in lake temperature, food availability, competition, oxygen availability, and weather. These were thought to affect the breeding success and growth rates of different fish species. Fluctuations of the parameters could turn a good baitfish producing lake into a poor one or vice versa.

Finescale dace, pearl dace, fathead minnow, and white sucker are the preferred baitfish species in the northwestern Ontario area, with different fishermen favouring, or specifically targeting, certain species. This is dependent on both customer demand and the harvester's personal preference. It was indicated that finescale dace is a very desirable species due to their hardiness, attractive colouration and the fact that they are available in the size classes that customers prefer. Pearl dace and white sucker are used to provide larger size classes of minnow, while fathead minnows are desired for their high reproductive rate and rapid growth to retail size. The demand for specific size classes of baitfish can vary throughout the year and the area of the province. While some fishermen indicated that their customers wanted smaller minnows in the spring and larger baitfish as the season progressed, others indicated that this fluctuates from month-to-month.

One of the problems that some baitfishermen reported was that baitfish availability and customer demand often do not coincide. Some species trap better at certain times of the year, while mid-June to mid-July are usually the most difficult times to harvest nearly all baitfish species. Peak customer demand occurs between the mid-May opening of the (sport) fishing season and the end of July, although this can vary from location to location within the province. Therefore, baitfish supply is frequently poor during the latter portion of the peak demand period. Even when minnow harvests are high early in the season, customer demand can be so great that some fishermen find it difficult to maintain their supplies.

Fishermen indicated that they used specific strategies to prevent overharvesting in their baitfish lakes. Although each lake is unique and will therefore respond differently to fishing pressure, there are specific signs that commercial fishermen use to determine when to stop harvesting a lake and allow the fish populations to recover. **(1)** The catch is reduced to a level that is below a certain threshold. This number varies with individual fishermen, but most do have a minimum number of fish per trap per day (measured in dozens or gallons) that they use to determine when to stop harvesting from a specific lake. **(2)** The average size of individual fish captured begins to decline. **(3)** When the size of the fish that are captured is inconsistent. If the first catch from a lake has a high degree of inconsistency this is thought to indicate that the lake has probably experienced some degree of winterkill, and its baitfish population is still in the recovery stage.

The amount of time that a lake is left to recover between harvesting periods varies between fishermen and the characteristics of the lake. While some use a basic rule, such as allowing all of their lakes to have a two year recovery period before resuming harvesting activities, others use more specific criteria to determine how long to leave each lake. For example, one fisherman uses the following guidelines: when catches from a lake remain consistently high, 2 gallons or more (about 2000 to 2400 minnows depending on species), after three visits, he will likely return to the lake in the same year. If catches drop off quickly on the second visit to a lake, he will stop harvesting and let the lake recover for 1 year before returning to fish again. When the first day's catch from a lake is only 2 gallons and the second day's catch is low, with most of the bait still remaining in the trap, he will stop harvesting the lake and allow it to recover for 2 years.

Fishermen indicated that there is a minimum number of gallons of minnows that a lake must produce to make it economically viable to harvest. This volume of fish will varies between individual baitfish harvesters as well as the size and the location of the lake. Reported values ranged from between 10 and 100 U.S. gallons of fish per lake per year. Lakes that are isolated and require greater travelling time will become uneconomical to fish when catches fall below 1.5-2 gallons per visit, while lakes that are more easily accessible and those that are in areas containing other harvest lakes may be worth fishing for longer time periods. According to Meronek *et al.* (1997) a gallon of minnows is measured by putting one gallon of water into a bucket containing gallon marks and then adding fish (from which excess water has been allowed to drain) until the volume of the bucket reached the next gallon mark. The actual number of fish per gallon will vary with species and average fish size, but fishermen indicated that a gallon of pearl dace would be about 1000 fish, while finescale dace would be slightly higher at about 1200 fish. The species of baitfish that is harvested can also determine the economic value of a lake. Lakes that may not be good producers of dace and fathead minnows can still be worth fishing if larger white sucker, which can fetch high prices in some regions, are present.

Other areas of interest that baitfishermen mentioned which may have the potential to lead to cooperative research projects included: 1) controlling perch populations, into which some work has already been done (Mohr 1986). 2) Investigating the effects that brook trout (*Salvelinus fontinalis*) and splake (*Salvelinus fontinalis* x *Salvelinus namaycush*) introductions into baitfish lakes have on baitfish production. 3) Increasing baitfish production in lakes, including the effects of whole-lake fertilization. Fishermen were interested to know if there were any way to determine what the "ideal" conditions would be for minnow production, if it were possible to provide them. This was also suggested for leeches. 4) Increasing the amount of information available on local leech populations. This interest is due to the recent ban on imported leeches from the United States, which has increased the demand for locally caught leeches. Improving the catching and holding capabilities of leech traps was a major area of interest for commercial harvesters.

5.1 Mark-Recapture Population Estimates

Of the two mark-recapture methods used in this study, the Jolly-Seber death-only model had the tightest confidence intervals. The narrower confidence intervals for the death-only model, in comparison to the Jolly-Seber open model, were due to differences in how the estimates are calculated. While both models work on the same basic principles there are more parameters (recruitment and immigration) estimated at the same time in the open model than in the death-only model. This requires more complicated formulae to estimate the standard errors of the estimate which results in greater confidence intervals (Jolly 1965).

The use of the Jolly-Seber death-only model, which allows for death or emigration but not immigration or recruitment, was appropriate for Lake 115 finescale dace abundance estimates. The mark-recapture experiment began in late May and ended in late July. As a result, the young-of-the-year fish for 1999 did not reach a sufficiently large size during the marking period to contribute to population estimates. If this had occurred these fish would have been detected by the appearance of a size class with a modal length of approximately 34mm during the latter sampling dates, rather than the observed absence of fish in the lower size range (Appendix 2). In addition, last year's (1998) young-of-the-year fish had already reached a trappable size (>34mm forklength) prior to the start of the marking period. The assumption of a closed population was met in Lake 115, because it was a first order lake no downstream immigration into the population could occur. Fish movement into or out of the population through the lake's outlet was also not possible during the study period. There was no visible outflow that could have enabled fish passage throughout the entire duration of this study. Lake 115 is probably connected to the downstream Lake 467 only in periods of very high flow.

There were a number of factors contributing to the success of the mark-recapture population estimates for the early sampling periods. The most important of these was the capture and marking of a sufficiently large percentage of the fish in the population early in the study. This was possible due to the relatively small size of the lake (6.5 ha). The tight confidence intervals for the mark-recapture population estimates are due in a large part to the fact that a high proportion of fish that were marked were later recaptured in subsequent sampling periods. In a bigger lake the greater abundance of cyprinids would make it much more difficult to mark and recapture a significant proportion of the population. An additional factor contributing to the success of mark-recapture abundance estimates was low sampling mortality. This was kept to a minimum by emphasizing efficient handling time. The drop in catches that occurred after marking period 2 was probably due to the fact that, as commercial baitfish harvesters have pointed out, baitfish are generally become more difficult to trap as the summer progresses. The unreasonably high estimates that were calculated for the later death-only abundance estimates were probably due to some combination of tag loss (dorsal and anal fin clips were harder to detect than caudal fin clips) or the development of a small degree of trap shyness in some marked fish. Mortality may have also been more of a factor in the latter sampling periods because the difficulty of clipping of dorsal and anal fins on such small fish increased handling times.

5.2 Removal Population Estimates

Ten thousand-six-hundred and forty-one fish were captured during the 7 day removal experiment (Table 4.1). This is greater than half of the population, as estimated by the Leslie (estimated population = 18 468), Delury (estimated population = 20 135), or Moran and Zippin (estimated population = 19 330) methods. While the abundance estimates obtained through the use of removal methods still fall within the confidence limits of the Jolly-Seber open model, they are noticeably smaller than those obtained through mark-recapture methods (Figure 4.1). There are a number of possible explanations for this discrepancy. The simplest explanation for the difference between the mark-recapture and removal estimates is that they represent the estimated abundance of Lake 115's finescale dace population for different moments in time. The Jolly-Seber death-only abundance estimate of 27 244 (+/- 2532) fish and the Jolly-Seber open model abundance estimate of 22745 (+/- 5802) fish were calculated for the May 22-24th and June 7-10th sampling periods respectively. In contrast the Leslie estimate of 18468 fish, Delury estimate of 20 135 fish, and Moran and Zippin estimate of 19 330 fish were calculated for the 7-day period beginning on August 25th.

Differences between abundance estimates could be explained by a moderate decrease in the size of Lake 115's finescale dace population due to natural mortality. A mortality rate of 10% each month for the three months between the May 24th and August 25th estimates would result in a decrease from an original estimate of 27 444 fish to an August estimate of 19 861 fish. Although there were no predatory fish species in Lake 115, there were substantial numbers of aquatic macro-invertebrates present that are capable of preying on finescale dace, such as large dragonfly and damselfly naiads (order

Odonata), giant water bugs (*Lethocerus americanus*), and large diving beetles (*Dytiscus* spp.). Piscivorous birds, such as loons (*Gavia immer*) and Great blue herons (*Ardea herodias*) were also seen periodically fishing this lake throughout the summer. Additional sources of finescale dace mortality could include: post spawning mortality, disease, or predation by leeches (*Macrobdella decora*). Leech predation on finescale dace was observed numerous times throughout the sampling period. However, it is unknown whether this is a common occurrence under natural conditions or whether these leeches were only able to capture and consume dace due to the inability of these fish to avoid them in the narrow confines of a minnow trap.

An alternative explanation for the difference in removal and mark-recapture abundance is that the reduction in catch sizes that occur during a removal experiment for cyprinids do not necessarily reflect the actual decrease in fish numbers. At the September Baitfish Association meeting, commercial baitfish harvesters indicated that even though minnow catches can progressively decline in a lake as fish are harvested, catches may return to their previously high levels if the lake is left for a short period of time (a few weeks). This indicates that the rate at which catch sizes decline is actually more rapid than the rate at which the number of fish remaining in the population is declining, which would lead to an underestimate of abundance. The short time period that exists between the two harvesting sessions insures that the new individuals in an area are not the result of recruitment. However, in large lakes or those that are connected to other water bodies, immigration into an area after it has been fished down is possible. If some schools of minnows reside in specific areas of a lake and one of these schools is harvested heavily, a delay in the redistribution of the remaining minnow population could lead to some areas having decreased catches for a short period of time. Several authors (Brandt and Schreck 1975; Larimore 1954) found that minnow populations that had been intensively harvested recovered rapidly. Their studies examined stream dwelling cyprinid populations and they suggested that one of the primary mechanisms for recovery was the immigration of fish from upstream and downstream populations.

