Growth and Survival of Juvenile Sockeye Salmon (*Oncorhynchus nerka*) in three Northwestern British Columbia Lakes – an evaluation of an International Stock Enhancement Program

Karin L. Mathias

A thesis submitted to the Faculty of Graduate Studies in
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Abstract

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The Transboundary sockeye salmon stock enhancement program began as part of the Pacific Salmon Treaty in 1987. The goal of the enhancement program was to increase the numbers of adult salmon returning to the Stikine and Taku rivers, for the benefit of American and Canadian commercial, and First Nations fisheries. The enhancement strategy involved collecting sockeye eggs from wild stocks, raising them to the fry stage at a hatchery, and stocking the fry into nursery lakes with underused rearing capacities. Tatsamenie, Tahltan, and Tuya lakes were predicted to have enhancement potential, and have been stocked with fry since 1991, 1990, and 1992, respectively.

The objective of this thesis was to analyse and compare the growth and survival of both wild and enhanced (stocked) juvenile sockeye (egg and fry-to-smolt), in order to evaluate the success of the enhancement program at each of the three lakes. For the enhancement to be successful, growth and survival of enhanced fry must exceed growth and survival of wild fry by a large enough margin that the value of the enhanced fish is greater than the cost of producing them. Tuya Lake was barren of sockeye before stocking. Both growth and survival of enhanced fry were excellent, and stocking resulted in a mean annual production of approximately 1,182,300 smolts (and up to 128,400 adults). In view of the success of the Tuya Lake enhancement program, it is recommended that the stocking program continue, and perhaps be modestly increased. Tahltan Lake had both wild and enhanced sockeye. Growth of enhanced fry was comparable to the growth of wild fry, but survival of enhanced fry was almost four times higher than the survival of wild fry. Mean annual production was 306,500 smolts (and up to 33,300 adults). Based on these results, it is recommended that a cost:benefit analysis be done to ensure that the benefits derived from increased adult production outweigh fry production and evaluation costs. Tatsamenie Lake had both wild and enhanced sockeye. Growth of enhanced fry was comparable to the growth of wild fry, but survival of enhanced fry was three times lower than the survival of wild fry. Overall, enhancement resulted in a mean annual production of only 77,000 smolts (and up to 8,400 adults), which is less than would have been produced if the eggs had been left to develop naturally in the lake. Growth analyses suggested that enhanced fry experienced size-selective mortality to a greater degree than wild fry, and feeding, disease, and predation were investigated as mechanisms of mortality. Predation by piscivores was identified as the most likely cause of enhanced fry mortality. Since the Tatsamenie Lake enhancement program was unsuccessful, it is recommended that the stocking program be cancelled.

Acknowledgments

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Table of Contents

List of Tables

List of Figures

Definitions and Abbreviations

(as they apply to the Transboundary Sockeye Enhancement Program)

1. *Broodstock*: That portion of a wild fish stock that is captured, and whose gametes are used to produce offspring that are raised in a hatchery.

2. *Broodyear*: The year in which gametes were collected from broodstock to produce fry that hatch the following year (i.e. fry stocked in 1991, belong to the 1990 broodyear).

3. *Escapement*: That portion of an anadromous fish population that escapes commercial, First Nations, and recreational fisheries, and reaches the freshwater spawning grounds.

4. *FOC*: Fisheries and Oceans Canada (based in Whitehorse, Yukon and Nanaimo, British Columbia).

5. *PBS*: Pacific Biological Station (located in Nanaimo, British Columbia, Canada).

6. *ADF&G*: Alaska Department of Fish and Game (based in Juneau, Alaska)

Preface

This M.Sc. project was organized and initiated in September 1998 by Dr. K. Hyatt (Research Scientist, FOC, Nanaimo), with funding provided by the Transboundary Technical Committee (TTC). My thesis research was directed by Dr. D. McQueen (York University). The primary role of my research was to analyse the following data that were collected since 1987 from Tatsamenie, Tahltan, and Tuya lakes:

- limnology (water temperature/dissolved oxygen, secchi depths, water chemistry,)
- zooplankton (biomass, density and mean size of all taxa in vertical hauls and horizontal tows)
- juvenile sockeye – i.e. from beach seines, mid-water trawls, and smolt sampling (population estimates, growth, survival, diet)

The research objective was to make conclusions about the success of the enhancement program at each lake, and to make recommendations to the TTC about future enhancement activities. Most of my research involved computer analysis of all limnological data, and most of the zooplankton and juvenile sockeye data presented in this thesis. Zooplankton data from 1987 to 1996 had been previously analysed by Johannes et al. (1997), and preliminary analyses of adult escapement and juvenile population estimates were provided for me by the TTC and P. Rankin (Research Biologist, FOC, Nanaimo). It should be noted that my analysis of zooplankton data from 1987 to 1998 involved using the original data spreadsheet, but was different in approach and depth. In addition to computer analyses, I also assisted with field and lab activities.

Fieldwork during one of the fall sampling surveys at Tatsamenie, Tahltan, and Tuya lakes involved:

- water chemistry sampling
- secchi depth measurements
- vertical haul zooplankton sampling
- beach seining for inshore juvenile sockeye and other fish species
- hydroacoustic surveying for generating limnetic fish population estimates
- mid-water trawling for limnetic fish

Although the field portion of my graduate project was limited, I have had extensive experience as a field biologist and was previously familiar with all techniques used in the field (with the exception of specific hydroacoustic and trawl techniques). The lab work I performed involved processing all 1998 Tahltan and Tatsamenie lake zooplankton samples and all 1999 sockeye fry samples. Sockeye fry sample processing included:

- sockeye fry length and weight measurements
- otolith extraction, mounting, and reading (i.e. examining otoliths for a thermal mark indicating a fish of hatchery origin)
- stomach content extraction, identification, and weight measurement

The remainder of the zooplankton samples were processed by AMC Technical Services Ltd., and 1998 sockeye fry samples were processed by B. Hanslit (Fisheries Technician, FOC, Nanaimo). Many 1998 and all 1999 otolith samples were also read by the Alaska Department of Fish and Game Otolith and Ageing Lab, Juneau, AK. Unless specified to the contrary, all field sampling methods, sample processing methods, and associated data sets contained in this thesis have been acquired as components of a long term Sockeye Index Stocks Program conducted from 1976 to present under the coordination of Dr. K. Hyatt's research group at the Pacific Biological Station, Nanaimo, BC.

Chapter 1 - Introduction

HISTORY OF THE ENHANCEMENT PROGRAM

The Transboundary rivers salmon enhancement program began in 1987 as a cooperative venture between Canada and the US, under the mandate of the 1985 Pacific Salmon Treaty. The goal of the enhancement program was to initiate projects that would increase the numbers of returning adult sockeye salmon to each of the Taku, Stikine and Alsek rivers, which originate in northwestern BC and flow out to the Pacific Ocean through southeast Alaska (panhandle). Sockeye salmon are the most economically valuable salmon species in both BC and Alaska, with annual catches often bringing in more than $100 million (Hume *et al.* 1996). The enhancement agreement was such that increased numbers of adult sockeye would be shared by Canadian and American commercial fisheries and Canadian First Nations fisheries. To administer the Transboundary salmon enhancement program, a Transboundary Technical Committee (TTC), made up of Canadian and Alaskan (Alaska Department of Fish and Game (ADF&G), Juneau, Alaska) fisheries biologists, was established by the Pacific Salmon Commission (PSC) in 1987. Canadian partners consist of Fisheries and Oceans Canada (FOC) personnel in Whitehorse, Yukon, as well as at the Pacific Biological Station (PBS), Nanaimo. In fall of 1998, senior FOC scientist, Dr. K. Hyatt (PBS), offered to support my graduate research (supervised by Dr. D. McQueen), and asked me to assist the TTC with the analyses of eight years of zooplankton and juvenile sockeye data, in order to find explanations for vexing problems that have emerged from preliminary analysis of the Transboundary program data.

Before proceeding with further description of the enhancement program, a brief review of sockeye salmon life history is required. Sockeye salmon spawn and then die, in late summer to fall, within tributaries and shallow beach areas of a nursery lake. The female prepares for spawning by selecting a redd site, and digging a nest (depression) with her tail in the gravel. She deposits a batch of eggs while the male (or males) simultaneously releases milt (sperm) and fertilizes the eggs. Egg fertilization rate is usually near 100% (Burgner 1991). The female covers the eggs with gravel, and then may begin digging more nests, repeating the spawning process several times. She then covers and guards her redd (collection of three to seven nests) until death. The eggs incubate overwinter, 15-23 cm below the surface of the gravel. Fry typically emerge in late April to late May (before lake ice breakup in northern BC), at a time presumed to be optimal for growth and feeding in their nursery lake. Fry which emerge earlier or later than the optimum may experience high mortality rates (Bams 1969; Miller and Brannon 1982; Brannon 1984). Fry initially remain in littoral (inshore) areas to feed primarily on immature insects for one to three months before migrating to the limnetic (offshore) zone of the lake to feed primarily on zooplankton. Most fry rear in the lake for one year before emigrating as smolts. The remaining fry spend two, and rarely three, years in the lake. Smolts migrate down the rivers to the Pacific Ocean, where they spend one to four years before migrating back to their nursery lake of origin to spawn and die.

Within this life history context, five sockeye salmon enhancement strategies have been used historically in BC and Alaska. These include: (1) stocking hatchery raised fish, (2) creating spawning channels (when fish production is limited by suitable spawning habitat), (3) lake fertilization (to increase the food base), (4) obstruction removal or construction of fishways (to provide access to suitable habitat), and (5) removal of sockeye predators. During the summers of 1987 and 1988, the TTC conducted preliminary surveys at eleven lakes in the Taku, Stikine and Alsek drainages, that were considered to have sockeye salmon enhancement potential based on lake size, broodstock (see Definitions and Abbreviations, p. xx) considerations (number, and ease of collection), water turbidity, stock identification potential (for commercial fisheries management), and quantity of background information available (Pacific Salmon Commission 1987). Using the results of the limnological and fish surveys conducted from 1987-88 (water chemistry, secchi depth, zooplankton, limnetic fish density), the TTC evaluated the enhancement potential of the eleven sockeye nursery lakes using two models: (1) the Euphotic Volume (EV) model (Koenings and Burkett 1987a) which uses euphotic volume to predict the number of adults (and therefore smolts) that a lake can produce, and (2) the Zooplankton Density model (Pacific Salmon Commission 1988) which uses zooplankton densities (food base) to predict the number of smolts that a lake can produce.

1. Euphotic Volume Model

The Euphotic Volume (EV) Model is based on the strong, positive, linear relationship between euphotic volume (volume of the lake where phytoplankton production takes place) and total adult sockeye production, found in six oligotrophic (clear, organically stained and glacial), rearing-limited Alaskan lakes (Fig. 1.1), that were considered to be at full sockeye production capacity (Koenings and Burkett 1987a). Koenings and Burkett (1987a) noted that primary production is somewhat reduced in lakes containing abiotic particles (either glacial silt or organic stain).

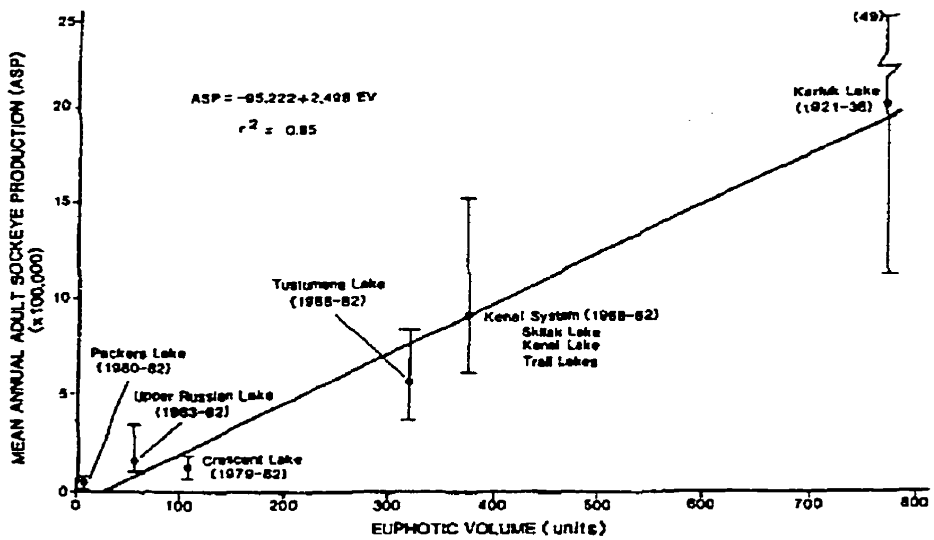


Figure 1.1. Relationship between adult sockeye production and nursery lake euphotic volume, as measured in six oligotrophic (clear, stained, and glacial), rearing limited (at production capacity) Alaskan lakes. Taken from Koenings and Burkett (1987a).

Euphotic volume is measured as: EV = (lake area in m^2) (euphotic depth in m), where the euphotic depth is equal to the compensation depth (the water depth at which the penetration of photosynthetically active radiation is 1% of that at the surface). One EV unit is defined as 1 million m^3 of euphotic zone. The EV model regression equation (adults = -95,222 + 2,498*EV (r^2=0.95)) was used to predict the number of adults that could be produced by each lake using the EV measured at that lake (Koenings and Burkett 1987a). The enhancement potential of each lake was estimated by the difference between the predicted adult production and the observed adult production. The EV model predicted three lakes, Tatsamenie (Taku River drainage), Tahltan, and Tuya (Stikine River drainage), to have the highest potential for increased smolt and adult production. The enhancement potential calculations for these lakes are presented in Table 1.1.

Table 1.1. Estimation of the enhancement potential (potential to produce more adult sockeye) of Tatsamenie, Tahltan and Tuya lakes using the Koenings and Burkett (1987a) regression equation: Number of adults = -95,222 + 2,498*EV (r^2=0.95). Table was adapted from Pacific Salmon Commission (1988) and updated with information from P. Milligan (pers. comm.).

Lake	Euphotic zone depth estimate (m)*	Lake surface area (m^2)	Euphotic volume units**	Predicted adult production	Actual adult production	Enhancement potential
Tatsamenie	10.0	16,220,000	162	310,000	20,000	290,000
Tahltan	19.2	4,920,000	94	140,000	50,000	90,000
Tuya	9.1	31,270,000	284	614,000	0	614,000

* Euphotic zone depths (EZD) were converted from secchi depth (SD) measurements using the regression: EZD=2.23+1.49*SD (r^2=0.78).
** 1 EV unit = 1 million m^3 of euphotic zone

Tatsamenie, Tahltan and Tuya lakes were predicted to be able to produce 290,000, 90,000 and 614,000 more adults than they were producing at the time (Table 1.1). The next step was to determine which enhancement strategy to use: lake fertilization or fry stocking. If a lake is rearing-limited (due to limitations imposed by the forage base, or environmental conditions), good numbers of spring fry are produced but they exceed the forage base of the lake, which results in low numbers of smolts (Kyle *et al.* 1997). In this case, additional sockeye production could be achieved by lake fertilization. If a lake is recruitment-limited (due to low escapements (see Definitions and Abbreviations), or limited spawning areas), low numbers of spring fry are produced, resulting in low numbers of smolts. In this case, additional sockeye production could be achieved by stocking hatchery-raised fry. Using data from twelve oligotrophic Alaskan lakes, in which spring fry densities were at carrying capacity (as defined by the Euphotic Volume model), Koenings and Burkett (1987a) determined that an escapement of 400-450 spawning adults per EV unit was required to produce a maximum of 36,000 fall fry, 23,000 smolts, and 2,500 adults per EV unit. Thus, lakes with greater than 36,000 fall fry per EV unit (determined by hydroacoustic methods) were candidates for lake fertilization. Lakes with less than 36,000 fall fry per EV unit were candidates for fry stocking. Since Tatsamenie, Tahltan and Tuya lakes all had less than 36,000 fry per EV unit (10,900/EV unit, 7,900/EV unit, and 0/EV unit, respectively), the TTC determined them to be good candidates for fry stocking (Pacific Salmon Commission 1988).

2. Zooplankton Density Model

The second model used to assess the enhancement potential of the surveyed lakes is based on the relationship between fall fry and zooplankton (food base) densities (Pacific Salmon Commission 1988). When zooplankton production is limiting to fry growth, a lake can produce either many, small smolts, or few, large smolts. Koenings and

Burkett (1987a) asserted that in rearing-limited lakes, the optimal size of smolts, in terms of growth and survival, is 2-3 grams. This smolt size is achieved when the density of usable zooplankton (>0.4 mm) is about 5,000 zooplankters/m^3 (Pacific Salmon Commission 1988). This zooplankton density can likely sustainably support fry densities of 30,000 to 40,000 per EV unit in Alaskan lakes (Pacific Salmon Commission 1988), compared to 10,000 to 25,000 fry per EV unit in coastal BC lakes (Stockner and Hyatt 1984; Hyatt and Stockner 1985). Figure 1.2 shows the relationship between zooplankton density and sockeye fry density in Tatsamenie, Tahltan, and Tuya lakes, as measured in 1987.

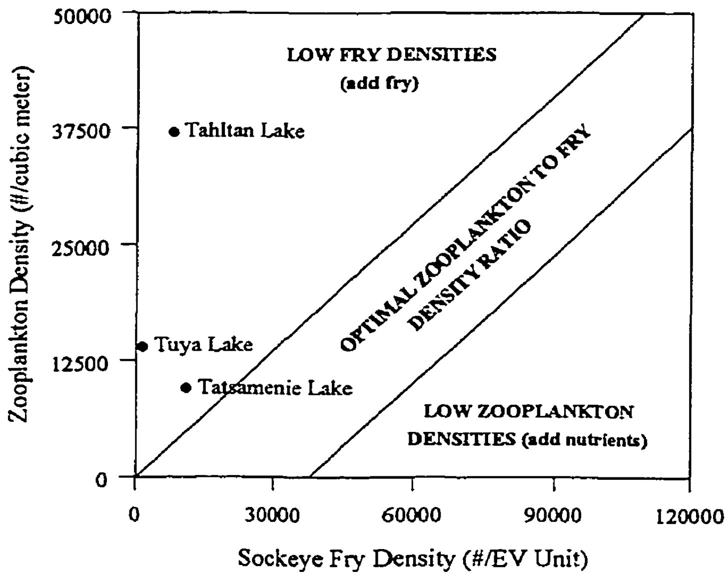


Figure 1.2. Relationship between zooplankton density and fall sockeye fry density in Tatsamenie, Tahltan and Tuya lakes in 1987. Taken from Pacific Salmon Commission (1988).

The area enclosed by the diagonal lines represents an approximate optimal range of zooplankton:fry densities. Lakes that fall above the optimal range have low fry densities relative to zooplankton production, and are considered to be candidates for enhancement through stocking of additional fry. Lakes that fall below the optimal range have high fry densities relative to zooplankton production, and are considered to be candidates for enhancement through nutrient addition.

3. Results of Enhancement Potential Models

Both the Euphotic Volume model and the Zooplankton Density model suggested that Tatsamenie, Tahltan and Tuya lakes had potential for sockeye enhancement using the fry stocking strategy. As a result, Canada and US joint enhancement began in 1989 by collecting sockeye salmon eggs from naturally occurring (wild) sockeye stocks, raising them to the fry stage at the Port Snettisham Central Incubation Facility (hatchery) near Juneau, Alaska, stocking the resultant fry back into the nursery lake of origin (or into other suitable nursery lakes in the same system), and monitoring the growth, survival, and impacts of stocked fry in each lake. Eggs were collected from the Tatsamenie Lake wild stock from 1990-99, and the resultant fry were stocked back into Tatsamenie Lake (1991-2000). Eggs were collected from Tahltan Lake wild spawning sockeye from 1989-99, and the resultant fry were stocked back into Tahltan Lake (1990-2000), as well as into Tuya Lake (which is barren of wild sockeye salmon) from 1992-2000.

Numerous studies have shown that hatchery fish have reduced growth and survival when released into natural environments (Greene 1952; Flick and Webster 1964; Vinyard *et al.* 1982). Traditional hatchery practices (such as use of inadequate numbers of broodstock, domestication of broodstock, and inappropriate mating protocols) have caused losses of genetic variability both between, and within anadromous salmon populations (Allendorf and Ryman 1987; Riddell 1993; Simon 1991). Declines in genetic diversity have been shown to result in reduced survival of hatchery fish due to abnormal anatomical and physiological characteristics and by unnatural behaviour patterns (National Research Council 1996). Although the fry produced by the Transboundary enhancement program resulted from artificial broodstock mate selection, gamete fertilization, and incubation, they were considered to be different from "hatchery" fry, and have been referred to as "enhanced" fry for three main reasons: (1) fry were produced from a substantial proportion (average of 15-18%, and up to 30%) of the total number of spawning sockeye at Tatsamenie and Tahltan lake stocks (over most of the spawning period), (2) broodstock were not domesticated (held captive in the hatchery), but were collected every year on the spawning grounds, and (3) the mating protocol followed was a 1:1 female to male ratio, with no fish used more than once. In addition, Transboundary fry were stocked from the hatchery as soon as their yolk sacs had been absorbed and they were ready to feed naturally in the lake. These procedures were used in an attempt to maintain the genetic diversity and natural feeding behaviours in the enhanced fish.

REVIEW OF OTHER SOCKEYE ENHANCEMENT PROJECTS

Since 1945, many sockeye salmon enhancement projects have been undertaken in BC with varying degrees of success. These projects have primarily involved: (1) the construction of fishways to improve passage conditions for adult sockeye past natural river falls and rapids (i.e. Fraser River fishways were built at Hell's Gate, Bridge River rapids, Farwell Canyon, and Yale rapids; Lister 1974), (2) the transplantation of juvenile sockeye salmon into 13 barren Fraser River creeks (Lister 1974), (3) the fertilization of sockeye nursery lakes (Hyatt and Stockner 1985), (4) the construction of spawning and incubation channels to improve natural production (i.e. Weaver Creek spawning channel (Fraser River stock) and Fulton and Pinkut creeks spawning channels (Babine Lake stock, Skeena River drainage); Lister 1974), and (5) the stocking of hatchery raised fry. In addition to these projects, the US, particularly Alaska, has undertaken many sockeye enhancement projects. To put the Transboundary enhancement program into perspective, I will review the outcomes of three other sockeye enhancement projects in BC and Alaska.

The Babine Lake (Skeena system, BC) sockeye stock enhancement program has been quite successful, resulting in a nearly threefold increase (an average annual increase of 106 million fry) in juvenile sockeye production (MacDonald and Hume 1984). Babine Lake and the Transboundary lakes are similar in that they have nursery areas that are underutilized by sockeye fry. Babine Lake fry recruitment was increased by the construction of three artificial spawning channels, potentially allowing an additional 220,000 adults to spawn (an increase of 33%). McDonald and Hume (1984) compared the growth and survival of wild (natural spawning beds) and channel-produced fry. Survival of channel-produced eggs to the fry stage was expected to be higher than for wild fry, due to more consistent substrate and controlled water flow conditions. With respect to growth, McDonald and Hume (1984) found that, although initial sizes and growth rates of wild and channel fry were not significantly different, the channel fry were consistently smaller due to the later migration of channel fry into the lake rearing area, compared to wild fry. With respect to survival, they found that average artificial channel egg-to-fry survival was 40.7% (30.1% - 48.7%) averaged over the three channels (n=8, 8 and 11 years), and average wild egg-to-fry survival was 19.0% (n=16 years). Average wild and channel fry-to-smolt survival rates were not significantly different (12.7% and 14.3%) (McDonald 1969). From this it may be concluded that the project was successful since the enhancement strategy improved wild sockeye survival from the egg-to-fry stages by an average of 21.7%.

The Frazer Lake (Alaska) sockeye enhancement project, which involved the planting of sockeye eggs from another system, was initially successful but eventually resulted in lowered lake productivity (Kyle *et al.* 1988). Frazer Lake is similar to Tuya Lake in that it was barren of anadromous fish due to a barrier on the lake outlet. In 1969 and 1979, fishways were built to allow spawning adults to have access to the lake. These adults originated from an egg planting program that began in 1951, and eventually produced a major run reaching over 600,000 adults in 1985. However, these record returns of adult sockeye resulted in increased fry populations which in turn led to a predator-resistant zooplankton community structure characteristic of rearing-limited lakes. Predator-resistant zooplankton communities are characterized by small, agile zooplankton such as Bosmina and nonovigerous Cyclops (Koenings and Kyle 1997). Kyle *et al.* (1988) found that once sockeye nursery lake rearing capacity is exceeded, and a predator-resistant zooplankton community is established, lower escapements will no longer result in improved smolt production, due to reduced productive capacity of the lake. This enhancement project illustrates the hazards of exceeding the carrying capacity of sockeye lakes.

The Ruth Lake (Alaska) sockeye enhancement project involved the stocking of sockeye fry into a lake after it was treated with rotenone (fish poison) to remove resident fish populations (Meehan 1966). The objective of the study was to determine if juvenile sockeye had better growth and survival in a lake with no potential predators and competitors, than in two control lakes containing a variety of other fish species. Meehan (1966) found that fry stocked into Ruth Lake had survival rates that were 8.2% and 14.3% higher than those in the control lakes. From this Meehan (1966) concluded that predators contributed significantly to sockeye fry-to-smolt mortality in the two control lakes, and that removal of sockeye predators from the experimental lake (Ruth Lake) significantly improved sockeye fry-to-smolt survival rates.

The Babine Lake enhancement project provided the TTC with the knowledge that artificially increasing fry recruitment in sockeye lakes with underused rearing capacities can significantly increase the total smolt, and subsequent adult sockeye production. The Frazer Lake enhancement project provided the TTC with the knowledge that exceeding the carrying capacity of the nursery lake can lead to an irreversible reduction in sockeye production. Using this knowledge, the TTC made it a priority to ensure that in the Transboundary lakes, stocked fry densities, combined with wild fry (if present) densities, did not exceed the nursery lake carrying capacity. They did this by setting maximum stocking densities equal to, or less than, half of the predicted enhancement potential. The Ruth Lake enhancement project provided the TTC with the knowledge that the presence of predators in the nursery lake can cause significant juvenile sockeye mortality. Using this knowledge, the TTC made it a priority to conduct surveys at each of the nursery lakes to determine the predator species present, and their approximate abundance. However, predator control programs could not be conducted in the Transboundary lakes due to conflicts with the mandate of the Provincial Fisheries authority to protect indigenous game fish. As we shall see later, this may have seriously compromised the success of the program in at least one of the three Transboundary lakes.

Armed with the lessons learned from these and other enhancement studies, the TTC began to stock Tahltan, Tatsamenie, and Tuya lakes in 1990, 1991 and 1992, respectively. The enhancement goal was to increase the total number of smolts (and therefore adults) produced by each lake. Because broodstocks were removed from Tatsamenie and Tahltan lakes, the implication was that enhanced fry growth had to be equal to, or higher than, growth of wild fry, and that survival of enhanced fry had to be higher than survival of wild fry. Thus, in order to evaluate the success of the enhancement program in each lake, it was necessary to investigate the following questions: (1) Growth: are enhanced smolt weights similar to, or higher than wild smolt weights in Tatsamenie and Tahltan lakes? (2) Survival: do enhanced fry have higher survival rates than wild fry within Tatsamenie and Tahltan lakes? (3) Feeding: are wild and enhanced fry diets similar in terms of quantity and quality of prey items, and is there evidence of overexploitation of the forage base? (4) Pathogens/parasites: could pathogens or parasites differentially affect wild or enhanced fry? (5) Predation: could predators differentially affect wild or enhanced fry?

BACKGROUND LITERATURE

To answer these questions, this thesis involves analyses and interpretation of the Transboundary project data, with respect to available literature pertaining to each of these five subject areas. The section that follows reviews some of the background literature, and establishes baselines against which the Transboundary project results can be judged.

1. Growth

The number, size, and age structure of sockeye smolts emigrating from a nursery lake can be used to evaluate the lake rearing conditions, and to estimate the eventual production of adults (Koenings and Burkett 1987a). This thesis will evaluate wild and enhanced fry-to-smolt growth, and smolt age structures, in Tatsamenie, Tahltan, and Tuya lakes.

Growth rates of juvenile sockeye can be influenced by fish density (in rearing-limited lakes), the temperature structure of the lake, and food quantity and quality (Goodlad *et al.* 1974). Initial sockeye fry lengths and weights range from 25 to 31 mm and 0.1 to 0.2 g (LeBrasseur *et al.* 1978; Rogers 1979; McDonald and Hume 1984), but growth rate can subsequently vary widely among populations. Within one growing season, sockeye smolts can attain sizes ranging from 56 to 200 mm in length, and 1.4 to 83.9 g in weight (Koenings and Burkett 1987a). If juvenile sockeye growth is poor, resulting age 1+ smolts will either be small, or fry will hold-over in the lake for an additional year (Krogius 1961; Burgner 1987). Neither of these results is desirable since smaller smolts tend to have lower marine survival than larger smolts (Foerster 1954; Ricker 1962; Barraclough and Robinson 1972; Hyatt and Stockner 1985), and a longer freshwater residence reduces egg-to-smolt survival (Burgner 1964; Johnson 1965; Foerster 1968). Since Tatsamenie, Tahltan, and Tuya lakes were selected for enhancement because they were recruitment-limited (as opposed to rearing-limited), we don't expect fish density to significantly affect juvenile sockeye growth in the three lakes.

Upon examination of 68 lake-year smolt populations, from 22 lake systems (size, number, and age structure), Koenings and Burkett (1987a) determined that the threshold (or minimal) smolt size for Canadian and Alaskan sockeye stocks is a population mean of 2.0 g. This means that juvenile sockeye populations will typically not emigrate as age 1+ smolts if their mean weights are less than 2.0 g. If the mean weight of pre-smolt populations is below 2.0 g, the age structure of the smolt populations will shift towards increasing numbers of age 2+ fish. Koenings and Burkett (1987a) found that recruitment-limited lakes produced mainly (>85%) age 1+ smolts that were above threshold size (>60-65 mm and >2.0g). In these lakes, fry densities were below the lake carrying capacity (as defined by the Euphotic Volume model), and the forage base was abundant.

Rearing-limited lakes produced <85% age 1+ smolts (or an increasing proportion of age 2+ and 3+ smolts) that were near threshold size (60-65 mm and 2.0 g). In these lakes, fry densities were at, or exceeded, the lake carrying capacity, which was limited by the forage base, or by environmental conditions. This thesis will confirm whether the enhancement lakes are recruitment or rearing limited, based on smolt size, numbers and age structure.

In Hugh Smith Lake, Alaska, Koenings and Burkett (1987a) found that from May to October, sockeye fry were rarely found outside the 7°C isotherm, indicating that in some lakes, temperature may be an important regulator of fry growth rate. Since Hugh Smith Lake was rearing-limited, fertilization was expected to increase sockeye smolt production by improving the forage base. However, since fertilization did not cause expected changes in smolt size and age structure, other factors limiting smolt production were investigated. Peltz (1986) found that lake rearing temperature, in combination with length of the growing season, accurately predicted (and therefore limited) smolt size (assuming fry growth was food satiated). The seasonal temperature profiles of the three enhancement lakes were not investigated in this thesis.

Primary and secondary production in north temperate oligotrophic lakes is influenced by temperature (and thermal stratification) and light (photoperiod and length of growing season), but is driven and sometimes limited by the nutrient supply entering the lake (Nelson 1958; Hyatt and Stockner 1985). Many studies have shown that increases in nutrient supply (Hanson and Leggett 1982) lead to increased primary productivity (Melack 1976; McConnell *et al.* 1977; Liang *et al.* 1981), secondary productivity (Dermott *et al.* 1979), and fish production (reviewed in McQueen *et al.* 1986). In rearing-limited lakes, the forage base (zooplankton) is usually the limiting factor for juvenile sockeye growth. Zooplankton can be limiting to sockeye growth if they are present in low densities (<5,000/m^3; Pacific Salmon Commission 1988), if they are below a threshold size (<0.40 mm) which prevents effective feeding (Koenings and Burkett 1987a), or if their distribution does not overlap spatially or temporally with fry (Hartman *et al.* 1967; Rankin *et al.* 1979; Koenings and Burkett 1987b).

2. Survival

Survival rates of juvenile sockeye can be extremely variable, and dependent on factors such as growth rate, feeding success, pathogens/parasites, and predation. To evaluate the success of the Transboundary sockeye stock enhancement program, it is important to determine the growth and survival rates of introduced sockeye. Stocked fry survival rates must exceed wild fry survival rates, in order for there to be clear benefits of the enhancement program. This thesis will evaluate wild egg-to-smolt, and enhanced egg and fry-to-smolt survival rates in Tatsamenie, Tahltan, and Tuya lakes. The survival rates of juvenile sockeye in other lakes are reviewed for comparison.

In a three year study of sockeye fry stocking into Cultis Lake, BC, Foerster (1938) found that sockeye fry survival was quite low (34.6%) within the first 2.5 months (June to August) of lake residence, with survival over the entire year (fry-to-smolt) reaching only 6.0%. Fry mortality was attributed to predation by northern squawfish (*Ptychocheilus oregonensis*), char (*Salvelinus malma*), and trout (*Salmo clarkii*) (Foerster 1937). In Babine Lake, McDonald and Hume (1984) found that average wild sockeye egg-to-fry survival was 19.0% (n=16 years), and average fry-to-smolt survival was 28.6% (7.5% to 45.9%; n=14 years). This means that on average, 100 sockeye eggs resulted in 19 fry, which in turn produced 5.4 smolts. Bradford (1995) examined survival rates of 40 naturally spawning populations of Pacific chum (*Oncorhynchus gorbuscha*), pink (*O. keta*) and sockeye salmon, and found that average sockeye egg-to-fry survival (river spawning populations) was 8.0%, and that average sockeye egg-to-smolt survival was 2.0%. However, it is thought that lake (beach) spawning sockeye populations can have much higher egg-to-fry survivals. One study of beach spawning sockeye emergence at Baker Lake showed average egg-to-fry survival over 4 years to be 65% (Quistorff 1962). In a study comparing growth and survival of stocked sockeye fry in two Alaskan lakes, one with piscivorous predators, and one without, Meehan (1966) found that fry-to-smolt survival averaged 24% (ranged from 7.3% to 46.9%) in the absence of predators, and averaged 14% (ranged from 5.0% to 28.0%) in the presence of predators. Foerster and Ricker (1941) did a similar study of survival in Cultis Lake and found that stocked fry-to-smolt survival averaged 4.2% prior to partial predator removal, and averaged 13.0% after partial predator removal.

3. Feeding

Successful acquisition of sufficient quantity and quality of prey items is a major determinant of juvenile sockeye growth and survival (Koenings and Burkett 1987b). Although Bilton and Robbins (1971) found that 6 month old sockeye fry (age 0+) could survive without food for 20 weeks (November to April) without significant mortality (1.3%), newly emerged fry suffered significant mortalities if starved for more than two weeks after yolk sacs had been used (Bilton and Robins 1973). LeBrasseur *et al.* (1969) found that although early survival of sockeye fry was low in Great Central Lake, the ability to feed on abundant, available prey of the optimum size, increased their survival. Many researchers have argued that survival rate of juvenile sockeye increases with increasing growth rate (Burgner 1964; Johnson 1965; Peterson and Wroblewski 1984; Houde 1987; Koenings and Burkett 1987a; Miller *et al.* 1988; Sogard 1992, 1994). This thesis involves analyses of fry feeding conditions in the littoral zone (through diet analyses) and in the limnetic zone (through analyses of zooplankton biomass, density, and mean size). Thus, two main areas related to juvenile sockeye feeding will be considered in this review: prey selection and feeding behaviour.

Shortly after emergence, sockeye fry typically migrate into inshore littoral rearing areas, where they feed primarily on immature insects for the first 1-2 months. At this stage, fry diets are largely a function of habitat and food availability (Groot and Margolis 1991). From spring to summer, most fry populations will migrate to offshore limnetic rearing areas where they feed primarily on entomostracan zooplankton until smolt emigration. To some extent, prey selection at this stage, is still a function of the temporal and spatial distribution of available prey, but increasingly, juvenile sockeye begin to exhibit strong size-selective predation on zooplankton. Eggers (1982) found that Lake Washington fry had strong preferences for large, non-evasive prey, although smaller, evasive prey were eaten if large, non-evasive prey were not available.

Foerster (1925) found that sockeye yearlings in Cultis Lake (limnetic zone), fed mainly on *Cyclops*, followed by *Daphnia* and *Bosmina*, and to a lesser extent, *Epischura*.

Goodlad *et al.* (1974) found that fry feeding in the littoral zone from April to June ate approximately 40-90% chironomid pupae, with the remainder made up of zooplankton. During fall limnetic feeding, 90% of the fry diet consisted of zooplankton, and fry selected strongly for the largest zooplankters such as *Daphnia* and *Heterocope*. An examination of sockeye fry diets in BC and Kamchatkan (Russia) lakes showed that newly emerged fry (littoral zone) fed primarily on immature insects, particularly chironomid larvae (Groot and Margolis 1995). Twelve studies of sockeye fry diets in Washington, BC, Alaskan, and Kamchatkan lakes showed that fry in the limnetic zone fed primarily on cyclopoid and calanoid copepods (*Cyclops*, *Epischura*, *Diaptomus*) and cladocerans (*Daphnia*, *Bosmina*, *Diaphanosoma*, *Holepedium*, *Alona*) (Groot and Margolis 1995).

As juvenile sockeye shift from littoral to limnetic zone feeding, there may be a shift from mainly daytime, to mainly crepuscular feeding (Groot and Margolis 1991). Many fry populations may also begin diel vertical migrations, characterized by daytime schooling in deep, cold water followed by nighttime dispersal (breakdown of schools) into the epilimnion to feed. Since fish are visual predators (Brett and Groot 1963; Doble and Eggers 1978; Eggers 1977, 1978, 1982; Eggers *et al.* 1978), diel migration is thought to be a result of tradeoffs between feeding on zooplankton, avoiding fish predators, and bioenergetic advantage (fry have a growth optimum at 15°C, and a growth conversion efficiency (% food to flesh) optimum at 11.5°C (Brett 1979). Diel migrations of juvenile sockeye may also be genetically controlled feeding behaviours that have resulted in improved growth and survival over time (Burgner 1987). It is relevant to note that day lengths are long and night lengths are short in the summer at northern latitudes. Although the specific diel migration patterns of sockeye fry in Tatsamenie, Tahltan, and Tuya lakes have not been investigated, it is likely that fry in these lakes undergo diel vertical migrations to some extent, since fry inhabiting lakes further north (Bristol Bay, Alaska) have been found to vertically migrate (Pella 1968; Margolis and Groot 1991).

4. Pathogens and Parasites

Pathogens such as infectious hematopoietic necrosis virus (IHNV) and bacterial kidney disease (BKD), and parasites, can contribute significantly to sockeye fry mortality. West and Larkin (1987) suggested that smaller, slower growing juvenile sockeye can experience higher mortality due to disease or parasitism, than larger, faster growing juveniles.

IHNV and BKD are the most common and serious diseases of sockeye salmon. IHNV is pathogenic to all life stages from eggs to adults, and can result in a 100% mortality rate in fry populations over a two to three week period (Mulcahy and Pascho 1985). IHNV is most commonly transmitted directly from fish to fish, but can be transmitted indirectly through the water by urine, feces and mucus shed by infected fish. Fortunately, IHNV is destroyed by iodiphore disinfectants, which can be very effective in preventing transmission on the outside of broodstock eggs, and for disinfecting the hatchery environment in case of outbreaks. BKD is caused by the bacterium *Renibacterium salmoninarum*, and is believed to be transmitted through direct contact with infected fish (Roberts 1989). BKD develops slowly in the infected fish and signs of the disease may not be present until the fish reaches the adult stage.

Over their extended period of lake residence, juvenile sockeye become infected by many species of freshwater parasites (Margolis 1982). The effects of these parasites on wild Pacific sockeye populations are not well known, with the exception of *Eubothrium salvelini*. *E. salvelini* infects sockeye fry at an early age, through an intermediate copepod host, causing infected fry to have reduced growth, stamina, and ability to adapt to sea water as smolts (Smith 1973; Boyce 1979; Boyce and Clarke 1983). Approximately 30% of fry in Babine Lake, BC, are infected with *E. salvelini* (Boyce 1974).

5. Predation

Predation is usually considered the most significant cause of sockeye fry mortality in lakes (Johnson 1965; Hartman and Burgner 1972; Margolis and Groot 1991). Many studies have attributed low sockeye fry survival to predation. Brett and McConnell (1950) determined that the low survival (0.4% to 1.1%) of juvenile sockeye in Lakelse Lake, BC, was attributable to predation by northern squawfish. Ricker (1941) reported that young sockeye in Cultus Lake, BC, were an important source of food for predators. Foerster and Ricker (1941) found that partial removal of predators by gillnetting Cultus Lake, resulted in more than a three fold increase in sockeye survival.

Potential predators of juvenile sockeye in lakes of western Alaska and Kamchatka include Arctic char (*Salvelinus alpinus*), rainbow trout (*Oncorhynchus mykiss*), bull trout

(*Salvelinus confluentus*), lake trout (*Salvelinus namaycush*), juvenile coho salmon (*O. kisutch*), northern pike (*Esox lucius*), and birds such as Arctic terns and Bonaparte's gulls (Hartman and Burgner 1972). Known predators of juvenile sockeye in Cultus Lake, BC, include northern squawfish, Dolly Varden (*Salvelinus malma*), cutthroat trout (*Salmo clarkii*), juvenile coho salmon, and sculpin (Family Cottidae). Predators of sockeye fry tend to be benthic and inshore feeders most of the time. Although fry populations can experience significant predation during their littoral feeding stage, the presence of other prey species such as stickleback (Family Gasterosteidae), sculpin, and fry of Arctic char and bull trout may help to buffer them from predators.

Numerous studies have shown that smaller or slower growing juvenile fish are generally more susceptible to predation than larger or faster growing juveniles (Sogard 1997). West and Larkin (1987) found evidence of size selective mortality in Babine Lake sockeye fry populations, which was attributed to predation or disease/parasitism. Parker (1971) suggested that juvenile chum and pink salmon experienced size-selective predation by juvenile coho. Size-biased predation can be attributed to gape limitation in predators, to the feeding behaviors of the predators, and to the greater ability of larger juveniles to evade predators (Sogard 1997). At the small end of the size spectrum, sockeye fry are potential prey for a wide spectrum of predators. As fry grow larger, the spectrum of predators would presumably decline, along with mortality associated with predation. As we shall see in the following chapters, predation in general, and size-selective predation in particular, will become important in our consideration of mortality sources in at least one of the Transboundary lakes.

Chapter 2 – Objectives and Approach

The initial objective of this thesis was to analyse and compare the growth and survival of wild and enhanced juvenile sockeye in Tatsamenie, Tahltan, and Tuya lakes, with the goal of evaluating the success of the sockeye enhancement program at each lake. Preliminary survival data indicated that enhanced fry in Tatsamenie Lake, and possibly Tahltan Lake, had lower mean survival rates than wild fry. Preliminary fry size data suggested that at the time of stocking, enhanced fry were smaller than wild fry, although by the following spring, enhanced and wild smolt weights were virtually the same. Thus, the hypothesis that emerged to explain the low survival of enhanced fry was size selective mortality. This thesis research involved the analyses of all available growth and survival data to first confirm that enhanced fry did have lower survival than wild fry, and in lakes where enhanced fry survival was lower, to test the hypothesis that smaller fry had higher rates of mortality. In addition, the objective was to determine a mechanism (feeding, disease, or predation) for the low survival.

The direction of my research followed the flow diagram shown in Figure 2.1. The first step was to compare wild and enhanced sockeye fry weight frequency and mean weight data (step **a** in Fig. 2.1). This analysis was intended to reveal whether enhanced fry were similar in size to wild fry shortly after stocking (step **b**) or whether they were significantly smaller than wild fry (step **h**). If growth and survival analyses (step **a**) showed that wild and enhanced fry weights were comparable from the time of stocking until fall (step **b**), then comparisons of wild and enhanced fry diets were done (step **c**) to

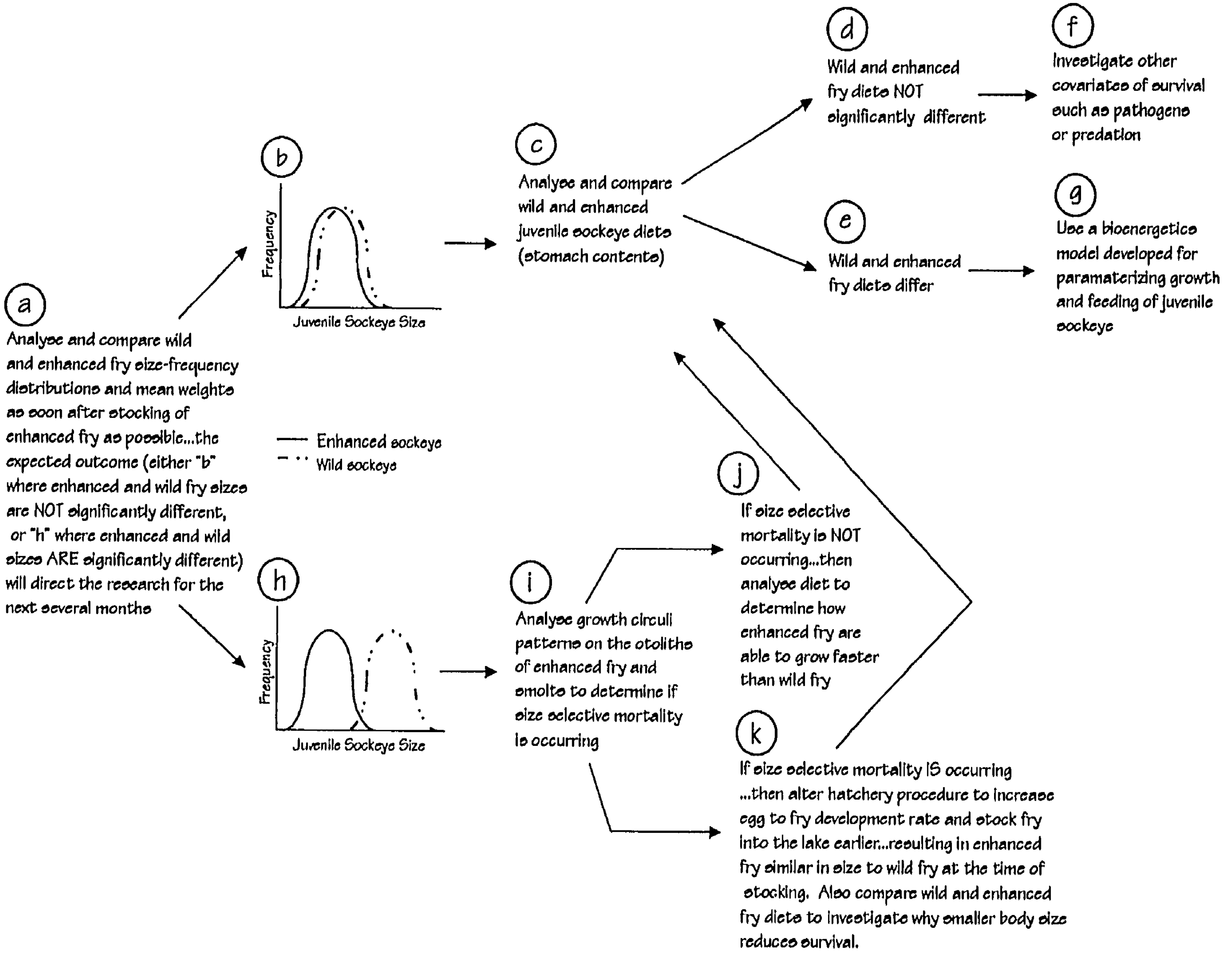


Figure 2.1. Flow chart showing sequence of research activities investigating growth of juvenile sockeye salmon in Tatsamenie, Tahltan, and Tuya lakes.

look for indications that would suggest enhanced fry had lower success acquiring food in the littoral zone. Comprehensive analyses of zooplankton biomass, densities and mean sizes were completed prior to analyses of sockeye growth and survival (Chapter 5). This was intended to ensure that the forage base in each lake was not impacted by stocking increased numbers of fry.

If differences were detected between wild and enhanced fry diets (step **e**), then I planned to use a new fish bioenergetics model (step **g**) that has been developed for juvenile sockeye (Stockwell and Johnson 1997), to predict fry growth rates based on differing diets. If no differences were detected between wild and enhanced fry diets (step **d**), then other covariates of survival (disease and predation) were to be investigated (step **f**).

If growth and survival analyses (step **a**) showed that enhanced fry were significantly smaller than wild fry at the time of stocking (step **h**), then I planned to do an analysis of the growth circuli that were laid down on the otoliths (step **i**). Since preliminary data showed that by the following spring, wild and enhanced smolts had similar weights, it seemed possible that size selective mortality of enhanced fry could have occurred (i.e. the smaller enhanced fry experienced higher mortality than larger enhanced fry). Analyses of growth circuli from enhanced smolts would have allowed us to determine the size-at-stocking of the fish that survived. If all of the survivors were very large shortly after stocking, this would suggest that only the largest enhanced fry survived (i.e. size selective mortality did occur). If, on the other hand, size-at-stocking represented a random sample of the enhanced fish stocked into the lake, this would suggest that the enhanced fish were able to show exceptional weight gains during their year of lake rearing (i.e. size selective mortality did not occur).

If growth circuli analyses showed that size selective mortality did occur (step **k**), then the smaller mean size of enhanced fry at stocking is a likely explanation for the observed lower enhanced fry survival. A remedy for this problem would be to alter hatchery procedure to increase the egg-to-fry development rate in order to stock fry earlier in the spring. This would result in enhanced fry that are similar in size to wild fry at the time they are stocked. Two possible hypotheses for smaller size resulting in higher mortality are: (1) the smaller fry were food-limited (i.e. available prey were too large), or (2) the smaller fry were more vulnerable to pathogens or predation. The first hypothesis would be tested by comparing the diets (step **c**) of small and large enhanced fry to those of wild fry. If differences in diets were detected (step **e**) then I planned to use the bioenergetics model (step **g**) to predict how the growth rates of smaller fry are limited by the available prey composition. If no differences in diets were detected (step **d**), then other covariates of survival such as disease or predation were to be investigated (step **f**).

If the analyses of growth circuli patterns showed that size selective mortality did not occur (step **j**), then this would suggest that enhanced fry had higher growth rates than wild fry. At this point, an analysis and comparison of wild and enhanced fry diets would be undertaken (step **c**) to determine if diet could account for a higher enhanced fry growth rate.

If differences in wild and enhanced fry diets were detected (step **e**) then I planned to use the bioenergetics model (step **g**) to predict whether the observed fry growth rates could be accounted for by the differences in diet. It may be possible to show that higher quantities of prey organisms were available to the smaller enhanced fry, or that the smaller enhanced fry were feeding on higher quality prey (higher energy density) compared to wild fry. If no differences in wild and enhanced fry diets were detected (step **d**), then other covariates of survival such as disease and predation were to be investigated (step **f**).

Using the flow diagram research approach, we identified five thesis objectives: (1) to assess and compare the growth of wild and enhanced sockeye (fry-to-smolt), (2) to quantify and compare the survival rates of wild and enhanced sockeye (egg/fry-to-smolt), (3) to investigate feeding as the mechanism responsible for the low survival of Tatsamenie Lake fry, (4) to assess pathogens and parasites as mechanisms responsible for the low Tatsamenie Lake fry survival, and (5) to examine predation as the mechanism responsible for the low survival of Tatsamenie Lake fry. To address these objectives, the thesis is broken down into eight chapters.

Chapter 1 introduced the Transboundary Rivers sockeye stock enhancement program and sockeye life history, and reviewed literature that was relevant to the thesis objectives. This chapter (Chapter 2) provides an outline of the path the thesis research took. Chapter 3 describes the physical (water temperature), biological (fish species present), and chemical (dissolved oxygen, secchi depths, water chemistry) characteristics of Tatsamenie, Tahltan, and Tuya lakes. Chapter 4 summarizes: the methods used to produce enhanced fry (broodstock collection), how many fry were stocked and when, and how the stocking techniques were modified to address observed fry survival problems.

Chapter 5 focuses on results of the zooplankton analyses that were done to determine whether zooplankton species composition, biomass and mean size changed after fry stocking. Chapter 6 presents the analyses of juvenile sockeye growth and survival data, within and between-lakes. Chapter 7 addresses the problem of low enhanced fry survival in Tatsamenie Lake, by comparing fry and smolt mean weights to test the hypothesis that enhanced fry mortality is size-selective. Three mechanisms of size-selective mortality were identified, investigated and discussed. Chapter 8 is a synthesis of the significant conclusions about lake characteristics, zooplankton, and juvenile sockeye growth and survival in Tatsamenie, Tahltan, and Tuya lakes. Based on these conclusions, recommendations about the success of the sockeye enhancement program at each lake were made.

Chapter 3 – Enhancement Lake Descriptions

INTRODUCTION

This chapter describes the physical and limnological characteristics of Tatsamenie, Tahltan and Tuya lakes. Physical characteristics include details about the watershed drainages, lake locations, lake dimensions and biogeoclimatic zones. This section contains a map showing the locations of the Taku and Stikine river watersheds in British Columbia, and two maps of each lake showing (1) lake outlines and locations of sampling sites, and (2) bathymetric contours. Limnological characteristics include a summary of basic water chemistry and chlorophyll *a* concentrations. Since a variety of lake characteristics can influence primary, secondary and tertiary production, the purpose of this chapter is to provide a framework within which the standing crop of zooplankton (Chapter 5) and the production of sockeye fry (Chapter 6) in Tatsamenie, Tahltan, and Tuya lakes can be evaluated.

LAKE AND WATERSHED DESCRIPTIONS

Tatsamenie Lake (Figs. 3.2-3.3, Table 3.1) (58°20'N, 132°20'W), is located approximately 140 km west of the town of Dease Lake, British Columbia, within the Taku River watershed (Fig. 3.1). The lake is only accessible by float plane (60 minutes flying time from Dease Lake, BC). Tatsamenie Lake forms the headwaters of Tatsatua Creek which drains to the north-northeast into Little Tatsamenie Lake (Tatsatua Lake),

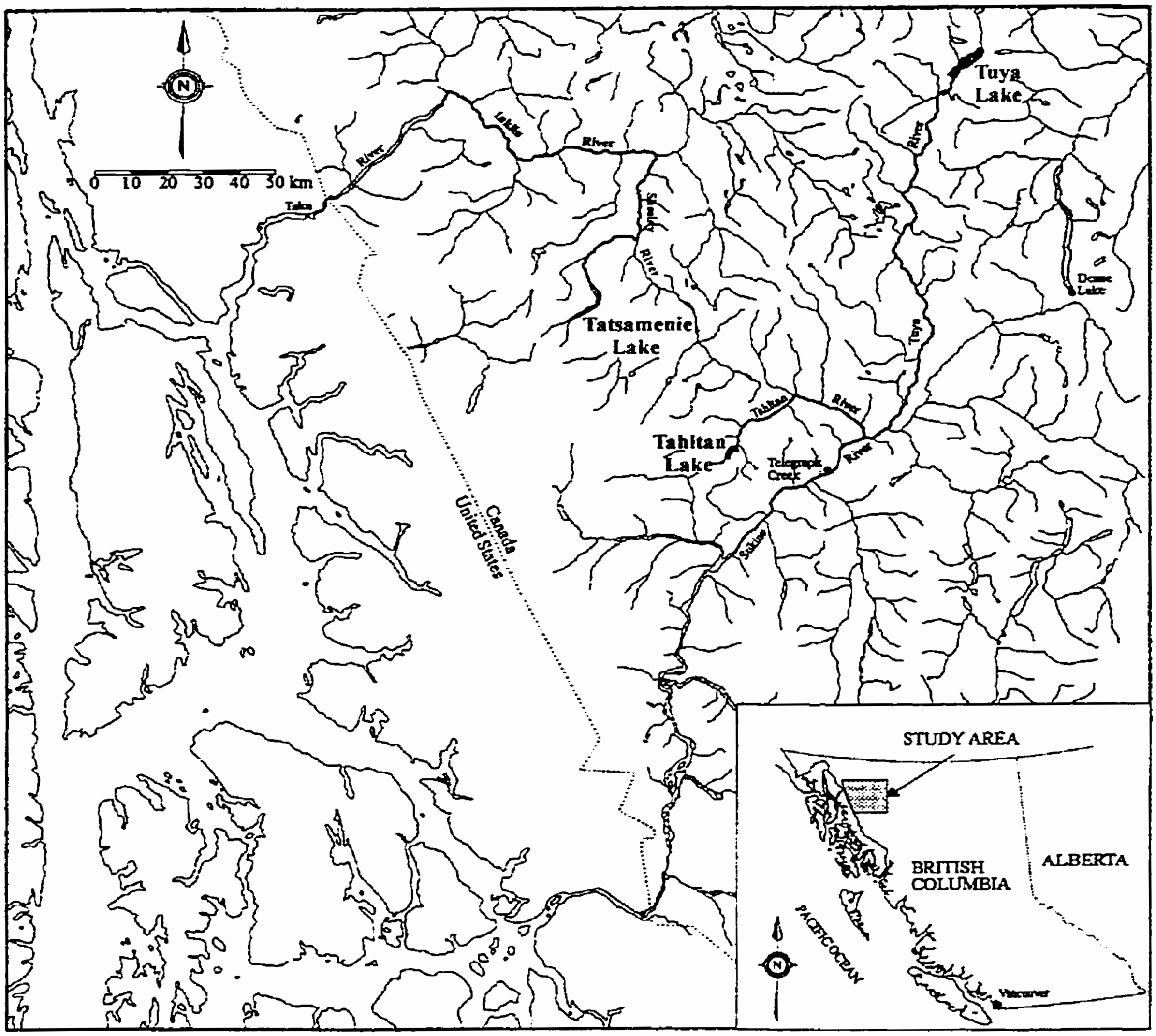


Figure 3.1. Overview map of the Taku (Tatsamenie Lake) and Stikine (Tahltan and Tuya lakes) river drainages located in northwestern British Columbia.

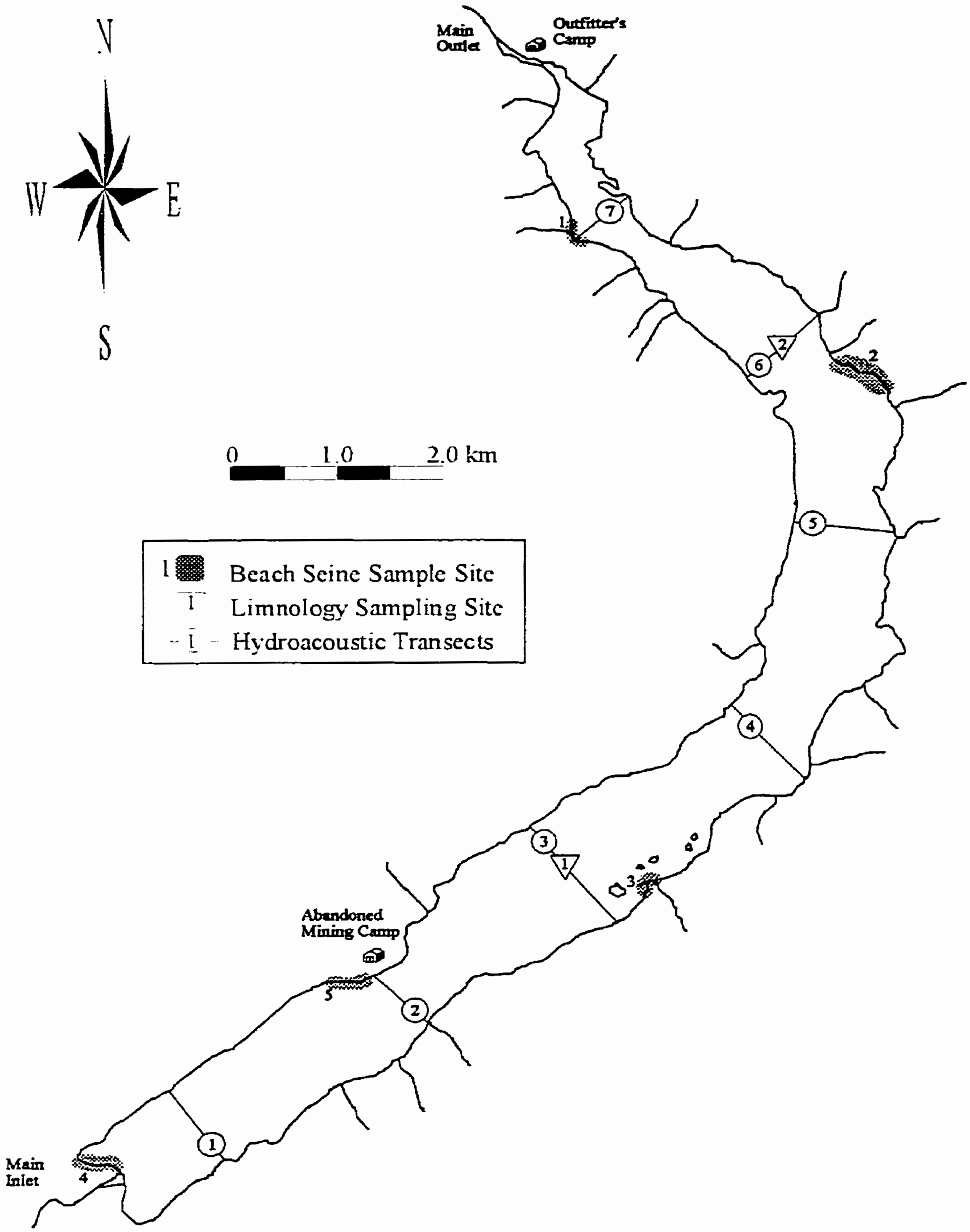


Figure 3.2. Tatsamenie Lake outline showing locations of the five beach seine sample sites, the seven hydroacoustic transects, the two limnology sampling sites, and the lake inlets and outlet. Outline adapted from Triton Environmental Consultants Ltd. (1993).

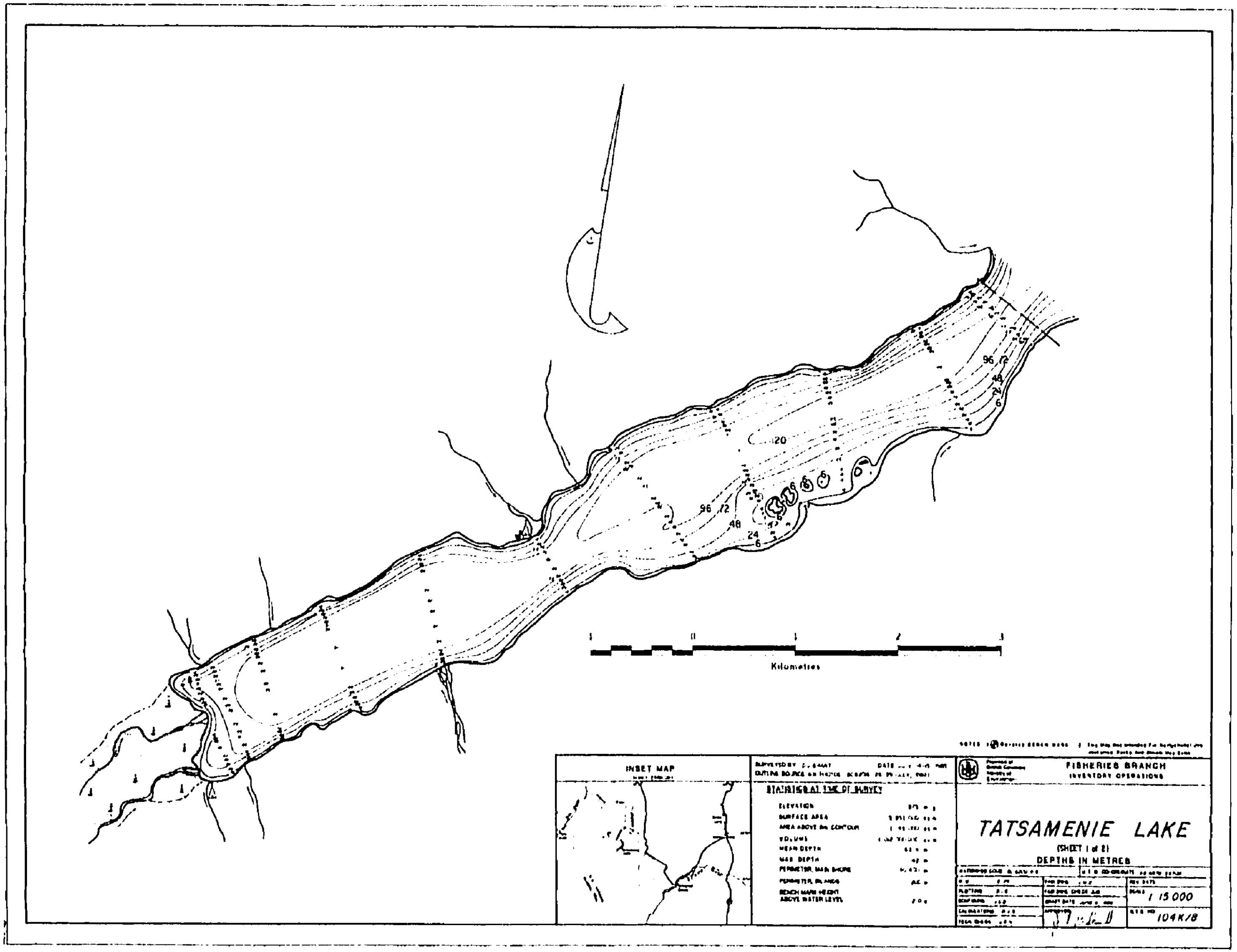


Figure 3.3. Tatsamenie Lake bathymetric map (section 1 of 2). Printed with permission from the BC Ministry of Finance and Corporate Relations, Intellectual Property Program.

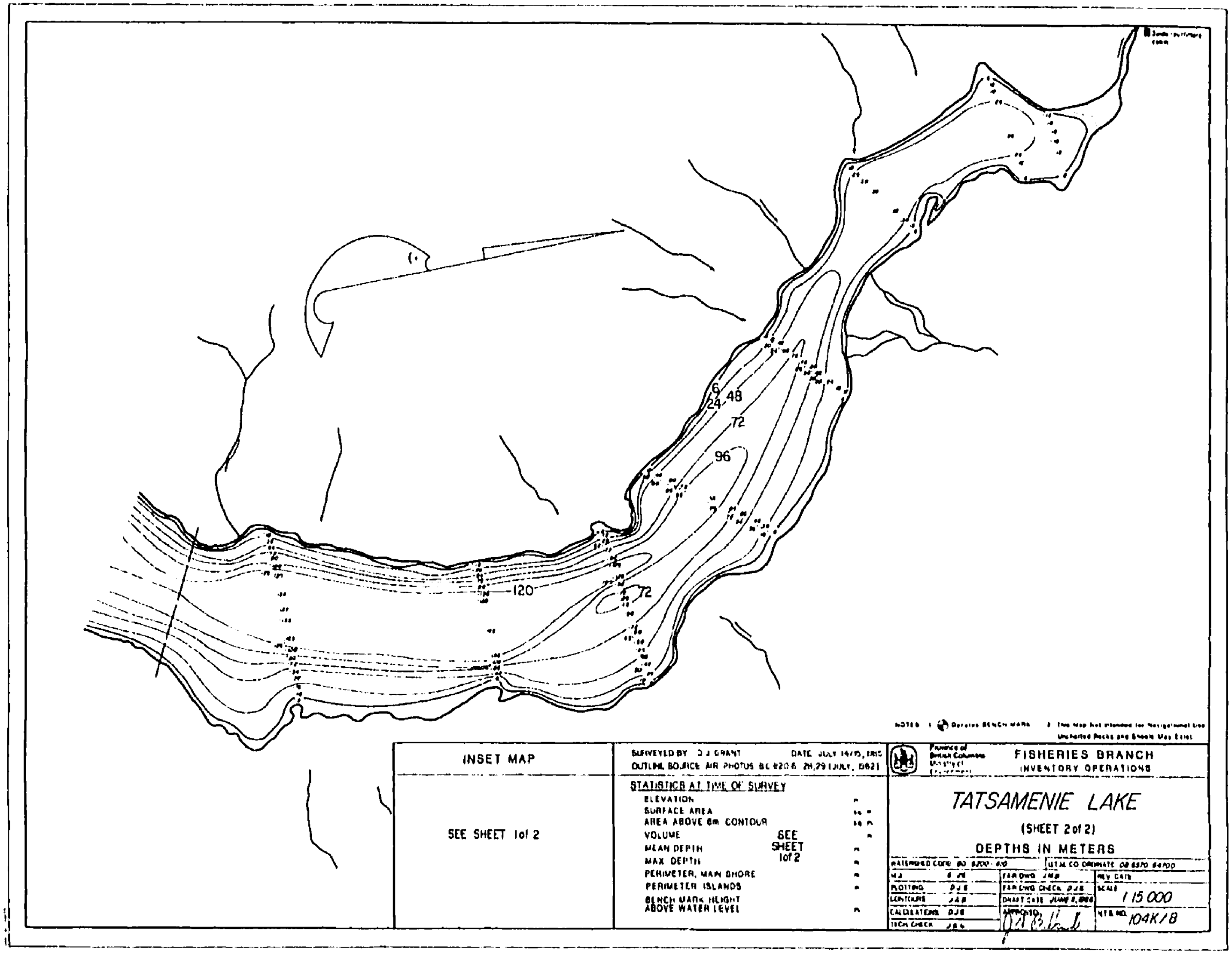


Figure 3.3 continued. Tatsamenie Lake bathymetry map (section 2 of 2). Printed with permission from the BC Ministry of Finance and Corporate Relations, Intellectual Property Program.

located approximately 5 km downstream. Tatsatua Creek then flows out of Little Tatsamenie Lake to drain into the Sheslay River approximately 20 km downstream. The Sheslay River is a tributary of the Inklin River which drains into the Taku River. The Taku River ultimately flows into Taku Inlet, Southeast Alaska (Pacific Ocean), approximately 150 km from its headwaters. The Taku River watershed covers an area of 45,000 km^2, 97% of which is within northwestern BC.

Tatsamenie Lake is situated within the Subalpine Engelmann Spruce - Subalpine Fir biogeoclimatic zone, and is located on the northeastern edge of the Chechidla Range of the Coast Mountains. Tatsamenie Lake is approximately 17 km long and 1.5 km wide, and has an elevation of 790 m. The lake has a surface area of 1,622 ha and a volume of 889.9×10^6 m^3. The maximum measured depth is 142 m and the mean depth is 53 m. Tatsamenie Lake has semi-glacial water owing to its numerous seasonal and year-round, glacially fed tributaries. Since the lake is ice-covered from November until May, it is assumed that the lake turns over once in spring and again in fall (dimictic).

The immediate shoreline is fairly flat at the southwest end of the lake (where the main inlet flows in) and at the north end of the lake (where the outlet stream flows out), but is steep to moderately steep along the sides of the lake (Fig. 3.3). Along the steep sides of the lake are found narrow beaches composed of sand to cobble, with frequent bedrock outcroppings and boulders. The lake bottom drops off quite rapidly from shore to an almost flat bottom at 70 to 120 m. As a result, Tatsamenie Lake has a limited littoral area, which is almost barren of aquatic plants.

Tahltan Lake (Figs. 3.4-3.5, Table 3.1) (57°57'N, 131°37'W), is located approximately 115 km southwest of the town of Dease Lake, BC, within the Stikine River watershed (Fig. 3.1). The lake is only accessible by float plane (50 minutes flying time from Dease Lake, BC). Tahltan Lake is the headwater of the Tahltan River, which is a tributary of the Upper Stikine River. The confluence of the Tahltan and Stikine rivers is approximately 25 km northeast and upstream of the town of Telegraph Creek (a Tahltan First Nations community). The Stikine River ultimately flows through Southeast Alaska into Frederick Sound, approximately 250 km from its headwaters. The Stikine River system drains an area of 51,200 km^2, of which 98% lies in northwestern BC.

Tahltan Lake is situated within the Subalpine Engelmann Spruce - Subalpine Fir biogeoclimatic zone. Tahltan Lake is approximately 7 km long and 0.5 - 1.25 km wide, and has an elevation of 812 m. The lake has a surface area of 492 ha and volume of 113.4×10^6 m^3 (the smallest of the enhancement lakes). The maximum measured depth is 48 m and the mean depth is 23 m. Tahltan Lake is dimictic, and has clear water. The lake has two main basins with many interspersed small islands (Fig. 3.5). Tahltan Lake has a large, productive littoral zone with marshy shoals and gravel beaches around the lake perimeter. There are no main inlets to Tahltan Lake, and only a single outlet creek at the north end of the lake.

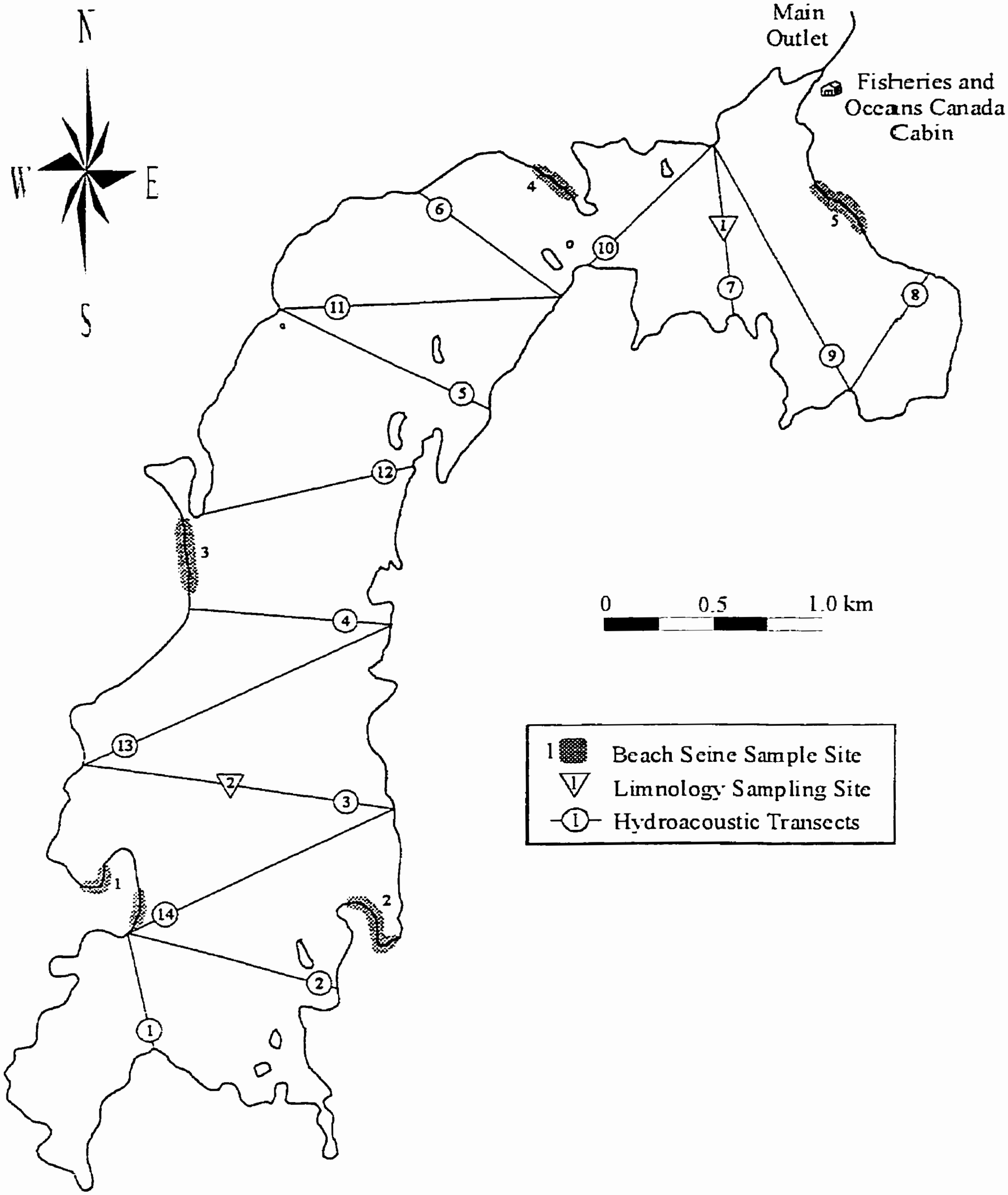


Figure 3.4. Tahltan Lake outline showing locations of the five beach seine sample sites, the fourteen hydroacoustic transects, the two limnology sampling sites, and the lake outlet. Outline adapted from Triton Environmental Consultants Ltd. (1993).

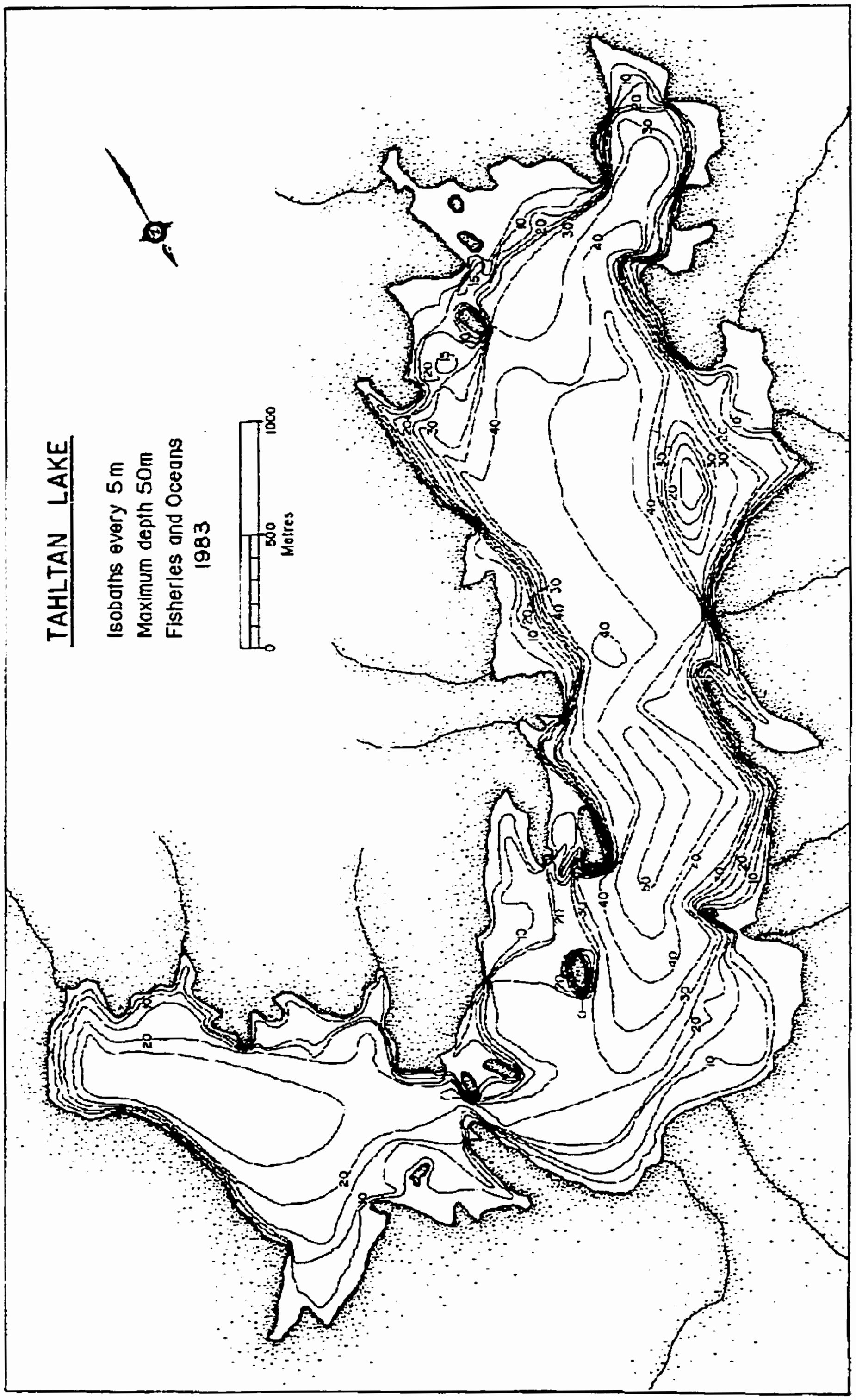


Figure 3.5. Tahltan Lake bathymetric map (Fisheries and Oceans Canada 1983).

Tuya Lake (Figs. 3.6-3.7, Table 3.1) (59°05'N, 130°35'W), is located approximately 72 km north northwest of the town of Dease Lake, BC, within the Stikine River watershed (Fig. 3.1). The lake is only accessible by float plane (30 minutes flying time from Dease Lake, BC). High Tuya Lake is the headwater of the Tuya River, which flows 13.5 km to Tuya Lake. The Tuya River exits Tuya Lake and flows 132 km to its confluence with the Stikine River. This portion of the Tuya River has several areas of entrenched falls which are barriers to fish passage. The confluence of the Tuya and Stikine rivers is approximately 10 km northeast and upstream of the confluence of the Tahltan and Stikine rivers. The Stikine River ultimately flows through Southeast Alaska into Frederick Sound, approximately 250 km from its headwaters. The Stikine River system drains an area of 51,200 km^2, of which 98% lies in northwestern BC.

Tuya Lake is situated within the Subalpine Engelmann Spruce - Subalpine Fir biogeoclimatic zone, while the slopes above the lake are in the Alpine Tundra biogeoclimatic zone. Tuya Lake is approximately 16 km long and 3 km wide, and has an elevation of 1,117 m. It has a surface area of 2,948 ha and a volume of 708.4×10^6 m^3 (the largest of the enhancement lakes). The maximum measured depth is 54 m and the mean depth is 23 m. Tuya Lake has clear, organically-stained water (due to a high concentration of dissolved organic carbon). Since the lake is ice-covered from October until May, it is assumed that the lake turns over once in spring and again in fall (dimictic). There are extensive shoal and shallow, rocky areas, particularly in the northeastern and southwestern ends of the lake (Fig. 3.7). The shoreline is made up of many beaches composed of sand to large cobble, along with boulder and bedrock

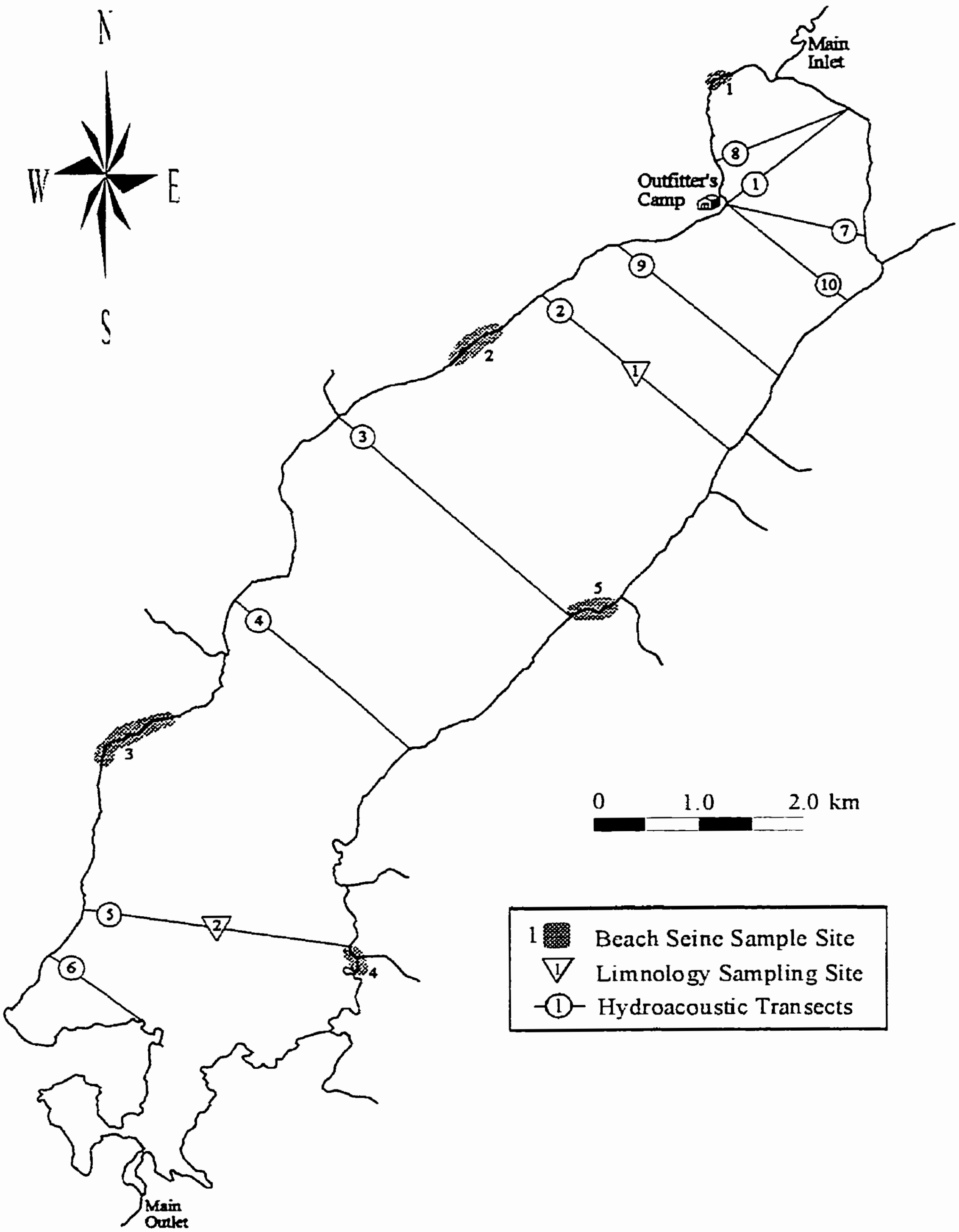


Figure 3.6. Tuya Lake outline showing locations of the five beach seine sample sites, the ten hydroacoustic transects, the two limnology sampling sites, and the lake inlet and outlet. Outline adapted from Triton Environmental Consultants Ltd. (1993).