The most likely explanation for the decrease in abundance is natural mortality. Totsche (1998) calculated finescale dace abundance in a small (0.9 ha) wetland pond in northwestern Ontario using both mark-recapture (Jolly-Seber and Peterson estimates) and removal (Leslie and Delury estimates) procedures. He found that the estimated population size was very similar for all four calculation methods (3268, 3022, 3075 and 3237 fish). However, the time period between the mark-recapture and the removal procedures was less in Totsche's study than in this Lake 115 study. This would reduce the effects of natural mortality on abundance estimates. Additionally, Totsche did not begin his mark-recapture experiment until late June and it is likely that spawning for that year had already finished, with any post-spawning mortality that occurs for finescale dace having already occurred. In contrast, the mark-recapture abundance estimates for finescale dace in Lake 115 began in late May and took place throughout the spawning season. Stasiak (1978) found that the breeding season of a population of finescale dace in a northwestern Minnesota wetland pond began shortly after ice-out in April, peaked in early May, and was essentially finished by late May. Post-spawning mortality has been observed in a number of cyprinid species. Dramatic reductions in the populations of adult fathead minnows (*Pimephales promelas*) following the spawning season have been observed by Duffy (1998) and Payer and Scalet (1978), the latter of whom reported a post-spawning reduction in brood stock of 87%. Other species that exhibit high incidences of post-spawning mortality include bluntnose minnow (*Pimephales notatus*) (Lyons 1987) and longnose shiner (*Notropis longirostris*) (Heins et al. 1980). However, the presence of older fish in breeding populations of finescale dace, which are composed primarily of 2 and 3 year old fish, but can include fish up to 5 or 6 years of age (Stasiak 1978), suggests that spawning may not be as significant a source of mortality for *P. neogaeus* as it is for some other cyprinid species. High post-spawning mortality is much more likely to occur in cyprinid populations that are characterized by few individuals that are older than the age of sexual maturity (1 year of age for fathead minnows) than in populations that have many individuals that are older than the age of first sexual maturity. When high post-spawning mortality occurs, the majority of mature individuals die after they have reproduced, leaving few older fish in the population.

A final factor that could be responsible for the differences in the degree of correlation between mark-recapture and removal methods in Totsche's (1998) study and the Lake 115 study is possible differences in trap attractiveness to fish. Totsche suggested that in his mark-recapture study there was a chance that the fish had learned to associate the minnow traps with food. If this "trap happy" behavior carried over to the removal experiment it could lead to higher removal estimates (Ricker 1975). In contrast, baited traps were not used in Lake 115 until the removal experiment. Because fish were only trapped once in baited traps before being removed from the population it was less likely that fish learned to become trap happy.

5.3 Comparison to Other Cyprinid Abundance Estimates

The abundance estimates for the Lake 115 finescale dace population range from 4191 fish • ha^{-1} (May 24th Jolly-Seber death-only model) to 2841 fish • ha (August 25th Leslie plot). The average of these estimates is 3516 fish • ha, which is nearly identical to the finescale dace population estimate of 3540 fish • ha calculated for a 0.9 ha boreal wetland pond by Totsche (1998). The calculated densities for cyprinid populations in other water bodies differ quite widely from those of Lake 115 (Table 1.5). A number of factors, such as the species for which abundance is being calculated, the size and type of water body being studied, the number of species present, and the time of year that the estimate took place are likely to account for these differences. The abundance estimates for finescale dace in Lake 115 fall in the middle range of those calculated for cyprinids in other water bodies. While this estimate is considerably less than most of those listed for fathead minnows in prairie wetlands, it is higher than many of the density estimates for other lakes. It is interesting to note that the estimates for finescale dace in bog lakes in three different studies (this study, Totsche 1998 and He and Lodge 1990) were all very similar. This occurred despite the fact that the lake in He and Lodge's study also contained central mudminnow and a large population of northern redbelly dace. The primary productivity of these dystrophic lakes is typically low, which is usually reflected in low productivity and biomass at upper trophic levels.

While the abundance estimates for cyprinid species in many of the other lakes are smaller than those found in Lake 115, most of these lakes also have more species. Most abundance estimates were only made for some of the species in each waterbody, and as a result are probably underestimates of the actual total abundance of all fishes that were present. Lakes that have more fish species may actually have more biomass overall but due to competition for limited resources, such as food, the abundance of individual species, particularly when niche overlaps are occurring, can be lower than they would be in a system with fewer species (Wootton 1990). The presence of predators or competitors can also affect the potential population size of a lake's cyprinid population. For example, Gauthier and Boisclair (1997) found that the foraging success of hybrid dace (*Phoxinus eos* x *P. neogaeus*) confined to the littoral zone was reduced in the presence of a stronger competitor, pumpkinseed sunfish (*Lepomis gibbosus*).

Table 5.1: A comparison of cyprinid abundance estimates from various waterbodies.

Species	Estimated Density (fish•ha^{-1})	# of Species Present in Water Body	Water Body	Water Body Size (ha)	Geographic Location	Source
Fathead minnow (*Pimephales promelas*)	241 000	4 species 1 of which was a cyprinid	Larson (prairie wetland)	69.6	South Dakota	Duffy 1998
Fathead minnow	178 000	5 species 1 of which was a cyprinid	Oak (prairie wetland)	87.7	South Dakota	Duffy 1998
Fathead minnow	95 000	3 species 1 of which was a cyprinid	Ratfield (prairie wetland)	41.1	South Dakota	Duffy 1998
Fathead minnow	52 000	2 species 1 of which was a cyprinid	Little Brush (prairie wetland)	15.2	South Dakota	Duffy 1998
Fathead minnow	78 300	2 species 1 of which was a cyprinid	Knapper (prairie pothole)	5.0	South Dakota	Carlson and Berry 1990
Fathead minnow	67 400	2 species 1 of which was a cyprinid	Cotton (prairie pothole)	3.3	South Dakota	Carlson and Berry 1990
Fathead minnow	39 100	2 species 1 of which was a cyprinid	Refuge (riparian wetland)	2.2	South Dakota	Carlson and Berry 1990
Fathead minnow	28 300	1 species	Bolstad (prairie pothole)	20.5	South Dakota	Carlson and Berry 1990
Fathead minnow	25 000	3 species 1 of which was a cyprinid	Beck (prairie pothole)	7.1	South Dakota	Carlson and Berry 1990
Northern redbelly dace (*Phoxinus eos*)	50 449	3 species 2 of which were cyprinids	Tuesday Lake (small bog lake)	0.8	Northern Michigan	He and Lodge 1990
Finescale dace (*Phoxinus neogaeus*)	3459	3 species 2 of which were cyprinids	Tuesday Lake (small bog lake)	0.8	Northern Michigan	He and Lodge 1990
Finescale dace	3540	1 species	Lake 632 (bog lake)	0.9	Northwestern Ontario	Totsche 1998
Finescale dace	3516	1 species	Lake 115 (bog lake)	6.5	Northwestern Ontario	This study
Creek chub (*Semotilus atromaculatus*)	2860	15 species 10 of which were cyprinids	Small pond	0.1	Northwestern Ontario	Pot *et al.* 1984
Common shiner (*Notropis cornutus*)	610	15 species 10 of which were cyprinids	Small pond	0.1	Northwestern Ontario	Pot *et al.* 1984

Table 5.1 (cont'd): A comparison of cyprinid abundance estimates from various waterbodies.

Species	Estimated Density (fish•ha^{-1})	# of Species Present	Water Body	Water Body Size	Geographic Location	Source
Golden shiner (*Notemigonus crysoleucas*)	2111	8 species 5 of which were cyprinids	Pine Lake	16.4	Southern Ontario	Fraser 1981
Golden shiner	2061	8 species 5 of which were cyprinids	Lonesome Lake	3.6		
Golden shiner	481	8 species 5 of which were cyprinids	Sawlog Lake	6.3		
blacknose shiner (*Notropis heterolepis*)	859	22 species 7 of which were cyprinids (including carp (*cyprinus carpio*))	Long Pond (lagoon on Long Point Lake Erie)	2.4	Southern Ontario	Mahon and Balon 1977
bluntnose minnow (*Pimephales notatus*)	413					
Golden shiner	53					
creek chub	23	6 species 2 of which were cyprinids	Red Chalk Lake	56.9 ha	Southern Ontario	Jackson and Harvey 1997
creek chub	36	5 species 1 of which was a cyprinid	Harp Lake	66.9 ha		
golden shiner	400	6 species 2 of which were cyprinids	Crosson Lake	56.8 ha		
creek chub	7					
golden shiner	93	5 species 2 of which were cyprinids	Plastic Lake	32.6 ha		
creek chub	25					
Bluntnose minnow	105-424	25 species 8 of which were cyprinids	Sparkling Lake	88 ha	North-central Wisconsin	Lyons 1987
5 shiner species (*Notropis* and *Notemigonus*)	6-47					
fathead minnow	12-26 (could be low due to heavy salamander predation)	1 species	Pickering Slough (Prairie wetland)	16.2 ha	South Dakota	Payer and Scalet 1978

5.4 Biomass Estimates

The estimated biomass for Lake 115's finescale dace population was calculated for adult fish (fish that were age 1+ or older). The biomass of young-of-the-year (YOY) finescale dace was probably increasing its contribution to total biomass as the season progressed. In the spring, prior to spawning, the YOY biomass was 0%, but this would have increased throughout the summer as fish hatched and grew in size. Finescale dace grow rapidly. Lake 115 YOY fish reach forklengths of about 35mm by the end of their first season. This corresponds to a biomass of just under 0.4g (calculated by length-weight regression from section **4.3**),.

The estimated biomass for Lake 115 finescale dace during the May 24th sampling period, based on a Jolly-Seber death-only abundance estimate of 27 244 fish, was 52.0 kg, which translates to 8.0 kg • ha^{-1}. However, adult finescale dace biomass would probably increase throughout the summer as fish grew in length and weight.

Biomass estimates for Lake 115 fell within the range cyprinid biomass estimates in other studies. The biomass of adult finescale dace in Lake 115 was much lower than that calculated for fathead minnows in prairie wetlands, even if YOY fish are taken into consideration (Table 5.2). While the Lake 115 finescale dace biomass was much higher than the biomass that was calculated for cyprinids in a number of other waterbodies, many of the other estimates did not include all fish species present. If non-cyprinid species were included in the calculation of biomass, Lake 115 would have a much lower biomass than that of many of the other waterbodies presented in Table 5.2. For example, the total biomass of all species in Pine, Lonesome and Sawlog lakes was 86.1, 27.8 and 72.6 kg • ha^{-1}, respectively.

Table 5.2: Cyprinid biomass estimates from various waterbodies.