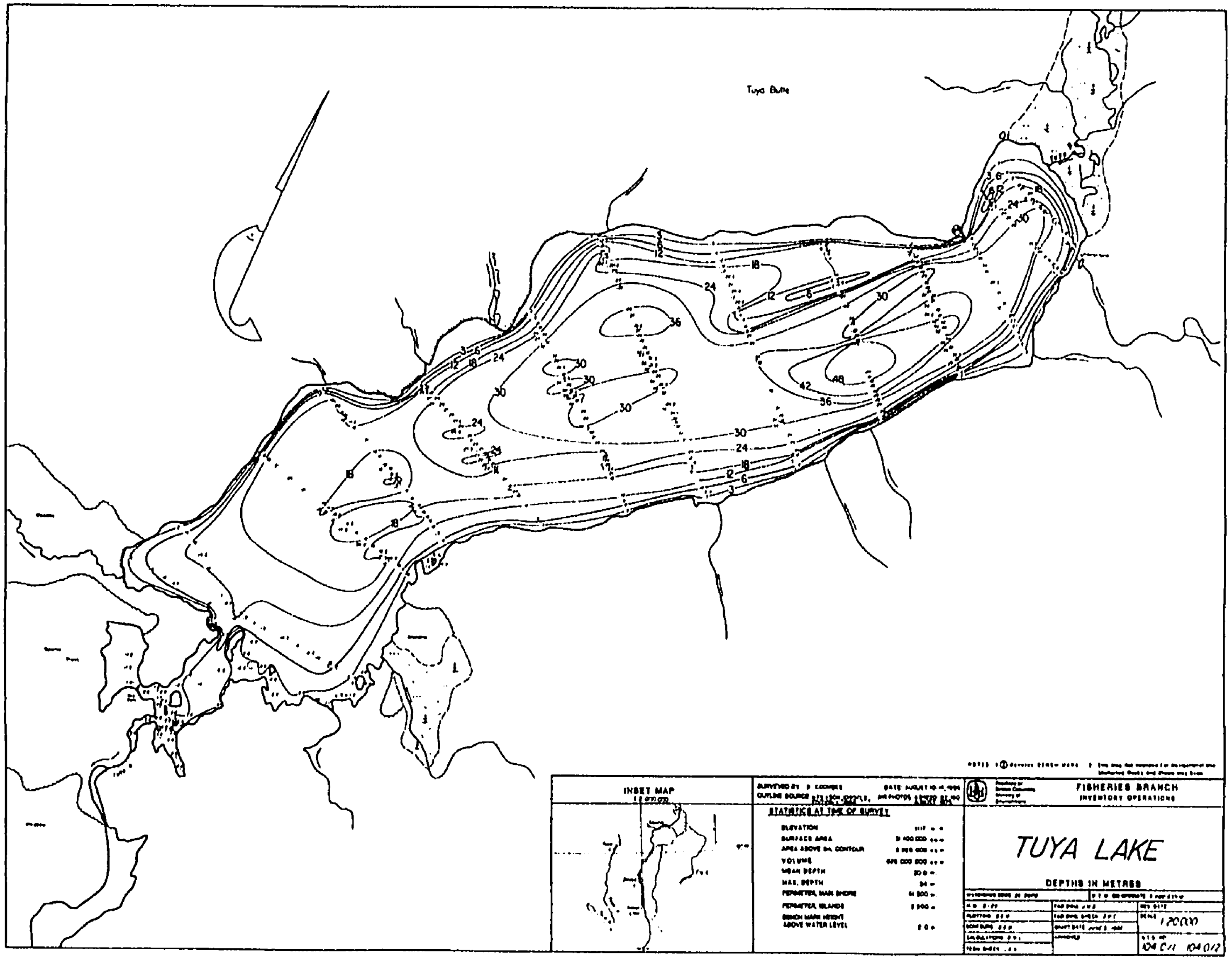


Figure 3.7. Tuya Lake bathymetric map. Printed with permission from the BC Ministry of Finance and Corporate Relations, Intellectual Property Program.

outcroppings. Much of the lake is exposed to prevailing westerly winds, frequently creating rough surface conditions. Tuya Lake has one main inlet at the southwest end of the lake (in addition to many minor inlets) and one main outlet creek at the northeast end of the lake.

Table 3.1. Summary of physical characteristics of Tatsamenie, Tahltan and Tuya lakes.

Lake	Lake Area (ha)	Lake Drainage Area (km^2)	Shoreline Length (km)	Lake Volume ($10^6 m^3$)	Maximum Measured Depth (m)	Mean Depth (m)
Tatsamenie	1,622	308.2	42.5	889.9	[a] 142	53
Tahltan	492	56.8	20.5	113.4	48	23
Tuya	2,948	446.8	44.5	708.4	54	23

Table 3.1 continued.

Lake	Elevation (m)	Mean Annual Precipitation (mm)	Latitude (North)	Longitude (South)	Biogeo-climatic zone
Tatsamenie	975	292	58°20'	132°20'	subalpine engelmann spruce - subalpine fir
Tahltan	825	320	57°57'	131°37'	subalpine engelmann spruce - subalpine fir
Tuya	1,117	395	59°05'	130°35'	subalpine engelmann spruce - subalpine fir

[a] Maximum depth taken from Grant (1985).

FISH SPECIES PRESENT

Tatsamenie Lake has a wild population of sockeye salmon and, since 1991, has been supplemented with outplants of enhanced sockeye fry. Tatsamenie Lake produces an average of 20,000 wild sockeye adults, making up about 12% of the total Taku River sockeye population (averages 170,000 adults) (Pacific Salmon Commission 1988). Other fish species (or genera) known to be present in Tatsamenie Lake include chinook salmon (*Oncorhynchus tschawytscha*), bull trout (*Salvelinus confluentus*), lake trout (*Salvelinus namaycush*), coho salmon (*Oncorhynchus kisutch*), rainbow trout (*Oncorhynchus mykiss*), mountain whitefish (*Prosopium williamsoni*), sculpins (*Cottis sp.*), and suckers (*Catostomus sp.*).

Tahltan Lake has a wild population of sockeye salmon and since 1990, has been supplemented with outplants of enhanced sockeye fry. It is an important producer of Stikine River sockeye, with wild stocks making up 17% (in 1988) to 62% (in 1982) of the total Stikine River sockeye population (ranges from 40,000 to 200,000 adults, and averages 100,000 adults) (FOC Whitehorse 1991). Other fish species known to be present in Tahltan Lake include bull trout, rainbow trout, coho salmon, longnosed suckers (*Catostomus catostomus*), slimy sculpin (*Cottus cognatus*), and lake chub (*Couesius plumbieus*).

Tuya Lake was originally barren of anadromous fish due to barriers (falls) on the Tuya River, downstream of the lake, but has been outplanted with enhanced fry since 1992. Other fish species (or genera) known to be present in Tuya Lake include limnetic sculpin (*Cottis sp.*), arctic grayling (*Thymallus arcticus*), bull trout, lake trout, and longnose sucker. In all three lakes, it is possible that the lists of fish species present are not complete since thorough sampling for indiginous fish was done infrequently.

Table 3.2. Summary of fish species or genera known to be present in Tatsamenie, Tahltan and Tuya lakes.

Tatsamenie Lake	Tahltan Lake	Tuya Lake
1. sockeye salmon 2. bull trout 3. lake trout 4. rainbow trout 5. chinook salmon 6. coho salmon 7. mountain whitefish 8. sculpin 9. suckers	1. sockeye salmon 2. bull trout 3. rainbow trout 4. coho salmon 5. longnosed sucker 6. slimy sculpin 7. lake chub	1. sockeye salmon 2. bull trout 3. lake trout 4. arctic grayling 5. limnetic sculpin 6. longnose sucker

LIMNOLOGY

Limnological conditions were sampled 1-3 times during each ice-free period (Appendix A). Samples and measurements included temperature and dissolved oxygen profiles, secchi disk readings, water chemistry, and zooplankton. This section will describe methods and summarize results pertaining to water chemistry and zooplankton. Zooplankton methods and results are presented in Chapter 5.

1. Water Temperature Profiles

In all lakes, from 1990 to 1999, water temperature profiles were measured using a YSI Model 51-B (1990-92), or YSI Model 57 (1993-99). Measurements were taken at 2-3 m intervals from the surface to 30 m to locate the thermocline. Additional readings at 1 m intervals were taken near the thermocline to determine the exact depth. In all lakes, from 1990 to 1994, dissolved oxygen profiles were measured using a YSI Model 51-B (1990-92), or YSI Model 57 (1993-94).

In all three lakes, ice break-up usually occurred during May (or early to mid-June in the case of Tuya Lake). From ice break-up to mid-June, lake water was usually not stratified. Water temperatures were generally 6-7°C at the surface and 4-5°C at 30 m. In July and August, the thermocline was usually located between 6-15 m, and water temperatures ranged from 10-16°C (Tatsamenie), 12-17°C (Tahltan), and 12-15°C (Tuya) at the surface, and 5-7°C at 30 m (Table 3.3). In September at Tatsamenie and Tahltan lakes, a thermocline was usually present between 11-15 m, and water temperatures were generally 8.5-12.5°C at the surface, and 7°C at 30 m. Lake stratification usually broke down during September. In Tuya Lake, stratification usually persisted through September, but in some years strong winds caused de-stratification in early August. In those years, water temperatures ranged from 8-10°C at the surface, to 7-8°C at 30 m. All three lakes were usually ice covered from November until June. Dissolved oxygen (DO) was measured from 1990 to 1994. Spring and fall DO concentrations ranged from 10-13 mg/L from the surface to 30 m, regardless of whether the lake was stratified. In summer, DO concentrations ranged from 10-14 mg/L in the epilimnion, often dropped to 3-4 mg/L in the metalimnion (at the thermocline), and ranged from 9-14 mg/L in the hypolimnion. DO concentration ranged from 9-11 mg/L, if no stratification was present.

Table 3.3. Summary of summer ranges of surface and 30 m water temperatures and dissolved oxygen (DO) concentrations, and thermocline depths in Tatsamenie, Tahltan, and Tuya lakes.

	Tatsamenie Lake	Tahltan Lake	Tuya Lake
Range of August surface water temperatures	10 – 16°C	12 - 17°C	12 - 15°C
Range of August 30 m water temperatures	5 - 7°C	5 - 7°C	6 - 7°C
Range of August thermocline depths	6 – 14 m	10 – 14 m	12 – 15 m
Range of August surface water DO concentration	8 – 10 mg/L	9 - 10 mg/L	10 - 14 mg/L
Range of August 30 m DO concentration	12 – 13 mg/L	9 – 14 mg/L	11 - 12 mg/L

2. Secchi Depth

Mean annual secchi depths (Table 3.4) were deepest at Tahltan Lake (averaged 11.7 m from 1987-88, 1990-99), followed by Tuya Lake (averaged 5.6 m from 1987, 1990-99), and Tatsamenie Lake (averaged 5.0 m from 1987, 1991-99). Within-lake variation in mean annual secchi depth was minimal.

Table 3.4. Mean annual secchi depth measurements, standard deviations (SD), and sample sizes (n) from Tatsamenie, Tahltan and Tuya lakes from 1987 to 1999.

	Mean Annual Secchi Depth								
	Tatsamenie Lake			*Tahltan Lake*			*Tuya Lake*		
Year	**n**	**Mean (m)**	**SD**	**n**	**Mean (m)**	**SD**	**n**	**Mean (m)**	**SD**
1987	1	3.1	n/a	1	12.0	n/a	1	6.0	n/a
1988	0	n/a	n/a	1	13.5	n/a	0	n/a	n/a
1989	0	n/a	n/a	0	n/a	n/a	0	n/a	n/a
1990	0	n/a	n/a	4	12.4	2.2	3	4.7	0.1
1991	4	4.7	1.2	4	10.1	0.9	3	5.3	1.0
1992	4	4.5	2.0	4	8.9	1.8	4	4.8	0.4
1993	2	4.7	2.4	2	10.9	1.5	2	5.1	1.1
1994	2	9.4	7.0	3	13.7	5.5	2	4.7	0.4
1995	2	3.6	0.4	1	12.5	n/a	1	6.9	n/a
1996	2	6.2	1.8	2	13.0	1.4	1	5.5	n/a
1997	3	3.6	0.4	2	13.0	0.1	1	6.1	n/a
1998	6	6.7	3.6	1	9.4	n/a	2	6.8	1.0
1999	3	3.8	0.4	7	11.3	2.0	2	5.5	0.4
	Mean:	**5.0**		*Mean:*	**11.7**		*Mean:*	**5.6**	

3. Water Chemistry

In all three lakes, duplicate water samples were taken at each of two standard limnology sites at depths of 1 m, 5 m, 15 m and at a "deep" depth using a 3 L Van Dorn water sampler. The "deep" depth was defined as 2 m above the bottom, or 30 m (whichever applied). Water samples were transferred to 1 L opaque polyethylene bottles and kept cool and dark until they could be processed on shore. Onshore processing of water samples (from each site and depth) followed the techniques outlined in Nidle *et al.* (1984) and Stephens and Brandstaetter (1983), and included collecting water in prerinsed glass culture tubes for total phosphorus determination, filtering 200 ml of water from each depth through 47-mm diameter, 0.7 μm GFF filters for nitrate-nitrite analysis, and filtering 500 ml of water from each depth onto separate 47 mm diameter, 0.45 μm cellulose nitrate filters for chlorophyll *a* analysis. It should be noted that measurements of chlorophyll *a* may underestimate true concentrations because samples were filtered using a hand pump, and because samples could not be frozen in the field.

Nitrates (plus nitrites) were determined by analysis of the azodye after cadmium reduction. Total phosphorus (TP) was analysed by hot alkaline persulphate digestion of unfiltered samples, followed by analysis using the molybdate-blue-ascorbic acid method of Murphy and Riley (1962) as modified by Eisenreich *et al.* (1975). TP-turbidity values, which represent biologically unavailable phosphorus in particulates (turbidity) and absorption in the colorimeter (color), were subtracted from TP values to correct for turbidity or color interferences. Total chlorophyll *a* concentration (estimate of algal standing crop) was determined by fluorometric analyses of 90% acetone extractions (Strickland and Parsons 1972) without an acidification and phaeopigment subtraction.

Mean annual concentrations of nitrate, total phosphorus, and chlorophyll *a*, at a depth of 1 m, were analysed for Tatsamenie, Tahltan and Tuya lakes (Tables 3.5-3.7). Measurements from 1 m samples are assumed to be representative of epilimnion concentrations. Mean annual values for nitrate, total phosphorus, and chlorophyll *a* were calculated by averaging values from the two replicate samples (if taken) from each site, then by averaging site #1 and #2 values for each sample date, and finally by averaging values from each sampling date.

Tatsamenie Lake had the highest mean annual concentrations of nitrate (plus nitrite) in lake surface water (averaged 4.0 μg/L from 1991-92), followed by Tahltan (averaged 1.2 μg/L from 1990-93) and Tuya (1.2 μg/L in 1992) lakes (Table 3.5).

Table 3.5. Mean annual concentrations of nitrate (NO_3^-) plus nitrite (NO_2^-), and standard deviations (SD), in 1 m samples from Tatsamenie, Tahltan and Tuya lakes. Sample size (n) represents the number of sampling dates. Years for which data are not available are indicated with *n/a*.

	Tatsamenie Lake			***Tahltan Lake***			***Tuya Lake***		
Year	**n**	**Mean Annual Nitrate (μg/L)**	**SD**	**n**	**Mean Annual Nitrate (μg/L)**	**SD**	**n**	**Mean Annual Nitrate (μg/L)**	**SD**
1990		*n/a*		4	2.3	1.3		*n/a*	
1991	4	3.6	4.6	4	1.3	1.5		*n/a*	
1992	4	4.4	2.7	4	0.6	0.4	4	1.2	0.9
1993		*n/a*		2	0.5	0.5		*n/a*	
Mean:		**4.0**			**1.2**			**1.2**	

Tuya Lake had the highest mean annual concentrations of total phosphorus (TP) in lake surface water (averaged 10.6 μg/L from 1992-99), followed by Tahltan Lake (averaged 7.9 μg/L from 1990-99), and Tatsamenie Lake (averaged 5.2 μg/L from 1991-99) (Table 3.6). These results indicate that all three lakes had concentrations that were similar to comparable Alaskan lakes. Koenings and Burkett (1987a) found that 13 oligotrophic Alaskan sockeye nursery lakes had average TP concentrations of 10.3 μg/L.

Table 3.6. Mean annual concentrations of total phosphorus (TP), and standard deviations (SD), in 1 m samples from Tatsamenie, Tahltan and Tuya lakes. Sample size (n) represents the number of sampling dates. Years for which data are not available, or years for which SD could not be calculated (n=1), are indicated with *n/a*.

	Tatsamenie Lake			***Tahltan Lake***			***Tuya Lake***		
Year	**n**	**Mean Annual TP (µg/L)**	**SD**	**n**	**Mean Annual TP (µg/L)**	**SD**	**n**	**Mean Annual TP (µg/L)**	**SD**
1990		*n/a*		4	8.6	1.5		*n/a*	
1991	4	3.9	0.8	4	6.8	1.7		*n/a*	
1992	4	3.9	0.2	4	6.1	0.8	4	9.5	1.8
1993	2	7.1	1.4	2	10.8	2.0	2	12.1	0.2
1994	2	3.0	0.6	2	5.8	1.0	2	8.3	0.2
1995	2	4.4	2.2	1	6.7	*n/a*	2	9.0	0.6
1996	2	3.7	1.1	2	6.5	1.9	2	13.6	4.5
1997	3	6.7	1.3	2	9.6	1.9	1	8.4	*n/a*
* 1998	6	8.3	2.5	3	9.5	1.2	2	13.0	1.4
* 1999	7	5.5	1.2	8	8.6	0.8	2	13.0	1.5
Mean:		**5.2**			**7.9**			**10.6**	

* 1998 and 1999 values are from integrated 0-12 m samples (Tatsamenie, Tuya), or from integrated 0-10 m samples (Tahltan).

In 1991, total dissolved phosphorus (TDP) was measured at Tatsamenie and Tahltan lakes to determine if substantial amounts of total phosphorus were bound to particulates. Levels of TP and TDP were very similar in Tahltan Lake, indicating that substantial amounts of TP were not bound by particulates, while in Tatsamenie Lake, moderate concentrations of TP were bound to particulates (glacial sediment). As a result of the 1991 surveys, measurements of TP-turbidity, which reflect the amount of suspended material in the water sample that is not completely digested during analysis, were subtracted from subsequent TP measurements to provide estimates of biologically available phosphorus. Tuya Lake water samples were found to be virtually turbidity-free, thus a turbidity correction for TP was not necessary.

Tuya Lake had the highest mean annual concentrations of chlorophyll *a* (averaged 1.9 µg/L from 1992-99), followed by Tahltan Lake (averaged 0.6 µg/L from 1990-99), and Tatsamenie Lake (averaged 0.5 µg/L from 1991-99) (Table 3.7).

Table 3.7. Mean annual concentrations of chlorophyll *a*, and standard deviations (SD), in 1 m samples from Tatsamenie, Tahltan and Tuya lakes. Sample size (n) represents the number of sampling dates. Years for which data are not available, or years for which SD could not be calculated (n=1), are indicated with *n/a*.

	Tatsamenie Lake			*Tahltan Lake*			*Tuya Lake*		
Year	**n**	**Mean Annual Chl. *a* (µg/L)**	**SD**	**n**	**Mean Annual Chl. *a* (µg/L)**	**SD**	**n**	**Mean Annual Chl. *a* (µg/L)**	**SD**
1990		*n/a*		4	0.61	0.31		*n/a*	
1991	4	0.29	0.14	4	0.32	0.17		*n/a*	
1992	4	0.97	0.61	4	0.84	0.81	4	1.55	0.96
1993	2	0.28	0.11	2	0.59	0.18	2	2.07	0.76
1994	2	0.62	0.13	2	0.64	0.29	2	1.49	0.19
1995	1	0.29	*n/a*		*n/a*		1	1.50	*n/a*
1996	2	0.48	0.32	2	0.49	0.17	2	1.89	0.53
1997	3	0.81	0.45	2	0.50	0.30	1	1.52	*n/a*
* 1998	6	0.40	0.10		*n/a*		2	1.38	0.17
* 1999	5	0.78	0.21	1	1.1	*n/a*	2	3.45	0.89
Mean:		**0.5**			**0.6**			**1.9**	

* 1998 and 1999 values are from integrated 0-12 m samples (Tatsamenie, Tuya), or from integrated 0-10 m samples (Tahltan).

BETWEEN-LAKE COMPARISONS of LIMNOLOGICAL CONDITIONS and PREDICTIONS FOR SOCKEYE FRY

1. Lake Morphometry

Between-lake comparisons of the physical characteristics of Tatsamenie, Tahltan, and Tuya lakes (Table 3.1) show that the lakes are very different. Tuya Lake is the largest (2,948 ha), compared to Tatsamenie (1,622 ha) and Tahltan (492 ha) lakes, and Tatsamenie Lake is the deepest (mean = 53 m), compared to Tahltan (mean = 23 m) and Tuya (mean = 23 m) lakes. As a result, Tatsamenie and Tuya lakes have comparable lake volumes (890 x 10^6 m^3 and 708 x 10^6 m^3), and the volume of Tahltan Lake is six times smaller than that of Tuya Lake, and almost eight times smaller than that of Tatsamenie Lake. Despite these volumetric differences, the implication for sockeye enhancement is that Tuya Lake (the largest) is likely to produce more sockeye than Tatsamenie Lake, and many more than Tahltan Lake.

2. Water Temperature

Tahltan Lake had the warmest surface temperatures (12-17°C), followed by Tuya (12-15°C) and Tatsamenie (10-16°C) lakes. Since surface water temperatures in the three lakes did not exceed 17°C, and the summer sky was light for most of 24 hours, sockeye diel migration is expected to have been minimal. The implication is that in all three lakes, the zooplankton were under predation pressure from sockeye fry throughout the epilimnion (LeBrasseur and Kennedy 1972), and for longer periods each day throughout the summer (compared to sockeye nursery lakes at more southern latitudes).

3. Phosphorus, Nitrogen, and Chlorophyll

Average mean annual concentration of total phosphorus was 5.2 µg/L in Tatsamenie Lake, 7.9 µg/L in Tahltan Lake, and 10.6 µg/L in Tuya Lake. Average mean annual concentration of nitrate (plus nitrite) was 4.0 µg/L in Tatsamenie Lake, 1.2 µg/L in Tahltan Lake, and 1.2 µg/L in Tuya Lake. Although all three lakes had relatively low concentrations of chlorophyll *a*, Tuya Lake had the highest concentration (1.9 µg/L), compared to Tatsamenie (0.5 µg/L,) and Tahltan (0.6 µg/L) lakes. This suggests that phytoplankton abundance in Tuya Lake was almost three times higher than in Tahltan and Tatsamenie lakes. Thus we would expect zooplankton standing crop and fish production to be higher in Tuya Lake than in Tahltan and Tatsamenie lakes.

4. Water Clarity

The clarity of a lake is affected by algal blooms and/or suspended particles. Tatsamenie Lake (semi-glacial) has a substantial amount of glacial melt water intrusion, which increases turbidity (caused by inorganic, colloidal particles), and which can have significant adverse impacts on aquatic production (Judy *et al.* 1984; Koenings *et al.* 1986). Glacial turbidity is absent in both Tahltan (clear water) and Tuya (organically stained water) lakes. The glacial turbidity of Tatsamenie Lake is reflected in the low mean annual secchi depths (averaged 5.0 m), compared to Tuya (averaged 5.6 m), and Tahltan (averaged 11.7 m) lakes. It is important to note that although the average secchi depths in Tatsamenie and Tuya lakes are not very different, light penetration in Tatsamenie Lake is limited by turbidity which reflects light energy, whereas light penetration Tuya Lake is limited by dissolved organic carbon which absorbs light energy, and by a higher standing crop of phytoplankton.

Turbidity is not only strongly correlated with decreased depth of light penetration (euphotic zone depth) (Edmundson and Koenings 1985; Lloyd *et al.* 1987), it has also been found to reduce seasonal mean lake temperatures (Hecky 1984) due to light reflectance by particles. These factors can lead to reduced primary productivity (Goldman 1960, 1961; Tizler *et al.* 1976; Edmundson and Koenings 1985), which in turn leads to reduced zooplankton densities and diversity (Koenings *et al.* 1985; Lloyd *et al.* 1987). Several studies (Allan 1976; Richman and Dodson 1983) have shown that copepod species (selective feeders) have a competitive advantage over cladocerans (filter feeders) under conditions of low primary production, especially in the presence of suspended glacial particles. Hence, cladocerans such as *Daphnia* and *Bosmina* (the preferred food of fry) are usually absent from glacial lakes (Koenings *et al.* 1986). It follows that reduced zooplankton densities and diversity, will result in reduced fish production. Koenings *et al.* (1986) found that smolts produced from glacial lakes are consistently smaller than those produced by stained or clear lakes, and argued that the cause was a combination of limited forage, and cooler sockeye fry rearing temperatures. In addition, limited light conditions caused by turbidity, may influence sockeye fry feeding behaviour (Koenings *et al.* 1986). Although most fry populations school in deep, cold waters in the day, and disperse into the epilimnion to feed during the night, this pattern has been found to be reversed in glacial lakes (Thomas *et al.* 1984). Thus, in glacial lakes containing substantial predator populations, sockeye fry may experience significant mortality while balancing predator avoidance with foraging on low zooplankton densities (Koenings *et al.* 1986).

In terms of turbidity effects on primary, secondary, and tertiary production, the implication is that Tatsamenie Lake (compared to Tahltan and Tuya lakes), is expected to show: (1) lower algal (chlorophyll *a*) standing crop, (2) lower zooplankton densities, (3) lower zooplankton diversity, (4) lower smolt weights, and (5) lower fry survival.

5. Fish Species Composition

Tatsamenie Lake is thought to have the greatest number of fish species/genera present (9), compared to Tahltan and Tuya lakes, which have 7 and 6 fish species/genera, respectively (Table 3.2). Most of the species present in the three lakes are known, or suspected to be predators of juvenile sockeye, particularly bull trout, lake trout, rainbow trout, coho salmon, and sculpin. Aside from having a few fish groups in common (sockeye, bull trout, sculpin, and suckers), all three lakes have very different fish communities, especially Tatsamenie which has several piscivorous species not present in the other two lakes. Based on species composition alone, the implication is that top-down impacts of fish on zooplankton and sockeye fry will be very different in the three lakes, and that the Tatsamenie Lake fry are most likely to be under considerable pressure from piscivores (Meehan 1966).

Chapter 4 - History of Fish Stocking in the Transboundary Lakes

INTRODUCTION

The objective of this thesis is to analyse sockeye fry growth and survival in order to evaluate the success of the Transboundary enhancement program. Integral to these analyses is a description of how enhanced fry were produced and stocked, since the timing of stocking, and the methods used to stock fry, may have affected subsequent fry growth and survival.

Eggs collected in fall from Tatsamenie Lake broodstock (adult spawners) were incubated over-winter at the Snettisham Hatchery Central Incubation Facility near Juneau, AK. Emergent (newly hatched) fry in the spring were stocked back into Tatsamenie Lake. Eggs taken from Tahltan Lake broodstock in fall were incubated over-winter at the Snettisham Hatchery. Emergent fry in the spring were stocked into Tahltan and Tuya lakes.

Hatchery incubation of wild sockeye eggs substantially reduces naturally high egg-to-emergent fry mortality by eliminating predation, and by reducing fluctuations in environmental conditions. This type of sockeye stock enhancement is done to increase the numbers of fry using under-utilized rearing areas of a nursery lake. This chapter provides information on broodstock and egg collection, fry stocking timing and methods, and on changes in fry stocking regimes attempted in response to observed survival problems.

BROODSTOCK AND EGG COLLECTION

1. Tatsamenie Lake

Sockeye salmon spawn from mid-August to mid-November in areas along the lake shore of Tatsamenie Lake, as well as in the stream connecting Tatsamenie Lake with Little Tatsamenie Lake (5 km downstream). The site of broodstock collection has changed during the course of the enhancement program. From 1990 to 1994, broodstock was captured at the Little Tatsamenie Lake weir, located 1 km downstream of the outlet of Little Tatsamenie Lake. From 1995 to 1999, broodstock was collected from a weir constructed annually at the Tatsamenie Lake outlet (Figure 3.2). This was done because of concerns that the fish spawning in Tatsamenie Lake, and the fish spawning in the inter-connecting stream, may be distinct sub-stocks which should not be mixed genetically.

Approximately equal numbers of male and female spawning adults were collected for broodstock. The total number of fish used for broodstock (Table 4.1) ranged from 220 to 2,293 (average of 1,049), which was always less than 30% of the total escapement. Egg fertilization took place at the lake. Female fecundity (the number of eggs per female) was measured for each portion of the egg take. Average fecundities for each broodyear (see Definitions and Abbreviations, p. xx) are reported in Table 4.1. The eggs of each female were fertilized with the milt (sperm) of two males, with each male being used twice with different females. After fertilization, the eggs were disinfected prior to being shipped to the Snettisham Central Incubation Facility near Juneau, AK. Each year, broodstock were tested for infectious haematopoietic necrosis virus (IHNV) and bacterial

Table 4.1. Tatsamenie Lake. Relationship between the numbers of female and male spawning sockeye used for broodstock, and the numbers of eggs taken from broodstock to stock Tatsamenie Lake for broodyears 1990 to 1999.

Tatsamenie Lake				
Brood year	**Number of females used for broodstock**	**Number of males used for broodstock**	**Broodstock female fecundity**	**Number of eggs taken from broodstock**
1990	280	280	3,518	985,000
1991	371	363	3,666	1,360,000
1992	435	356	3,416	1,486,000
1993	331	312	3,671	1,144,000
1994	381	332	3,056	1,229,000
1995	726	550	3,796	2,408,000
1996	1,243	1,050	4,068	5,000,000
1997	1,212	867	4,113	4,979,935
1998	648	535	4,124	2,557,594
1999	124	96	4,241	496,370

kidney disease (BKD). Further details of egg-take operations are reported in unpublished annual contractor reports (B. Mercer & Associates Ltd. 1990-1999). A description of hatchery facilities and methods are reported in Pacific Salmon Commission reports (1991, 1994, 1998).

2. Tahltan and Tuya Lakes

The majority of Tahltan Lake sockeye spawn during September, along a beach shoal (in 1-3 m of water) approximately 2 km from the lake outlet (Figure 3.4). Broodstock was collected using a 60m x 6m seine net set with a powerboat. Approximately equal numbers of ripe male and female spawners were held in net pens until the egg take the following day. The total number of fish taken for broodstock (Table 4.2) ranged from 2,210 to 4,850 (average of 3,495), which was always less than 30% of the total escapement. Egg fertilization took place at the lake. Female fecundity (the number of eggs per female) was measured for each portion of the egg take (Table 4.2). The eggs of each female were fertilized with the milt of two males, with each male being used twice with different females. After fertilization, the eggs were disinfected prior to being shipped to the Snettisham Central Incubation Facility near Juneau, AK. Each year, broodstock were tested for infectious haematopoietic necrosis virus (IHNV) and bacterial kidney disease (BKD). Further details of egg-take operations are reported in unpublished annual contractor reports (Triton Environmental Consultants Ltd. 1989-1999). A description of hatchery facilities and methods are reported in Pacific Salmon Commission (1991, 1994, 1998).

Table 4.2. Tahltan and Tuya lakes. Relationship between the numbers of female and male Tahltan Lake spawning sockeye used for broodstock, and the numbers of eggs taken from broodstock to stock Tahltan and Tuya lakes for broodyears 1989-1999.

Tahltan and Tuya Lakes						
Brood year	**Number of females used for broodstock**	**Number of males used for broodstock**	**Broodstock female fecundity**	**Total number of eggs taken from broodstock**	**Number of eggs taken for Tahltan stocking**	**Number of eggs taken for Tuya stocking**
1989	1,110	1,100	2,952	2,955,000	2,955,000	n/a
1990	1,615	1,687	2,960	4,511,000	4,511,000	n/a
1991	1,766	1,852	2,800	4,246,000	1,514,000	2,732,000
1992	1,847	1,847	2,653	4,901,000	2,154,000	2,747,000
1993	2,253	2,253	2,700	6,140,000	969,000	5,171,000
1994	1,689	1,689	2,517	4,182,000	1,417,000	2,765,000
1995	2,425	2,425	2,500	6,891,000	3,008,000	3,883,000
1996	2,226	2,226	2,900	6,455,400	2,986,569	3,468,831
1997	1,140	1,099	2,946	3,187,100	2,595,581	591,519
1998	1,574	1,574	2,676	4,212,024	2,149,239	2,062,785
1999	1523	1523	2,675	4,180,000	3,135,000	1,045,000

SOCKEYE FRY THERMAL OTOLITH MARKING

During over-winter incubation in the hatchery, thermal otolith marks (Fig. 6.4) were applied to the embryos (pre-hatch), and/or to the alevins (post-hatch). This involved manipulating incubation water temperatures to induce the deposition of evenly spaced, alternating light and dark ring patterns on otoliths (Hoyseth 1995, unpublished). Unique otolith thermal mark patterns were assigned for each lake (Tatsamenie, Tahltan and Tuya), and for each brood year (Table 4.3).

Table 4.3. Summary of thermal otolith marks applied to fry stocked into Tatsamenie, Tahltan and Tuya lakes. Marks are coded by the notation Region:Band.rings. Region indicates whether the mark was applied to the pre-hatch region (1) of the otolith, post-hatch region (2), or both (3). Band refers to the number of bands that make up the mark; rings refer to the number of dark rings in a band. Underlined numbers indicate that the band of rings is narrower than usual.

	Thermal Otolith Marks		
Brood year	**Tatsamenie Lake**	**Tahltan Lake**	**Tuya Lake**
1989	n/a	1:1.4	n/a
1990	1:1.3	1:1.3	n/a
1991	3:1.4	1:1.4	1:1.6
1992	3:1.5	1:1.5+2.3	1:1.7
1993	2:1.5	1:1.6+2.5	1:1.4+2.5
1994	1:1.5	1:1.6	1:1.4
1995	2:1.5	2:1.7	1:1.4+2.4
1996	1:1.5	1:1.6	1:1.4
1997	2:1.5	2:1.6	2:1.4
1998	1:1.4+2.3	1:1.7	1:1.4
1999	2:1.5	2:1.6	2:1.4

Note: 1:1.3 indicates the mark was applied to the pre-hatch region (1), made up of one band containing 3 rings. A mark with notation 1:1.4+2.3 indicates the mark was applied to the pre-hatch region (1), made up of one band containing 4 rings (1.4), and a second band containing 3 rings (2.3).

SOCKEYE FRY STOCKING

1. Tatsamenie Lake

Sockeye fry have been stocked to supplement the natural population since 1991. The survival of enhanced fry has been consistently and considerably lower than the survival of wild fry (Chapter 6). Attempts to improve survival have brought about several changes to the stocking regime. These include changes in:

(a) timing of stocking (shift from early in the season, to later, to early again).
(b) stocking methodologies (transportation, acclimation, netpen holding).
(c) location of stocking (offshore vs. onshore).
(d) netpen feeding of enhanced fry to increase stocking weight.

(a) Timing of Stocking: Table 4.4 shows Tatsamenie Lake stocking dates, numbers of fry stocked, and mean fry stocking weights. From 1991 to 1992, fry were stocked fairly early, at the end of June. From 1993 to 1995, the timing of stocking was shifted to a few weeks later in the season (mid-July), in response to the idea that fry would benefit from being stocked during the early summer plankton bloom. From 1996 to 1998, the timing of stocking was changed back to mid-to-late June, and in 1999, stocking was done in early June. The change back to an earlier stocking date in 1996 was based on the fact that wild fry emerge from April to May (before ice-off) and therefore have an adaptive strategy for early emergence (Groot and Margolis 1991). The hypothesis was that enhanced fry would have better survival if stocked closer to the time of wild fry emergence. Chapter 6 details the effects of stocking date on juvenile growth and survival.

Table 4.4. Tatsamenie Lake stocking dates, numbers of fry stocked, and mean fry stocking weights from 1991 to 1999.

Tatsamenie Lake				
Stocking date			**# fry stocked**	**Mean stocking weight (g)**
year	**month**	**day**		
1991	June	22	673,000	0.17
1992	June	22-26	1,232,000	0.15
1993	July	9-14	909,000	0.13
1994	July	14	521,000	0.15
1995	July	18-21	898,000	0.15
1996	June	16-25	1,724,000	0.11
1997	June	15-27	3,941,000	0.17
1998	June	15-29	3,597,000	0.14
1999	June	1 -9	1,769,000	0.15

(b) Stocking Methodologies: All fry transport flights followed Alaska Department of Fish and Game (ADF&G) standard high altitude aerial transport protocols, and total dissolved gas levels did not exceed 100% during ascent and descent. Rates of ascent and descent were never more than 200 feet/min (61 m/sec), and maximum altitude achieved was 5,000 feet (1,524 m). Average transport time from the Snettisham Hatchery to Tatsamenie Lake was 38 min. Fry were acclimated for 10 to 15 minutes if lake surface temperatures were greater than 2.5°C different than the transport water. These transport and stocking methodologies were scrutinized closely by the TTC for possible impacts on enhanced fry condition. Three years (1997-1999) of short-term holding studies (32-72 hours) have indicated an average mortality of only 1.3% (range of 1%-2%), and in a long-term holding study (2 months), 2 of 150 enhanced fry (1.3% mortality) died, suggesting that initial fry mortality due to transport stress is low. Since short-term post-transport stress appears to be low, and since the same stocking techniques are successful when used at other lakes, it was concluded that the transport and stocking techniques do not substantially contribute to the low survival of enhanced fry stocked into Tatsamenie Lake.

(c) Location of Stocking: From 1990 to 1996, fry were stocked offshore by float plane. In 1997, it was hypothesized that enhanced fry stocked in deep water would have lower survival than fry stocked near shore. In Tatsamenie Lake, newly emerged fry rear in shallow, littoral areas for 1 to 2 months before migrating offshore to feed in the limnetic zone. Enhanced fry stocked in deep water areas of Tatsamenie Lake (142 m maximum depth) may fail to orient towards littoral areas due to the absence of visual or tactile cues. From 1997 to 1999, all enhanced fry were stocked near shore. The effect of nearshore releases on enhanced fry-to-smolt survival was inconclusive since nearshore versus offshore releases were not compared within years. However, nearshore releases did not substantially improve enhanced fry survival relative to wild fry survival.

(d) Netpen Feeding Studies: Enhanced fry feeding studies were done in 1998 and 1999 to determine if increasing the weight of fry before release, improved their survival (Chapter 7). Unfed enhanced fry ranged from 0.10g-0.14g in weight, which was substantially lower than wild fry weights in some years. Fed enhanced fry ranged from 0.25g-0.50g. It was hypothesized that the larger enhanced fry would more closely mimic the behaviour of wild fry and migrate to offshore rearing areas sooner, thereby reducing nearshore predation and improving survival. Fed enhanced fry stocked in 1998 had improved survival over a group of unfed enhanced fry, but fed enhanced fry survival did not exceed wild fry survival. Survival of fed enhanced fry stocked in 1999, compared to wild and unfed enhanced fry survivals, will not be determined until the 2000 smolts have been sampled.

2. Tahltan Lake

Sockeye fry have been stocked to supplement the natural population since 1990. The survival of enhanced fry has been consistently and considerably higher than the survival of wild fry (Chapter 6). However, from stocking year 1994 to 1998, both wild and enhanced egg-to-smolt survivals were lower (8% enhanced egg-to-smolt survival) than from 1990 to 1993 (16% enhanced egg-to-smolt survival). Attempts to improve enhanced fry survival brought about several changes to the stocking regime. These include changes in:

(a) timing of stocking (shift from early in the season, to later, to early again).
(b) stocking methodologies (transportation, acclimation, netpen holding).

(a) Timing of Stocking: Table 4.5 shows Tahltan Lake stocking dates, numbers of fry stocked, and mean fry stocking weights. From 1990 to 1993, fry were stocked fairly early, from early to mid-June. From 1994 to 1995, the timing of stocking was shifted a few weeks later in the season, to late June. From 1996 to 1997, the timing of stocking was changed back to mid-June, and in 1998 and 1999, stocking was done from late May to early June. The change back to an earlier stocking date in 1996 was based on the fact that wild fry emerge from April to May (before ice-off) and therefore have an adaptive strategy for early emergence (Groot and Margolis 1991). The hypothesis was that enhanced fry would have better survival if stocked closer to the time of wild fry emergence. Chapter 6 details the effects of stocking date on juvenile growth and survival.

Table 4.5. Tahltan Lake stocking dates, numbers of fry stocked, and mean fry stocking weights from 1990 to 1999.

Tahltan Lake				
Stocking date			**# fry stocked**	**Mean stocking weight (g)**
year	**month**	**day**		
1990	June	6-25	1,042,000	0.13
1991	June	4-21	3,585,000	0.13
1992	June	9-10	1,415,000	0.13
1993	June	14-20	1,947,000	0.13
1994	June	24-28	904,000	0.13
1995	June/July	26-3	1,143,000	0.13
1996	June	15-25	2,296,000	0.12
1997	June	16-27	2,248,000	0.14
1998	June	7-13	1,900,000	0.12
1999	May/June	29 - 2	1,670,600	0.13

(b) Stocking Methodologies: All fry transport flights followed ADF&G standard high altitude aerial transport protocols. Rates of ascent and descent were never more than 200 feet/min (61 m/sec), and the maximum altitude achieved was 6,300 feet (1,920 m). Average transport time from the Snettisham Hatchery to Tahltan Lake was 57 min. Fry were acclimated for 10 to 15 minutes if lake surface temperatures were greater than 2.5°C different than the transport water.

In April 1989, a FOC study was conducted to investigate the effects of aerial transport on sockeye fry mortality. In particular, there was concern that gas bubbles might form in the bloodstream of fry in response to the relatively rapid ascents and descents that occur when stocking Tahltan Lake. Newly emerged fry from the Weaver Creek spawning channel (Fraser River system, BC) were transported by truck (100 fry in each of two 5 gallon, aerated containers) from near sea level to up to 970 m elevation over 25 minutes (38.8 m/min). Fry were held at 970 m for 30 minutes, then transported back to sea level. During the transport, elevation, water temperature and dissolved gas pressure were monitored. The total dissolved gas level reached 103.8%. All fry appeared healthy after being monitored for four days in net pens within Weaver Creek. A similar ADF&G study was also conducted in 1989. Sockeye fry from Speel Lake, AK were loaded into a fry transport plane and monitored on a flight simulating flight conditions to Tahltan Lake. No short term fry mortality occurred. During the first year of fry stocking into Tahltan Lake (1990), 2,000 fry from each flight were held in net pens in the lake for 96 hours. No mortalities or unusual behaviour was observed. Two years (1998-1999) of short-term holding studies (29-30 hours) have indicated an average mortality of only 0.01%, suggesting that initial fry mortality due to transport stress is very low. Since short-term post-transport stress appears to be low, and since the same stocking techniques are successful when used at other lakes, it was concluded that the transport and stocking techniques do not substantially contribute to the mortality of enhanced fry stocked into Tahltan Lake.

3. Tuya Lake

Tuya Lake does not have a wild stock of sockeye salmon. Sockeye fry have been stocked into Tuya Lake to take advantage of the under-utilized food resources since 1992. The growth and survival of enhanced fry has been consistently high. Because of the success of the enhancement program at Tuya Lake, no changes to the transport and stocking methods were made. A description is given of the following aspects of enhanced fry stocking:

(a) timing of stocking.
(b) stocking methodologies (transportation, acclimation).

(a) Timing of Stocking: Table 4.6 shows Tuya Lake stocking dates, numbers of fry stocked, and mean fry stocking weights.

Table 4.6. Tuya Lake stocking dates, numbers of fry stocked, and mean fry stocking weights from 1992 to 1999.

Tuya Lake				
Stocking date			**# fry stocked**	**Mean stocking weight (g)**
year	**month**	**day**		
1992	June	17-21	1,632,000	0.13
1993	June/July	16-7	1,990,000	0.13
1994	June/July	24-13	4,691,000	0.13
1995	June/July	21-3	2,267,000	0.13
1996	June/July	21-3	2,474,000	0.11
1997	June/July	24-1	2,611,000	0.14
1998	June	26	433,000	0.12
1999	June/July	21-2	1,603,400	0.12

Tuya Lake fry were generally stocked later in the season (late-June to early-July) than Tatsamenie and Tahltan Lake fry because ice-off, which is necessary for float plane access, is usually latest at Tuya Lake.

(b) Stocking Methodologies: All fry transport flights followed ADF&G standard high altitude aerial transport protocols. Rates of ascent and descent were never more than 200 feet/min (61 m/min), and the maximum altitude achieved was 5,500 feet (1676 m). Average transport time from the Snettisham Hatchery to Tuya Lake was 89 min. Fry were acclimated for 10 to 15 minutes if lake surface temperatures were greater than 2.5°C different than the transport water.

Chapter 5 – Zooplankton Analyses

INTRODUCTION

The objective of sockeye enhancement programs is to stock fry densities that can use the zooplankton community without drastically changing its structure (Kyle 1996). The zooplankton communities in Tatsamenie (Fig. 5.1), Tahltan (Fig. 5.2), and Tuya (Fig. 5.3) lakes were sampled before and after sockeye fry stocking to ensure that the increased densities of fry did not substantially alter the zooplankton community biomass, density and mean size. Pre-stocking data were collected from 1987-90 at Tatsamenie Lake, from 1987-89 at Tahltan Lake, and from 1987-91 at Tuya Lake to establish baseline conditions. Post-stocking data were collected from 1991-99 at Tatsamenie Lake, from 1990-99 at Tahltan Lake, and from 1992-99 at Tuya Lake to monitor the impacts of fry on the zooplankton communities. Changes in the biomass, size structure and composition of the zooplankton community, induced by sockeye fry predation, can be used to assess the limits of fish stocking (Brooks and Dodson 1965, Galbraith 1967, O'Neill and Hyatt 1987). Sockeye fry tend to strongly select for the largest, non-evasive zooplankters available to them (Brooks and Dodson 1965, Woodey 1972, Goodlad *et al.* 1974, Eggers 1982) in order to maximize their energy gain and minimize their energy expenditure (prey capture). Size selective predation typically results in decreased biomass and densities, and smaller mean sizes, of preferred prey types. In Tatsamenie and Tahltan lakes, which had wild sockeye populations, it was hypothesized that stocking of enhanced fry would cause changes (in biomass, density, mean size, or species composition) in the zooplankton communities if lake rearing capacities were approached

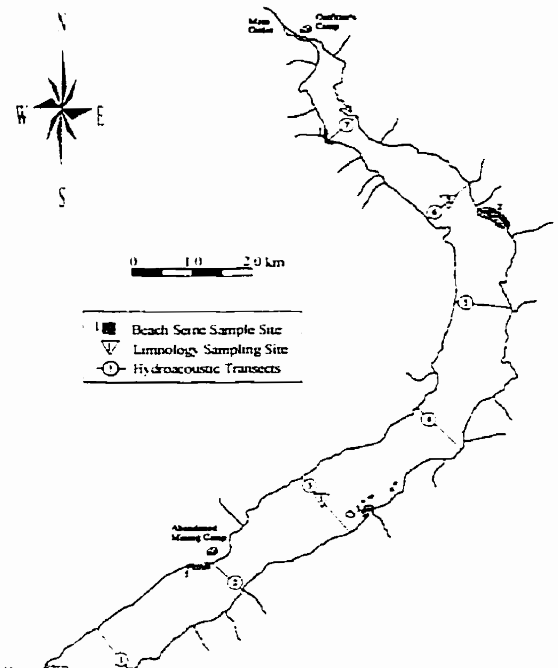


Figure 5.1. Tatsamenie Lake

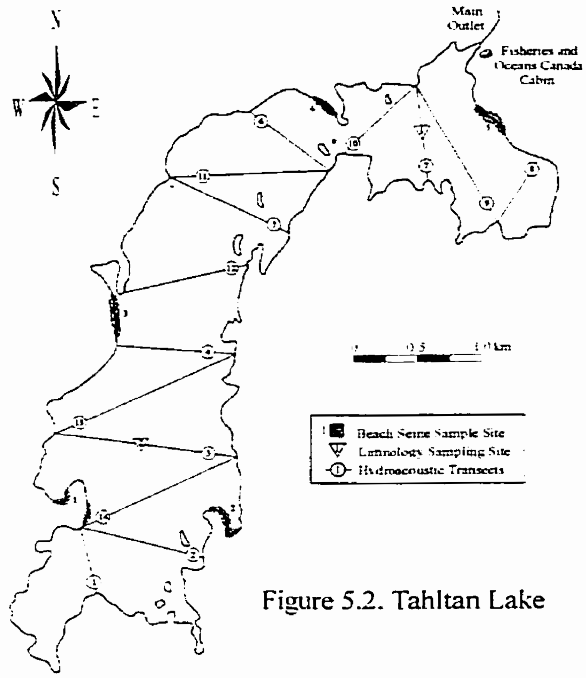


Figure 5.2. Tahltan Lake

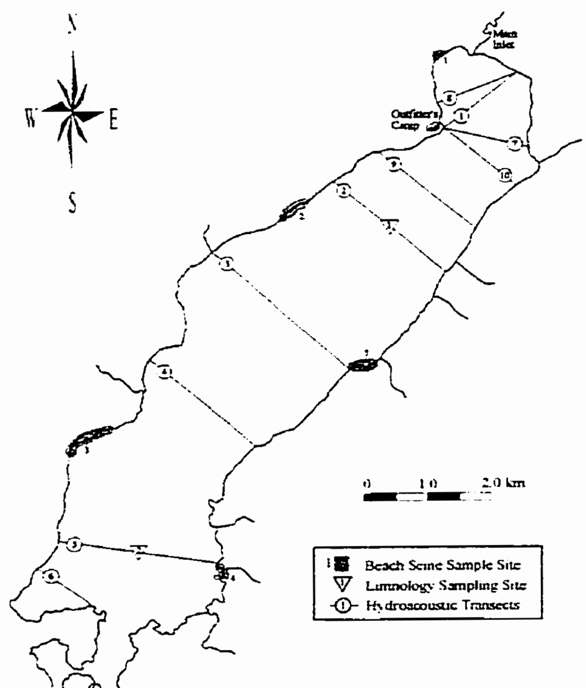


Figure 5.3. Tuya Lake

Figures 5.1, 5.2 and 5.3. Tatsamenie, Tahltan and Tuya lake outlines showing locations of the limnology (and zooplankton) sampling sites.

or had been reached. Since the lakes were stocked at, or below, half of their predicted (EV model) rearing capacities, it was expected that enhanced fry stocking would not cause changes in the zooplankton communities. Our predictions for Tuya Lake were different since the zooplankton community was initially exposed to very low limnetic predation levels prior to fry stocking. It was hypothesized that fry stocking would: (1) cause decreased zooplankton biomass and density, decreased mean size, and a change in species composition, particularly for the largest-bodied zooplankton groups, and (2) cause components of the zooplankton community to develop a diel vertical migration pattern as a predation avoidance mechanism.

To test the research hypotheses, data were collected on: taxon specific zooplankton biomass, density, mean size (vertical haul sampling) and distribution within the water column during the daytime, twilight and nighttime (horizontal tow sampling at Tuya Lake). The objectives of this chapter are to: 1) determine whether changes in the zooplankton communities of Tatsamenie, Tahltan, and Tuya lakes were observed in association with enhanced fry stocking, and 2) determine whether there is evidence that sockeye fry growth is limited by the zooplankton forage base at current stocking densities.

METHODS

This section describes zooplankton sample collection, sample processing, and data processing.

1. Zooplankton Sample Collection

1.1 Vertical Hauls

Zooplankton were sampled 1-6 times (typically 3-4 times) each year between June and October from 1987 to 1998 (Appendix B). Replicate hauls at each of two standardized sites per lake were taken during daylight hours (Figs 5.1-5.3). A 100 μm mesh size, SCOR-UNESCO (Scientific Committee of Oceanic Research-United Nations Educational, Scientific and Cultural Organization) net was used (mouth area = 0.25 m^2). Hauls were taken at a speed of approximately 0.5 m/s from a depth of 25 m. The exceptions were at the shallower Tahltan #1 and Tuya #2 sites, where 15 or 20 m hauls were taken. A 10 lb weight was usually attached to the cod-end of the net to facilitate sinking and to reduce lateral drift. In recent sampling years (1994-1998) at all three lakes, a larger mesh (153 μm) may have been used on the net collection reservoir that attaches to the cod-end of the net. This allowed more smaller-bodied zooplankton to escape the net (see Tatsamenie Lake, in the results section). Several additional vertical hauls were taken by Snettisham hatchery staff during fry outplanting in spring of 1997. They used a 3:1 conical plankton net of 153 μm mesh size (mouth area = 0.20 m^2). Data from these samples were eliminated from analyses (see Data Processing, in the methods section). Although a General Oceanics flow meter (model #2030R2) was used during many hauls to measure the volume of water actually sampled, the resultant flow data were too inconsistent to be useful in estimating net efficiency or volume of water sampled. Problems with the flow meter included both the non-uniform spinning of the flow meter rotor while the net was lowered to depth, and the excessive spinning of the rotor when the net was pulled from the water. During the 1998 field season, a Rigosha flow meter was used to estimate the volume of water sampled. However, for reasons that were not clear, these flow data were also too inconsistent to be used.

The zooplankton samples were emptied (and thoroughly rinsed from the collection reservoir) into 250 ml glass jars containing 50 ml of sugared, borax-buffered 16 % formalin solution, which were subsequently topped up with 150 ml of lake water, resulting in a 4 % formalin solution (Haney and Hall 1973). Labels were inserted into each sample jar showing the lake name, date, time, depth and site number. Records were usually kept of the general weather conditions at the time of sampling as well as any other relevant information. Wind speed and wave height information, when available, were useful in determining whether the actual depth from which the sample was taken was less than the measured depth due to plankton net drift (i.e. in high winds a 25 m haul would be <25 m).

1.2 Horizontal Tows

Horizontal zooplankton tows were conducted in Tuya Lake in late August or early September from 1990-1996, and in 1998. Seven SCOR-UNESCO nets of 100 μm mesh size (mouth area = 0.25 m^2), horizontally attached to a 30 m vertical line at 1.3, 3.9, 6.5, 9.1, 13.1, 19.9 and 26.7 m, were used to sample at depths of 1, 3, 5, 7, 10, 17 and 24 m respectively. The stratified tows were conducted for 20 minutes each, during the daytime (11:00 to 14:00 hrs), twilight (start time was between 20:40 and 20:57 hrs) and nighttime (approximately 02:00 hrs). The 20 minute tow period was measured from the time the nets were lowered into place until just before they were brought up. The location of the tows, which was consistent over all sampling years, was at the north end of the lake. The starting point was approximately mid-lake along a compass bearing of 24°, out from the tip of the spit of land near the outfitter's camp (Fig. 5.3). From this point, tows were taken in a straight line on a compass bearing of 150°, ending on or near the shore. Based on a boat speed that varied from 0.5 to 2.0 m/s (due to wind and water conditions), the horizontal tow distance was estimated to be 600 to 2400 m. The variation in tow distance makes it impossible to make comparisons of absolute abundance data between years and sometimes, within years (day, twilight, night). However, the original objective of the horizontal tow sampling was to test for diel vertical migration of zooplankton on a taxa specific basis (this is not addressed in this thesis). Although records were usually kept of the general weather conditions at the time of sampling, this information was not useful in estimating the horizontal tow distance.

The horizontal plankton net arrangement was deployed from a 14 foot Zodiak inflatable boat powered by a 15 hp outboard motor. A small pole was lashed across the gunwales, to which a small yachting snatch-block was tied. After a 25 lb weight was attached to the end of the 30 m line, the line was fed out through the block. As each net attachment loop passed out through the block, a plankton net was clipped to it. While nets were being attached and lowered into the water, the boat was maintained at a slow forward speed, circling tightly around the nets in order to avoid net tangling and to minimize the amount of water being filtered by the nets. While at towing speed, the vertical line was kept at a 40° angle from vertical (as measured from the water surface). At the end of the 20 min tow, the motor was stopped in order to minimize sample contamination as the nets were pulled to the surface, if shore had not been reached. The nets were then detached and clipped in known order to another line tied across the gunnels. This line and the nets were then stretched out on shore with the net cod-ends in the water. The samples in the net collection reservoirs were emptied, rinsed into 250 ml glass jars and preserved as per the vertical haul samples. Labels were inserted into each sample jar indicating the lake name, date, time and horizontal tow depth.

2. Zooplankton Sample Processing

Processed samples from the three lakes include vertical haul samples collected up to 1998, and horizontal tow samples collected from 1990-95. At least one replicate vertical haul sample from at least one site (but usually both sites) was processed for each sampling date.

Zooplankton samples were analysed for biomass (mg/m^3), density (#/m^3) and mean size (mm) using an Apple microcomputer caliper measuring system (Sprules *et al.* 1981). In 1987, samples were processed by PBS staff. From 1988-1998, samples were processed by a contractor (AMC Technical Services Ltd.), assisted by K. Mathias. Samples were stained for at least 12 hours by adding 3-5 ml of Methylene blue, followed by rinsing and re-suspension in tap water using a 64 μm mesh sieve. After the sample was split (generally 3-4 times) using a Folsom plankton splitter, the resultant sample fraction was transferred to a 300 ml round-bottomed glass flask and topped up to 300 ml with tap water. The sample fraction was then stirred rapidly before one or more 3 ml aliquots were taken with an automatic pipette and placed into the counting wheel. The number of aliquots taken from the sample fraction was determined by the number of individuals in each zooplankton group. At least 30 animals of each major group were counted and measured, although generally many more were processed. A scan (called a rare scan) of the whole sample fraction was subsequently done to count and measure animals that were either rarely (<30 individuals) or not at all encountered previously. This included animals called large beasts, that were substantially larger than anything else in the sub-sample, and included Chironomidae larvae, fish larvae, Acarina (mites), and Araneida (spider). All splits, sub-sample fractions and aliquots were then returned to the sample jar and topped up with the original 4% formalin solution. Processed samples were then put into warehouse storage at the PBS along with samples not intended for processing.

The measuring apparatus consisted of a Wild M5A microscope connected to a black and white Hitachi CCTV video camera. Images sent to a TV monitor, allowed the measurement of animals using calipers that transferred length data to an Apple II Plus computer. Initial scan length measurements were taken at 25X magnification; rare scan magnification was usually 12X, and occasionally 25X. Caliper calibrations using a calibration slide were conducted at least every day and often prior to each sample. A linear calibration of the calipers was performed approximately once each year.

Zooplankton were identified to genus with the exception of rotifers, copepod nauplii, calanoid copepods (except for *Skistodiaptomus*, which was treated separately because of its high abundance), Chydoridae and harpacticoid copepods (Table 5.1).

Table 5.1. Common and rare zooplankton groups identified in Tatsamenie, Tahltan and Tuya lakes.

	Tatsamenie Lake	***Tahltan Lake***	***Tuya Lake***
Common	*Bosmina.* *Daphnia* *Cyclops* copepod nauplii rotifers	*Bosmina* *Daphnia* *Cyclops* copepod nauplii rotifers *Skistodiaptomus.*	*Bosmina.* *Daphnia* *Cyclops* copepod nauplii rotifers *Skistodiaptomus* *Holopedium* calanoid copepods
Rare	*Skistodiaptomus.* *Holopedium* calanoid copepods	*Diaphanosoma*	*Diaphanosoma* Chydoridae harpacticoid copepod

Biomass estimates for each zooplankton group were generated from software using length/wet weight regression formulas (Table 5.2). Regression formulas for *Daphnia*, *Bosmina* and copepods were taken from Edmondson and Winberg (1971). Regression formulas for *Diaphanosoma*, *Holopedium*, and nauplii were adopted from those of similar animals (P. Rankin, pers. comm.). The regression formula for large beasts (i.e. insect larva, fish larva, terrestrial insects, etc.) was estimated by PBS personnel, resulting in large beast biomass calculations that are associated with high error. Large beast biomass values are likely to be considerably overestimated (P. Rankin, pers. comm.). Each computer output count sheet summarized the total biomass, total density, mean size and mean weight of the zooplankton groups measured from one sample.

Table 5.2. Length (L in mm) / wet weight (W in mg) regression formulas used for zooplankton groups identified in Tatsamenie, Tahltan, and Tuya lakes. References listed were those cited by Edmondson and Winberg (1971).

Zooplankton groups	**Length / wet weight regression formula**	**Author**
Bosmina	$W = (0.124)\ L^{2.181}$	Pechen (1965)
Daphnia	$W = (0.052)\ L^{3.012}$	Pechen (1965)
copepods (*Cyclops*, *Skistodiaptomus*, other calanoid copepods)	$W = (0.055)\ L^{2.73}$	Klekowski & Shushkina (1966)
Diaphanosoma	$W = (0.052)\ L^{3.012}$	adopted from *Daphnia*
Holopedium	$W = (0.052)\ L^{3.012}$	adopted from *Daphnia*
copepod nauplii	$W = (0.055)\ L^{2.73}$	adopted from copepods
rotifers	$W = (0.00082)\ L^{1.0}$	unknown
large beasts	$W = (2.6)\ L^{3.0}$	estimated by PBS staff

3. Zooplankton Data Processing

The first step of vertical haul zooplankton data processing was to create a zooplankton sampling summary to catalog all samples by lake, collection date, site, time, depth, thermocline depth (if known), net type, net mesh size and sampling personnel (Appendix B). This was done by compiling and comparing details recorded in Survey Trip Reports and/or field notes, as well as zooplankton count sheets (maintained on file at PBS). Data from 1996-1998 were added to an existing database summarizing the biomass, density and mean size for each zooplankton group per date from 1987-1995.

Much time was spent cross checking data, making necessary corrections and adding information such as haul depth. Criteria were established to discard inconsistent sample data. These criteria were as follows:

1. Net type: sample must have been collected with a SCOR plankton net of 100 µm mesh size and 0.25 m^2 mouth area.
2. Haul depth: depth from which the sample was taken must have been standard for that site and deeper than the thermocline depth (if known).
3. Haul location: sample must have been collected from a standard site 1 or 2 (Figs. 5.1 – 5.3).
4. Sample time: sample must have been taken during daylight hours (early June twilight samples were retained).

Sampling dates were converted to day-of-year (DOY; 1 to 365 or 366) and subsequently to day-of-series (DOS; 365 or 366 days per year added over the entire sampling period, 1987-1998). Average zooplankton biomass, density and mean size were summarized per lake over time, using x-y scatter plots. To reduce large spaces between each group of annual data points, 150 winter days per year were subtracted from DOS values. Outlier data were identified in the Tahltan and Tuya lake data sets, which represent samples associated with extremely high or low biomass, density, or mean size values for 4 or more zooplankton groups (for unknown reasons). Since the outlier samples did not meet the elimination criteria listed above, outlier data were plotted with unique symbols in average biomass and density/mean size figures to bring them to the reader's attention (Figs. 5.4 – 5.21). Outlier data were included in calculations of mean annual biomass and density (Figs. 5.28 – 5.30). Error bars (Figs. 5.4 – 5.21) indicate the amount of variation between site #1 and site #2 data (where both sites were sampled on one date).

No attempt was made to analyse the zooplankton data using formal statistical methodologies. Since data within and between years are not independent, the only valid statistical method that could be used to test for changes in community structure after fish stocking is Randomized Intervention Analysis (Stewart-Oaten *et al.* 1986; Carpenter *et al.* 1989). However, this analysis was not applied for two reasons: (1) data were not collected from a control lake in which fry were not stocked, and (2) data were sparse (sometimes collected only once per year) and suffered from a number of reliability problems resulting from changes in sampling personnel (Appendix B) and possible gear substitutions.

Horizontal tow data processing involved creating a spreadsheet summarizing sample collection information that included lake, collection date, time, depth, net type and net mesh size, as well as biomass (mg/m^3), density (#/m^3) and mean size (mm) for total zooplankton. The biomass data per depth were then bar plotted using Axum 5.0. Although horizontal tow samples were processed for the same zooplankton groups as the vertical haul samples, only the total zooplankton data (minus large beast values) were entered and analysed. These data are useful however, because they indicate whether major components of the Tuya Lake zooplankton community developed diel vertical migration patterns to avoid fish predation following sockeye fry outplanting in 1992. Since sockeye fry are generally known to feed primarily at dusk and dawn (Groot and Margolis 1991), and since a major reason for zooplankton sampling is to determine what the fry are encountering as prey, knowledge of the diel zooplankton distribution is important in assessing the validity of daytime zooplankton sampling.

RESULTS

This section comprises four main components:

1) a summary of trends observed in the Tatsamenie Lake average biomass, density and mean size data for all zooplankton groups collected by vertical hauls from over 11 (1988-98) years (Figs. 5.4 – 5.8).
2) a summary of the trends observed in the Tahltan Lake average biomass, density and mean size data for all zooplankton groups collected by vertical hauls from over 11 (1988-98) years (Figs. 5.9 – 5.14).
3) a summary of the trends observed in the Tuya Lake average biomass, density and mean size data for all zooplankton groups collected by vertical hauls over 12 (1987-98) years (Figs. 5.15 – 5.21), and by horizontal tows over 5 years (Figs. 5.22 – 5.27).
4) a summary of the mean annual biomass (Figs. 5.28 – 5.29) and density (Fig. 5.30) trends observed for Tatsamenie, Tahltan, and Tuya lakes, and between-lake comparisons.

1. Tatsamenie Lake

Common zooplankton groups found in Tatsamenie Lake vertical haul samples (Table 5.1) included *Bosmina*, (most or all of which are *B. longispina*), *Daphnia*, *Cyclops*, copepod nauplii and rotifers (*Kellicottia longispina* being most common, but including *Keratella* and *Asplanchna*). Rare zooplankton groups (encountered only once or twice in vertical haul samples) included *Holopedium*, *Skistodiaptomus* and other calanoid copepods.

In response to fry stocking, there were no obvious changes in the average total biomasses, densities, and mean sizes of total zooplankton (Figs. 5.4a, 5.6a) and of all common zooplankton groups identified from 1988 to 1998 (Figs. 5.4b-c, 5.5a-c, 5.6b-c, and 5.7a-c). However, several changes obvious in the data are thought to be unrelated to fry stocking. In Tatsamenie Lake, from 1995 to 1997, the average total zooplankton density appeared to decrease, and the average total zooplankton mean size appeared to increase (Fig. 5.6a). These trends were also evident for *Bosmina* (Fig. 5.6b), nauplii (Fig. 5.7b) and rotifers (Fig. 5.7c), but less evident for *Daphnia* (Fig. 5.6c) and *Cyclops* (Fig. 5.7a). These trends are thought to be an artifact resulting from sampling equipment substitution. It is likely that in 1995, the collection reservoir on the cod-end of the 100 μm plankton net was mistakenly fitted with a mesh of 153 μm (rather than the usual 100 μm). This larger mesh would have allowed more of the smaller-bodied *Bosmina*, nauplii and rotifers to escape the net (thus the apparent decrease in average density), leaving behind the larger individuals of these groups (thus the apparent increase in mean size), as well as the larger-bodied *Daphnia* and *Cyclops*. It is uncertain how often and at which lakes the larger mesh net was used, but the trend is most noticeable in the Tatsamenie Lake zooplankton data from 1995 to 1997. In 1998, all zooplankton nets used at all three lakes had 100 μm mesh. It must be noted that the plankton sampling methodology used (i.e. SCOR net versus submersible pump) was not intended to fully quantify nauplii and rotifer densities (i.e. they are underestimated in samples) since sockeye fry rarely feed on these components of the zooplankton community. Because of this, a plankton net mesh substitution has a minimal effect on our analysis here.

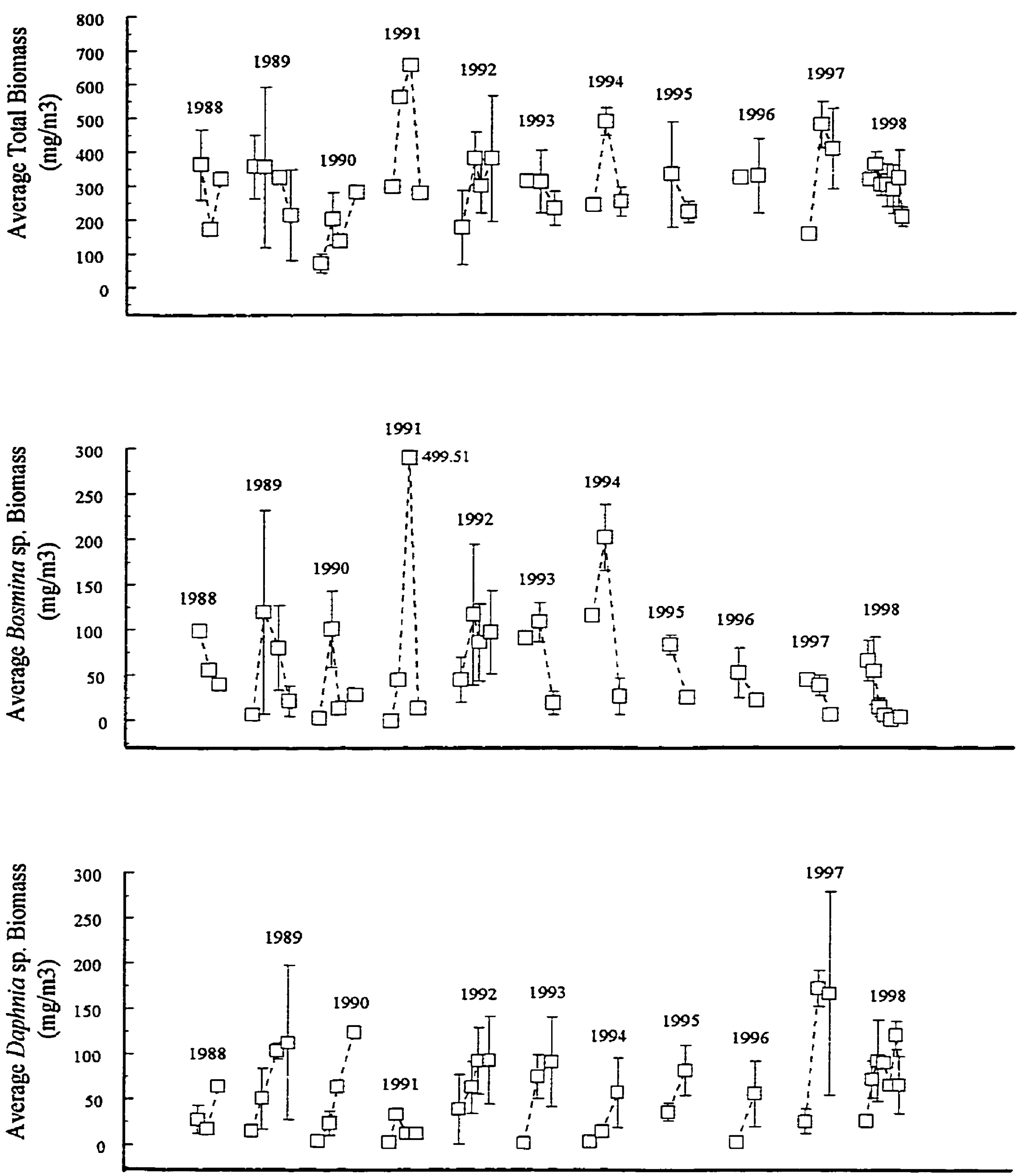


Figure 5.4. Tatsamenie Lake. Average biomass (mg/m^3) of total zooplankton, (a) *Bosmina* (b) and *Daphnia* (b) from 1988 to 1998. No outlier data points were removed from the data. Fry stocking began in 1991. Error bars represent range.

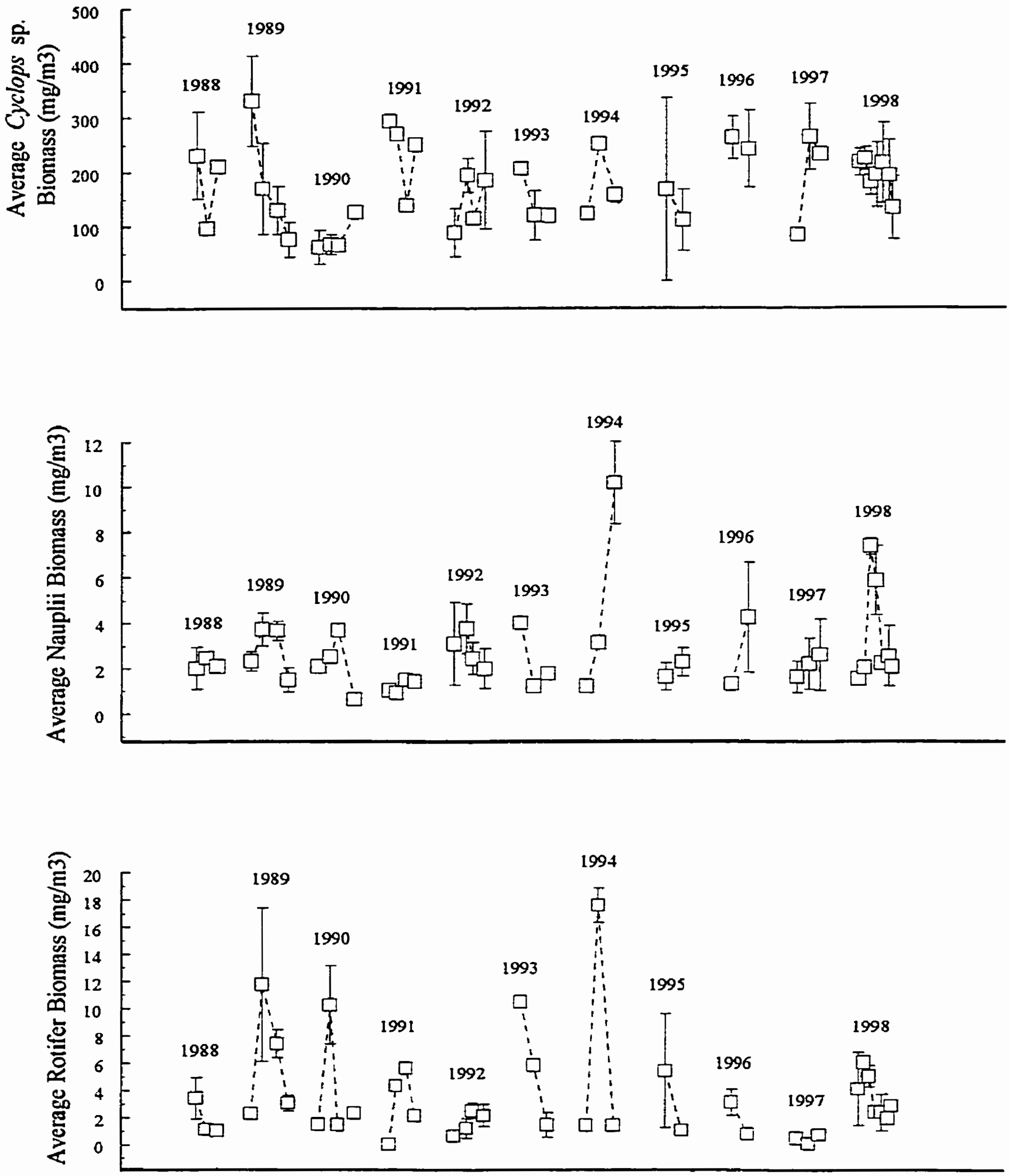


Figure 5.5. Tatsamenie Lake. Average biomass (mg/m^3) of *Cyclops* (a), nauplii (b) and rotifers (c) from 1988 to 1998. No outlier data points were removed from the data. Fry stocking began in 1991. Error bars represent range.

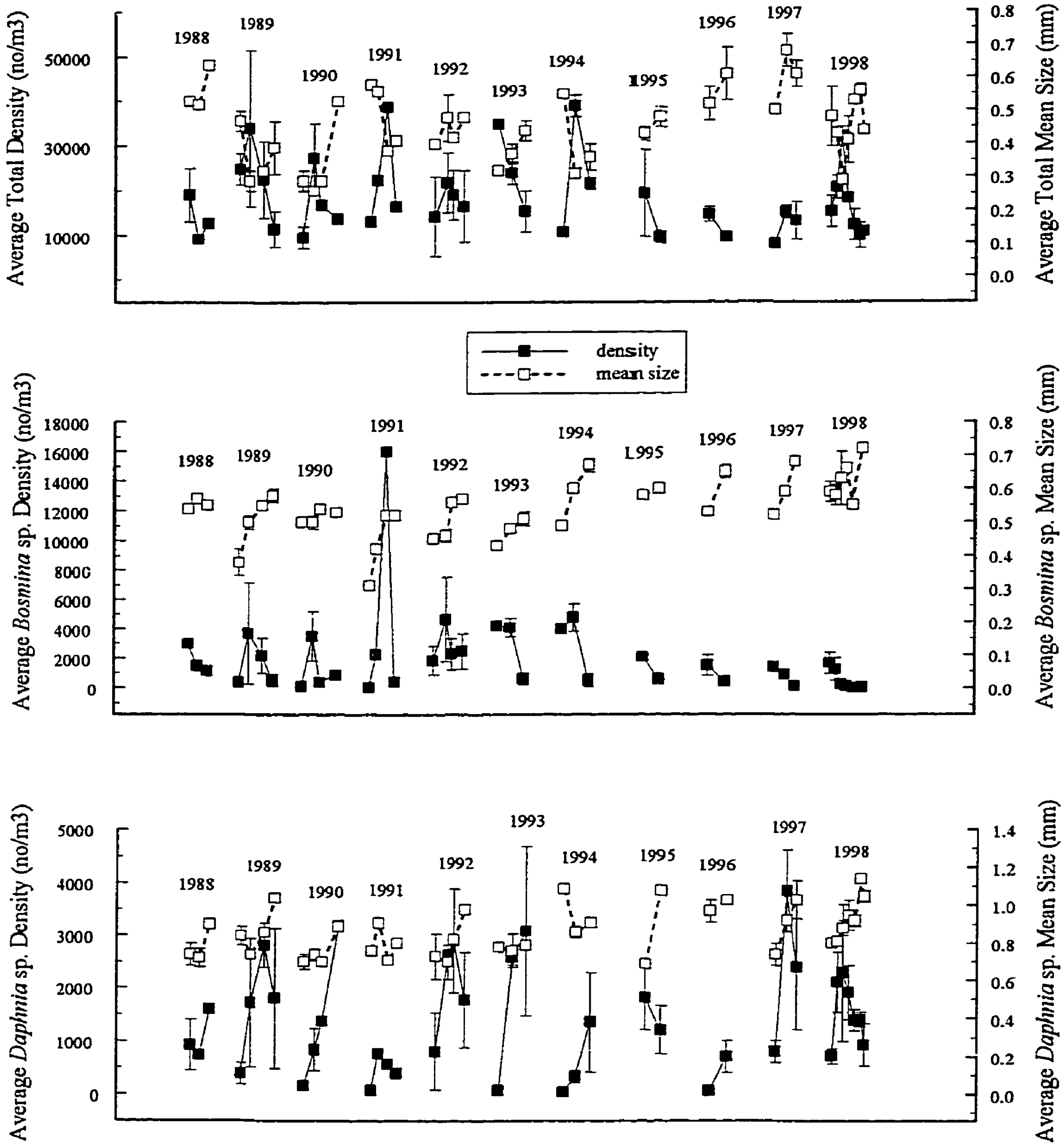


Figure 5.6. Tatsamenie Lake. Average density (#/m^3) and mean size (mm) of total zooplankton (a), *Bosmina* (b) and *Daphnia* (c) from 1988 to 1998. No outlier data points were removed from the data. Fry stocking began in 1991. Error bars represent range.

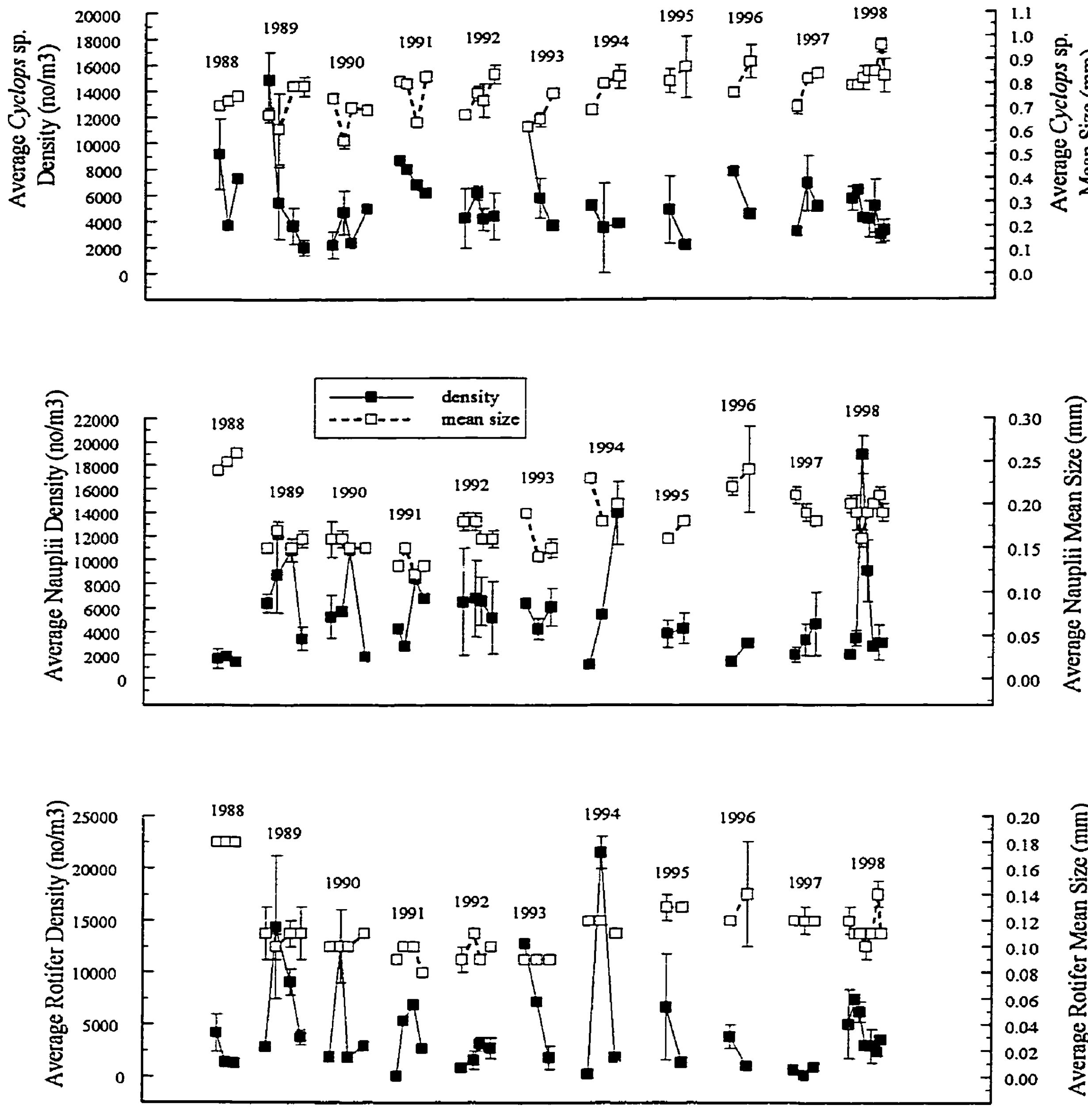


Figure 5.7. Tatsamenie Lake. Average density (#/m^3) and mean size (mm) of *Cyclops* (a), nauplii (b) and rotifers (c) from 1988 to 1998. No outlier data points were removed from the data. Fry stocking began in 1991. Error bars represent range.

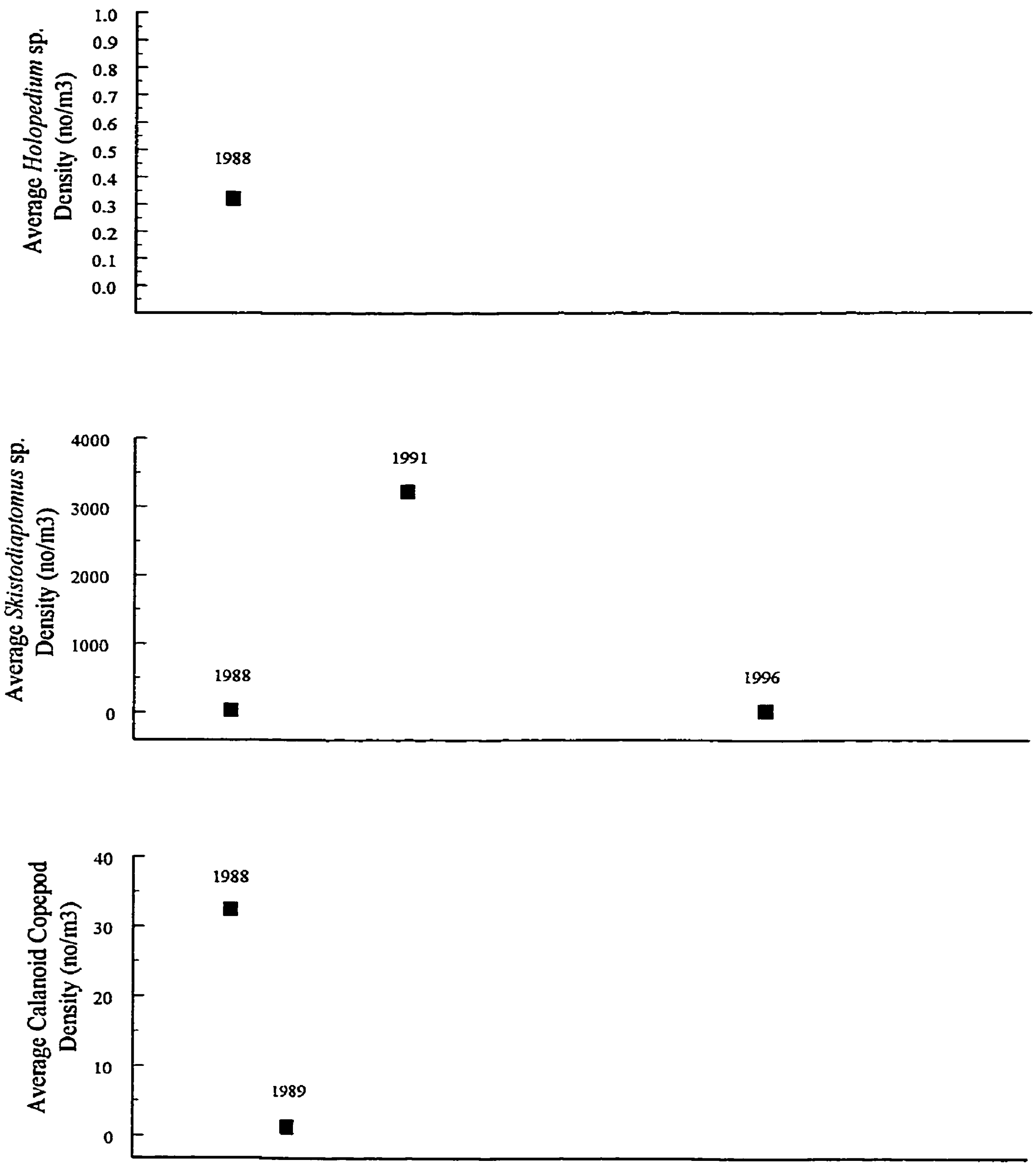


Figure 5.8. Tatsamenie Lake. Average density (#/m^3) of *Holopedium* (a), *Skistodiaptomus* (b) and other calanoid copepods (c) from 1988 to 1998. No outlier data points were removed from the data. Fry stocking began in 1991.