Species	Estimated Biomass (kg•ha^{-1})	# of Species Present in Water Body	Water Body	Water Body Size	Geographic Location	Source
fathead minnow (*Pimephales promelas*)	88.9*	4 species 1 of which was a cyprinid	Larson (prairie wetland)	69.6	South Dakota	Duffy 1998
fathead minnow	114.5*	5 species 1 of which was a cyprinid	Oak (prairie wetland)	87.7		
fathead minnow	117.6*	3 species 1 of which was a cyprinid	Ratfield (prairie wetland)	41.1		
fathead minnow	81.0*	2 species 1 of which was a cyprinid	Little Brush (prairie wetland)	15.2		
golden shiner (*Notemigonus crysoleucus*)	1.0	8 species 5 of which were cyprinids	Pine Lake	16.4	Southern Ontario	Fraser 1981
creek chub (*Semotilus atromaculatus*)	0.3					
pearl dace (*Semotilus margarita*)	<0.1					
golden shiner	0.7	8 species 5 of which were cyprinids	Lonesome Lake	3.6		
creek chub	<0.1					
pearl dace	0.1					
Redbelly dace (*Phoximnus eos*)	0.3					
Golden shiner	2.5	8 species 5 of which were cyprinids	Sawlog Lake	6.3		
Creek chub	0.5					
Pearl dace	0.3					
Blacknose shiner (*Notropis heterolepis*)	3.8	22 species 7 of which were cyprinids (including carp (*cyprinus carpio*))	Long Pond (lagoon on Long Point Lake Erie)	2.4	Southern Ontario	Mahon and Balon 1977
Bluntnose minnow (*Pimephales notatus*)	1.7					
Golden shiner	0.7					
Finescale dace (*Phoxinus neogaeus*)	8.0	1 species	Lake 115 (bog lake)	6.5	Northwestern Ontario	This study

* includes young-of-the-year fish

The majority of the finescale dace biomass in Lake 115 was centered around a modal forklength of about 60mm (Figure 4.2), which are probably age 2+ fish (Stasiak 1978). These individuals are likely to make the greatest contribution to the population's reproduction, as the majority of age 1+ fish are not sexually mature (Stasiak 1978). This could have important implications for baitfish harvest. Finescale dace have a relatively low fecundity for cyprinids. Stasiak (1978) found that ripe females contained between 784 and 3060 eggs. This is quite low in comparison to other cyprinid species such as fathead minnow, which Duffy (1998) calculated to have an annual fecundity of 6800 to 10 600 eggs per female. If an overly large portion of the age 2+ and 3+ fish, which fall within the preferred size range for baitfish, is harvested, the population's spawning success could be compromised. This possibility could be reduced by not harvesting finescale dace until after spawning has been completed, which would allow most fish to reproduce at least once before they are removed from the population. Substantial pre-spawn harvest of finescale dace that results in a reduction in age 2+ and older fish could depress a population's production for that year, as the remaining age 1+ fish are not yet able to reproduce. If this reduction took place for several consecutive years, the majority of the spawning population could be removed and would take a number of years to recover. This highlights the importance of taking into account the biology of the species being managed when determining how to harvest within sustainable limits.

Finescale dace are a relatively long-lived species that can reach at least 6 or more years of age (Stasiak 1978) and do not breed until they are at least 2 years old. In contrast, the majority of individuals in a population of fathead minnow spawn at age 1+ and suffer high levels of post-spawning mortality (Held and Peterka 1974). This post-spawning mortality, which tends to range anywhere from 80 to 100%, results in a natural population structure for fathead minnow that is composed primarily of young fish. The combination of high productivity, a lack of dependence on older age classes, and the ability to rapidly recover from low population sizes (Duffy 1998) allows fathead minnow populations to be more resilient to frequent harvesting pressure than finescale dace.

5.5 Growth Estimates

Three distinct age classes of Lake 115 finescale dace were identified using the Cassie (1954) analysis. The change in probable mean forklength between the May 24th and September 14th sample periods indicated that these fish grew about 7 to 10mm in length during the sample period. Fish in older age classed were found to grow at slower rates than fish in younger age classes. This is not surprising, as young fish are able to allocate more of their energy towards growth, while reproduction takes up a greater portion of the energy of older fish (Wootton 1990).

5.6 Baitfish Harvester Input

The considerable length of time (at least 20 years) that most baitfish harvesters have been in the industry makes them a substantial source of information on the dynamics of the commercial bait fishery. These fishermen displayed a detailed knowledge of the requirements of baitfish species and harvesting techniques, as well as developing harvesting guidelines to prevent overexploitation of baitfish stocks in their lakes.

The physical characteristics that commercial fishermen listed as being common to many productive baitfish lakes can be related to the biology of the species that they harvest. Shallow bog lakes that occasionally undergo winterkill are able to support large populations of winterkill-resistant species such as finescale dace, as this prevents less resistant piscivorous fish species from becoming permanently established (Carpenter *et al.* 1987). In addition, these lakes generally have areas of dense shoreline cover in the form of aquatic vegetation or sunken brush that are required for the successful spawning of finescale dace (Stasiak 1978), pearl dace, and fathead minnows (Scott and Crossman 1973). The presence of broken rock structure around the lakeshore in oligotrophic lakes can be important to baitfish species as a source of cover from predators. Baitfish in lakes that have piscivorous species, such as lake trout (*Salvelinus namaycush*), that do not have adequate cover may be exposed to higher rates of predation. This could lower the potential baitfish harvest that this type of lake can produce.

Although lakes that occasionally experience winterkill can be excellent baitfish producers, because they will have no predatory fish species (Carpenter *et al.* 1987), those that winterkill too often may not be able to support sufficiently high baitfish populations to make them economically viable to harvest. As a result, commercial baitfishermen prefer lakes that have high dissolved oxygen levels throughout the year. This allows a lake to support larger populations of baitfish of commercially preferred size classes.

Although the presence of lake trout and more often northern pike (*Esox lucius*) is generally thought to have a detrimental effect on baitfish harvests, there are obvious exceptions. The factors that affect whether baitfish lakes containing predatory species can produce high volumes of bait remain unclear. The presence of competitor species, such as yellow perch (*Perca flavescens*), is also thought to decrease the quality of a baitfish lake. Yellow perch can compete for food resources, act as predators of young cyprinids and interfere with trapping success (Mohr 1986). Gauthier and Boisclair (1997) found that hybrid redbelly x finescale dace in the presence of a competitor species, pumpkinseed sunfish, were forced to make onshore-offshore migrations in order to feed, and that these migrations occurred at night to avoid predation by lake trout. However, baitfishermen indicated that the presence of several cyprinid species in a lake could be beneficial. Even though species such as pearl dace, finescale dace, and fathead minnows can compete to varying degrees for food and habitat (Cochran et al. 1988), these species will be easier to trap at different times of the year. This can allow greater overall production from a lake, even if catches of individual species are less, because it may be harvested several times a season for different species.

Annual abundance of baitfish species in individual lakes and variation in community composition make it difficult to predict which lakes will be good baitfish producers at any given time. Baitfish species may affect the size and composition of a lake's invertebrate species assemblage, as well as primary production, transparency, and chemical characteristics such as pH, total nitrogen, and total phosphorus (Carpenter *et al* 1987; Henrikson *et al* 1980). If this is true, the increase or decrease of a lake's minnow population, through such factors as harvest levels, temperature changes, food availability, and reproductive success, will affect its potential productivity of baitfish.

Commercial baitfishermen suggested that one of the biggest problems they have is that the demand for baitfish is often greater than the available supply. This is related to the cyclical nature of baitfish production in most lakes. In mid-June to mid-July most baitfish species become very difficult to harvest and demand tends to exceed supplies. This need for more baitfish during certain times of the year has been expressed by baitfishermen in other studies (Meronek *et al* 1997; Frost and Trial 1993 and Nielsen 1982), indicating that it is not a local phenomenon.

Fishermen had a clear understanding of the importance of developing sustainable methods of harvest and have developed a number of strategies to ensure that they do not overexploit their baitfish lakes. Contrary to Brandt and Schreck's (1975) conclusions that harvesting pressures do not appear to affect the densities of baitfish populations, northwestern Ontario commercial fishermen recognize that their activities can affect baitfish abundance and take steps to prevent overharvest. While each harvester's specific method of determining when to cease harvesting activities on a lake will vary, they all appear to practice some form of rotational harvesting, in which some lakes are left to recover for 1 or 2 years once catches drop below a certain level. In addition, daily catches will fall as fish density decreases until a lake is no longer economically viable to harvest. As a result fishermen cease harvesting a lake well before baitfish populations are reduced to the point where their abundance become greatly diminished. Lake rotation and economic viability limits on harvests work in combination with the short life cycle and high fecundity of most baitfish species (which allows for rapid population recovery (Duffy 1998; Tallman and Gee 1982)) to reduce the chances of taking more fish than a lake can handle.

Perhaps the key component contributing to the sustainability of the northwestern Ontario baitfish industry is the use of baitfish blocks, in which (for a modest fee) each fisherman has the exclusive rights to harvest baitfish from the lakes within his own block(s). This limited-access fishery provides individual baitfishermen with the incentive to practice sustainable management of their lakes. In addition, when only one commercial harvester is utilizing a lake, it is possible to more accurately gauge the total fishing pressure to which individual baitfish populations are being exposed.

5.7 Suggestions for Further Research

A number of areas of interest were identified by commercial baitfishermen that may have the potential to lead to cooperative research. Many of these suggestions focused on maximizing bait production, which includes leeches. However, other recommendations included developing methods to control competitor species (yellow perch (*Perca flavescens*)), on which some work has already been done (Mohr 1986), and investigating the effects that introduced predatory species (lake trout and splake (*Salvelinus fontinalis* x *Salvelinus namaycush*)) that have been stocked in baitfish lakes can have on baitfish production. The Experimental Lakes Area is in the unique position of being able to undertake research projects that would be of direct interest to the members of the northwestern Ontario commercial baitfish industry. Many of the lakes in which ELA studies are undertaken are characteristic of the lakes that the northwestern Ontario region's commercial baitfish harvesters utilize. This allows the findings of any future studies performed on baitfish related concerns to be directly applicable to the local baitfish industry.

To take advantage of this common ground, the ELA and the Baitfish Association should work together to develop projects that would be of interest to both parties. Each of these organizations has specific skills and knowledge that could be used to improve the quality and relevance of cooperative research ventures. The ELA has the scientific expertise and research facilities, while local baitfishermen have an immense body of accumulated knowledge regarding local baitfish production and harvest. Both parties would benefit from undertaking studies that have been cooperatively developed. The ELA would benefit from the knowledge gained in the dynamics of bait species populations and their role in boreal lake ecosystems, while baitfishermen would gain a better understanding of the factors that influence baitfish or leech production.

6. Summary, Conclusions and Recommendations

6.1 Summary

The abundance and biomass and growth of the adult fish in the finescale dace population of Lake 115 were estimated by both multiple mark-recapture and removal methods. The mark-recapture data were analyzed by Jolly-Seber death-only and open models, while the data from removal methods were analyzed using Leslie's, Delury's, and Moran and Zippin's methods. The best estimates of the abundance of finescale dace in Lake 115 were 27 244 fish for the death-only model, 22 745 fish for the open-model, 18 468 fish for the Leslie method, 20 135 fish for the Delury method and 19 330 fish for Moran and Zippin's method. Biomass estimates were based on the May 24th death-only abundance estimate. The estimated adult finescale dace biomass for Lake 115 was 52.0 kg for the entire lake, which translates to 8.0 kg • ha^{-1}. The majority of the Lakes finescale dace biomass at this time was fish in the 52 to 68mm size range, which are probably age 2+ fish.