2. Tahltan Lake

Common zooplankton groups found in Tahltan Lake vertical haul samples (Table 5.1) included *Bosmina* (most or all of which are *B. longispina*), *Daphnia*, *Cyclops*, *Skistodiaptomus*, copepod nauplii and rotifers (which included *Conochilus*, *Brachionus*, *Trichocera* and *Asplanchna*). *Diaphanosoma* was encountered only once in Tahltan Lake vertical haul samples.

In response to fry stocking, there were no obvious declines in the average total biomasses, densities, and mean sizes of total zooplankton (Figs. 5.9a, 5.12a), and of all common zooplankton groups identified from 1988 to 1998 (Figs. 5.9b-c, 5.10a-c, 5.11 and 5.12b-c, 5.13a-c, 5.14a). Outlier data were identified from six sampling dates: July 27, 1994 (site #1 only), July 30, 1995 (sites #1 and #2), and all 1998 data (July 14 and 29, August 21, and October 9). Outlier data were plotted with distinctive symbols (Figs. 5.9 – 5.14) to bring them to the reader's attention, but since no reason could be found to eliminate these data, they were included in mean annual biomass and density calculations. No conclusive explanation can be given to account for the outlier data points, however it is suspected that incorrect sample collection or sampling gear substitution (or both) occurred.

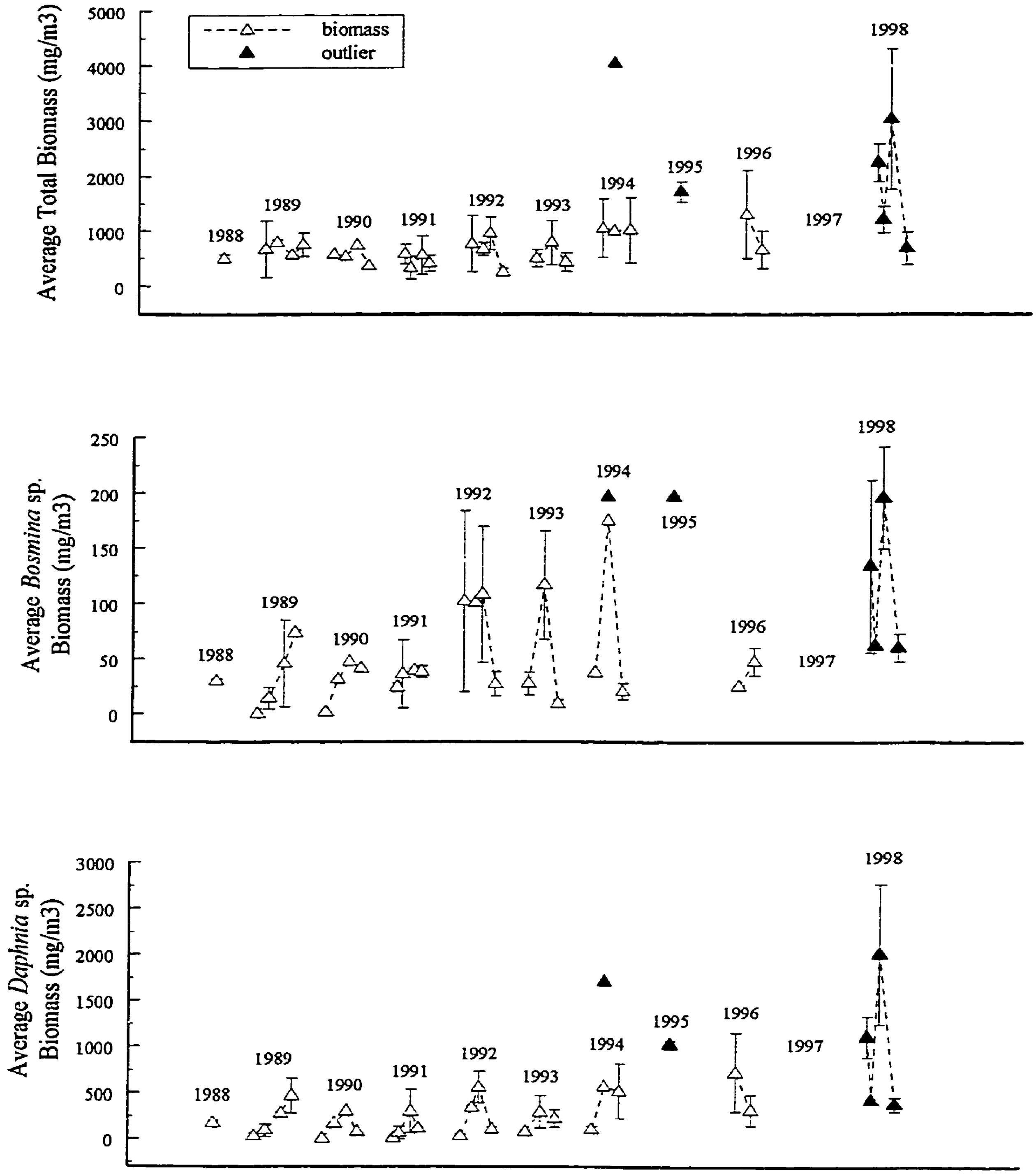


Figure 5.9. Tahltan Lake. Average biomass (mg/m3) of total zooplankton (a), *Bosmina* (b) and *Daphnia* (c) from 1988 to 1998. Six outlier data points were identified. Fry stocking began in 1990. Error bars represent range.

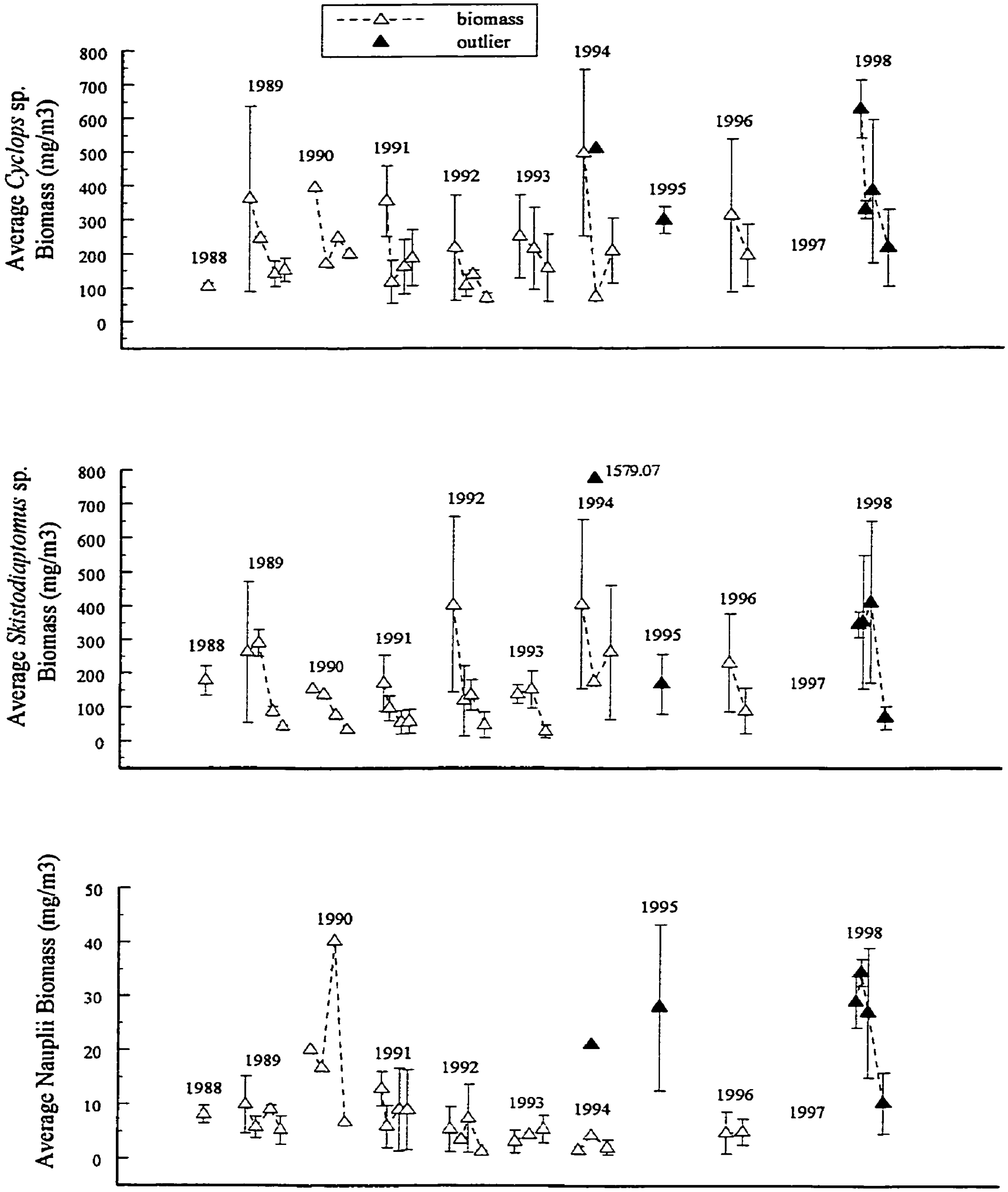


Figure 5.10. Tahltan Lake. Average biomass (mg/m3) of *Cyclops* (a), *Skistodiaptomus* (b) and nauplii (c) from 1988 to 1998. Six outlier data points were identified. Fry stocking began in 1990. Error bars represent range.

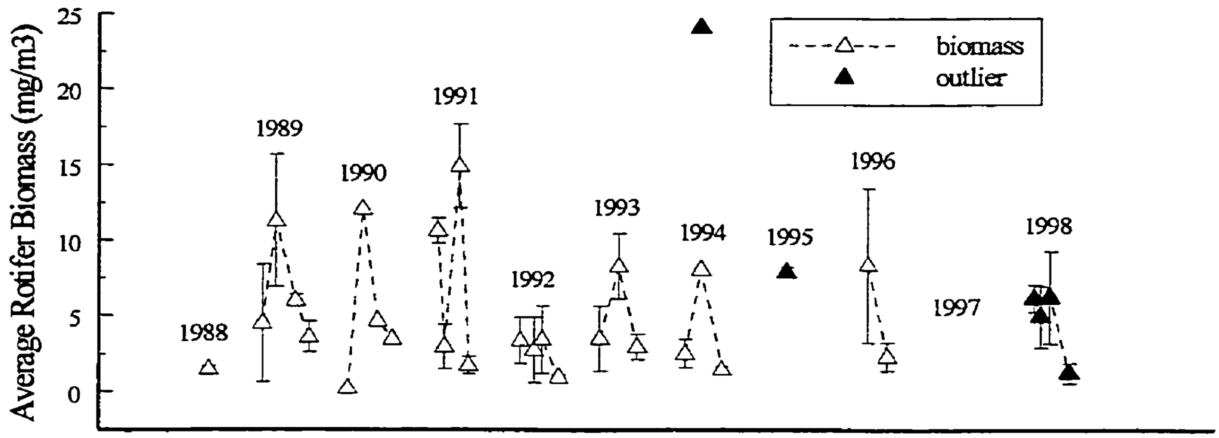


Figure 5.11. Tahltan Lake. Average biomass (mg/m3) of rotifers from 1988 to 1998. Six outlier data points were identified. Fry stocking began in 1990. Error bars represent range.

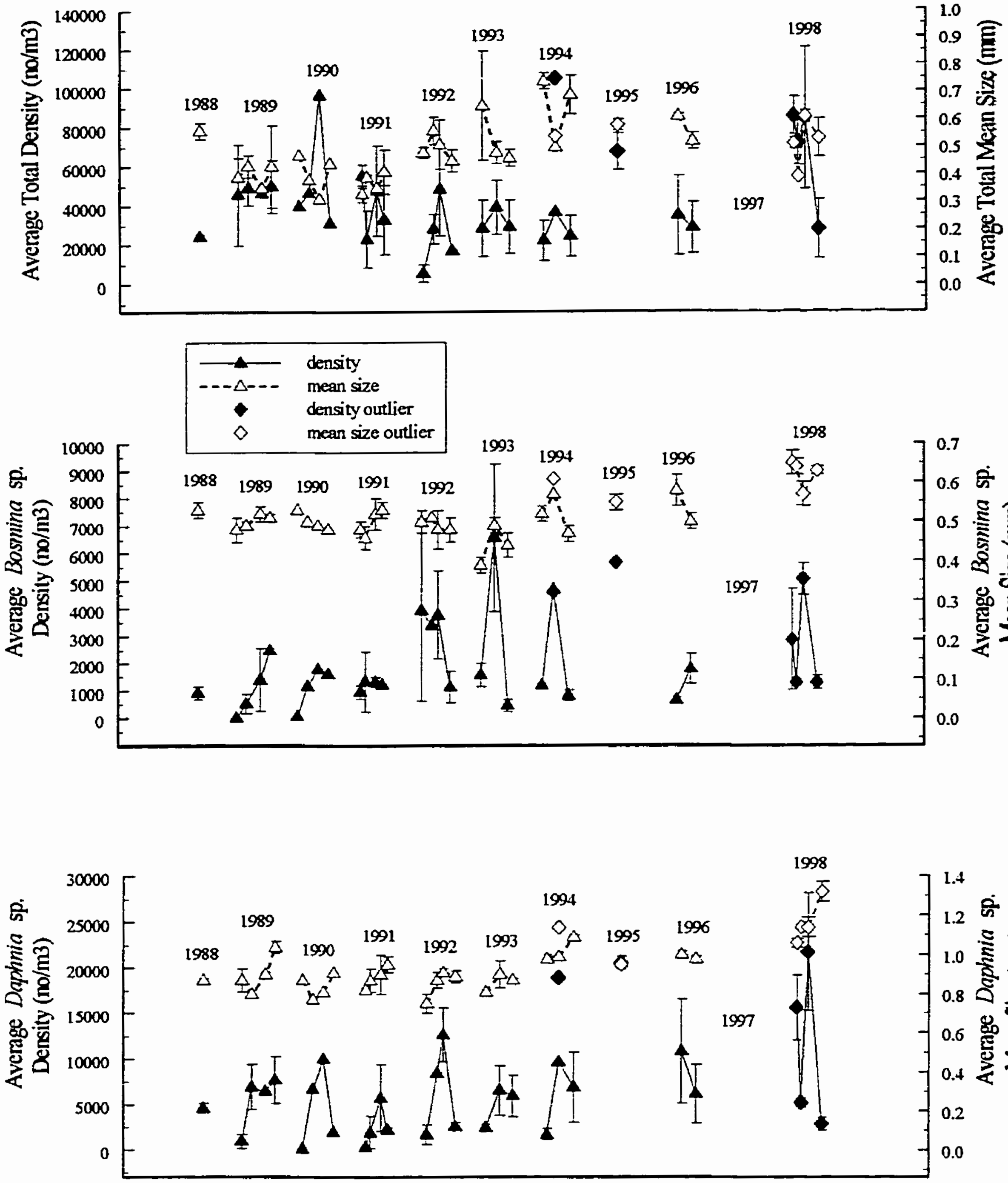


Figure 5.12. Tahltan Lake. Average density (#/m3) and mean size (mm) of total zooplankton (a), *Bosmina* (b) and *Daphnia* (c) from 1988 to 1998. Six outlier data points were identified. Fry stocking began in 1990. Error bars represent range.

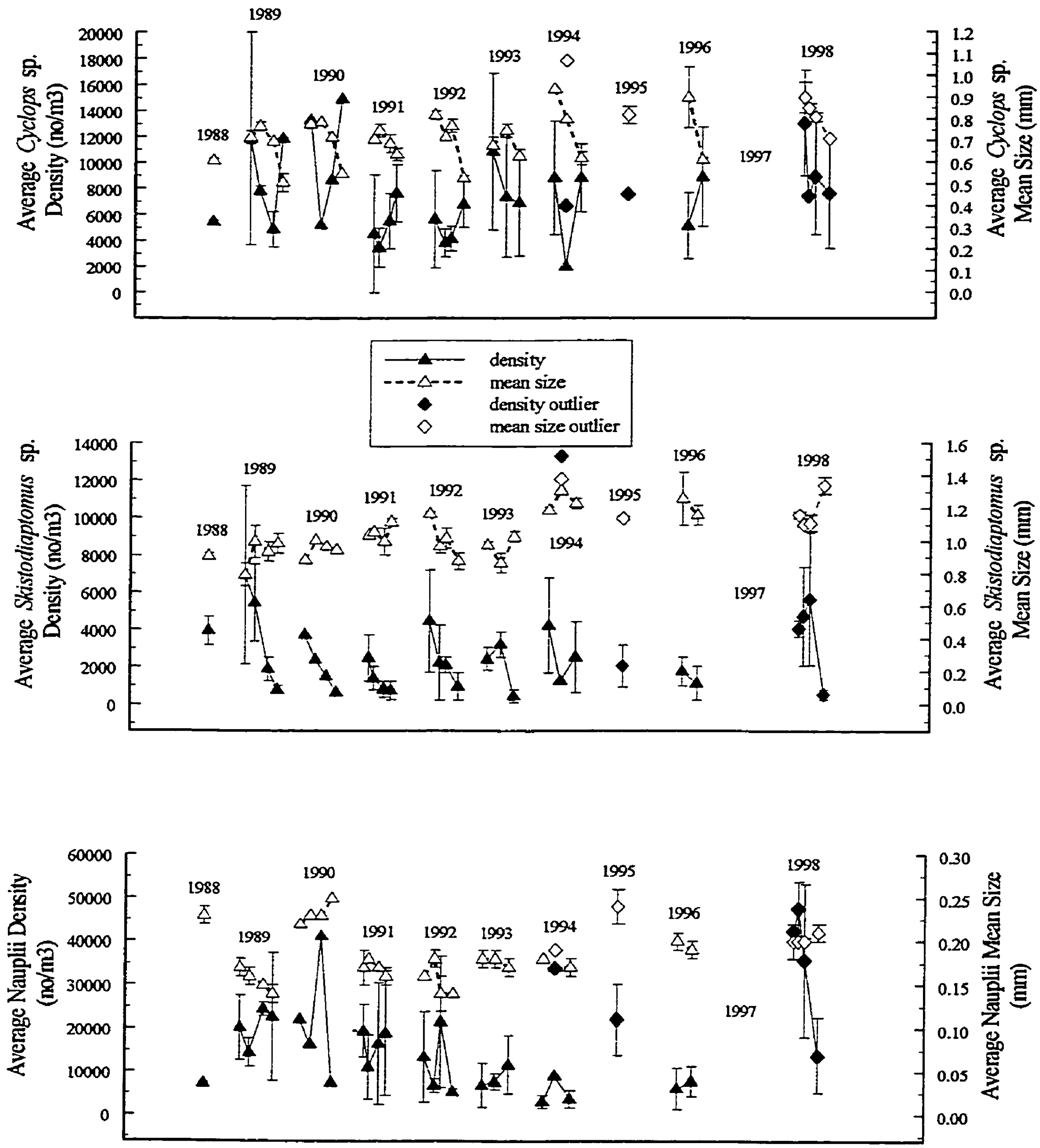
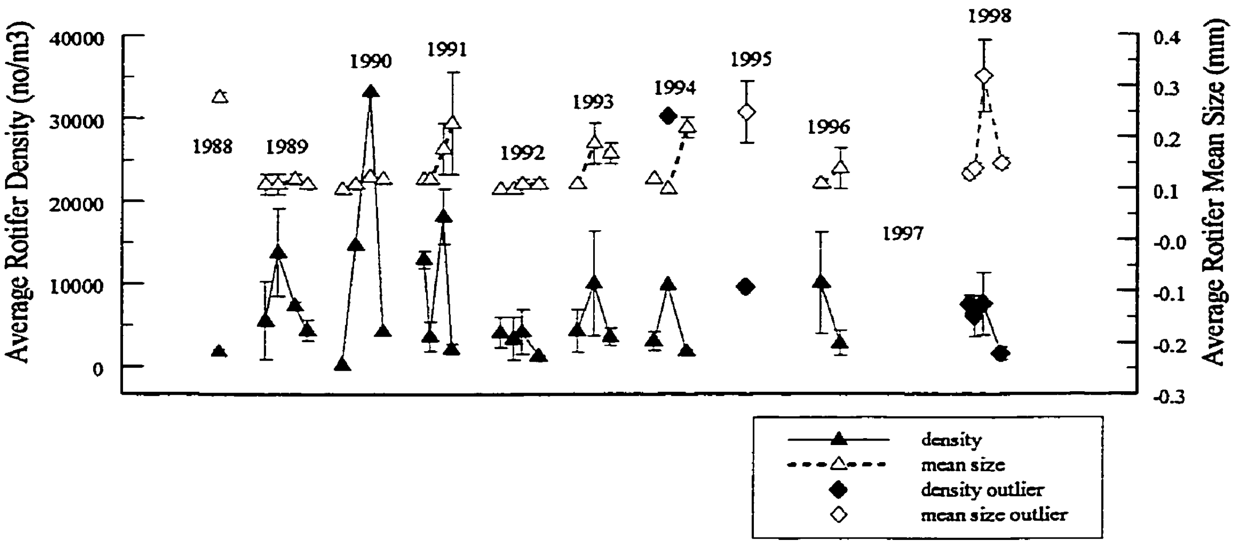


Figure 5.13. Tahltan Lake. Average density (#/m3) and mean size (mm) of *Cyclops* (a), *Skistodiaptomus* (b) and nauplii (c) from 1988 to 1998. Six outlier data points were identified. Fry stocking began in 1990. Error bars represent range.



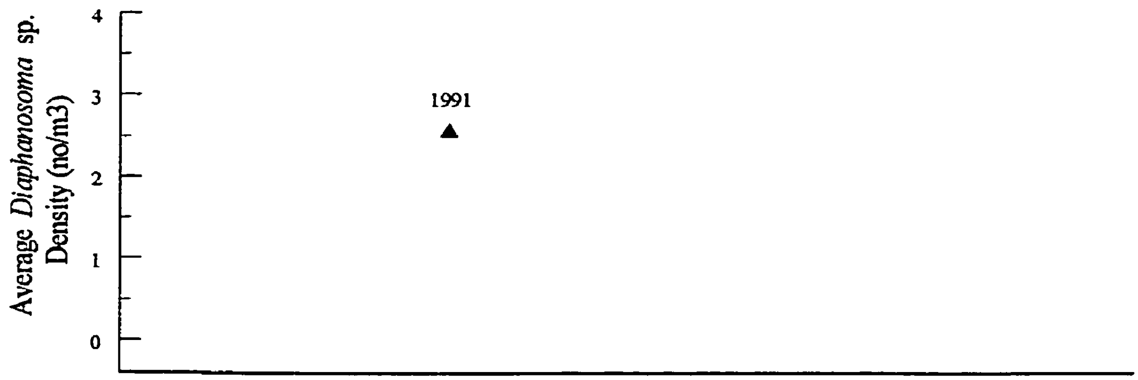


Figure 5.14. Tahltan Lake. Average density (#/m3) and mean size (mm) of rotifers (a), and average density (#/m3) of *Diaphanosoma* (b), from 1988 to 1998. Six outlier data points were identified. Fry stocking began in 1990. Error bars represent range.

3. Tuya Lake

3.1 Vertical Zooplankton Sampling

Common zooplankton groups found in Tuya Lake vertical haul samples (Table 5.1) included *Bosmina* (most or all of which are *B. longispina*), *Daphnia*, *Holopedium* (most or all of which are *H. gibberum*), *Cyclops*, calanoid copepods, (*Epischura nevadensis* and *Heterocope septentrionalis*), *Skistodiaptomus*, copepod nauplii and rotifers (*Kellicottia longispina* and *Conochilus*). Rare zooplankton groups sporadically found in Tuya Lake vertical haul samples included *Diaphanosoma*, Chydoridae and harpacticoid copepods.

In response to fry stocking, no changes were obvious in the average mean biomass, density and mean size of total zooplankton (Figs. 5.15a, 5.18a) and of all but two of the common zooplankton groups identified (Figs. 5.15b, 5.16a-b, 5.17a-c, 5.18b, 5.19a-b, 5.20a-c). *Daphnia* (Fig. 5.15c) and calanoid copepods (Fig. 5.16c), the two largest-bodied zooplankton groups, were affected. From 1994 to 1998, average *Daphnia* biomass appeared to increase (Fig. 5.15c). Over the same time period, average *Daphnia* density increased and average mean size decreased from approximately 1.3 mm to 0.8 mm (Fig. 5.18c). These trends suggest that intense size selective predation may have selected for smaller *Daphnia* with higher reproductive rates (not measured). Size selective predation on less evasive and larger-bodied zooplankton (Brooks and Dodson 1965), and increased zooplankton reproductive rates after periods of heavy predation (Kyle 1996), are well documented consequences of introducing planktivorous fish into barren lakes.

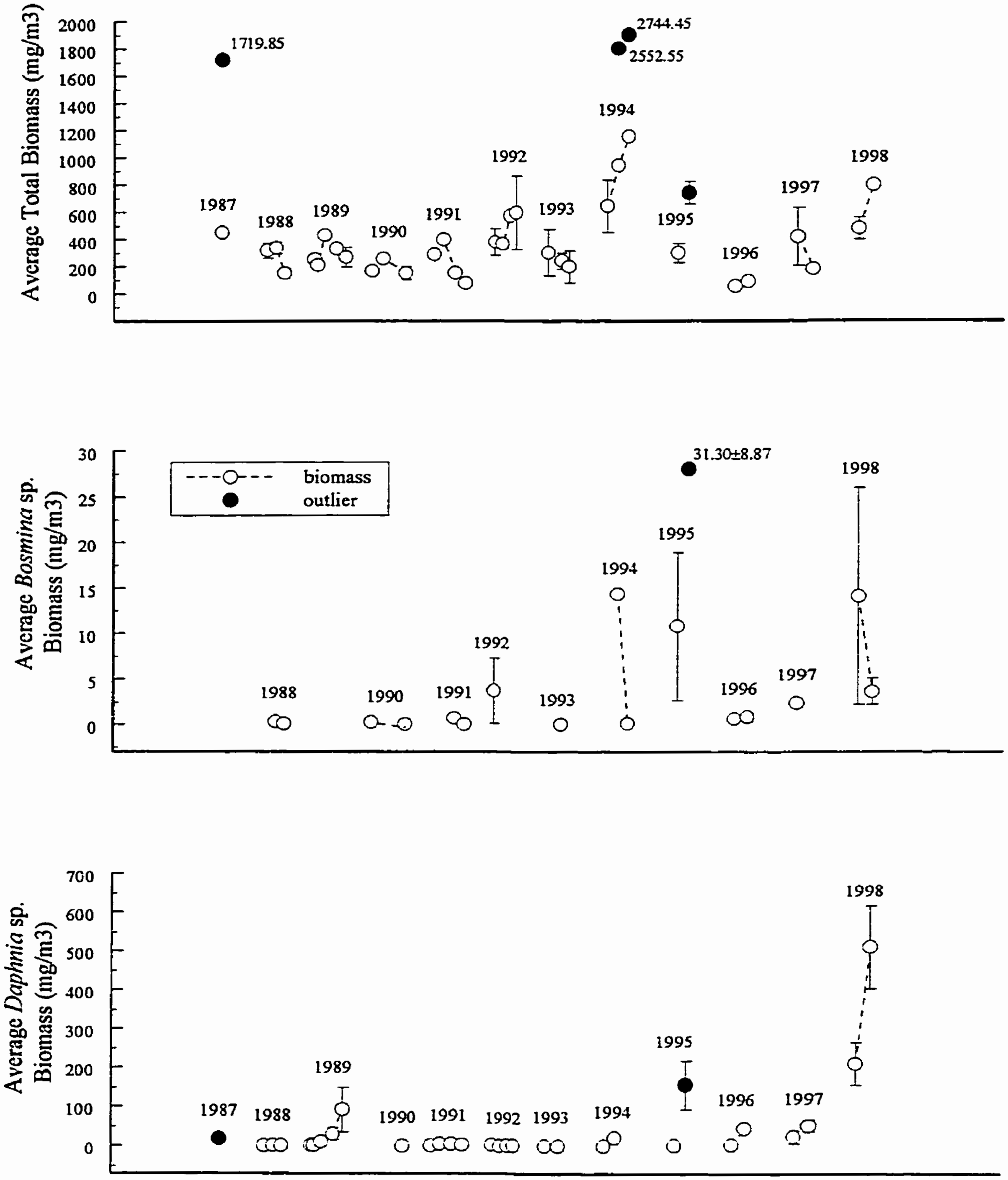


Figure 5.15. Tuya Lake. Average biomass (mg/m3) of total zooplankton (a), *Bosmina* (b) and *Daphnia* (c) from 1987 to 1998. Four outlier data points were identified. Fry stocking began in 1992. Error bars represent range.

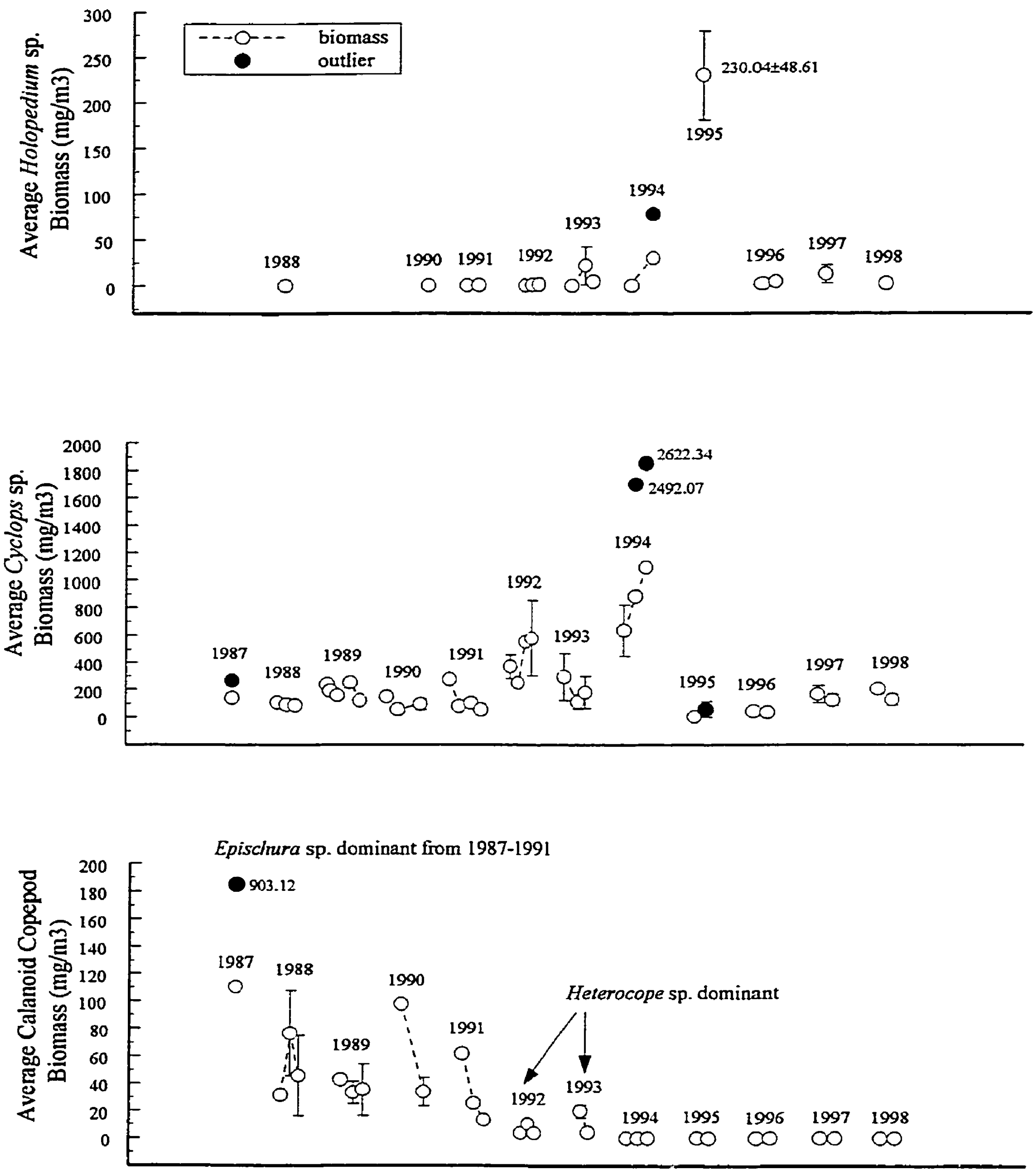


Figure 5.16. Tuya Lake. Average biomass (mg/m3) of *Holopedium* (a), *Cyclops* (b) and calanoid copepods (c) from 1987 to 1998. Four outlier data points were identified. Fry stocking began in 1992. Error bars represent range.

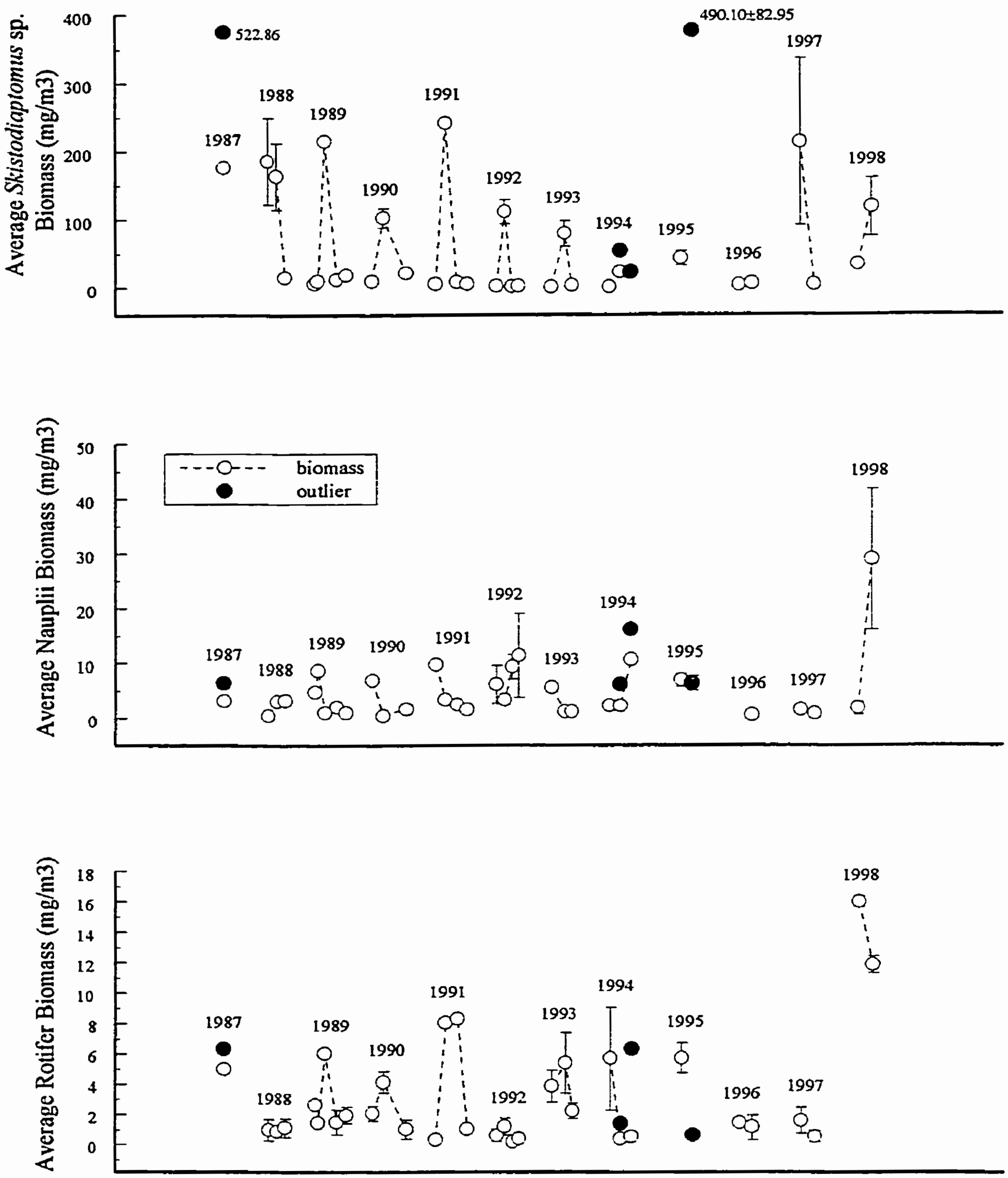


Figure 5.17. Tuya Lake. Average biomass (mg/m3) of *Skistodiaptomus* (a), nauplii (b) and rotifers (c) from 1987 to 1998. Four outlier data points were identified. Fry stocking began in 1992. Error bars represent range.

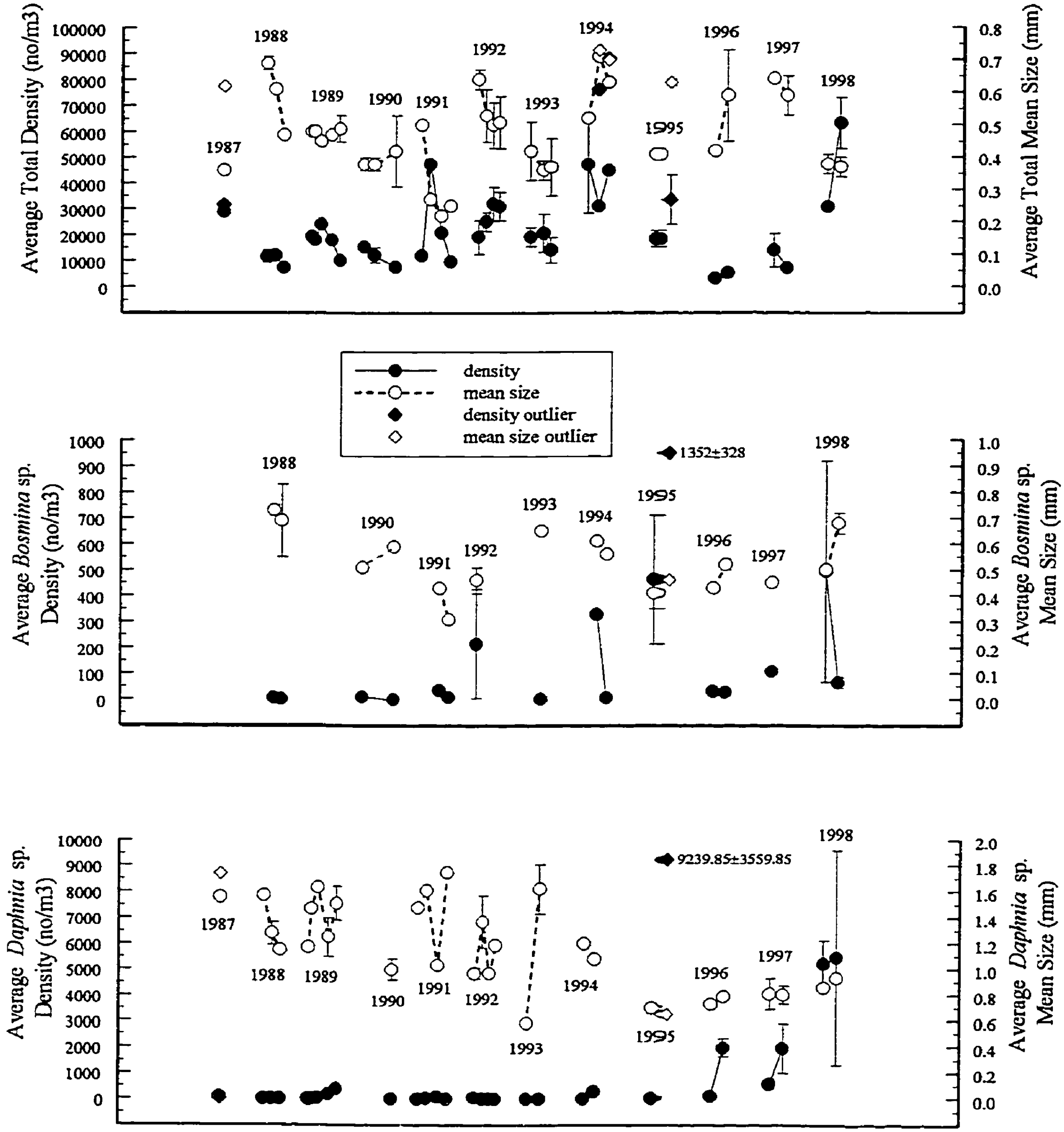


Figure 5.18. Tuya Lake. Average density (#/m3) and mean size (mm) of total zooplankton (a), *Bosmina* (b) and *Daphnia* (c) from 1987 to 1998. Four outlier data points were identified. Fry stocking began in 1992. Error bars represent range.

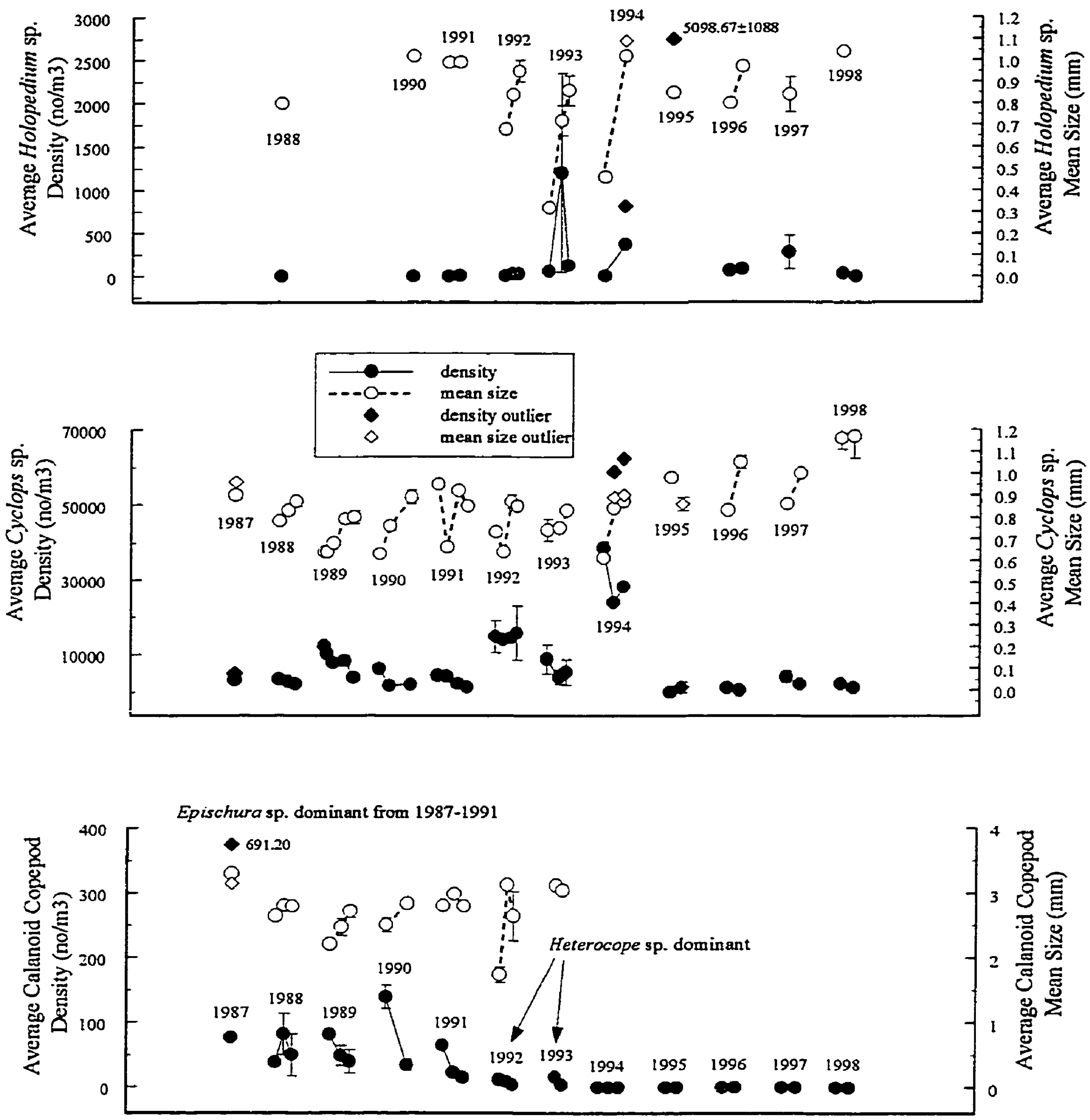


Figure 5.19. Tuya Lake. Average density (#/m3) and mean size (mm) of *Holopedium* (a), *Cyclops* (b) and calanoid copepods (c) from 1987 to 1998. Four outlier data points were identified. Fry stocking began in 1992. Error bars represent range.

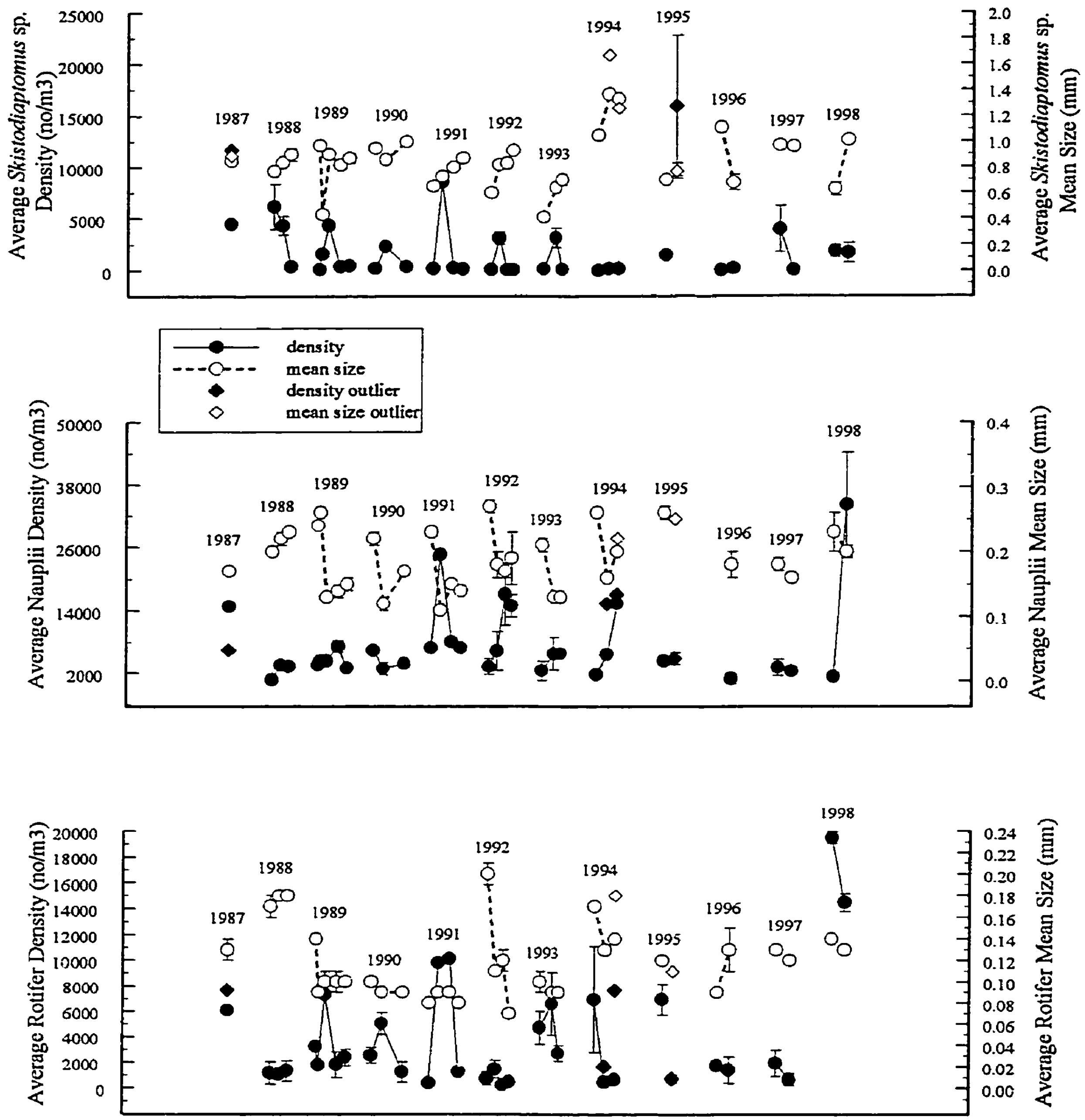


Figure 5.20. Tuya Lake. Average density (#/m3) and mean size (mm) of *Skistodiaptomus* (a), nauplii (b) and rotifers (c) from 1987 to 1998. Four outlier data points were identified. Fry stocking began in 1992. Error bars represent range.

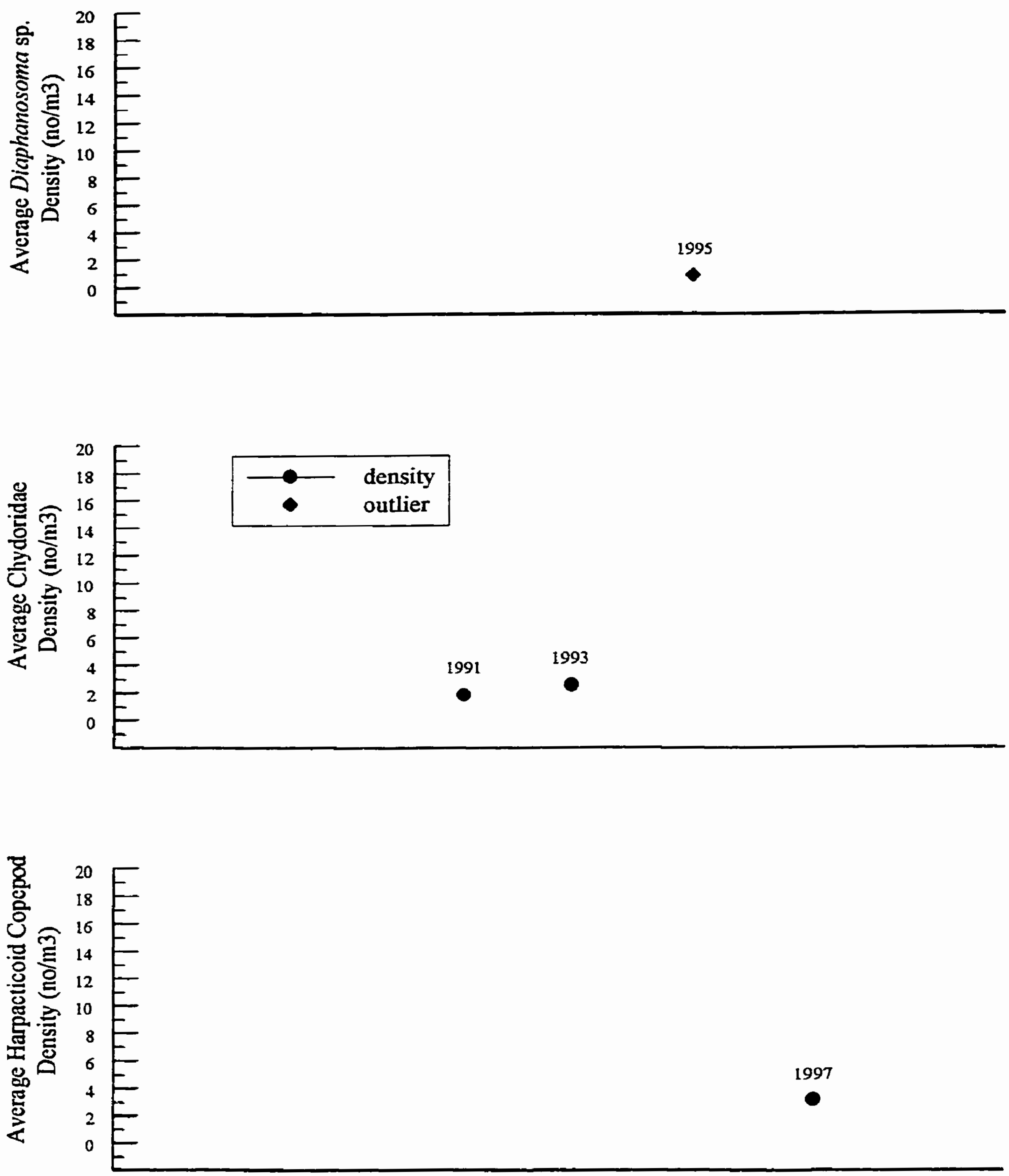


Figure 5.21. Tuya Lake. Average density (#/m3) of *Diaphanosoma* (a), Chydoridae (b) and Harpacticoid copepods (c) from 1987 to 1998. Four outlier data points were identified. Fry stocking began in 1992. Error bars represent range.

In response to fry stocking, average calanoid copepod (excluding *Skistodiaptomus*) biomass (Fig. 5.16c) and density (Fig. 5.19c) decreased in 1992 and 1993. After 1993, calanoid copepods became undetectable in zooplankton samples. The average mean size of calanoid copepods (approximately 3.0 mm) was unchanged from 1987 to 1993. From 1987 to 1991 (pre-stocking), the calanoid copepod group consisted almost entirely of *Epischura*. From 1992 to 1993 (post-stocking), the calanoid copepod group shifted to consist mainly of *Heterocope*. From 1994 onward, these very large calanoid copepods were virtually eliminated from the zooplankton community. These trends suggest that sockeye fry introduced in 1992 grazed selectively, first on *Epischura*, and then on *Heterocope* until these large-bodied zooplankton were significantly reduced or eliminated.

Outlier data were identified from four sampling dates: Sept. 9, 1987 (site #2), July 24, 1994 (site #2), Sept. 4, 1994 (site #2), and Sept. 11, 1995 (site #1 and #2). Outlier data were plotted with distinctive symbols (Figs. 5.15 – 5.21) to bring them to the reader's attention, but since no reason could be found to eliminate these data, they were included in mean annual biomass and density calculations. No obvious explanation can be advanced to explain these deviations from the norm, however it is suspected that incorrect sample collection or sampling gear substitution (or both) occurred.

3.2 Tuya Lake Horizontal Zooplankton Sampling

In Tuya Lake (but not in Tatsamenie and Tahltan lakes), the horizontal distribution of the zooplankton community was examined to test the hypothesis that major components of the zooplankton community had developed a diel vertical migration strategy to avoid predation by sockeye fry introduced in 1992. The data showed that in all years (1990 to 1995), total zooplankton biomass was concentrated in the upper 7 m of the water column. The highest biomass was always found in the 1 m depth sample (Figs. 5.22 – 5.27). This distribution of total zooplankton was consistent from daytime to twilight to nighttime within years, and it did not change after fry stocking. These results suggest that major components of the total zooplankton community did not develop diel vertical migration patterns. It was concluded that daytime zooplankton sampling is a valid means for determining the distribution of major zooplankton groups potentially available as food to fry during dusk and dawn feeding periods.

4. Between-lake comparisons

Of the three lakes, Tuya had the highest diversity of common zooplankton groups (8), compared to Tahltan (6 groups) and Tatsamenie (5 groups) lakes (Table 5.1). Tahltan Lake had the highest mean annual zooplankton biomasses of the three lakes (Fig. 5.28), averaging 863 ± 577 mg/m^3 SD. Tuya and Tatsamenie lakes had similar mean annual biomasses (averaging 483 ± 405 mg/m^3 SD and 309 ± 65 mg/m^3 SD). Tahltan Lake also had the highest average mean annual zooplankton densities, averaging 38,945 ± 19,892 m^{-3} SD, compared to 23,441 ± 15,289 m^{-3} SD and 18,051 ± 4,776 m^{-3} SD for Tuya and Tatsamenie lakes (Fig. 5.30).

In Tatsamenie Lake, *Cyclops*, on average, accounted for most of the mean annual biomasses, followed by *Bosmina* and *Daphnia*. Other zooplankton groups combined

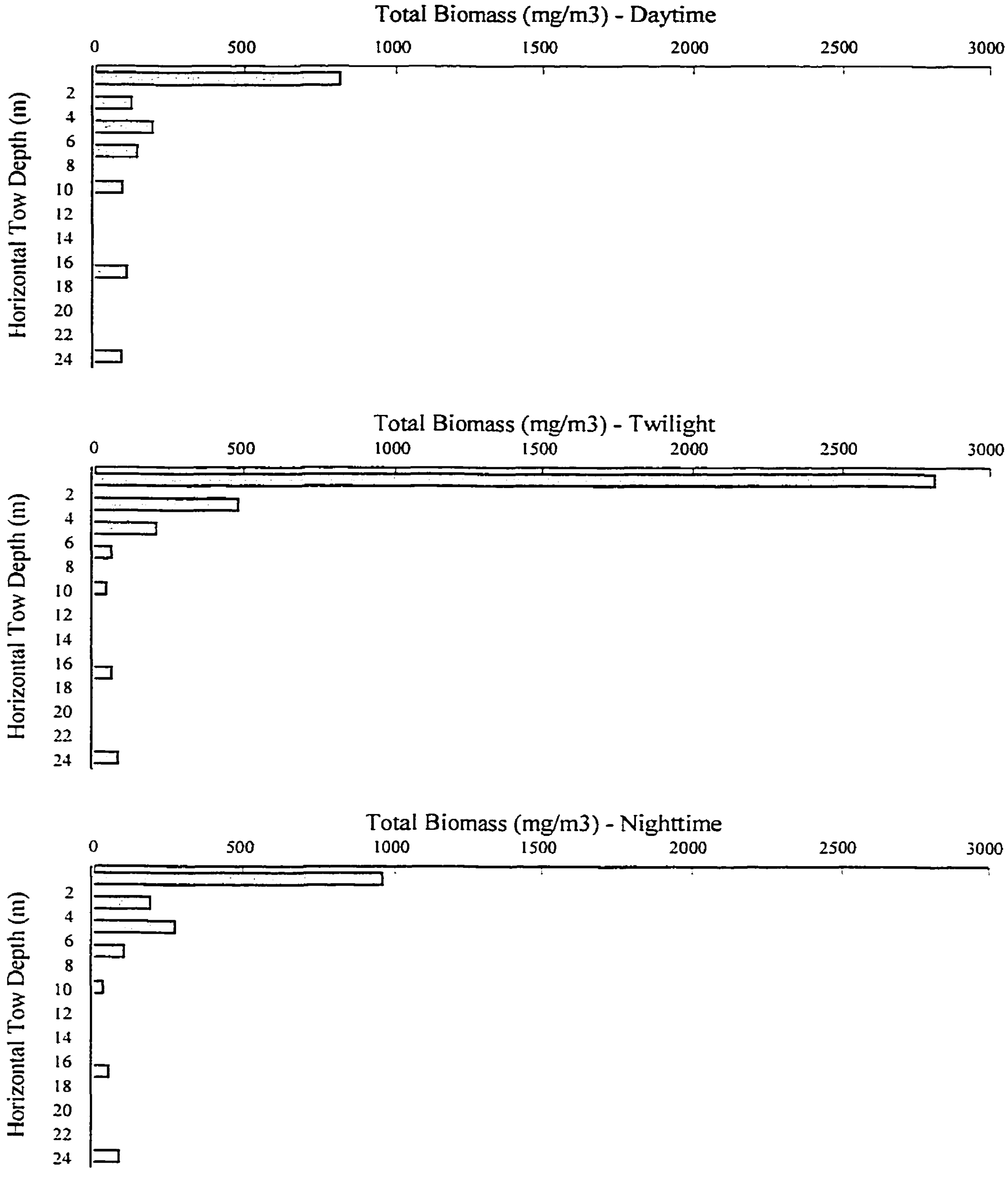


Figure 5.22. Tuya Lake 1990 (pre-stocking). Total zooplankton biomass (mg/m^3) of horizontal tow samples taken at 1, 3, 5, 7, 10, 17 and 24 m during the daytime (a), twilight (b) and nighttime (c) on August 30, 1990.

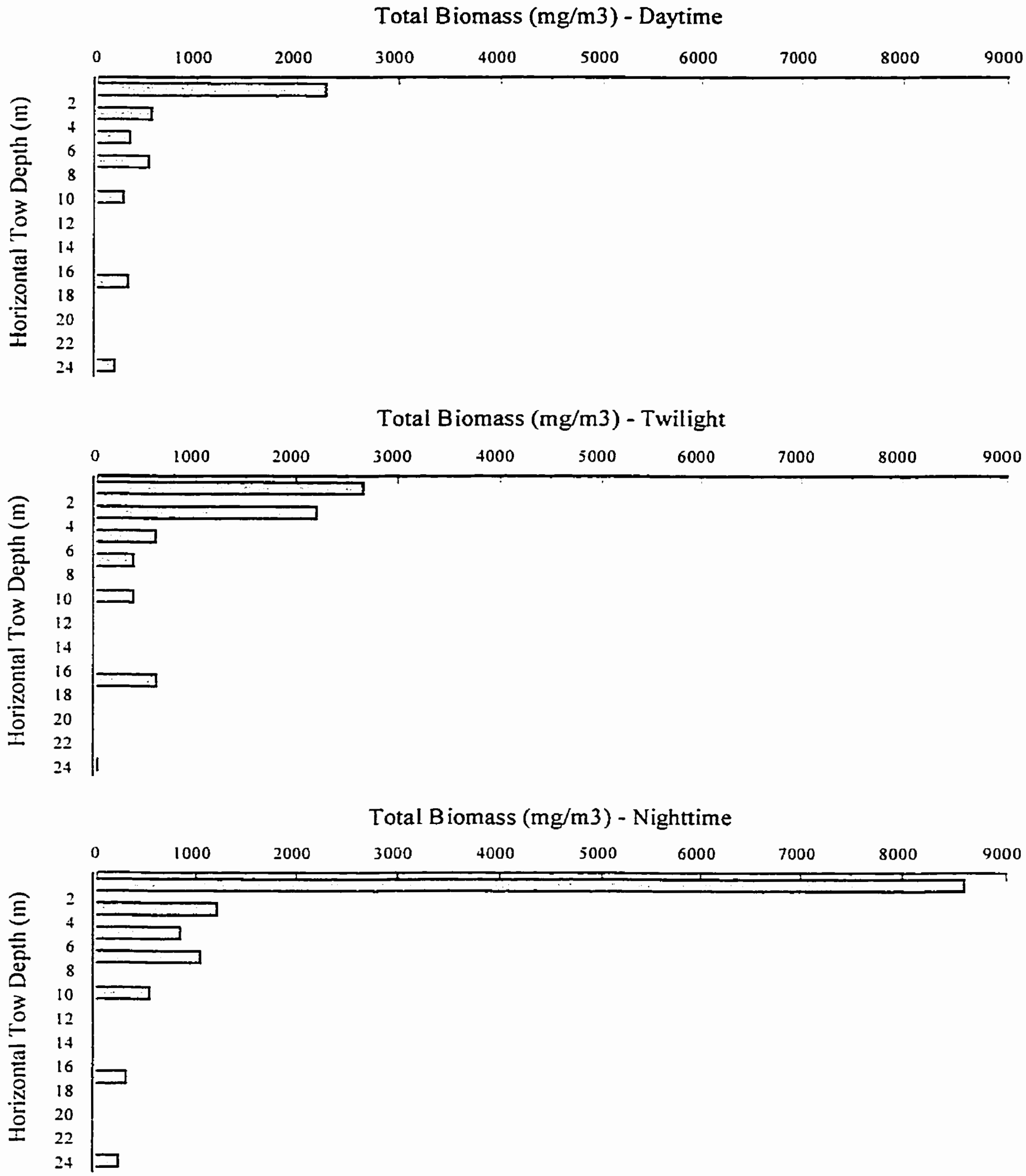


Figure 5.23. Tuya Lake 1991 (pre-stocking). Total zooplankton biomass (mg/m^3) of horizontal tow samples taken at 1, 3, 5, 7, 10, 17 and 24 m during the daytime (a), twilight (b) and nighttime (c) on September 4, 1991.

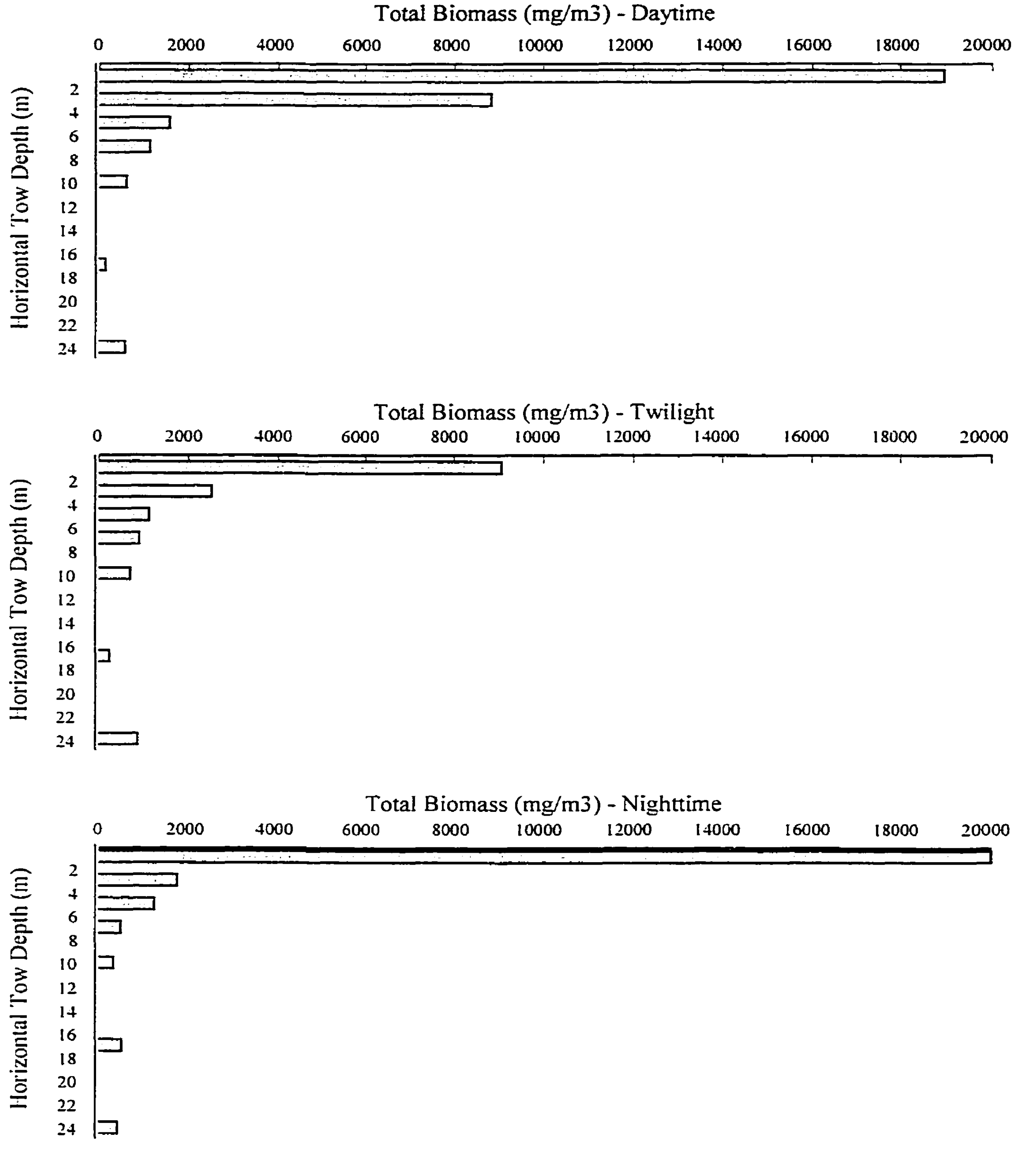


Figure 5.24. Tuya Lake 1992 (first year of fry stocking). Total zooplankton biomass (mg/m^3) of horizontal tow samples taken at 1, 3, 5, 7, 10, 17 and 24 m during the daytime (a), twilight (b) and nighttime (c) on September 2, 1992.

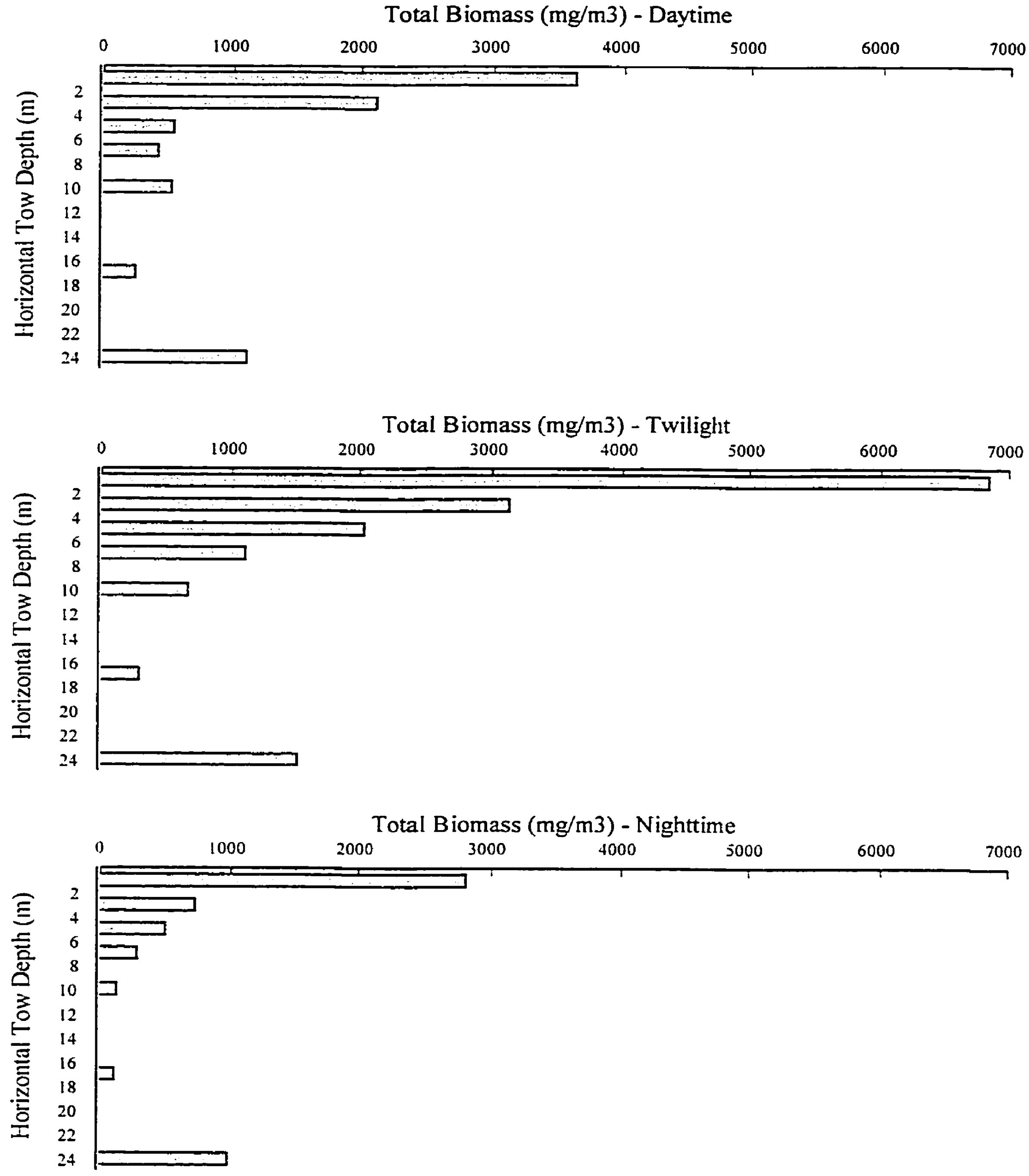


Figure 5.25. Tuya Lake 1993 (post-stocking). Total zooplankton biomass (mg/m^3) of horizontal tow samples taken at 1, 3, 5, 7, 10, 17 and 24 m during the daytime (a), twilight (b) and nighttime (c) on September 2, 1993.

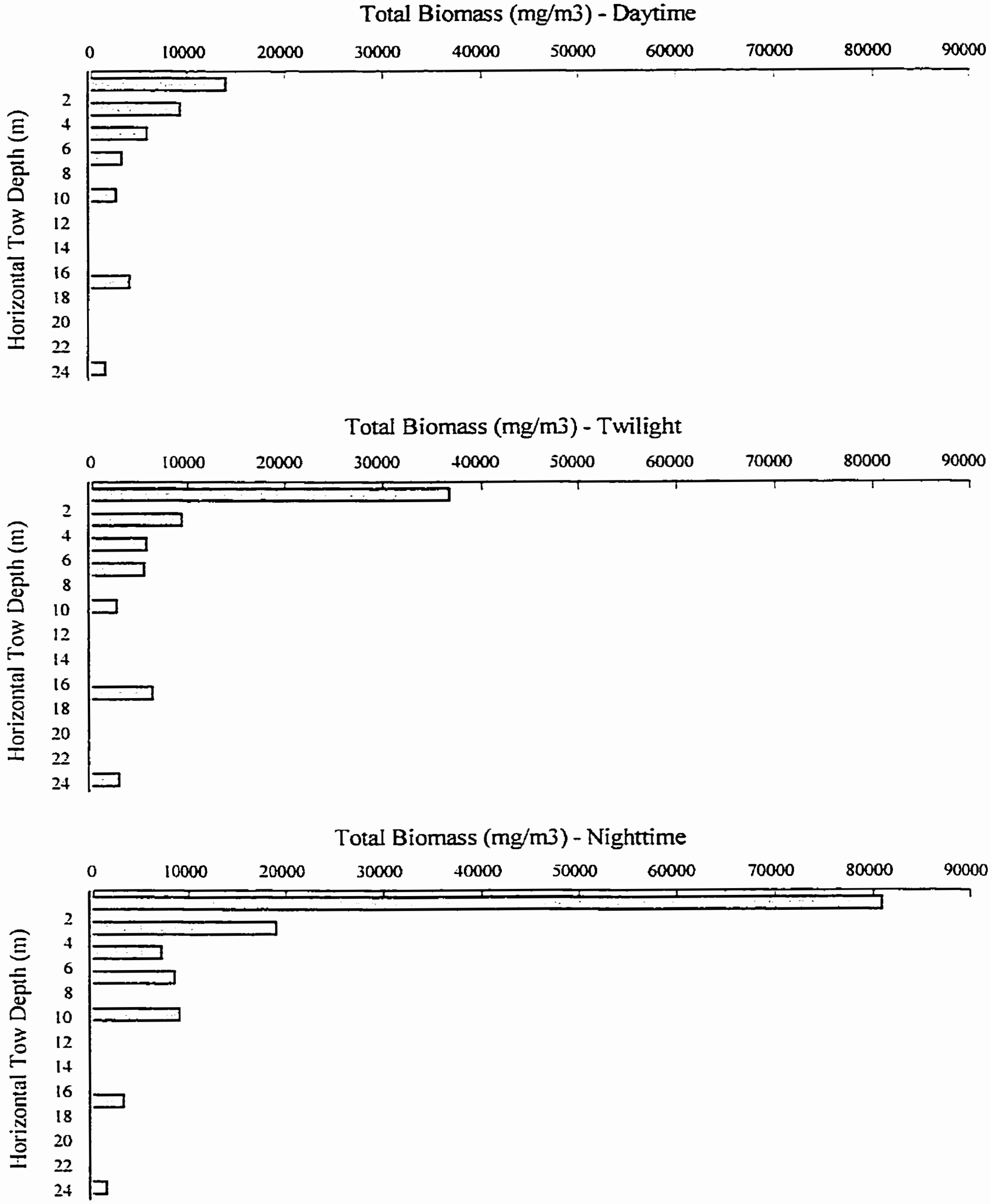


Figure 5.26. Tuya Lake 1994 (post-stocking). Total zooplankton biomass (mg/m^3) of horizontal tow samples taken at 1, 3, 5, 7, 10, 17 and 24 m during the daytime (a), twilight (b) and nighttime (c) on September 5, 1994.

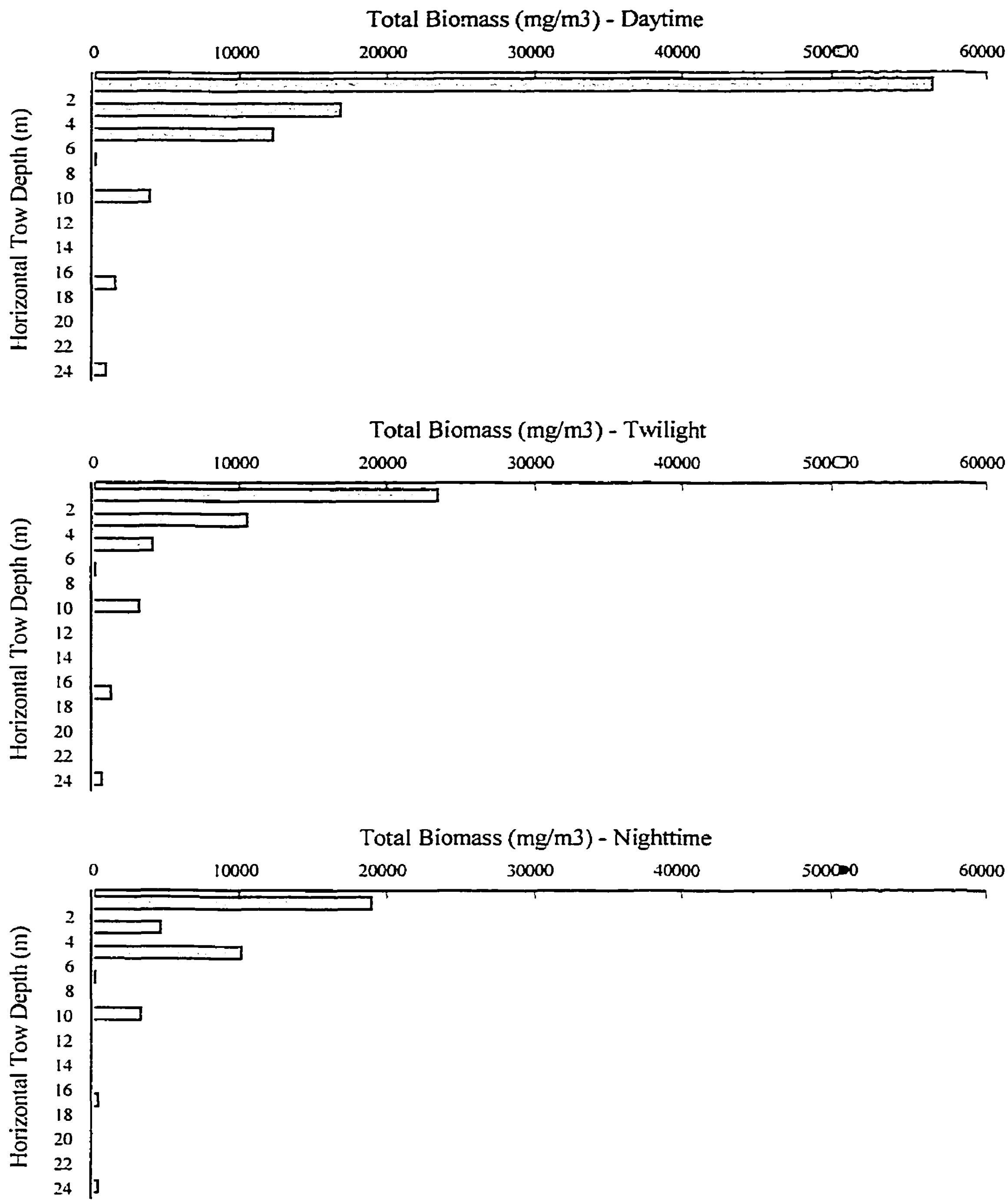


Figure 5.27. Tuya Lake 1995 (post-stocking). Total zooplankton biomass (mg/m^3) of horizontal tow samples taken at 1, 3, 5, 10, 17 and 24 m during the daytime (a), twilight (b) and nighttime (c) on September 12, 1995.

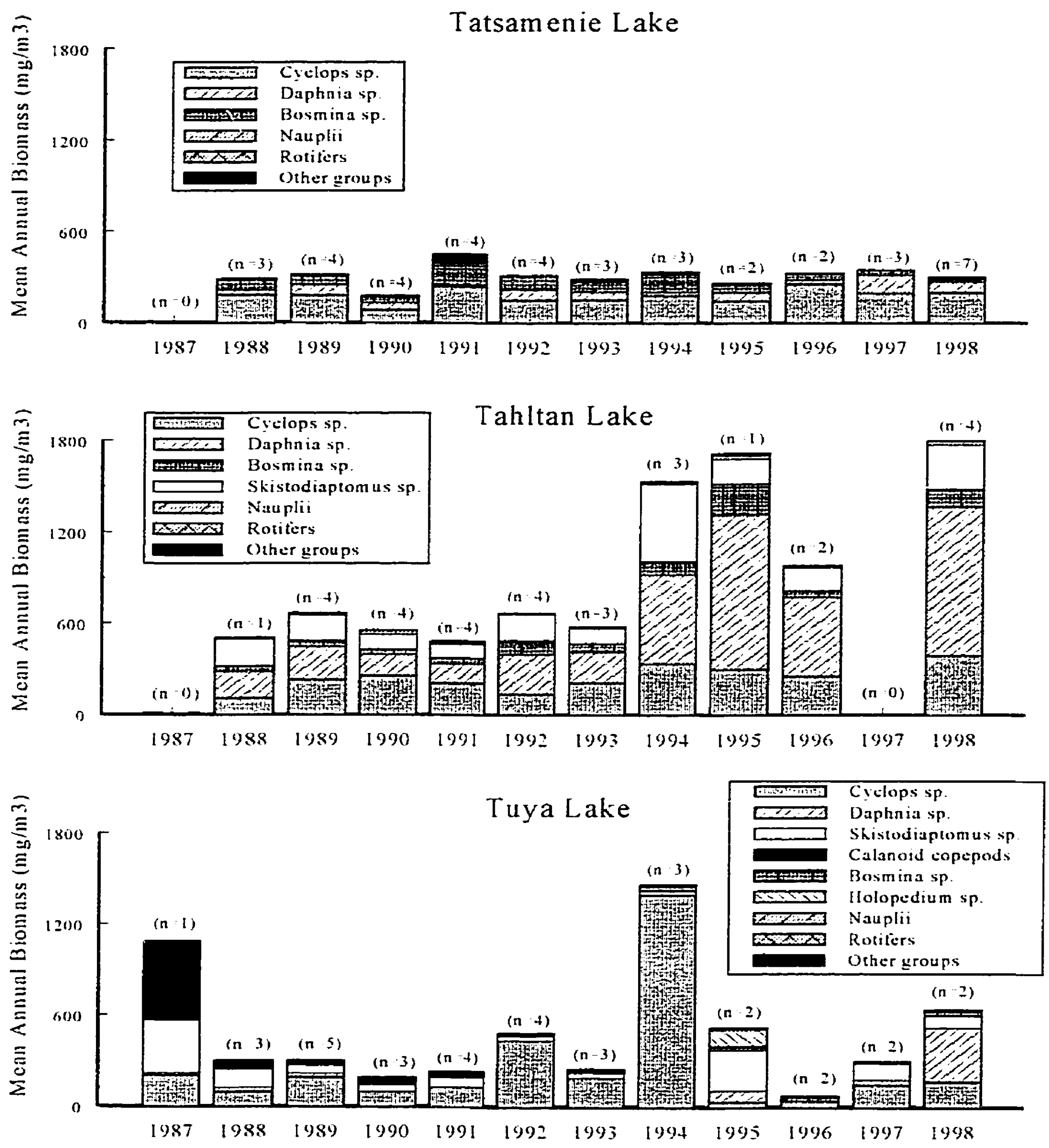


Figure 5.28. Mean annual biomass (mg/m^3) of zooplankton groups in Tatsamenie (a), Tahltan (b) and Tuya (c) lakes from 1987 to 1998. The number of annual sampling dates are indicated in brackets. For Tatsamenie Lake 'other groups' include *Holopedium*, *Skistodiaptomus* and other calanoid copepods; only *Diaphanosoma* contribute to 'other groups' in Tahltan and Tuya lakes. Note that Tahltan Lake outliers (1994-95, 1998; Figs. 5.9-5.14), and Tuya Lake outliers (1987, 1994-95; Figs. 5.15-5.21) have been included in mean annual calculations.