Northwestern Ontario commercial baitfish harvesters suggested that baitfish production fluctuates in and between lakes and is affected by a wide range of factors. These factors include the area and depth of a lake, its physical and chemical characteristics, species assemblages, and weather patterns. Commercial harvesters use specific strategies to prevent overharvesting in the baitfish lakes that they manage. While the Ontario Ministry of Natural Resources is responsible for the management of this fishery they have implemented a system of baitfish blocks in the northwestern Ontario region. This has effectively created a limited-access fishery that encourages block owners to practice ecologically sustainable harvest strategies and allows the industry in this part of the province to be essentially self-regulating.

6.2 Conclusions

Lake 115 lacked predatory fish and fish migration was not possible. The small size of the lake allowed a large trapping effort in proportion to its area, high numbers of fish to be marked and recaptured. These factors all contributed to the confidence in the abundance estimates. While marking periods were spaced 2 weeks apart to allow the redistribution of marked fish into the population, this period may have been long enough to allow mortality to influence the results, particularly the length of time separating mark-recapture and removal estimates. Consequently, it is recommended that future studies of this type use a shorter time period between marking periods as well as between mark-recapture and removal population estimates. An alternative solution (Ken Mills pers. comm. Feb. 2000) would be to use the final mark-recapture sampling period as a removal experiment, which also would provide an abundance estimate for the final sampling period.

While the abundance and biomass estimates for Lake 115 fell within those calculated in other studies, Lake 115 finescale dace estimates were higher than those calculated for cyprinids in a number of lakes. However, this could have been due in part to other non-cyprinid species making up significant portions of the productivity of these lakes. Biomass and abundance estimates that have been calculated for cyprinids (fathead minnows) in prairie wetlands were much higher than those of Lake 115's finescale minnows, which is likely to have been due to a combination of fathead minnow biology and the high productivity of eutrophic wetlands.

Most of the finescale dace biomass in Lake 115 was centered around a forklength of about 60mm, a size range favored by commercial baitfishermen. These fish are primarily the age 2+ fish that are likely to make up the majority of the lake's spawning population. This indicates that the productivity of finescale dace lakes may be enhanced by not harvesting this species until after spawning has occurred. This would allow most fish in the lake to reproduce at least once before being removed from the population and avoid compromising future year classes.

Commercial baitfish harvesters have accumulated detailed knowledge on the dynamics of baitfish populations in boreal lakes. The fact that some lakes containing predatory game fish can also be excellent producers of baitfish was an interesting piece of information that warrants further study. The use of baitfish blocks, which removes many of the problems associated with an open fishery, is one of the key components to the sustainability of this industry. This works in combination with the fact that most lakes will become uneconomical to harvest before minnow populations are reduced to unsustainably low levels, and the ability of most baitfish species to recover rapidly from population reductions, to reduce the likelihood of overharvesting. Baitfishermen recognize the importance of managing their lakes for long-term productivity and utilize a system of lake rotations to prevent overharvest. Further improving the sustainability of the northwestern Ontario commercial baitfish industry would be facilitated by increasing the amount of information available on such topics as baitfish species biology, population dynamics, baitfish productivity, intraspecific interactions, and the effects of harvesting activities.

6.3 Recommendations

Expanding the amount of information available to improve the sustainability of the baitfish industry could be greatly facilitated by cooperative research projects between such organizations as the Experimental Lakes Area and the Ontario Baitfish Association. There are a number of areas of research that could prove to be mutually beneficial to both the ELA and the baitfish industry. The following lists suggested topics for future research:

- More research is needed on the abundance, biomass, and growth of finescale dace in waterbodies other than bog lakes, such as mesotrophic and oligotrophic lakes;
- An investigation into the limiting factors for finescale dace populations is needed. This would be a basis to determine methods of improving their productivity;
- Investigation of finescale dace diet composition is necessary to determine whether differences exist between age classes and if these differences can be correlated with abundance and growth patterns;
- Comparative studies of exploited and unexploited populations of finescale dace are needed. These studies would focus on determining how different rates of harvest affect the size distribution, growth rates, productivity, average spawning age and other population dynamics of finescale dace. This information could then be used to help formulate harvesting strategies that maximize productivity without compromising baitfish populations;
- Further research in the above mentioned areas should also be conducted for other important baitfish species, such as pearl dace and fathead minnow;

- The productivity of baitfish populations in multi-species lakes and those in monocultures should also be investigated to determine the effects of species mixes on baitfish production;
- Research into the fluctuations of baitfish productivity in lakes may be able to determine some of the causes behind this phenomenon. This information would be useful in determining how to increase the productivity of baitfish lakes;
- More research on leech populations in boreal waters should be undertaken with emphasis being placed on how leech production can be increased for commercial harvest;
- The effects of baitfish removal on lake trout and northern pike populations are still poorly understood. Future research activities should focus on determining which factors allow some lake trout and northern pike lakes to remain good baitfish producers. Additionally, research should be undertaken on the effects of predatory game fish introductions on baitfish productivity in lakes, as well as the effects of baitfish removals on gamefish populations. This would ensure that any future regulations on baitfish harvest are based on actual biological responses.

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APPENDIX 1

BAITFISH INDUSTRY QUESTIONNAIRE

Questions on Questionnaire given out at Baitfish Association of Ontario meeting.

1. How long have you been in the baitfish industry?
2. In your opinion, what qualities does a good baitfish lake tend to have, in terms of size, depth, species composition etc.?
3. Which species and sizes are preferential for baitfish?
4. How does the demand for specific sizes and species of baitfish vary throughout the year?
5. At what times of the year have you found that the available supply of specific sizes or species of baitfish is unable to meet the demand for them? Also, are there any times when certain baitfish are in ample supply but there is low demand for them?
6. How do you determine when to stop harvesting from a lake?
7. How do you determine the time period that a lake will be left to recover before resuming harvesting fish from it?
8. What would be the minimum number of gallons of fish that a lake must be able to produce to make it economically viable to harvest?
9. What major concerns do you have that could be addressed through cooperative research with the Experimental Lakes Area?

APPENDIX 2

LENGTH-FREQUENCY DISTRIBUTION RAW DATA

Fish #	24-May	08-Jun	22-Jun	06-Jul	20-Jul	10-Aug	27-Aug	14-Sep
1	36	34	36	38	40	42	46	48
2	36	37	36	38	40	43	46	48
3	36	38	37	39	41	43	46	49
4	38	38	38	39	43	45	46	49
5	38	38	39	39	43	45	46	49
6	38	39	39	40	43	45	46	50
7	38	39	39	40	43	45	49	50
8	39	39	39	40	43	46	49	50
9	39	39	39	40	43	46	50	50
10	39	39	39	40	43	46	50	50
11	39	39	40	40	43	46	50	50
12	39	39	40	40	43	46	50	51
13	39	39	40	40	43	47	50	51
14	39	39	40	40	43	47	50	51
15	39	39	40	40	43	47	50	51
16	39	40	40	41	44	47	50	51
17	40	40	40	41	44	47	50	51
18	40	40	40	41	44	47	50	51
19	40	40	40	42	45	49	50	51
20	40	40	40	42	45	49	50	51
21	40	40	40	42	45	50	50	52
22	40	40	40	42	45	50	50	52
23	40	40	40	42	45	50	50	52
24	40	40	40	42	45	50	50	52
25	40	40	40	42	45	50	51	52
26	40	40	40	42	45	50	51	52
27	40	40	40	42	45	50	51	52
28	40	40	40	42	45	50	51	52
29	40	40	40	42	45	50	51	52
30	41	40	40	42	45	51	51	53
31	41	40	40	42	45	51	51	53
32	41	40	41	42	45	51	51	53
33	41	41	41	42	45	51	52	53
34	41	41	41	42	45	51	52	53
35	41	41	41	42	45	51	52	53
36	41	41	41	42	45	51	52	54
37	41	41	41	42	45	51	52	54
38	41	41	41	42	45	51	52	54
39	41	41	41	43	45	51	53	54
40	41	41	41	43	46	51	53	54
41	41	41	41	43	46	51	53	54
42	41	41	41	43	46	51	53	54
43	41	41	41	43	46	51	53	54
44	41	41	41	43	46	51	53	54
45	41	41	41	43	46	51	53	54
46	41	42	41	43	46	51	53	54
47	42	42	41	43	46	51	53	54
48	42	42	41	43	46	51	53	54
49	42	42	41	43	46	51	53	54
50	42	42	41	43	46	51	53	54

Fish #	24-May	08-Jun	22-Jun	06-Jul	20-Jul	10-Aug	27-Aug	14-Sep
51	42	43	41	43	46	51	54	54
52	42	43	41	44	46	51	54	54
53	42	43	41	44	46	51	54	54
54	42	43	41	44	46	51	54	54
55	42	43	41	45	46	51	54	54
56	42	43	41	45	46	51	54	54
57	42	43	41	45	46	52	54	54
58	42	43	41	45	46	52	54	54
59	43	43	41	45	46	52	54	55
60	43	43	41	45	46	52	54	55
61	43	43	41	45	46	52	54	55
62	43	43	41	45	46	52	54	55
63	43	44	41	45	46	52	54	55
64	43	44	42	45	46	52	54	55
65	43	44	42	45	46	52	54	55
66	44	44	42	45	46	52	54	55
67	44	45	42	45	47	52	54	55
68	44	45	42	45	47	52	54	55
69	45	45	42	45	47	52	54	55
70	45	45	42	45	47	52	54	55
71	45	45	42	45	47	52	54	55
72	45	45	42	45	47	52	54	55
73	45	45	42	45	47	52	54	55
74	45	45	42	45	47	52	54	55
75	45	45	42	45	47	52	55	55
76	45	45	42	46	47	52	55	55
77	45	45	42	46	47	52	55	55
78	45	45	42	46	47	52	55	55
79	45	46	42	46	47	52	55	55
80	45	46	42	46	47	52	55	55
81	45	46	42	46	47	52	55	55
82	45	46	42	46	47	52	55	56
83	45	46	42	46	47	52	55	56
84	45	46	42	46	47	52	55	56
85	45	46	42	46	47	52	55	56
86	45	46	42	46	47	52	55	56
87	45	46	42	46	47	52	55	56
88	45	46	42	46	47	52	55	56
89	45	46	42	46	47	52	55	56
90	45	46	42	46	49	52	55	56
91	45	46	42	46	49	52	55	56
91	45	46	42	46	49	52	55	56
93	45	46	42	46	49	52	55	56
94	46	46	42	46	49	52	55	56
95	46	46	42	46	49	52	55	56
96	46	47	42	46	50	52	55	56
97	46	47	42	46	50	54	55	56
98	46	47	42	46	50	54	55	56
99	46	47	43	46	50	54	55	56
100	46	47	43	46	50	54	55	56