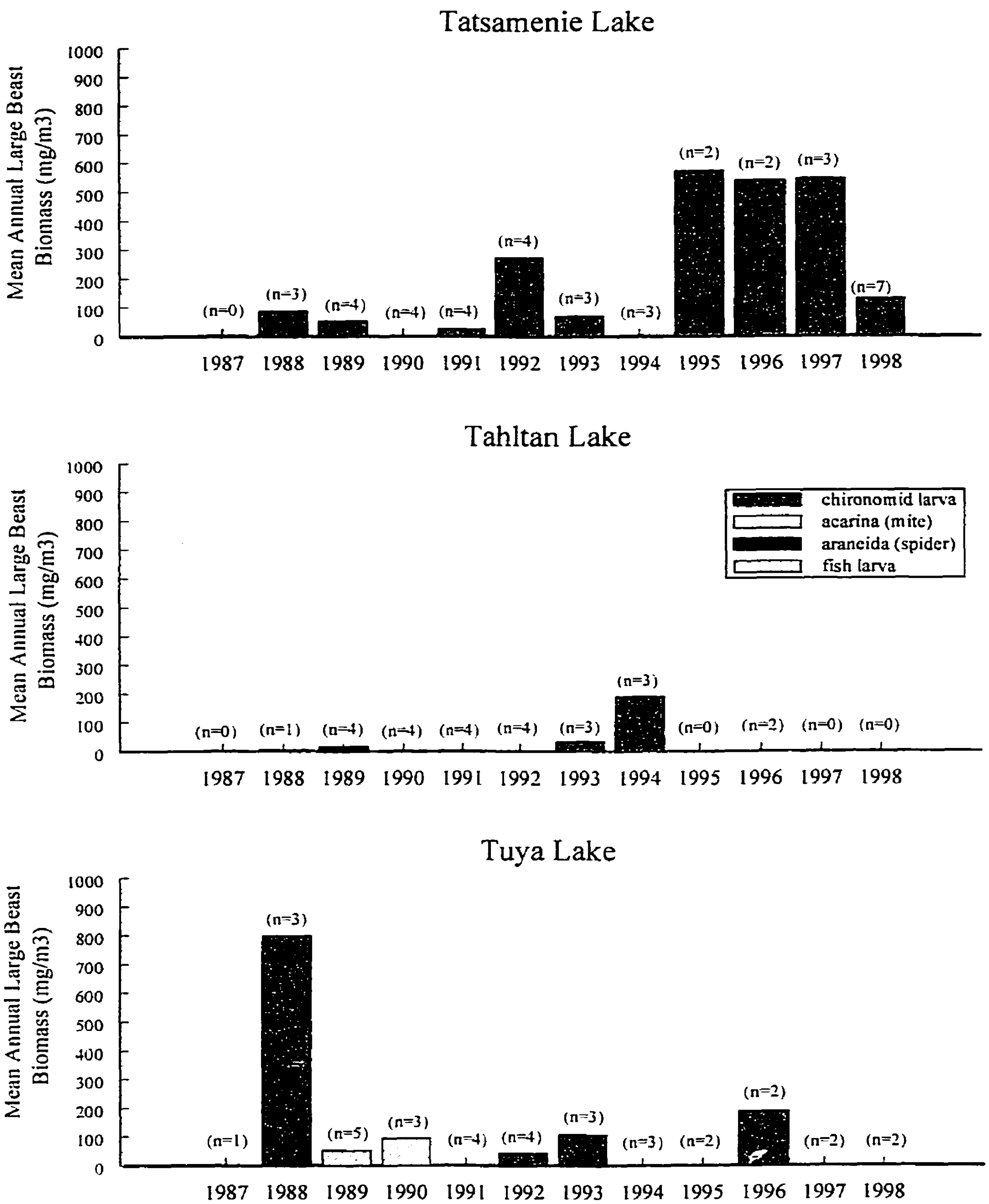


Figure 5.29. Mean annual biomass (mg/m^3) of large beast groups in Tatsamenie (a), Tahltan (b) and Tuya (c) lakes from 1987 to 1998. The number of annual sampling dates are indicated in brackets.

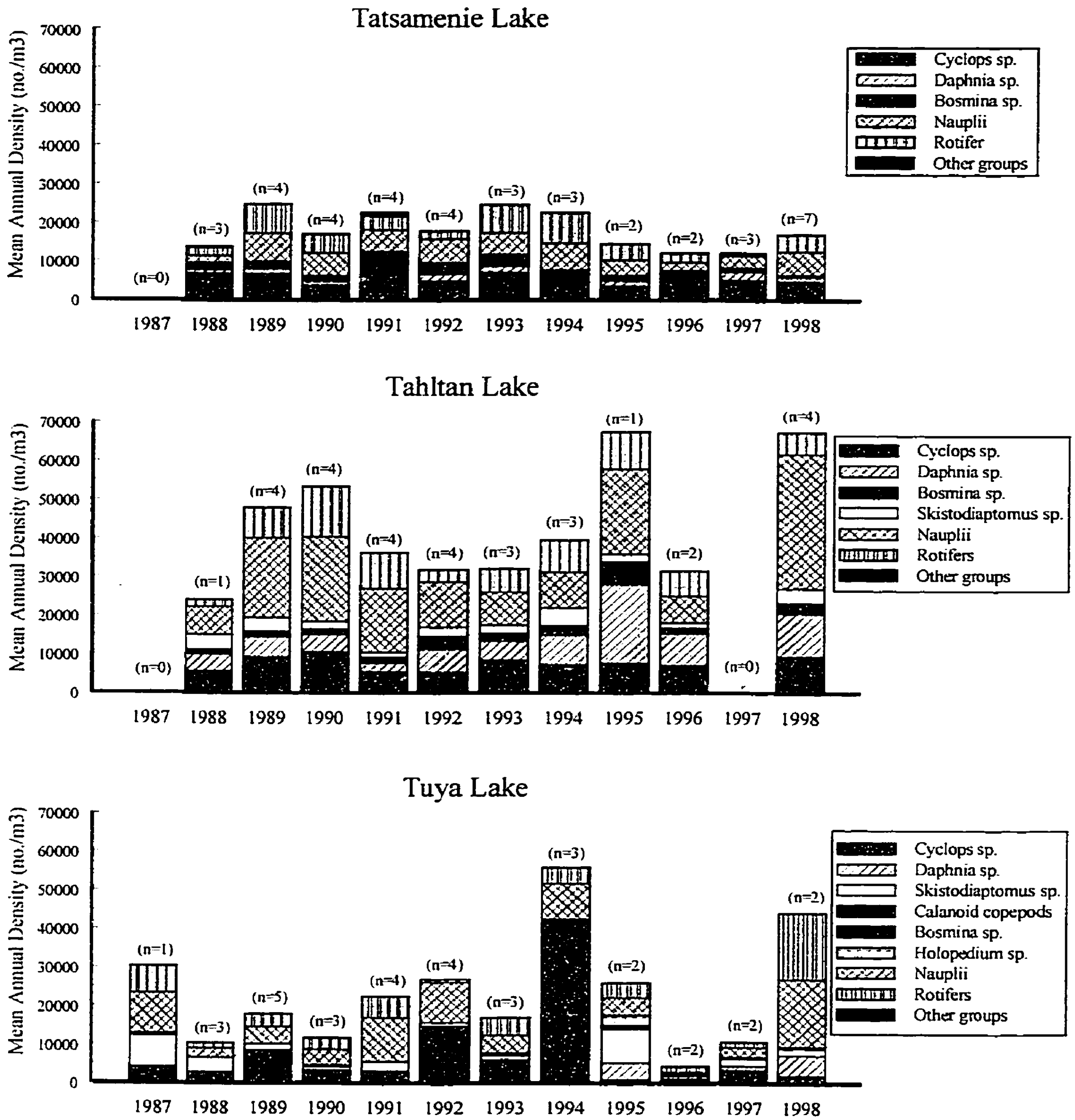


Figure 5.30. Mean annual density (#/m^3) of zooplankton groups in Tatsamenie (a), Tahltan (b) and Tuya (c) lakes from 1987 to 1998. The number of annual sampling dates are indicated in brackets. For Tatsamenie Lake 'other groups' includes *Holopedium*, *Skistodiaptomus* and other calanoid copepods; only *Diaphanosoma* contribute to 'other groups' in Tahltan and Tuya lakes.

including nauplii and rotifers), contributed relatively little to the mean annual biomasses. *Daphnia* was the largest component of Tahltan mean annual biomasses, on average, followed by *Cyclops* and *Skistodiaptomus*; *Bosmina*, nauplii and rotifers were relatively small components. In Tuya Lake, *Cyclops*, on average, comprised by far the major component of mean annual biomasses. Prior to fry stocking, *Skistodiaptomus*, followed by other calanoid copepods and *Daphnia*, were the next greatest contributors to mean annual biomasses. In post-stocking years, calanoid copepod contribution to mean annual biomasses decreased to zero, and *Daphnia* contribution increased. *Holopedium* contributed relatively little, as did nauplii, rotifers and other groups combined.

In Tatsamenie Lake, mean annual large beast (animals that were substantially larger than anything else in the sub-sample) biomasses (Fig. 5.29a) were made up almost entirely by chironomid larvae. In Tahltan Lake, contributors to mean annual large beast biomasses (Fig. 5.29b) included primarily chironomid larvae, followed by much lower levels of Araneida (spiders) and Acarina (mites). In Tuya Lake, mean annual large beast biomasses (Fig. 5.29c) were made up by chironomid and fish larvae.

In all three lakes, nauplii and rotifers contributed substantially to mean annual densities even though the sampling net mesh size was too large to sample them quantitatively. In Tatsamenie Lake, *Cyclops* was the most abundant zooplankton group, on average, followed by *Daphnia* and *Bosmina*. In Tahltan Lake, *Daphnia* and *Cyclops* were usually the most abundant groups, followed by *Skistodiaptomus* and *Bosmina*. In Tuya Lake, *Cyclops* followed by *Skistodiaptomus* and *Daphnia* were the most abundant taxa. *Holopedium, Bosmina* and calanoid copepods had quite low densities.

DISCUSSION

Sockeye fry growth is maximized when fry are able to feed size selectively (Goodlad *et al.* 1974). When fry are able to feed on fewer, larger-bodied zooplankton (compared to numerous, smaller-bodied zooplankton), there is a decline in the ratio of energy spent foraging to energy gained from the food particle eaten. As larger-bodied prey organisms are reduced, sockeye fry must become less selective feeders. The energy spent foraging increases, and the energy density of the food particles decreases. At this point, sockeye fry growth and survival are likely to decline, although growth rates may be sustained by very high densities of smaller-bodied zooplankton (Goodlad *et al.* 1974).

At the fry densities stocked (at, or below one half carrying capacity) in Tatsamenie and Tahltan lakes (which had wild sockeye populations), we did not expect to see changes in zooplankton taxa composition, or decreases in average zooplankton biomass, density, and mean size. The data suggest that no substantial changes occurred in the zooplankton communities at Tatsamenie and Tahltan lakes as a result of fry stocking. At Tuya Lake (which had no wild sockeye population), we expected there to be changes in zooplankton taxa composition, accompanied by decreases in average zooplankton biomass, density, and mean size. The data suggest that size selective predation by fry caused declines in *Daphnia* mean size (but increases in their abundance), and changes in zooplankton species composition (significant reduction or elimination of two species of calanoid copepods, *Epischura* and *Heterocope*, from the community). Contrary to expectations, fry stocking did not cause major components of the Tuya Lake zooplankton community to develop diel vertical migration (to avoid fry predation). This may be because the fry do not exhibit diel vertical migration (not tested) as a result of the long periods of daylight that occur in late summer (when these samples were collected) at northern latitudes, or as a result of low limnetic predation pressure on fry.

The impacts of sockeye fry on zooplankton were much more obvious in Tuya Lake than in the other two lakes, likely due to the fact that Tuya Lake had no endemic sockeye stocks, as well as having substantial abundances of larger-bodied, predator-vulnerable taxa. Also, it seems likely that the sockeye populations which were endemic to Tatsamenie and Tahltan lakes had, in the past, reduced the larger-bodied zooplankton taxa, and have held them at low levels. Increased fry densities (by fry stocking) in these lakes may have increased competition for smaller-bodied prey, but in all three lakes, mean annual zooplankton biomasses did not change after fry stocking (with the exception of a minor group in Tuya Lake), suggesting that, despite increased fry densities, interspecific competition for food did not result in reduced zooplankton prey or fry growth. Although fry may not have been limited by amounts of available prey, it is possible that the smaller-bodied prey in Tatsamenie and Tahltan lakes were not sufficiently large to yield the energy return that juvenile sockeye required for both foraging and optimal growth. If this was the case, we would expect to see lower than average growth and survival rates after fry stocking. This, in part, will be the subject of the next chapter.

Chapter 6 - Sockeye Growth and Survival

INTRODUCTION

The objectives of the analyses presented in this chapter are: (1) to quantify juvenile sockeye growth and survival in Tatsamenie, Tahltan and Tuya lakes, (2) to compare growth of wild and enhanced fry and smolts in Tatsamenie and Tahltan lakes, (3) to compare the survival of wild and enhanced juvenile sockeye within, and between lakes, and (4) to investigate a series of relationships between growth, survival, density and time of stocking.

To satisfy these objectives, this chapter comprises: (1) an explanation of methods used to collect and process juvenile sockeye in order to quantify juvenile growth and survival, (2) a summary of adult spawner escapement to Tatsamenie and Tahltan lakes, (3) an assembly of hydroacoustic population estimates for Tatsamenie, Tahltan and Tuya lakes, (4) an assembly of fry-to-smolt growth data, (5) a between-lake comparison of smolt weights, (6) an assembly and comparison of wild and enhanced juvenile sockeye survival data from Tatsamenie, Tahltan and Tuya lakes, (7) a discussion of the timing of enhanced fry mortality in Tatsamenie Lake, and (8) analyses of growth, survival, density and time of stocking data relationships.

METHODS

1. Sockeye Fry Collection

Sockeye fry were collected from each lake, usually every year, by beach seining and mid-water trawling. In most years, at least one beach seine and trawl sample was taken from each lake (dates are summarized in Appendix A). In general, beach seining was more effective for capturing fry from spring to mid-summer when most fry inhabit inshore areas. Mid-water trawling was more effective for capturing fry from late summer to fall since most fry had moved offshore by this time, and periods of nighttime darkness had increased. Beach seine samples were collected to monitor fry growth and movement of fry from initial inshore rearing areas to offshore areas. Hydroacoustic surveys were used to obtain limnetic sockeye population estimates, and to determine the horizontal and vertical distributions of sockeye fry. Data from mid-water trawls were used to monitor fry growth, and to determine the ratio of wild to enhanced fry in the limnetic area of the lake. These two methods combined, allowed the estimation of enhanced fry survival from stocking to the fall.

1.1 Beach Seine Sampling

Beach seining was used to sample fry inhabiting the inshore, littoral zone of the lake. Beach seines were done with a 30m x 3.8m net (0.64 cm mesh wings, 0.32 cm mesh bunt), at 5 standardized sites per lake (Figs. 6.1-6.3). Each standardized site consisted of two sub-sites, each located in a different habitat type.

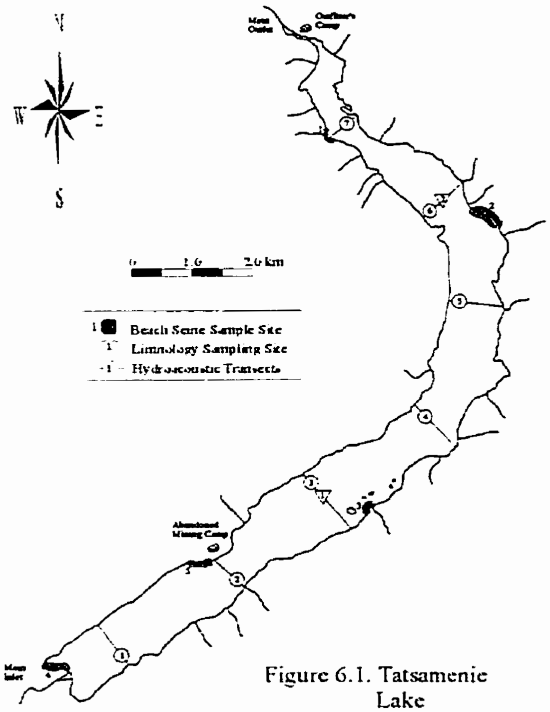


Figure 6.1. Tatsamenie Lake

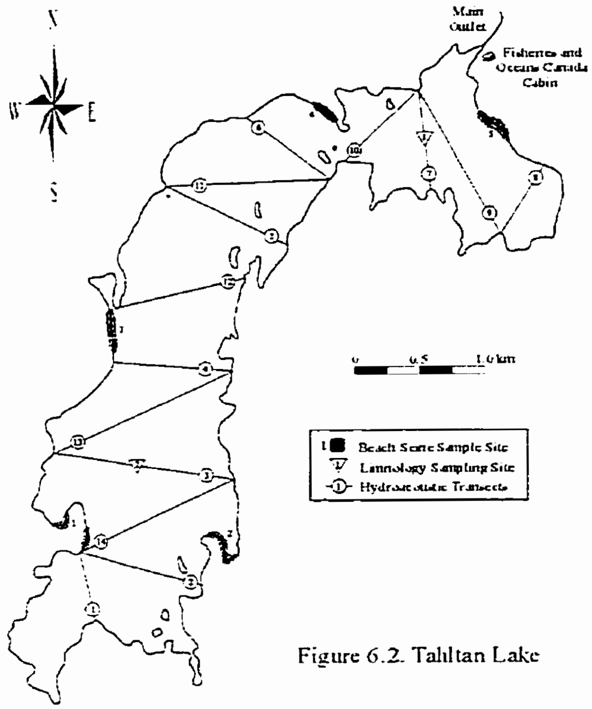


Figure 6.2. Tahltan Lake

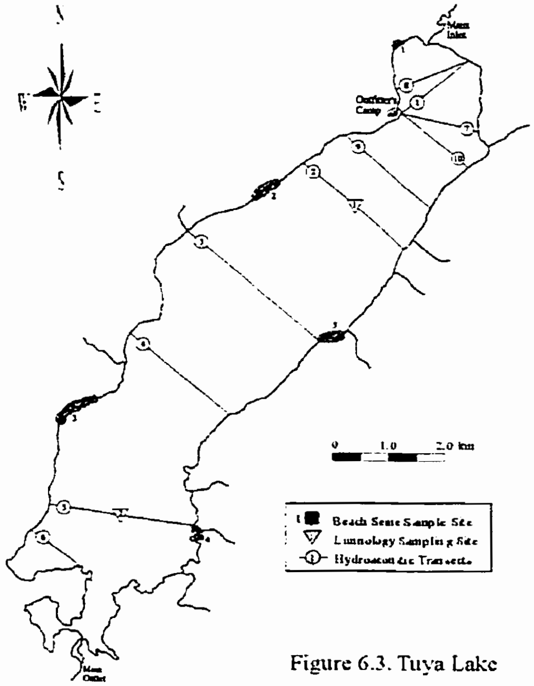


Figure 6.3. Tuya Lake

Figures 6.1, 6.2 and 6.3. Tatsamenie, Tahltan and Tuya lake outlines showing locations of beach seine sites and hydroacoustic transects.

With one end secured to shore, the net was pulled out into the lake using an outboard powered 14'zodiac inflatable boat and dragged back around to shore, forming a half circle. The two ends of the net were then pulled (lead lines first to prevent fish from escaping) until the entire net was onshore. Fish captured in the seine net were enumerated, and up to 100 fry from each site (or a total of 300 from all sites) were retained. Fry were preserved in 99% denatured alcohol (mix of ethanol (85-94%) and methanol (14-5%)) in labeled jars. Small numbers of other fish species were occasionally kept as voucher specimens (i.e. sculpins, Arctic grayling).

1.2 Hydroacoustic and Mid-water Trawl Sampling

Mid-water trawls were used to sample fry inhabiting the offshore, limnetic zone of the lake. Trawls were used in conjunction with hydroacoustic surveys, usually in mid-summer and/or fall. Hydroacoustic transects (Figs. 6.1-6.3) were traversed at night when low light levels result in the breakdown of juvenile sockeye schools, permitting the identification of individual fish on echograms (Gjernes *et al.* 1986). Low light conditions also make it harder for fry to avoid the trawl net, thereby improving catchability. Battery-powered flashing lights marked the start and end points of each transect. A Simrad EY-M echosounder and transducer were used to obtain a dry paper echogram record for each transect. A detailed description of the limnetic fish field census and analytical procedures is found in Hyatt *et al.* (1984), Gjernes *et al.* (1986) and Rankin (in prep.).

Trawls were run perpendicular to the portions of the acoustic transects that showed the highest recorded densities of fish targets. The 2m x 2m x 7.5m trawl net was constructed of Meketsu, low drag, knotless stretch mesh. The front and middle section mesh sizes were 7.62 cm and 3.81 cm, and the tail and codend section mesh sizes were 1.27 cm and 0.64 cm. A PVC container was attached to the codend with a hose clamp. A detailed description of the trawl equipment and its field operation is found in Gjernes (1979). A minimum of 15 trawls over one or more nights were usually conducted in an effort to capture at least 300 fry. Fry captured in the trawls were preserved and labeled as per the beach seine samples.

2. Sockeye Fry Processing

Processing of fry involved measuring fork length and wet weight, and extracting, mounting and reading otoliths. Fry otoliths were examined for the presence or absence of a thermal mark indicating that the fry were either hatchery raised or wild, respectively. Stomach contents of Tatsamenie Lake fry from early beach seine samples in 1998 and 1999 were also processed to determine if diets differed between wild and enhanced fry. Methods and results of the diet analyses are presented in the following chapter.

2.1 Length and Weight

Fry samples from 1990-1997 were processed by PBS staff (1990-1992 samples) and AMC Technical Services, Nanaimo, BC (1992-1997 samples). Samples from 1998-1999 were processed by a combination of AMC Technical Services, B. Hanslit (PBS), and K. Mathias. Fork lengths were measured using a fish measuring board (1.0 mm precision), and wet weights were measured using a calibrated balance with 0.01g precision.

2.2 Otoliths

Otolith samples collected from 1990-1993 were processed for thermal marks by Eric Volk of the Washington Department of Fisheries in Olympia, WA. Samples from 1994-1997, were processed by W. Hoyseth (Otolith Laboratory, PBS). Samples from 1998 were processed by B. Hanslit (PBS). In 1999, samples were extracted and mounted by AMC Technical Services and K. Mathias, and read for thermal mark by the Alaska Department of Fish and Game Otolith and Ageing Lab, and K. Mathias. Otolith thermal marks were usually read twice (i.e. by two different readers) to ensure reader consistency.

Both right and left otoliths were removed from either the ventral (first removing the gills) or the dorsal sides of the head using a scalpel and dissecting scope. Otoliths were mounted sulcus side up, on molten drops of thermoplastic glue on a glass microscope slide.

One or both otoliths were then wet-ground to mid-plane using geological lapping film (30 μ grit size) in order for the thermal mark to be visible under a compound microscope (100X to 400X). An otolith thermal mark (Fig. 6.4) consisted of one or more bands made up of a series of rings, with a unique number of bands and rings for each lake and broodyear. For a complete description of otolith thermal mark induction and recovery see Hoyseth (1995, unpublished). Otoliths processed at PBS were placed into labeled slide boxes and stored in the sample inventories maintained at PBS.

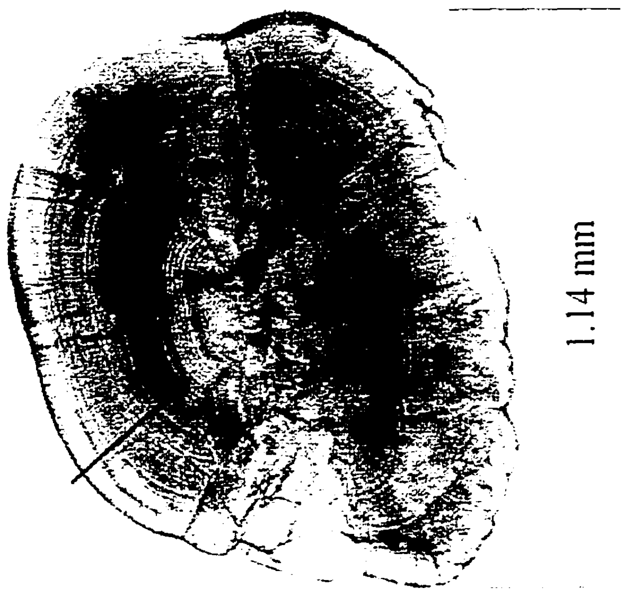


Figure 6.4. Right otolith removed from a newly emerged Tahltan Lake sockeye fry (1989 broodyear) shortly before stocking (fry weight ranged from 0.11 - 0.14 g). Arrow indicates the location of the single band thermal mark made up of 4 (dark) rings.

2.3 Hydroacoustic Echograms

Processing of hydroacoustic echograms involved dividing the echogram into depth strata (2-5, 5-10, 10-15, 15-20, 20-30 m, etc. by 10 m intervals), identifying and counting fish targets, and generating population estimates, as described by Hyatt et al. (1984), Hyatt and Stockner (1985), and Rankin (in prep.).

Total limnetic population estimates were broken down using the proportions of juvenile (or juvenile-sized fish such as limnetic sculpins) fish types (e.g. wild versus enhanced) caught in trawls. It must be noted that estimates of sockeye fry and limnetic sculpin in Tuya Lake may be subject to substantial error beyond that represented by 95% confidence intervals, which is the error attributed to the hydroacoustic method.

Additional error may result from the fact that trawl catches were used to break down the total acoustic estimate into fry and sculpin estimates. This is a concern since it is not known whether sockeye fry and limnetic sculpin exhibit similar catchability or net avoidance, or whether the distributions of fry and sculpin are similar throughout the limnetic zone. Unbiased sampling of fry and sculpin require that these assumptions be met. For this reason, estimates of enhanced fry density and percent survival in Tuya Lake should be used with caution. In years for which trawl sample size was low (< 75 fish), sockeye fry and limnetic sculpin population estimates were not used in mean density and survival calculations (1992-93, 1995, and 1998-99), since the proportions of fry and sculpin caught in trawls may not have been representative of the proportions of each present in the limnetic zone. In Tatsamenie and Tahltan lakes, it is assumed that wild and enhanced fry exhibited similar catchability (i.e. had similar swimming speeds), and were distributed similarly throughout the limnetic zone.

3. Sockeye Fry Data Analysis

Data files identifying capture date, capture method, capture site, fish length, weight and otolith data were created for each year (with multiple worksheets for multiple sampling dates) for each lake. Wet, preserved fry weights were corrected for the shrinking effects of the preservative (99% denatured alcohol) using a correction factor developed by the Sockeye Index Stocks Program (Hyatt *et al.* in prep.). The correction factor for juvenile sockeye preserved for 10 weeks in either 50% or 70% alcohol (ethanol/methanol mix) is:

predicted fresh wet weight (g) = [preserved wet weight (g)] / [0.841]

Preserved length correction factors were not calculated due to the relatively small changes in length (Hyatt *et al.* in prep.). Trawl net avoidance corrections were applied to the trawl catch length and weight means. In Woss, Cheewat, Yakoun and Skidegate lakes (located in southern BC and Queen Charlotte Islands), it has been determined that sockeye fry over 40 mm in length begin to swim at speeds that allow them to avoid the trawl net (P. Rankin pers. comm., PBS, Nanaimo, BC). This net avoidance effect becomes more pronounced as the fry increase in length. Fry lengths and weights, corrected for trawl net avoidance, are compared to uncorrected lengths and weights in Appendices C4-C6.

The weight-frequency distributions of wild and enhanced fry and smolts were compared. Raw data files were sorted by presence of thermal mark to separate enhanced from wild fry lengths and weights. Weight-frequency histograms were plotted, and summary statistics were calculated for wild and enhanced fry lengths and weights. Juvenile sockeye known or assumed to be older than age 0+ were omitted from the histograms and mean weight/length calculations.

The growth curves of wild and enhanced from the fry to smolt stages were compared. The individual fish data that were used to generate the weight frequency distributions were summarized by calculating mean weights for wild and enhanced fish in each beach seine, trawl and smolt sample. These mean weights were used to produce growth plots that allow quantitative comparisons between wild and enhanced fish. Growth plots start with mean stocking weight (for enhanced fry), or with mean weight found in the first beach seine sample (for wild fry), and end with mean weights of age 1+ smolts (for both wild and enhanced smolts). Fry sampling dates were converted to day-of-year (day 1 to 365 or 366) in order to plot growth curves. Mean fry lengths and weights (including 95% confidence intervals), and sample sizes for each sampling date of every year are summarized for each lake in Appendices C1-C3.

4. Sockeye Smolt Collection

Tatsamenie and Tuya lake smolts were sampled at night using a 2m x 2m x 7.5m fyke net set within the lake outlet. The net was generally set before dusk and operated for at least 3 hours depending on the numbers of smolts migrating. Field notes describing environmental conditions such as weather (air temperature, cloud cover, moon phase, precipitation), water levels, water temperatures and water clarity were taken at each lake. Tahltan Lake smolts were sampled and enumerated at a permanent weir at the lake outlet.

Tatsamenie Lake smolts were sampled annually from 1992-1999, starting no later than May 18 and continuing until approximately June 5. Sampling was conducted over at least three nights, evenly spaced over the migration period. Sample sizes generally varied between 150-450 smolts. In 1996, 1998 and 1999, a smolt mark-recapture program was conducted to estimate the total number of emigrating smolts, and the relative proportions of wild and enhanced smolts within the run. Smolts, captured with a fyke net (with an attached "live box") deployed in the lake outlet, were tagged using color coded staple tags (unique tags for each day), and released along an established transect across the lake, 4 km from the outlet. Smolts were continually captured day and night, and daily records were kept of the number of tagged smolts captured that were tagged that day, the number of tagged smolts captured that had a tag from any day, and the total number of smolts captured that day. Concurrent with the mark-recapture program, a total of about 300-500 smolts were retained from daily smolt sub-sampling to provide length, weight and age (scale samples) data, and wild:enhanced ratios (otolith samples) from which daily run estimates of each could be calculated. Methods and results of the 1996, 1998 and 1999 Tatsamenie Lake mark-recapture program are reported in Mercer & Associates Ltd. (1998, 1999, in prep.). General methodologies of fish population mark-recapture techniques are described in Ricker (1975).

Tahltan Lake smolts were enumerated annually (1984–1999) through a weir just downstream of the mouth of the lake outlet. The weir consisted of a V-shaped fence with the mouth (pointing downstream) leading to two incline plane Wolf traps. Since the enhancement program began at Tahltan Lake in 1990, the number of smolts migrating through the weir has been estimated daily by trapping and measuring the volume of all smolts (calibrated volumetric displacement method). This involved filling a 20 L bucket to a marked level with water (about 7-10 L), then adding smolts to the bucket until the water level reached a second mark. The number of smolts displacing the standardized volume of water was estimated from calibrations done six times per day. Calibrations involved adding known numbers of smolts to the bucket until the water level reached the second mark, in order to account for the range of smolt sizes. Daily estimates of smolt emigration were added together to estimate total smolt emigration. Smolt sub-samples were collected each day of the smolt run (for length, weight, age, and origin data), in numbers proportionate to the daily smolt count in order to achieve a representative total sample of approximately 500 smolts.

Tuya Lake smolts were sampled annually from 1994 to 1999. The sample period typically began no later than May 22 and ran as late as June 12. A fyke net was suspended from a rope crossing constructed approximately 200 m downstream of the outlet mouth. The width of the river at this site was approximately 55 m. Every night, sampling began at dusk and continued through the night until the peak of the evening run had passed. A minimum of 15 smolts were retained from each night of sampling (if possible), with the objective of capturing approximately 300 smolts evenly over the outmigration period.

5. Sockeye Smolt Processing

A sample of about 300-500 smolts was captured throughout the smolt run from each lake. As smolts were captured, they were anaesthetized with 2-phenoxyethanol to minimize scale loss. Scale samples were taken from each smolt and placed directly into labeled scale booklets. The smolts were then weighed (to 0.1 g precision) and measured (fork length of 1.0 mm precision) in their fresh state. The heads were removed for later otolith extraction and preserved in 10-15 ml of 99% denatured alcohol (ethanol/methanol mix) in individual, labeled vials. The smolt otoliths were processed as per the fry otoliths.

6. Sockeye Smolt Data Analysis

Smolt data were analysed as per the fry data with the exception of the preservation correction. Since smolts were fresh when processed for length and weight, no preservation corrections were necessary. Smolt capture dates, total numbers of smolts captured, and mean lengths and weights of wild and enhanced smolts are summarized in Appendices C7-C9.

Tatsamenie Lake mark-recapture data from 1996, 1998 and 1999 were analysed using the Babine Smolt Fence Model (Mercer and Associates Ltd. 1998, 1999, in prep.). Other estimator models, including the Lincoln-Petersen (Bailey Form) Model, and the Pooled Peterson, Schaefer, and Maximum Likelihood (ML) Darroch estimators in the Stratified Population Analysis System (SPAS), were used for comparison, and to estimate standard error and 95% confidence intervals. In 1996 and 1998, the coefficients of variation between four different population estimator models were 2.1% and 14.5%, demonstrating that there is good agreement between model estimates. A coefficient of variation for 1999 estimates has yet to be calculated.

Most of the population estimator models treat the entire mark-recapture program as a single tagging event, and therefore do not calculate daily emigration. The Babine Model, developed to enumerate emigrating smolts at Babine Lake, uses mark-recovery data to estimate daily and cumulative smolt population estimates. Total daily emigration is calculated as:

$$\frac{\text{(\# of tagged smolts that passed the weir that day)*(total daily catch)}}{\text{\# of tagged smolts that passed the weir that were tagged that day}}$$

Cumulative emigration was calculated by summing daily emigration estimates over the sampled smolt emigration period.

7. Calculation of Survival Data

7.1 Tatsamenie Lake

For the wild population, estimated egg deposition was calculated by multiplying the number of wild females by the average fecundity (the number of eggs per female), determined during the broodstock egg take. The annual adult enumeration program at the Tatsamenie Lake weir (carried out by FOC, Whitehorse Stock Assessment Division staff) provided estimates of the total number of spawners, and the male to female spawner ratio for each broodyear. Adults were enumerated (assumed to be an absolute count) as they passed through a counting chamber at the weir entrance. The weir was closed to fish passage when staff were not counting. The number of wild females was the total number of females, minus the number of females used for broodstock. The number of eggs taken from broodstock for enhanced fry production was calculated by multiplying the number of females used for broodstock, by the average fecundity of broodstock females. Broodstock egg collection data were reported in unpublished annual contractor reports (Mercer & Associates Ltd. 1990-1999). The numbers of enhanced fry stocked were estimated by Snettisham Hatchery personnel using the calibrated volumetric displacement method (see Methods section 4).

The absence of an outlet weir at Tatsamenie Lake prevented the direct enumeration of emigrating smolts. Therefore, estimates of smolt numbers were extrapolated using fall fry hydroacoustic estimates (Table 6.3), multiplied by 0.75 to account for 25% overwinter mortality and age 1+ holdovers (fry that spend two years in the lake instead of one). At Tahltan Lake, a significant relationship ($y = 0.4852x + 198076$; $r^2=0.66$, $p=0.02$) was found between fall hydroacoustic-derived juvenile sockeye population estimates, and spring smolt weir-derived population estimates (data are from smolt years 1986, 1988-89, 1992, 1994-95, and 1997-98). Hydroacoustic methods tended to underestimate the numbers of juvenile fish, but usually by a consistent amount. Acoustics likely underestimates the limnetic fry population to a greater degree in Tahltan Lake (clear and fairly shallow), compared to Tatsamenie Lake (semi-glacial and deep), due to higher light penetration and the maintenance of a higher degree of schooling by fry (i.e. individual targets are not completely differentiated during acoustic surveys). For this reason, fall acoustic estimates from Tatsamenie Lake were not corrected using the Tahltan Lake regression equation. For each year, the total Tatsamenie smolt estimate was broken down into wild age 1+, wild age 2+, enhanced age 1+, and enhanced age 2+, using the proportions of each found in the smolt sample (Appendix C7) taken each spring (as determined by scale age and otolith thermal mark analyses).

Wild and enhanced egg-to-age 1+ smolt percent survivals, for broodyears 1991 to 1997, were calculated by dividing the age 1+ smolt estimate by the number of eggs. Enhanced fry-to-age 1+ smolt percent survivals were calculated by dividing the enhanced age 1+ smolt estimate by the number of fry stocked. For broodyears 1994, 1996, and

1997, estimates of egg-to-age 1+ smolt percent survival were also calculated using data from smolt mark-recapture programs conducted in 1996, 1998, and 1999 (Mercer & Associates Ltd. 1998, 1999, in prep.).

7.2 Tahltan Lake

For the wild population, the number of eggs deposited was calculated by multiplying the number of wild females by the average fecundity (the number of eggs per female), determined during the broodstock egg take. The annual adult enumeration program at the Tahltan Lake weir (carried out by FOC, Whitehorse Stock Assessment Division staff) provided estimates of the total number of spawners, and the male to female spawner ratio for each broodyear. Adults were enumerated (assumed to be an absolute count) as they passed through a counting chamber at the weir entrance. The weir was closed to fish passage when staff were not counting. The number of wild females was calculated as the total female escapement minus the number of females used for broodstock. The total number of eggs taken from broodstock was calculated by multiplying the number of females used for broodstock by the average fecundity of broodstock females. Escapement and egg take data were reported in unpublished annual contractor reports (Triton Environmental Consultants Ltd. 1989-1999). From broodyear 1991 to 1999, the total number of eggs taken from Tahltan broodstock were split into those destined for Tahltan Lake stocking and those destined for Tuya Lake stocking. The numbers of enhanced fry outplanted were estimated by Snettisham Hatchery personnel using the calibrated volumetric displacement method (see Methods section 4).

Tahltan Lake smolts were enumerated at an outlet weir every spring. It must be noted however, that smolt enumeration at the Tahltan weir was not an absolute enumeration since smolt numbers were estimated using the calibrated volumetric displacement method. The total smolt population estimate was broken down into wild age 1+, wild age 2+, enhanced age 1+, and enhanced age 2+, based on the proportions of each found in the smolt samples (Appendix C8) taken each spring (as determined by scale age and otolith thermal mark analyses). Wild and enhanced egg-to-age 1+ smolt survivals, for broodyears 1989 to 1996, were calculated by dividing the age 1+ smolt estimate by the number of eggs. Enhanced fry-to-1+ smolt survivals were calculated by dividing the enhanced age 1+ smolt estimate by the number of fry stocked.

7.3 Tuya Lake

The number of eggs taken from Tahltan Lake broodstock to stock Tuya Lake was pre-determined by the Transboundary Technical Committee based on Tahltan Lake spawner abundance. The numbers of enhanced fry outplanted were estimated by Snettisham Hatchery personnel using the calibrated volumetric displacement method (see Methods section 4).

The absence of an outlet weir at Tuya Lake prevented the direct enumeration of emigrating smolts. Therefore, estimates of smolt numbers were extrapolated using fall fry hydroacoustic estimates (Table 6.4). In Tuya Lake, the spring smolt population estimate was arbitrarily assumed to be 75% of the previous fall fry population estimate. For each year, the total smolt estimate was broken down into enhanced age 1+ and age

2+, using the proportions of each found in the smolt sample (Appendix C9) taken each spring (as determined by scale age and otolith thermal mark analyses).

Estimates of percent enhanced egg and fry-to-age 1+ smolt survivals, for broodyears 1993, and 1995-96, were calculated by dividing the age 1+ smolt estimate by the number of eggs, and by the number of fry outplanted.

RESULTS AND DISCUSSION

Sockeye fry and smolt data collected from Tatsamenie, Tahltan and Tuya lakes have been organized into seven sections: (1) Total spawner escapements to each of Tatsamenie and Tahltan lakes are summarized in Tables 6.1 and 6.2. (2) Fall hydroacoustic population estimates for Tatsamenie, Tahltan and Tuya lakes are summarized in Tables 6.3 and 6.4. (3) Sockeye fry and smolt growth data from Tatsamenie, Tahltan and Tuya lakes are presented as weight frequency plots (Figs. 6.5-6.13, Figs. 6.14-6.19, and Figs. 6.20-6.27), and as growth curve plots (Figs. 6.28-6.30), for each year of stocking. (4) Between-lake comparisons of enhanced mean smolt weights (Tatsamenie, Tahltan and Tuya lakes), and between-lake comparisons of wild and enhanced mean smolt weights (Tatsamenie and Tahltan lakes) are summarized. (5) Wild and enhanced egg and fry-to-age 1+ smolt survival is estimated for Tatsamenie and Tahltan lakes (Figs. 6.33 and 6.35). Enhanced fry-to-age 1+ smolt survival is estimated for Tuya Lake (Figs. 6.37). (6) The timing of enhanced Tatsamenie Lake fry mortality is identified and discussed. (7) Finally, within-lake relationships between growth, survival, and density are examined, and between-lake comparisons of growth and survival are summarized.

1. Spawner Escapement

Tatsamenie Lake

Estimates of total adult sockeye salmon escapement to Tatsamenie Lake from 1990 to 1999 ranged from 2,104 to 9,381 (Table 6.1). From 1990 to 1993, escapement was counted at the Little Tatsamenie Lake weir, located downstream of Tatsamenie Lake. These escapement estimates included spawners returning to both Little Tatsamenie and Tatsamenie lakes. In 1994, weirs were operated at both Little Tatsamenie and Tatsamenie lakes to determine what percentage of the spawners passing the Little Tatsamenie weir reach the Tatsamenie Lake weir. It was estimated that 80% of the fish that passed the Little Tatsamenie weir reached the Tatsamenie weir (P. Milligan pers comm. FOC Whitehorse, YK). This estimate was used to correct total escapement estimates from

Table 6.1. Tatsamenie Lake total spawner escapement and percentage of total escapement used for broodstock for broodyears 1990 to 1999.

Tatsamenie Lake		
Brood year	**Total spawner escapement**	**% of total escapement used for broodstock**
1990	4,492	12%
1991	6,570	11%
1992	4,545	17%
1993	4,022	16%
1994	2,847	25%
1995	5,780	22%
1996	9,381	24%
1997	8,097	26%
1998	5,997	20%
1999	2,104	10%

1990 to 1993. From 1995 onward, escapement was counted only at the Tatsamenie Lake weir. The percentage of total escapement used for Tatsamenie Lake broodstock averaged 18% (ranged from 10% to 26%).

1.2 Tahltan Lake

Estimates of total spawner escapements to Tahltan Lake from 1989 to 1999 ranged from 8,316 to 59,907 (Table 6.2).

Table 6.2. Tahltan Lake total spawner escapement and percentage of total escapement used for broodstock for Tahltan and Tuya lakes from 1989 to 1999.

Tahltan Lake				
Brood year	**Total spawner escapement**	**% of total escapement used for broodstock**	**% of total escapement used for Tahltan broodstock**	**% of total escapement used for Tuya broodstock**
1989	8,316	27%	27%	n/a
1990	14,927	22%	22%	n/a
1991	50,135	7%	3%	5%
1992	59,907	6%	3%	3%
1993	53,362	8%	1%	7%
1994	46,363	7%	2%	5%
1995	42,317	11%	5%	6%
1996	52,800	8%	4%	5%
1997	12,483	18%	15%	3%
1998	12,658	25%	12%	13%
1999	10,748	28%	18%	10%

The percent of total escapement that was captured for broodstock averaged 15% (ranged from 6% to 28%). Tahltan Lake broodstock was used to produce fry that were stocked into both Tahltan and Tuya lakes. An average of 10% (range of 1% to 27%) of total Tahltan Lake broodstock was used to stock Tahltan Lake, and an average of 6% (range of 3% to 13%) was used to stock Tuya Lake.

2. Juvenile Sockeye Population Estimates

The size of the total limnetic juvenile population in each lake was estimated using hydroacoustic techniques (Tables 6.3 and 6.4). These estimates were broken down by origin (wild sockeye fry vs. enhanced sockeye fry in Tatsamenie and Tahltan lakes) and by species (enhanced sockeye vs. limnetic sculpins in Tuya Lake).

Table 6.3. Limnetic population estimates (and 95% confidence intervals (CI)) of wild and enhanced sockeye fry obtained during fall hydroacoustic and mid-water trawl surveys at Tatsamenie and Tahltan lakes from 1990 to 1999.