Fish #	24-May	08-Jun	22-Jun	06-Jul	20-Jul	10-Aug	27-Aug	14-Sep
101	46	47	43	46	50	54	55	56
102	46	47	43	46	50	54	55	56
103	46	47	43	46	50	54	55	56
104	46	47	43	46	50	54	55	56
105	46	49	43	47	50	54	55	56
106	47	49	43	47	50	54	55	56
107	47	49	43	47	50	54	55	56
108	47	49	43	47	50	54	55	56
109	47	49	43	47	50	54	55	56
110	47	49	43	47	50	54	55	56
111	47	50	43	47	50	54	56	56
112	47	50	43	47	50	54	56	56
113	47	50	43	47	50	54	56	56
114	47	50	43	47	50	54	56	56
115	47	50	43	47	50	54	56	56
116	47	50	43	47	50	54	56	56
117	47	50	43	47	50	54	56	56
118	47	50	43	47	51	54	56	56
119	47	51	43	47	51	54	56	56
120	48	51	43	47	51	54	56	56
121	49	51	43	47	51	54	56	56
122	49	51	43	47	51	54	56	56
123	49	51	44	47	51	54	56	56
124	49	51	45	47	51	55	56	56
125	49	51	45	47	51	55	56	56
126	49	51	45	47	51	55	56	57
127	49	51	45	47	51	55	56	57
128	49	51	45	47	51	55	56	57
129	49	51	45	49	51	55	56	57
130	49	51	45	49	51	55	56	57
131	49	51	45	49	51	55	56	57
132	49	51	45	49	51	55	56	57
133	49	51	45	49	51	55	56	57
134	49	51	45	49	51	55	56	57
135	49	51	45	49	51	55	56	57
136	49	51	45	49	51	55	56	57
137	49	51	45	50	51	55	56	57
138	49	51	45	50	51	55	56	57
139	49	51	45	50	51	55	56	57
140	50	51	45	50	51	55	56	57
141	50	51	45	50	51	55	56	57
142	50	51	45	50	51	55	56	57
143	50	52	45	50	51	55	56	57
144	50	52	45	50	51	55	56	57
145	50	52	45	50	51	55	56	57
146	50	52	45	50	51	55	56	57
147	50	52	45	50	51	55	56	57
148	50	52	45	50	51	55	56	57
149	50	52	45	50	51	55	56	57
150	50	52	45	50	51	55	56	57

Fish #	24-May	08-Jun	22-Jun	06-Jul	20-Jul	10-Aug	27-Aug	14-Sep
151	50	52	45	50	51	55	56	57
152	50	52	45	50	51	55	56	57
153	50	52	45	51	51	55	56	57
154	50	52	45	51	51	55	56	57
155	50	52	45	51	51	55	56	57
156	50	52	45	51	51	55	56	57
157	51	52	45	51	51	55	56	57
158	51	52	45	51	51	55	56	57
159	51	52	45	51	52	55	56	57
160	51	52	45	51	52	55	56	57
161	51	52	45	51	52	55	56	57
162	51	52	45	51	52	55	56	57
163	51	52	46	51	52	55	56	57
164	51	52	46	51	52	55	56	58
165	51	52	46	51	52	55	57	58
166	51	52	46	51	52	55	57	58
167	51	52	46	51	52	55	57	58
168	51	52	46	51	52	55	57	58
169	51	52	46	51	52	55	57	58
170	51	52	46	51	52	55	57	58
171	51	52	46	51	52	55	57	58
172	51	52	46	51	52	55	57	58
173	51	52	46	51	52	55	57	58
174	51	52	46	51	52	55	57	58
175	51	52	46	51	52	55	57	58
176	51	52	46	51	52	56	57	58
177	52	53	46	51	52	56	57	58
178	52	54	46	51	52	56	57	58
179	52	54	46	51	52	56	57	58
180	52	54	46	51	52	56	57	58
181	52	54	46	51	52	56	57	58
182	52	54	46	52	52	56	57	58
183	52	54	46	52	52	56	57	58
184	52	54	46	52	52	56	57	58
185	52	54	46	52	52	56	57	58
186	52	54	46	52	52	56	57	58
187	52	54	46	52	52	56	57	58
188	52	54	46	52	52	56	57	58
189	52	54	46	52	52	56	57	58
190	52	54	46	52	52	56	57	58
191	52	54	46	52	52	56	57	58
192	52	54	46	52	52	56	57	58
193	52	54	46	52	52	56	57	58
194	52	54	46	52	52	56	57	58
195	52	54	46	52	52	56	57	58
196	52	55	46	52	52	56	57	58
197	52	55	46	52	52	57	57	58
198	52	55	46	52	52	57	57	58
199	52	55	46	52	52	57	57	58
200	52	55	46	52	52	57	57	58

Fish #	24-May	08-Jun	22-Jun	06-Jul	20-Jul	10-Aug	27-Aug	14-Sep
201	52	55	47	52	52	57	58	58
202	52	55	47	52	52	57	58	59
203	54	55	47	52	52	57	58	59
204	54	55	47	52	52	57	58	59
205	54	55	47	52	52	57	58	59
206	54	55	47	52	52	57	58	59
207	54	55	47	52	52	57	58	59
208	54	55	47	52	52	57	58	59
209	54	55	47	52	52	57	58	59
210	54	55	47	52	52	57	58	59
211	54	55	47	54	52	57	58	59
212	54	55	47	54	52	57	58	59
213	54	55	47	54	54	57	58	59
214	55	55	47	54	54	57	58	59
215	55	56	47	54	54	57	58	59
216	55	56	47	54	54	57	58	59
217	55	56	47	54	54	57	58	59
218	55	56	47	54	54	57	58	59
219	55	56	47	54	54	57	58	59
220	55	56	47	54	54	57	58	59
221	55	56	47	54	54	57	58	59
222	55	56	47	54	54	57	58	59
223	55	56	49	54	54	57	58	59
224	55	56	49	54	54	57	58	59
225	55	56	49	54	54	57	58	59
226	55	56	49	54	54	57	58	59
227	55	56	49	54	54	57	58	59
228	55	56	49	54	54	57	58	59
229	55	56	49	54	54	57	58	60
230	55	56	49	55	54	57	58	60
231	55	56	49	55	54	57	58	60
232	55	56	50	55	54	57	58	60
233	56	56	50	55	55	57	58	60
234	56	56	50	55	55	57	58	60
235	56	56	50	55	55	57	58	60
236	56	56	50	55	55	57	58	60
237	56	56	50	55	55	57	58	60
238	56	56	50	55	55	58	58	60
239	56	56	50	55	55	58	59	60
240	56	56	51	55	55	58	59	60
241	56	56	51	55	55	58	59	60
242	56	56	51	55	55	58	59	60
243	56	56	51	55	55	58	59	60
244	56	56	51	55	55	58	59	60
245	56	56	51	55	55	58	59	60
246	56	57	51	55	55	58	59	60
247	56	57	51	55	55	58	59	60
248	56	57	51	55	55	58	59	60
249	56	57	51	55	55	58	60	60
250	56	57	51	56	55	58	60	60

Fish #	24-May	08-Jun	22-Jun	06-Jul	20-Jul	10-Aug	27-Aug	14-Sep
251	56	57	51	56	55	58	60	60
252	56	57	51	56	55	58	60	60
253	56	57	51	56	55	58	60	60
254	56	57	51	56	55	58	60	60
255	56	57	51	56	55	58	60	60
256	56	57	51	56	55	58	60	60
257	57	57	52	56	55	58	60	60
258	57	57	52	56	55	58	60	60
259	57	57	52	56	55	58	60	60
260	57	57	52	56	55	58	60	61
261	57	57	52	56	55	58	60	61
262	57	57	52	56	55	58	60	61
263	57	57	52	56	55	58	60	61
264	57	57	52	56	55	58	60	61
265	57	57	52	56	55	58	60	61
266	57	57	52	56	55	58	60	61
267	57	57	52	57	55	58	60	61
268	57	57	52	57	55	58	60	61
269	57	57	52	57	55	58	60	61
270	57	57	52	57	55	58	60	61
271	57	57	52	57	55	58	60	61
272	57	57	52	57	55	58	60	61
273	57	57	52	57	55	58	60	61
274	57	57	52	57	55	58	60	61
275	57	57	52	57	55	58	60	61
276	57	57	52	57	55	58	60	61
277	57	57	52	57	55	59	60	61
278	57	57	52	57	55	59	60	61
279	57	57	52	57	55	59	60	61
280	57	57	52	57	55	59	60	61
281	57	57	52	57	55	59	60	61
282	57	57	52	57	55	59	60	61
283	57	57	52	57	55	59	60	61
284	57	58	52	57	55	59	60	61
285	57	58	52	57	55	59	60	61
286	57	58	52	57	55	59	60	61
287	57	58	54	57	55	59	61	61
288	57	58	54	57	55	59	61	61
289	57	58	54	57	55	59	61	61
290	58	58	54	57	56	59	61	61
291	58	58	54	57	56	59	61	61
292	58	58	54	57	56	59	61	61
293	58	58	54	57	56	59	61	61
294	58	58	54	57	56	59	61	61
295	58	58	54	57	56	59	61	61
296	58	58	54	57	56	59	61	62
297	58	58	54	57	56	59	61	62
298	58	58	54	57	56	59	61	62
299	58	58	54	57	56	59	61	62
300	58	58	54	57	56	59	61	62

Fish #	24-May	08-Jun	22-Jun	06-Jul	20-Jul	10-Aug	27-Aug	14-Sep
301	58	58	54	57	56	59	61	62
302	58	58	54	57	56	59	61	62
303	58	58	54	57	56	59	61	62
304	58	58	54	57	56	59	61	62
305	58	58	54	57	56	59	61	62
306	58	58	54	58	56	60	61	62
307	58	58	54	58	56	60	61	62
308	58	58	54	58	56	60	61	62
309	58	58	54	58	56	60	61	62
310	58	58	54	58	56	60	61	62
311	58	58	55	58	56	61	61	62
312	58	58	55	58	57	61	61	62
313	58	58	55	58	57	61	62	62
314	58	58	55	58	57	61	62	63
315	58	58	55	58	57	61	62	63
316	58	58	55	58	57	61	62	63
317	58	58	55	58	57	61	62	64
318	58	58	55	58	57	61	62	64
319	58	58	55	58	57	61	62	64
320	59	58	55	58	57	61	62	64
321	59	58	55	58	57	61	62	64
322	59	58	55	58	57	61	62	64
323	59	59	55	58	57	61	62	64
324	59	59	55	58	57	61	62	64
325	59	59	55	58	57	61	62	64
326	59	59	55	58	57	61	62	64
327	59	59	55	58	57	61	62	64
328	59	59	55	58	57	61	62	64
329	59	59	55	58	57	61	62	64
330	59	59	55	58	57	61	62	64
331	59	59	55	59	57	61	62	64
332	59	59	56	59	57	61	62	64
333	59	59	56	59	57	62	62	64
334	59	59	56	59	57	62	62	64
335	59	59	56	59	57	62	62	64
336	59	59	56	59	57	62	62	64
337	59	59	56	59	57	62	62	64
338	59	59	56	59	57	62	62	64
339	59	59	56	59	57	62	62	64
340	59	59	56	59	57	62	62	64
341	59	59	56	59	57	62	62	64
342	60	59	56	59	57	62	62	64
343	60	59	56	60	57	62	62	64
344	60	60	56	60	57	62	62	64
345	60	60	56	60	57	62	62	64
346	60	60	56	60	57	62	62	65
347	60	60	56	60	57	62	62	65
348	60	60	56	60	57	62	62	65
349	60	60	57	61	58	62	63	65
350	60	60	57	61	58	62	63	65

Fish #	24-May	08-Jun	22-Jun	06-Jul	20-Jul	10-Aug	27-Aug	14-Sep
351	60	60	57	61	58	62	63	65
352	60	60	57	61	58	62	63	65
353	60	60	57	61	58	62	63	65
354	60	60	57	61	58	62	63	65
355	60	60	57	61	58	62	63	65
356	61	60	57	61	58	62	63	65
357	61	60	57	61	58	62	63	65
358	61	61	57	61	58	62	63	65
359	61	61	57	61	58	62	63	65
360	61	61	57	61	58	62	63	65
361	61	61	57	61	58	62	63	65
362	61	61	57	61	58	62	63	65
363	61	61	57	61	58	63	63	65
364	61	61	57	62	58	63	63	65
365	61	61	57	62	58	63	64	65
366	61	61	57	62	58	63	64	65
367	62	61	57	62	58	63	64	65
368	62	61	58	62	58	63	64	66
369	62	61	58	62	58	63	64	66
370	62	61	58	62	58	63	64	66
371	62	61	58	62	58	63	64	66
372	62	61	58	62	58	63	64	66
373	62	61	58	62	58	63	64	66
374	62	61	58	62	58	63	64	66
375	62	61	58	62	58	63	64	66
376	62	62	58	62	58	63	64	66
377	62	62	58	62	58	63	64	66
378	62	62	58	62	58	63	64	66
379	62	62	58	62	58	63	64	66
380	62	62	58	62	58	63	64	66
381	62	62	58	62	59	63	64	66
382	62	62	58	62	59	63	64	66
383	62	62	58	62	59	63	64	66
384	62	62	58	62	59	63	64	66
385	62	62	58	62	59	63	64	66
386	62	62	58	62	59	63	64	66
387	62	62	58	62	59	63	65	66
388	62	62	58	62	59	63	65	66
389	62	62	58	62	59	63	65	66
390	62	62	58	62	59	63	65	66
391	62	62	58	63	59	63	65	66
392	62	62	58	63	59	63	65	66
393	62	62	58	63	59	63	65	66
394	63	62	58	63	59	63	65	66
395	63	62	58	63	59	63	66	66
396	63	62	58	63	59	63	66	66
397	63	63	58	63	59	63	66	66
398	63	63	58	63	59	63	66	66
399	63	63	58	63	60	63	66	66
400	63	63	58	63	60	63	66	66

Fish #	24-May	08-Jun	22-Jun	06-Jul	20-Jul	10-Aug	27-Aug	14-Sep
401	63	63	58	63	60	63	66	66
402	63	63	59	63	61	63	66	67
403	63	63	59	63	61	63	66	67
404	63	63	59	63	61	63	66	67
405	63	63	59	63	61	63	66	67
406	63	63	59	63	61	63	66	67
407	63	63	59	63	61	63	66	67
408	63	64	59	63	61	63	66	67
409	63	64	59	63	61	63	66	67
410	63	64	59	63	61	64	66	67
411	63	64	59	63	61	64	66	67
412	63	66	59	64	62	64	66	67
413	64	66	59	64	62	64	66	67
414	64	66	59	64	62	64	66	68
415	64	66	59	64	62	64	66	68
416	64	66	59	64	62	64	66	68
417	64	66	59	64	62	64	66	68
418	64	66	59	64	62	64	66	68
419	64	67	59	64	62	64	66	68
420	64	67	60	64	62	64	66	68
421	64	67	60	64	62	64	66	68
422	64	67	60	66	62	64	66	68
423	64	67	60	66	62	64	67	68
424	64	67	61	66	62	64	67	68
425	66	67	61	66	62	64	67	68
426	66	67	61	66	62	64	67	68
427	66	67	61	66	63	66	67	68
428	66	67	61	66	63	66	67	68
429	66	67	62	66	63	66	67	68
430	67	68	62	66	63	66	67	68
431	67	68	62	66	63	66	67	68
432	67	68	62	66	63	66	67	68
433	67	68	62	66	63	66	67	69
434	67	68	62	67	63	66	67	69
435	68	68	62	67	63	66	67	69
436	68	68	62	67	63	66	67	69
437	68	68	62	67	63	66	67	69
438	68	68	62	67	63	66	67	69
439	68	68	62	67	63	66	68	69
440	68	68	62	68	63	66	68	69
441	68	68	63	68	63	66	68	70
442	68	69	63	68	63	66	68	70
443	68	69	63	68	63	66	68	70
444	68	69	63	68	64	67	68	70
445	68	69	63	68	64	67	68	70
446	68	69	63	68	64	67	68	70
447	68	69	63	68	64	67	68	70
448	68	69	63	68	64	67	68	70
449	68	69	63	68	64	67	68	71
450	68	69	63	69	64	67	68	71

Fish #	24-May	08-Jun	22-Jun	06-Jul	20-Jul	10-Aug	27-Aug	14-Sep
451	69	69	63	69	66	67	68	71
452	69	69	63	69	66	67	68	71
453	69	69	63	69	66	67	68	71
454	69	69	63	69	66	67	68	71
455	69	69	63	69	66	67	68	71
456	69	69	63	69	66	67	68	71
457	69	70	63	69	66	67	68	71
458	69	70	63	69	66	68	68	71
459	69	70	64	69	67	68	69	71
460	69	70	64	69	67	68	69	71
461	70	71	64	69	67	68	69	72
462	70	71	64	70	67	68	69	72
463	70	71	64	70	67	68	70	72
464	70	72	64	70	67	68	70	72
465	70	72	64	70	67	68	70	74
466	70	72	64	70	68	68	70	74
467	71	72	66	70	68	68	70	74
468	71	72	66	70	68	68	70	74
469	72	72	67	71	68	68	70	75
470	72	72	67	71	68	69	70	75
471	72	72	68	72	69	69	70	75
472	72	73	68	72	69	69	70	76
473	72	73	68	72	69	69	72	76
474	72	73	68	73	70	69	72	76
475	72	73	68	73	70	69	74	76
476	72	73	69	73	70	69	74	76
477	73	73	69	73	72	69	74	76
478	73	73	69	73	72	69	74	77
479	73	73	70	73	72	69	74	77
480	73	75	71	73	72	69	74	77
481	73	75	72	75	72	69	76	77
482	75	75	72	75	72	70	76	78
483	75	75	72	75	73	70	76	78
484	75	75	73	75	73	70	76	78
485	75	75	73	75	73	70	77	78
486	76	75	73	75	73	71	77	78
487	76	75	73	75	75	72	78	79
488	77	75	73	76	76	72	78	79
489	79	75	75	77	76	73	78	79
490	79	75	75	77	76	73	78	80
491	79	75	75	77	76	73	78	80
492	80	76	75	79	76	73	78	80
493	80	76	75	80	76	75	80	81
494	80	76	75	80	77	75	80	81
495	80	76	77	80	77	75	81	84
496	81	79	77	82	77	76	81	84
497	81	79	77	82	79	76	81	85
498	81	80	77	82	79	76	81	85
499	81	81	79	84	80	77	82	85
500	86	81	80	85	85	80	82	87

APPENDIX 3

LENGTH-FREQUENCY DISTRIBUTION HISTOGRAMS

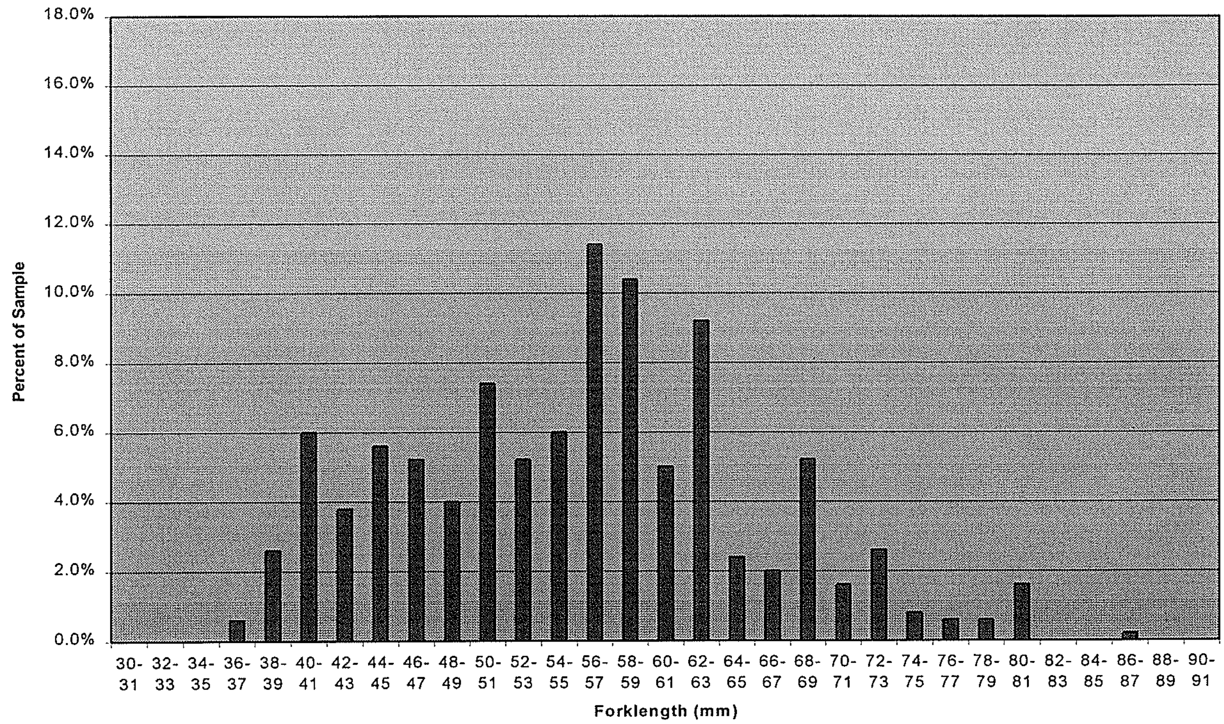

Figure 4.1: Finescale dace length frequency distribution for ELA Lake 115, May 24/99.

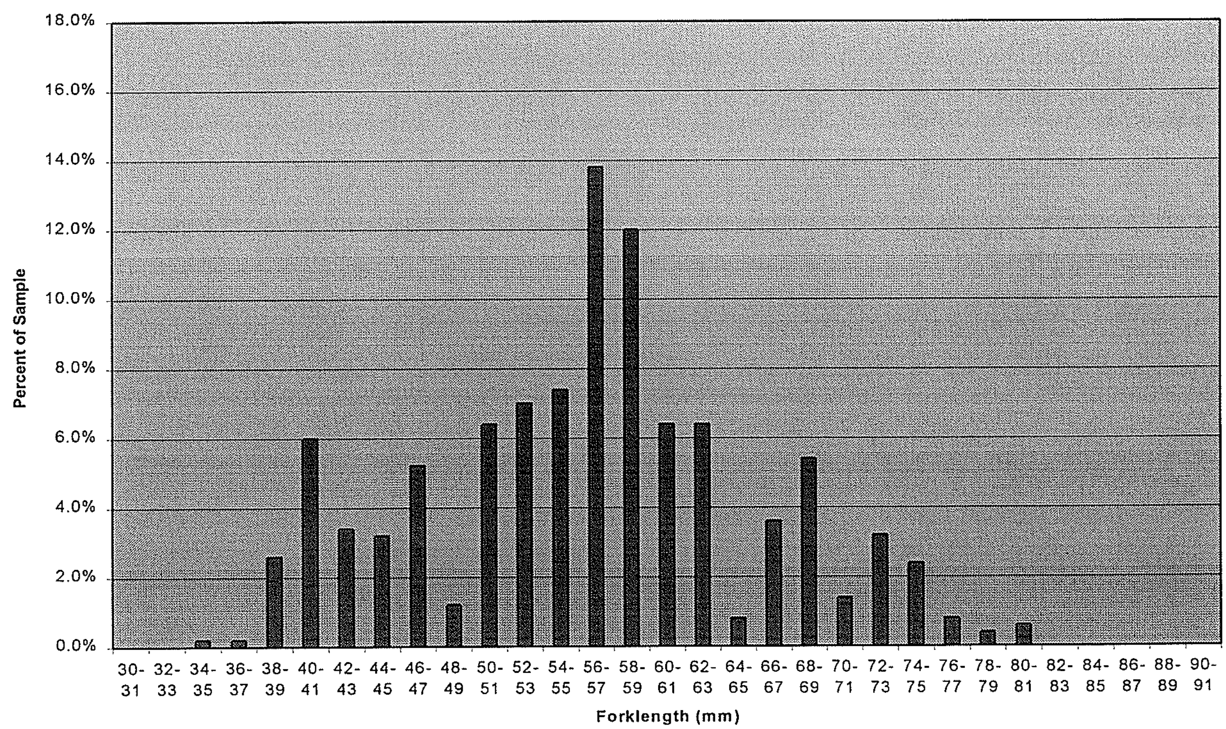

Figure 4.2: Finescale dace length frequency distribution for ELA Lake 115, June 8/99.

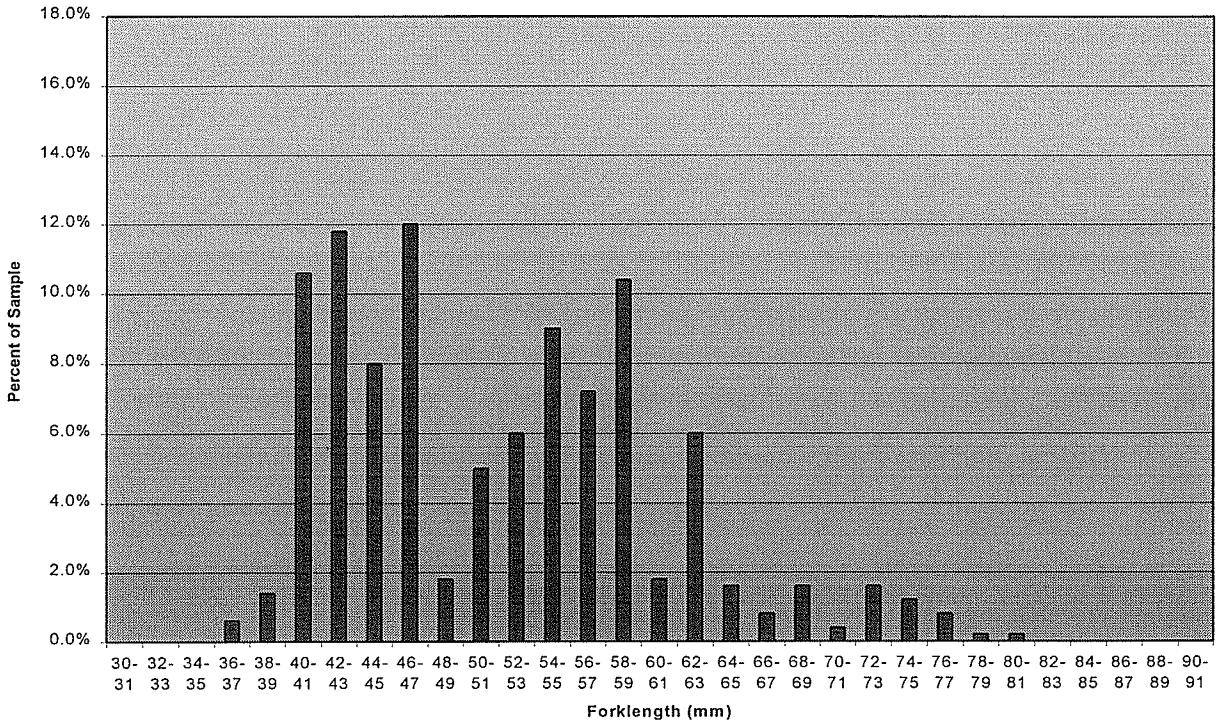

Figure 4.3: Finescale dace length frequency distribution for ELA Lake 115, June 22/99.

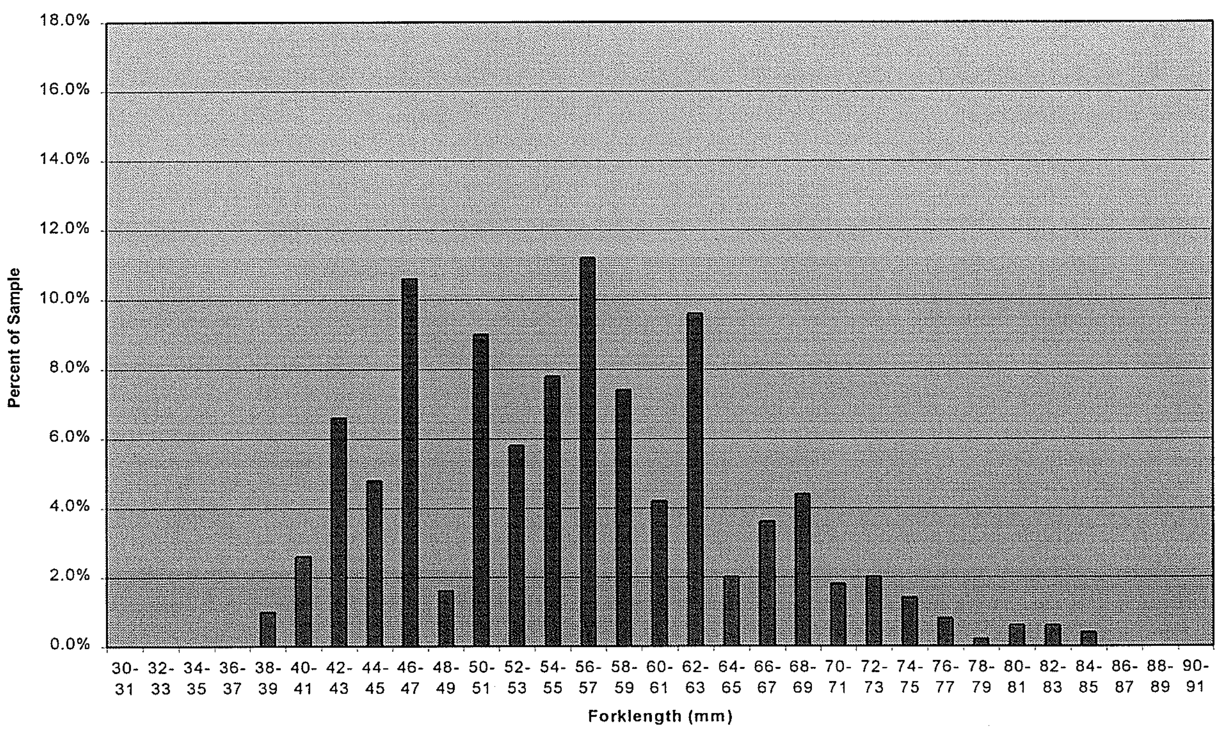

Figure 4.4: Finescale dace length frequency distribution for ELA Lake 115, July 6/99.

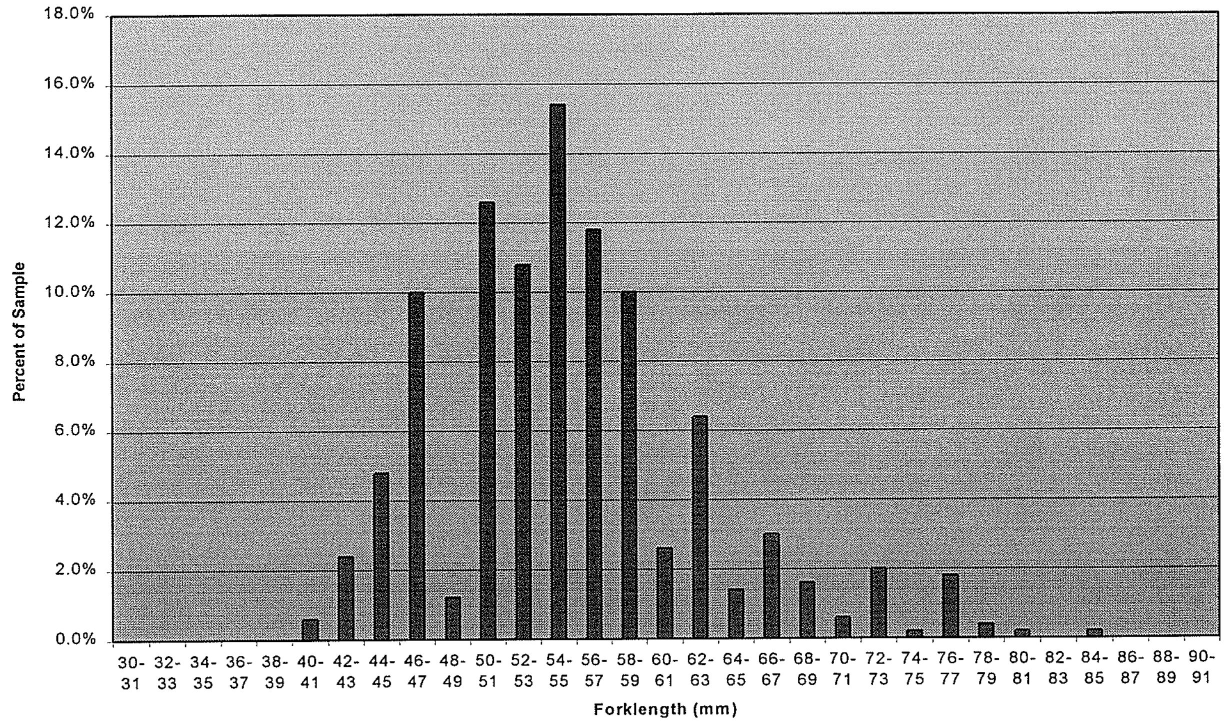

Figure 4.5: Finescale dace length frequency distribution for ELA Lake 115, July 22/99.

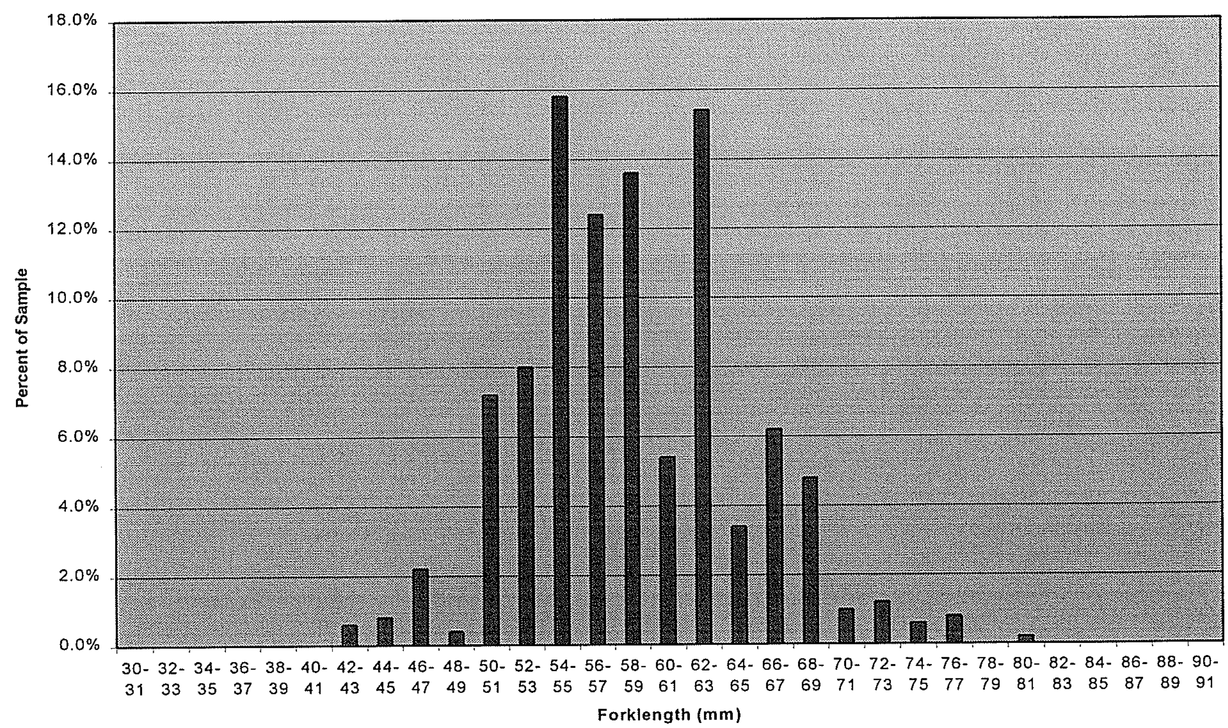

Figure 4.6: Finescale dace length/ frequency distribution for ELA Lake 115, August 10/99.

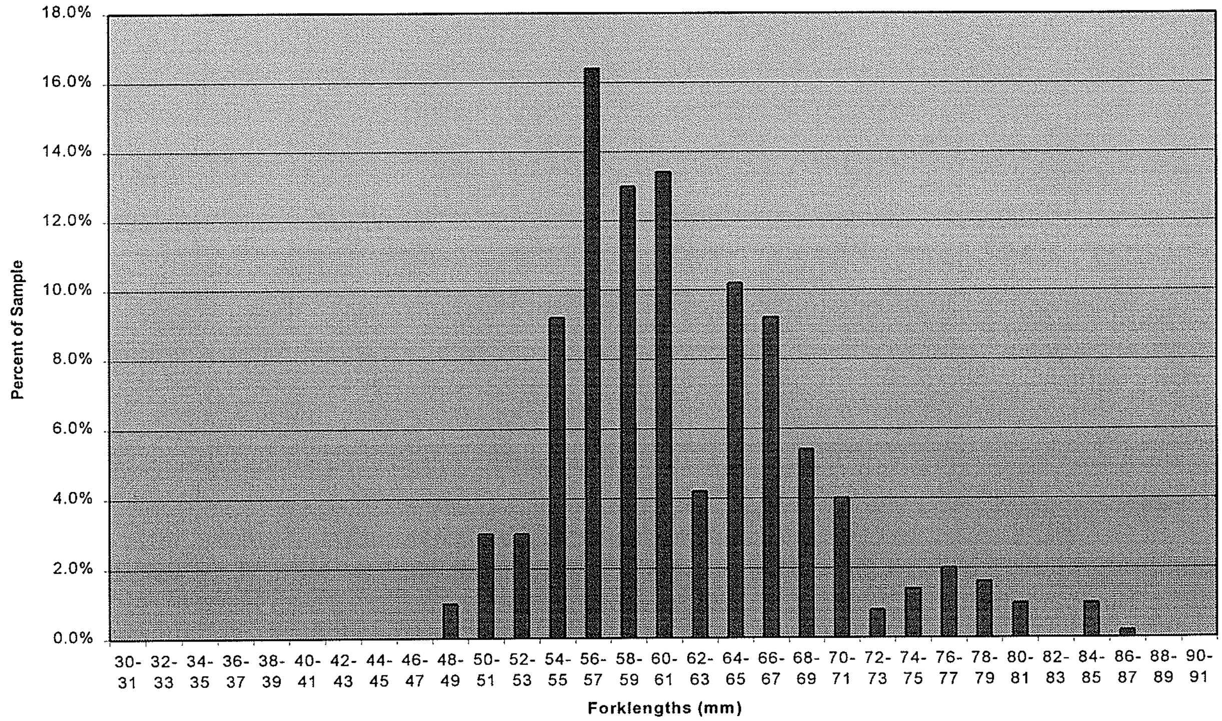

Figure 4.7: Finescale dace length frequency distribution for ELA Lake 115, August 27/99.

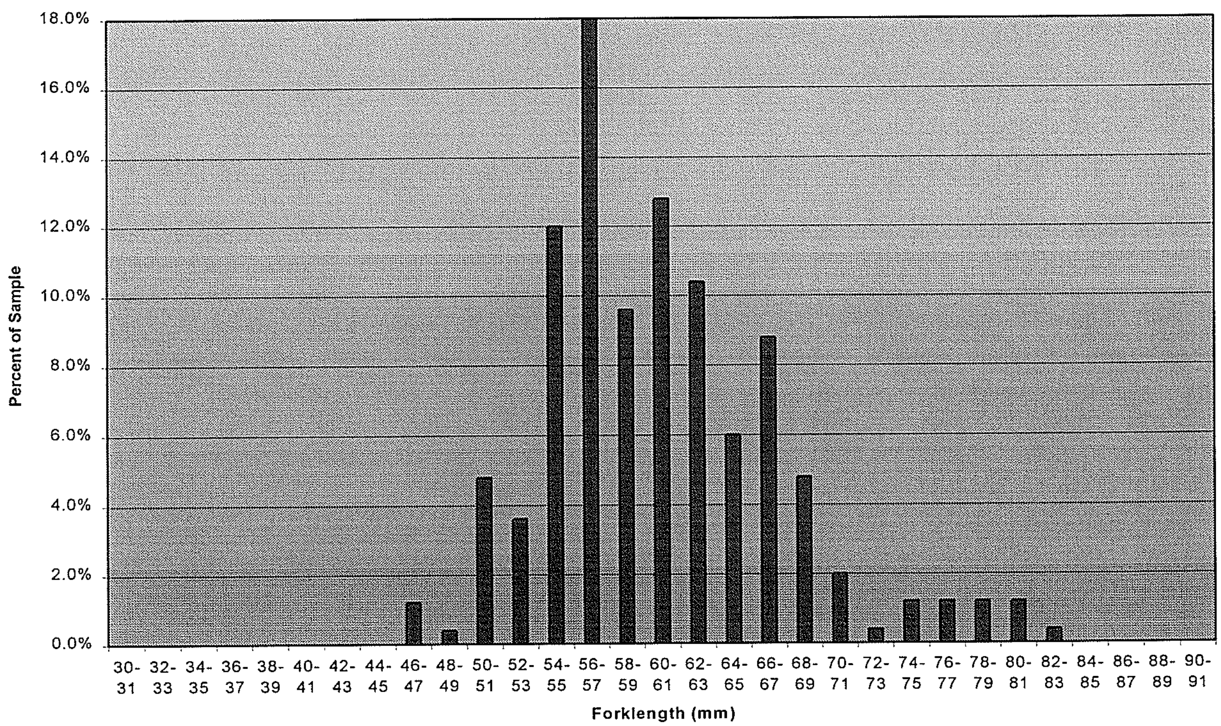

Figure 4.8: Finescale dace length Frequency distribution for ELA Lake 115, September 14/99.

APPENDIX 4

INDIVIDUAL TRAP CATCH DATA FOR REMOVAL EXPERIMENT
(Note: all traps located near shore, except 41, 46, 49 & 50)

trap #	day1	day2	day3	day4	day5	day6	day7
1	51	40	12	23	26	12	35
2	18	44	25	27	16	18	3
3	75	58	26	57	29	34	30
4	51	35	45	16	10	19	12
5	65	67	53	19	32	22	38
6	90	116	55	46	40	35	34
7	18	0	16	21	1	3	10
8	17	11	8	29	11	8	0
9	27	12	25	50	55	9	13
10	0	25	6	7	1	5	22
11	32	27	12	9	21	10	10
12	38	49	27	17	2	18	40
13	29	54	26	8	30	17	40
14	53	27	35	4	5	8	12
15	38	35	2	20	5	8	2
16	38	26	112	16	49	26	27
17	22	19	29	12	28	9	10
18	21	20	10	5	7	27	22
19	35	14	14	6	25	9	2
20	21	3	21	4	23	22	11
21	11	3	5	11	4	15	1
22	61	10	18	14	17	16	0
23	8	9	4	5	3	2	9
24	5	13	25	2	7	10	9
25	39	7	20	9	9	16	8
26	49	22	38	28	20	4	17
27	21	11	29	14	13	3	2
28	106	53	24	52	24	32	26
29	37	9	13	3	0	3	15
30	24	27	15	5	8	6	27
31	39	27	22	12	12	28	27
32	48	13	37	21	22	7	41
33	37	16	13	18	28	0	25
34	57	38	44	56	12	39	47
35	82	73	63	53	38	47	54
36	39	10	20	22	19	17	9
37	37	16	10	21	25	16	3
38	22	4	17	3	9	5	5
39	16	10	5	11	13	20	22
40	24	8	16	23	41	10	7
41	11	7	9	7	24	0	13
42	65	72	43	63	67	82	50
43	100	28	70	37	58	70	17
44	84	35	23	30	58	60	15
45	41	49	41	41	58	55	36
46	31	27	27	18	11	4	14
47	33	40	10	7	17	21	25
48	55	64	37	37	50	31	40
49	20	7	18	13	18	0	15
50	27	31	21	49	13	15	3
51	27	18	15	14	10	11	12
52	30	38	3	20	21	30	7
53	56	28	33	30	43	40	16
54	22	29	20	6	16	26	2
55	10	12	8	28	6	5	8
56	23	16	10	17	33	20	14
57	27	21	20	11	15	15	39
58	104	89	96	51	80	49	58
59	6	5	1	1	0	7	7
60	60	71	49	23	39	36	40