Tatsamenie Lake					***Tahltan Lake***				
Survey	**Hydroacoustic Estimate**				**Survey**	**Hydroacoustic Estimate**			
Year	**Total**	**95% CI**	**Wild**	**Enhanced**	**Year**	**Total**	**95% CI**	**Wild**	**Enhanced**
1990	no survey	n/a	n/a	n/a	1990	272,330	77,016	n/a	n/a
1991	821,688	289,562	767,347	32,653	1991	995,918	182,411	513,618	482,300
1992	1,795,965	772,015	n/a	n/a	1992	no estimate due to technical problems			
1993	1,146,100	409,859	1,000,409	145,691	1993	817,400	158,828	417,489	294,440
1994	1,053,200	358,658	1,034,393	18,807	1994	377,408	154,969	355,200	22,200
1995	940,100	366,896	852,649	87,451	1995	no survey	n/a	n/a	n/a
1996	831,900	324,400	772,479	59,421	1996	615,321	95,940	396,055	219,252
1997	1,977,646	679,250	1,773,765	203,881	1997	298,773	47,232	96,404	189,097
1998	629,660	283,898	561,619	68,041	1998	no survey	n/a	n/a	n/a
1999	352,000	94,076	321,376	30,624	1999	220,000	61,500	n/a	n/a

In Tatsamenie Lake, estimated fall limnetic densities (1991, 1993-99) averaged 546 ha^{-1} for wild sockeye, and 50 ha^{-1} for enhanced sockeye (596 ha^{-1} combined). In Tahltan Lake, estimated fall limnetic densities (1991, 1993-94, 1996-97) averaged 723 ha^{-1} for wild sockeye, and 491 ha^{-1} for enhanced sockeye (1214 ha^{-1} combined).

Table 6.4. Limnetic population estimates (and 95% confidence intervals (CI)) of enhanced sockeye fry and limnetic sculpins obtained during fall hydroacoustic and mid-water trawl surveys at Tuya Lake from 1992 to 1999. Total trawl catch sample size (trawl N) is also given.

Tuya Lake								
Survey Year	**Survey Date**	**Hydroacoustic Estimate**						
		Total	**95% CI**	**Trawl N**	**Enhanced**	**95% CI**	**Sculpin**	**95% CI**
1992	18-Sep	596,537	196,156	60	99,423	32,693	497,114	163,463
1993	2-Sep	437,304	228,578	7	374,832	194,911	62,472	32,485
* 1994	5-Sep	1,995,119	1,114,417	132	1,980,004	1,105,974	15,115	8,443
1995	9-Sep	1,526,065	1,429,780	26	1,349,981	1,312,192	176,084	171,155
* 1996	12-Sep	2,109,019	498,881	91	1,436,914	330,490	672,105	154,584
* 1997	25-Sep	2,066,449	550,088	177	1,926,351	512,794	140,098	37,294
1998	19-Sep	659,606	280,102	5	131,921	56,020	527,685	224,082
1999	14-Sep	1,026,517	314,830	11	93,320	28,621	933,197	286,209

* Only for years in which trawl catch was sufficient (>75 fish), were population estimates for sockeye fry and limnetic sculpin used in mean density and survival calculations (1994, and 1996-97).

In Tuya Lake, estimated fall limnetic densities (1994, 1996-97) averaged 604 ha^{-1} for enhanced sockeye and 94 ha^{-1} for limnetic sculpin (698 ha^{-1} combined).

3. Growth: Juvenile Sockeye

Data collected from sockeye fry and smolts comprised fork length, wet weight, otolith thermal mark presence/absence, age, and sample sizes of fish collected by beach seining, trawling and smolt sampling. Detailed data can be found in Appendices C1-C3. The data were collected to evaluate enhanced sockeye growth with respect to wild sockeye growth. Weight frequency distributions of wild and enhanced fry and smolts were plotted and analysed for differences. This lead to the analysis and comparison of wild and enhanced fish mean weights. For each year, Kruskal-Wallis tests were used to determine whether there were significant differences between wild and enhanced fry mean weights (in early spring) and between wild and enhanced smolts (at smolt outmigration the following spring).

3.1 Weight Frequency Distributions – Tatsamenie Lake

Weight frequency distributions were plotted for wild and enhanced fry captured in beach seines and trawls from 1992 to 1999 (Figs. 6.5-6.12). In general, for beach seine and trawl samples that had good numbers of enhanced fry, comparisons of weight frequency distributions revealed that enhanced fry weights were usually lower than wild fry weights, but that enhanced fry weights fell within the range of wild fry weights. It is interesting to note that wild fry caught in the August 21, 1992 beach seine (Fig. 6.5) appear to have been larger than those caught in the September 28, 1992 beach seine. This may be due to the migration of larger fry from inshore to offshore rearing areas within this time period, with fewer and fewer numbers of smaller fry remaining onshore. This is supported by the fact that fry caught in trawls are usually equal or greater in size than fry caught by beach seining on the same date.

Weight frequency distributions were plotted for wild and enhanced smolts captured by fyke netting the lake outlet during smolt outmigration from 1993 to 1999 (Fig. 6.13). Comparisons of wild and enhanced smolt weight frequency distributions show that enhanced smolt weights fell within the range of wild weights. In Tatsamenie Lake, the majority of smolts were age 1+, meaning they had inhabited the lake for one year after hatching (wild) or stocking (enhanced). From 1993 to 1999, the average total sample size of smolts was 329, ranging from 95 smolts in 1993, to 495 smolts in 1999 (Appendix C7). Age 1+ smolts made up an average of 85% (74% to 98%) of the total smolt population. On average, age 2+ smolts made up 15 % (2% to 26%) of the total smolt population. No age 3+ smolts were captured. Weight frequency distributions of age 2+ smolts were not plotted due to low sample sizes, and due to the fact that the most significant fry mortality occurs during the first year of lake residence. It is the growth and survival during this first year that we are primarily interested in.

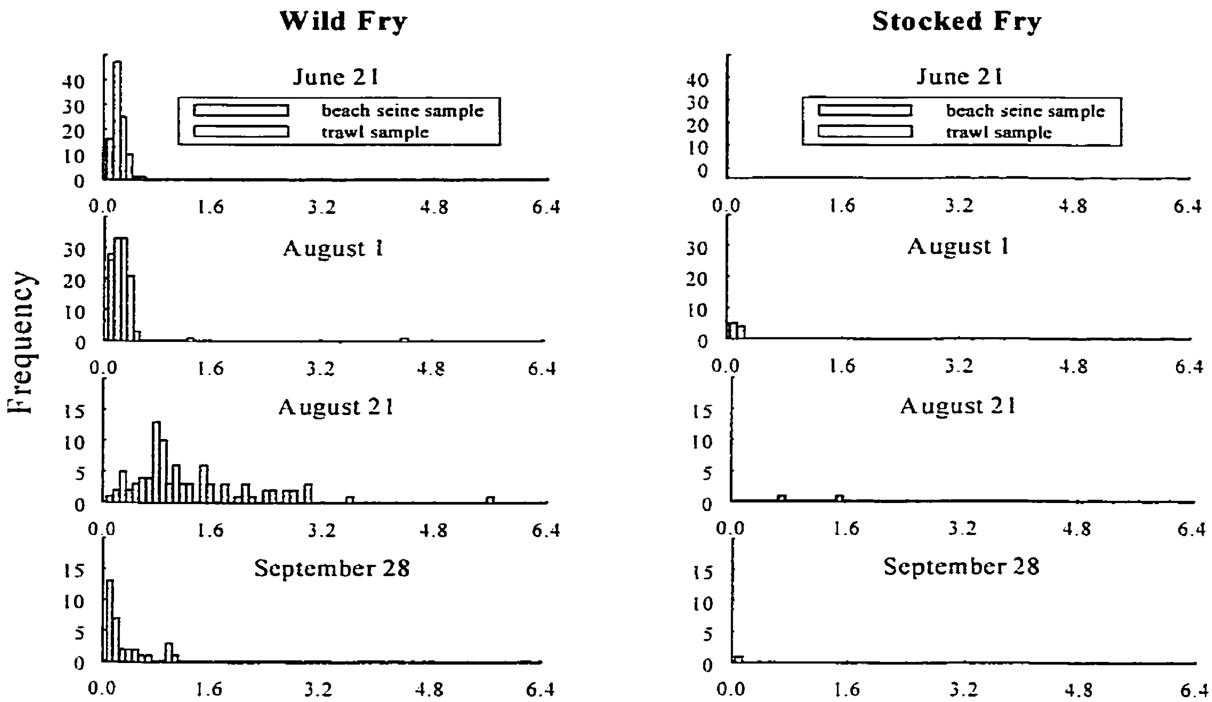


Figure 6.5. Tatsamenie Lake 1992. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls.

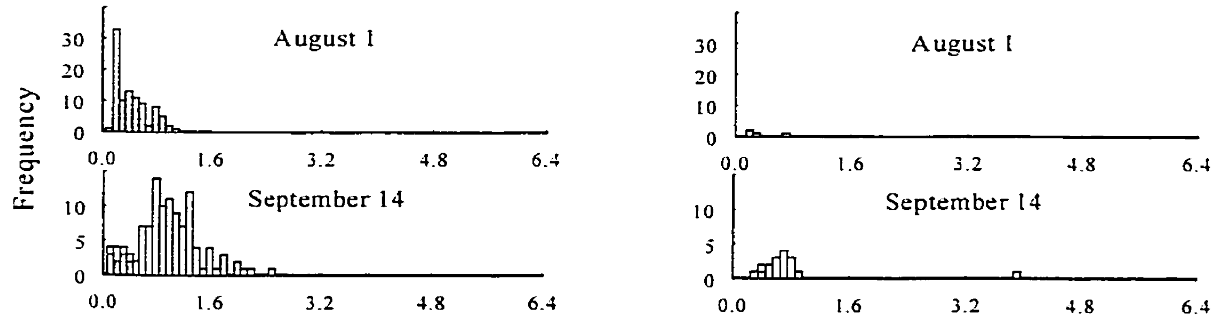


Figure 6.6. Tatsamenie Lake 1993. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls.

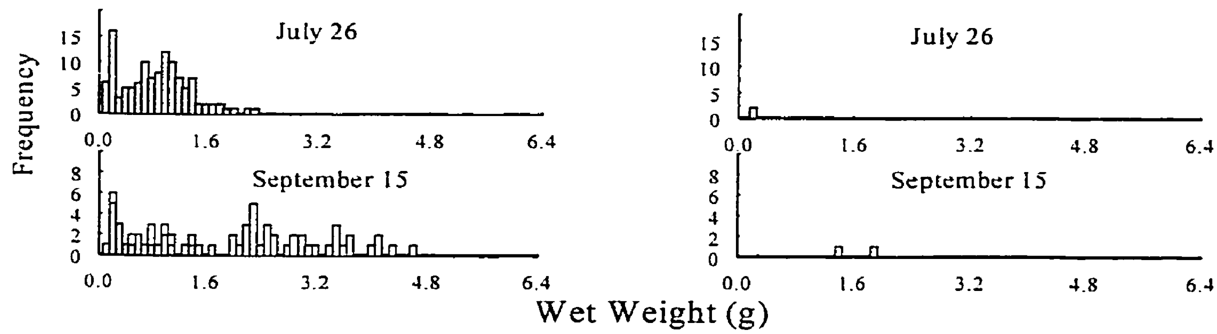


Figure 6.7. Tatsamenie Lake 1994. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls.

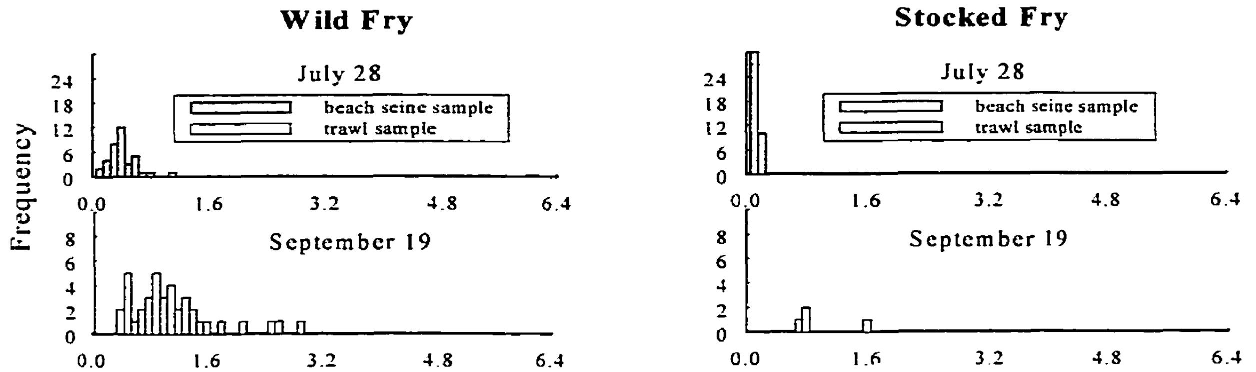


Figure 6.8. Tatsamenie Lake 1995. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls.

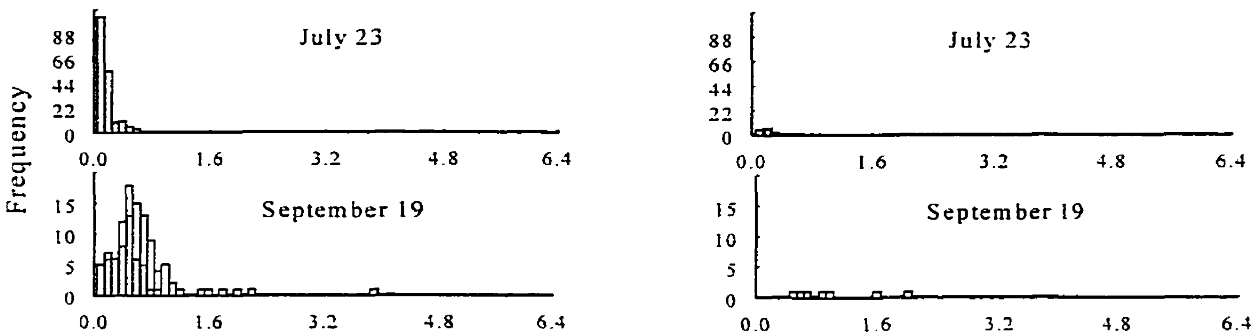


Figure 6.9. Tatsamenie Lake 1996. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls.

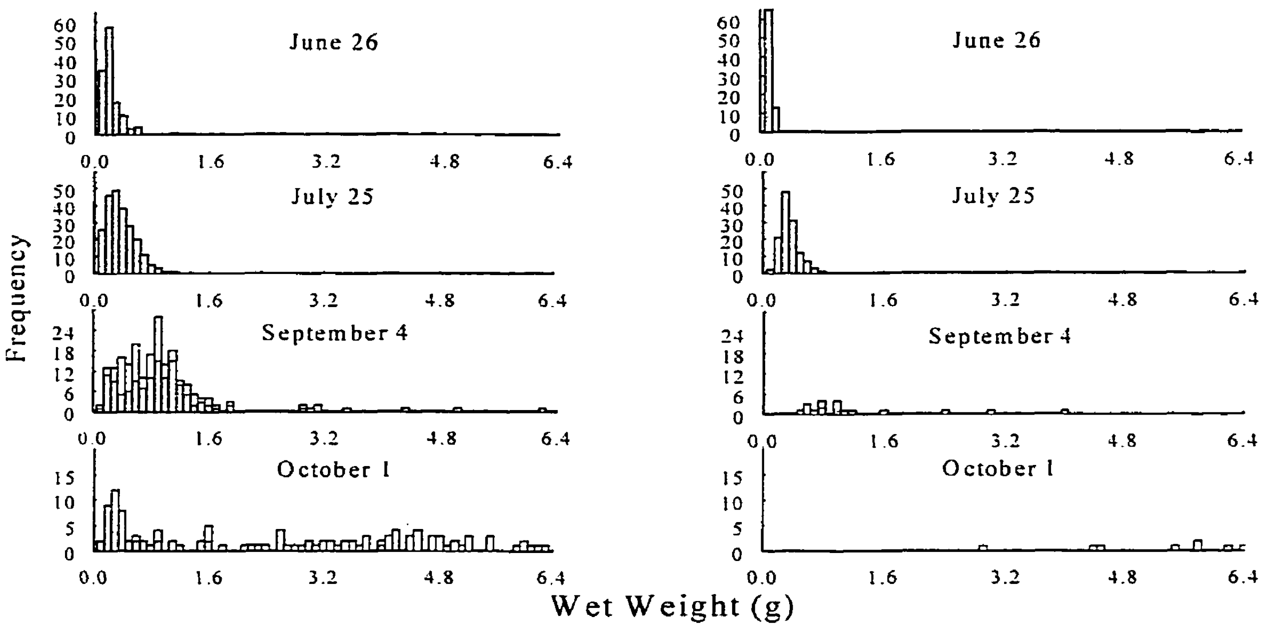


Figure 6.10. Tatsamenie Lake 1997. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls.

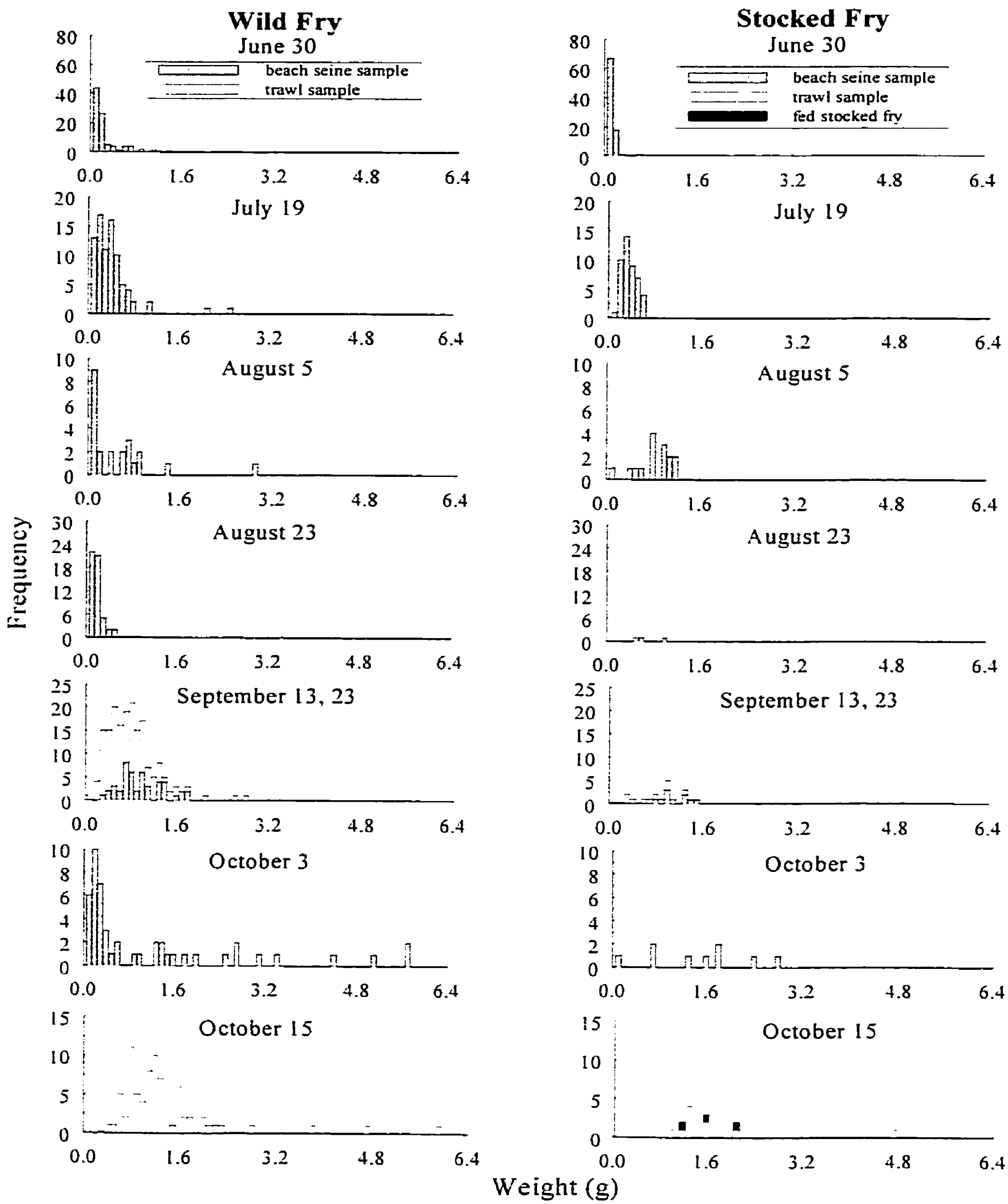


Figure 6.11. Tatsamenie Lake 1998. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls. Enhanced fry were either fed in net pens before stocking, or were stocked unfed, directly from the hatchery.

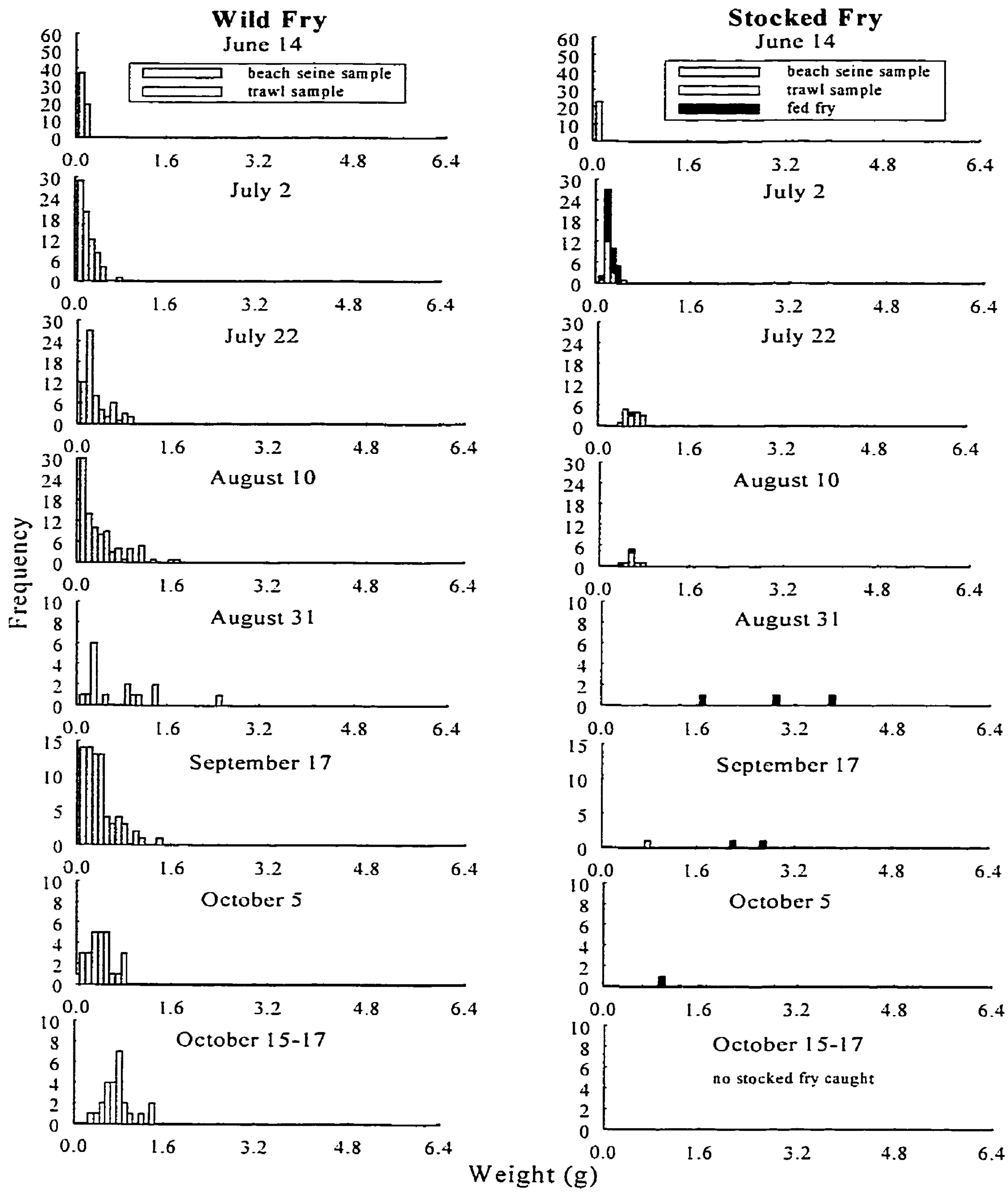


Figure 6.12. Tatsamenie Lake 1999. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls. Enhanced fry were either fed in net pens before stocking, or were stocked unfed, directly from the hatchery.

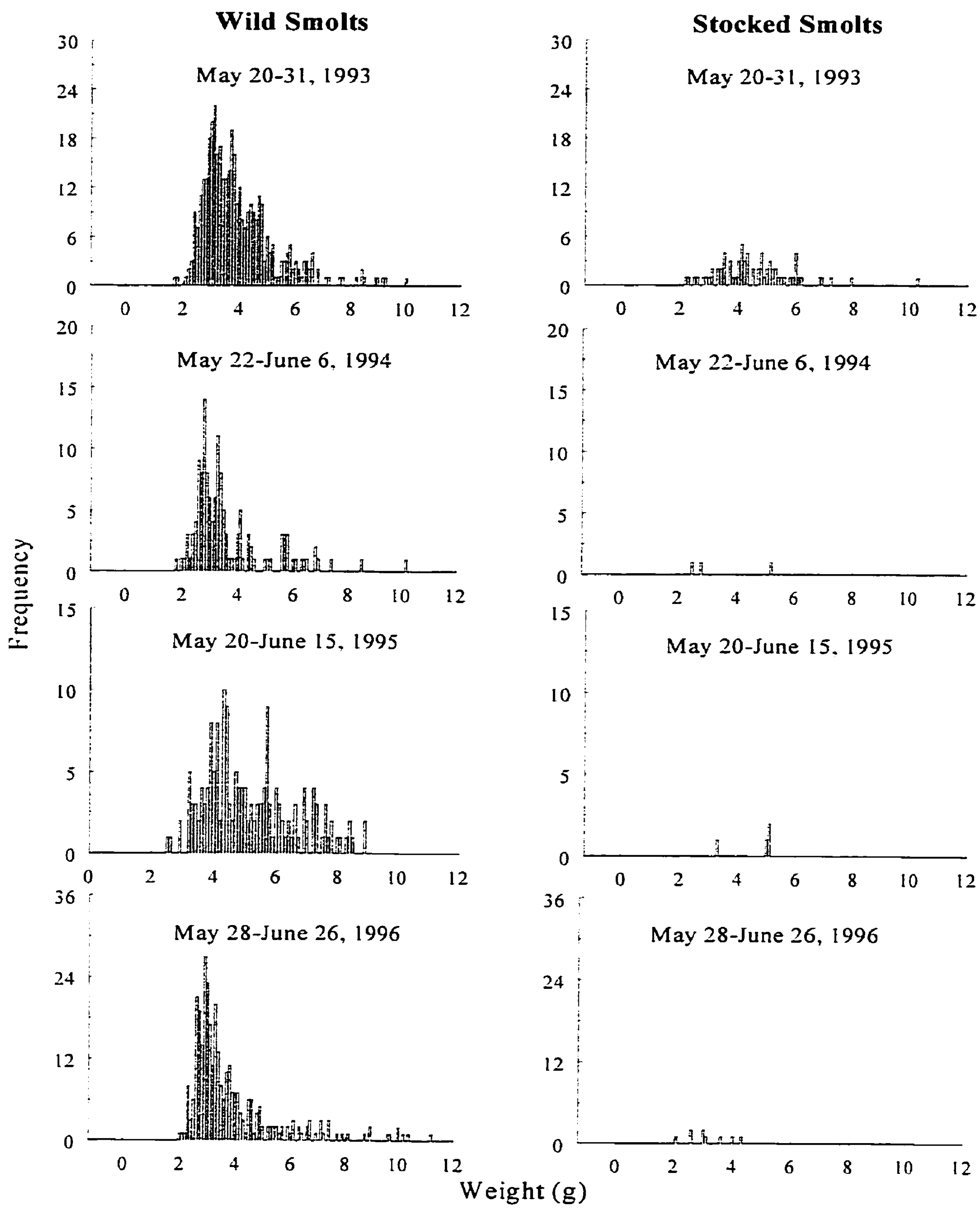


Figure 6.13. Tatsamenie Lake smolts. Weight-frequency distributions of wild and enhanced smolts captured by fyke netting during smolt outmigration from 1993 to 1999.

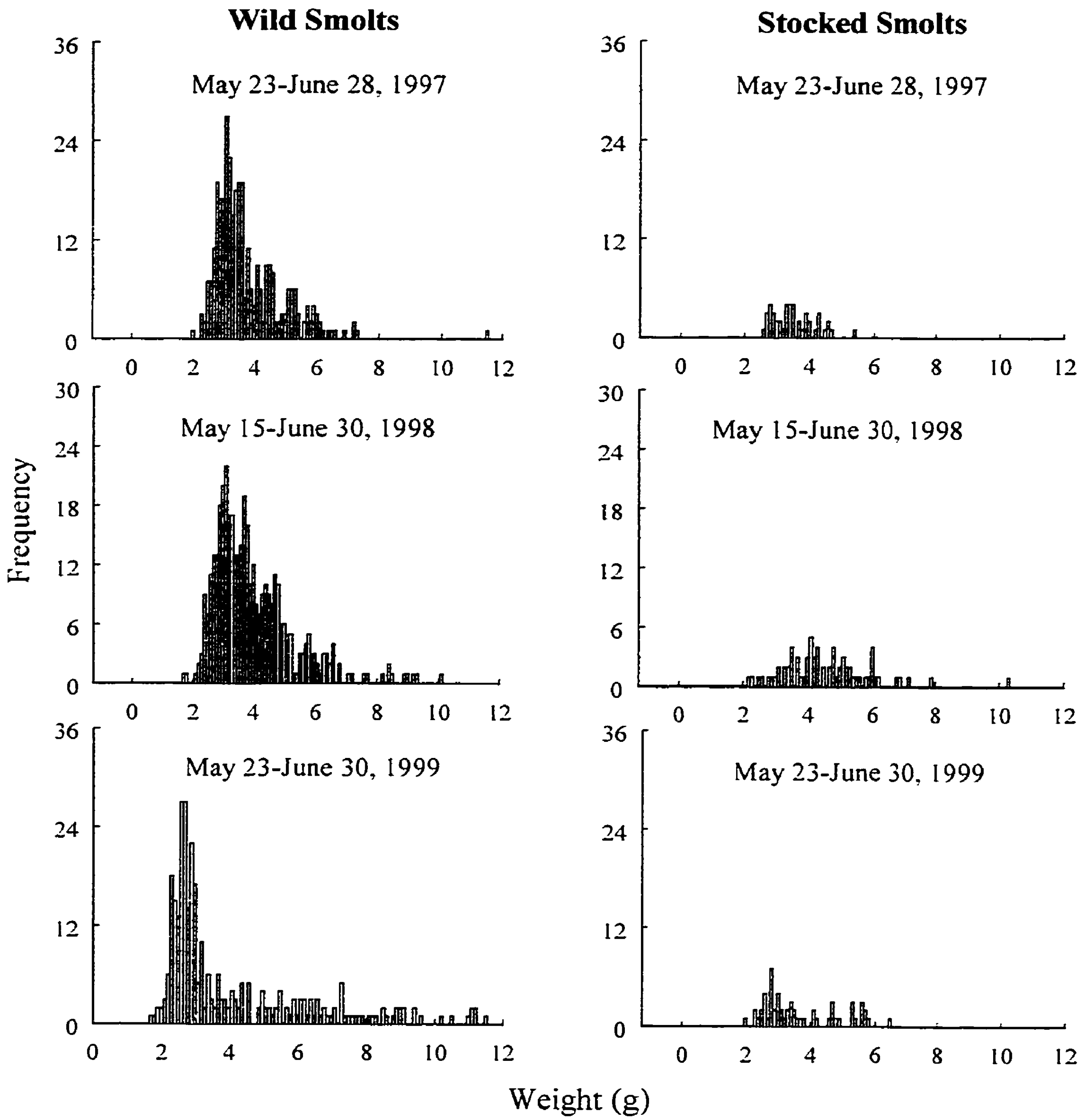


Figure 6.13 continued. Tatsamenie Lake smolts. Weight-frequency distributions of wild and enhanced smolts captured by fyke netting during smolt outmigration from 1993 to 1999.

3.2 Weight Frequency Distributions – Tahltan Lake

The weight frequency distributions of wild and enhanced fry were plotted for each beach seine and trawl sample taken from 1992 to 1999 (Figs. 6.14-6.18). For all comparisons between wild and enhanced weight frequency distributions, enhanced fry had lower weights than wild fry, but enhanced fry weights fell within the range of wild fry weights.

Weight frequency distributions were plotted for all wild and enhanced smolts sampled from the lake outlet weir from 1991 to 1999 (Fig. 6.19). Comparisons between wild and enhanced smolt weight frequencies show that enhanced smolt weights fell within the range of wild smolt weights. In Tahltan Lake, the majority of smolts were age 1+, meaning they had inhabited the lake for one year after hatching (wild) or stocking (enhanced). From 1991 to 1999, the average total sample size of smolts was 443, ranging from 199 smolts in 1994, to 677 smolts in 1998 (Appendix C8). Age 1+ smolts made up an average of 93% (91% to 98%) of the total smolt population. On average, age 2+ smolts made up 7 % (2% to 9%) of the total smolt population. Very few age 3+ smolts were captured. Weight frequency distributions of age 2+ and age 3+ smolts were not plotted due to low sample sizes, and due to the fact that it is the growth and survival during the first year of lake residence that we are primarily interested in.

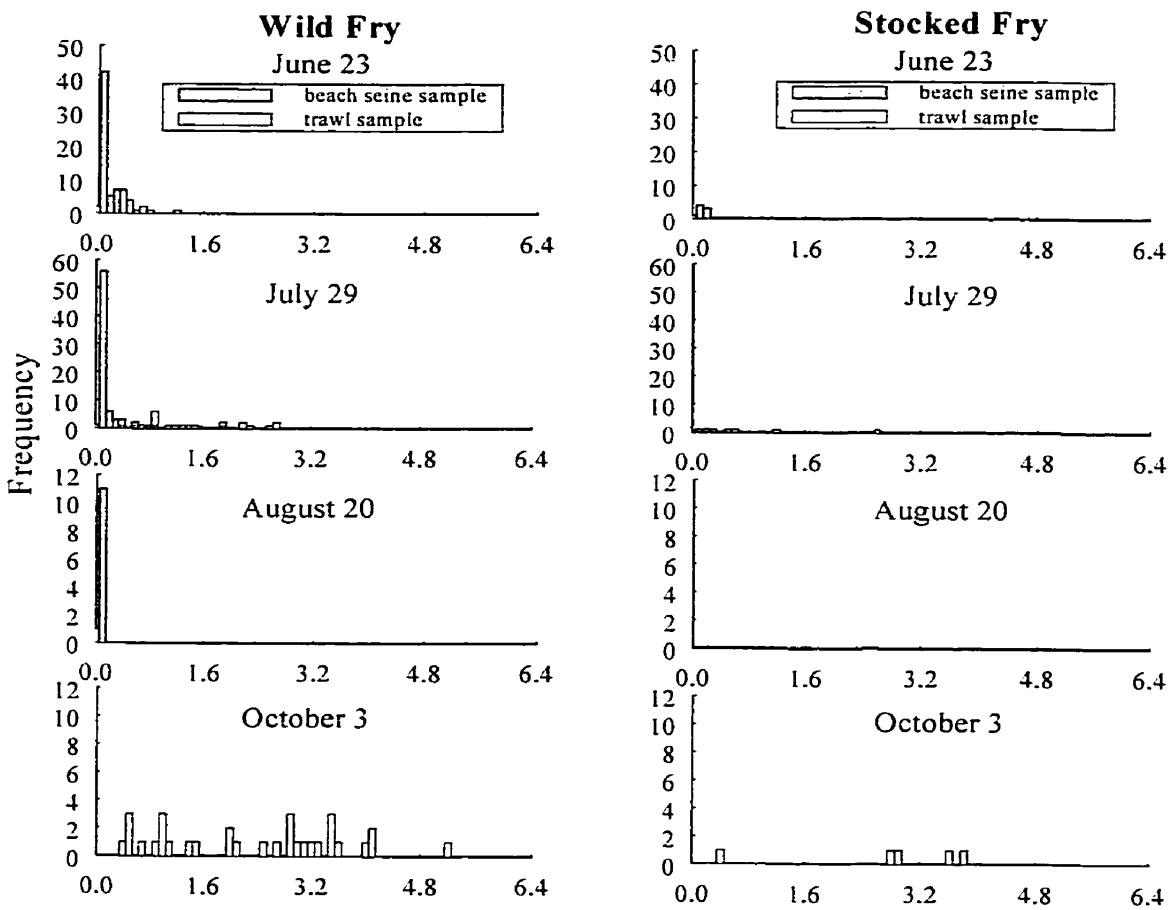


Figure 6.14. Tahltan Lake 1992. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls.

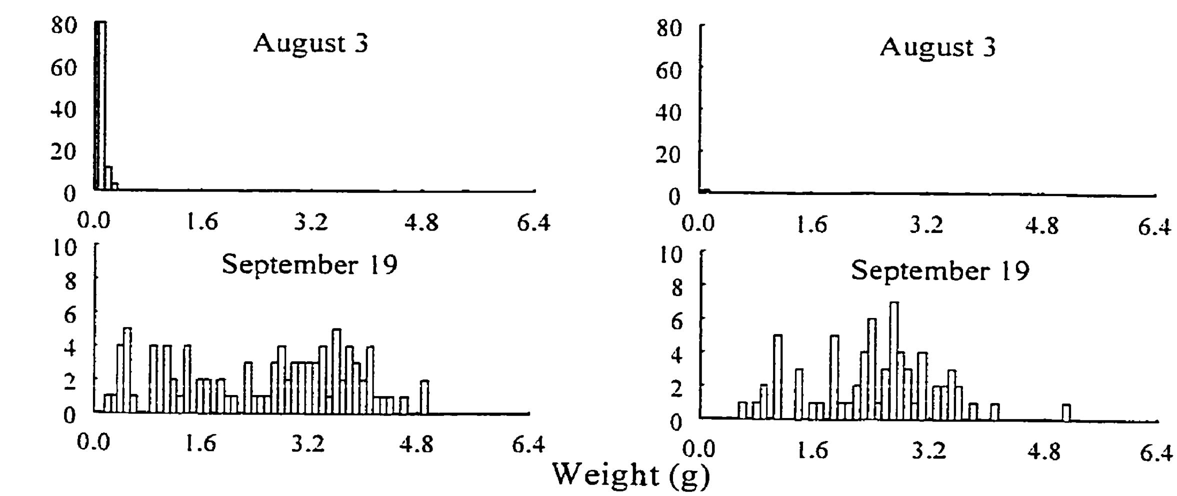


Figure 6.15. Tahltan Lake 1993. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls.

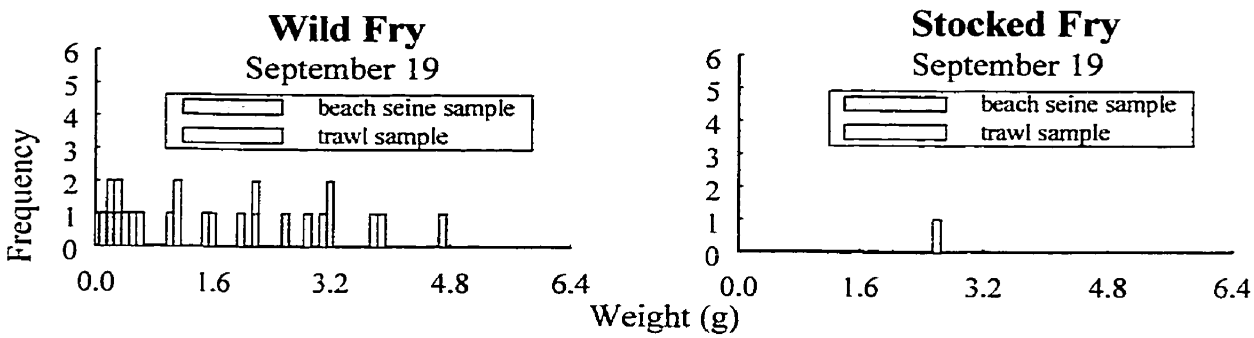


Figure 6.16. Tahltan Lake 1994. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls.

Fry sampling was not conducted in 1995

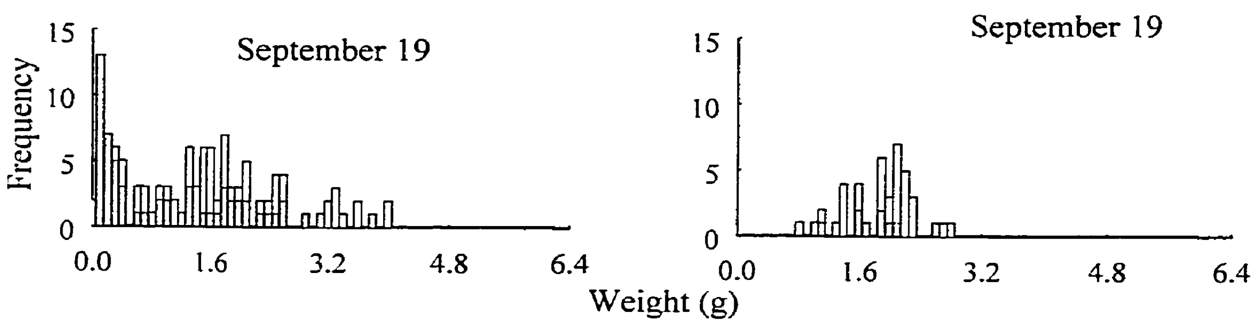


Figure 6.17. Tahltan Lake 1996. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls.

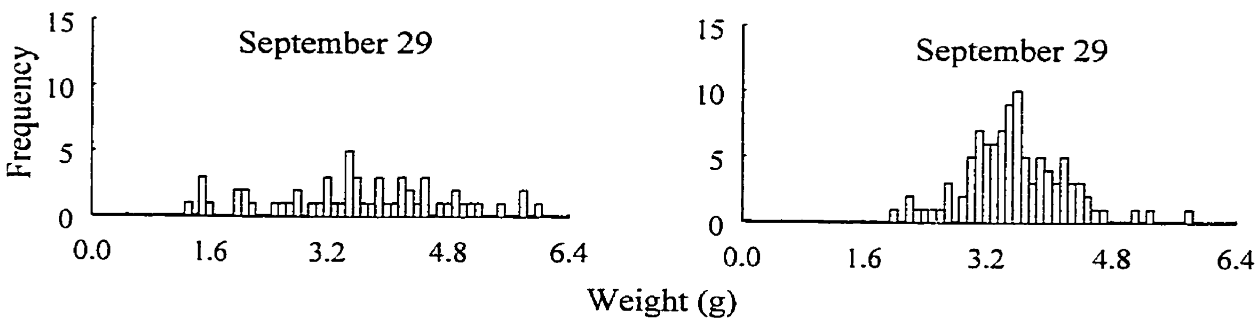


Figure 6.18. Tahltan Lake 1997. Weight-frequency distributions of wild and enhanced fry captured in beach seines and/or trawls.

Fry sampling was not conducted in 1998, and no fry were caught in 1999 trawls

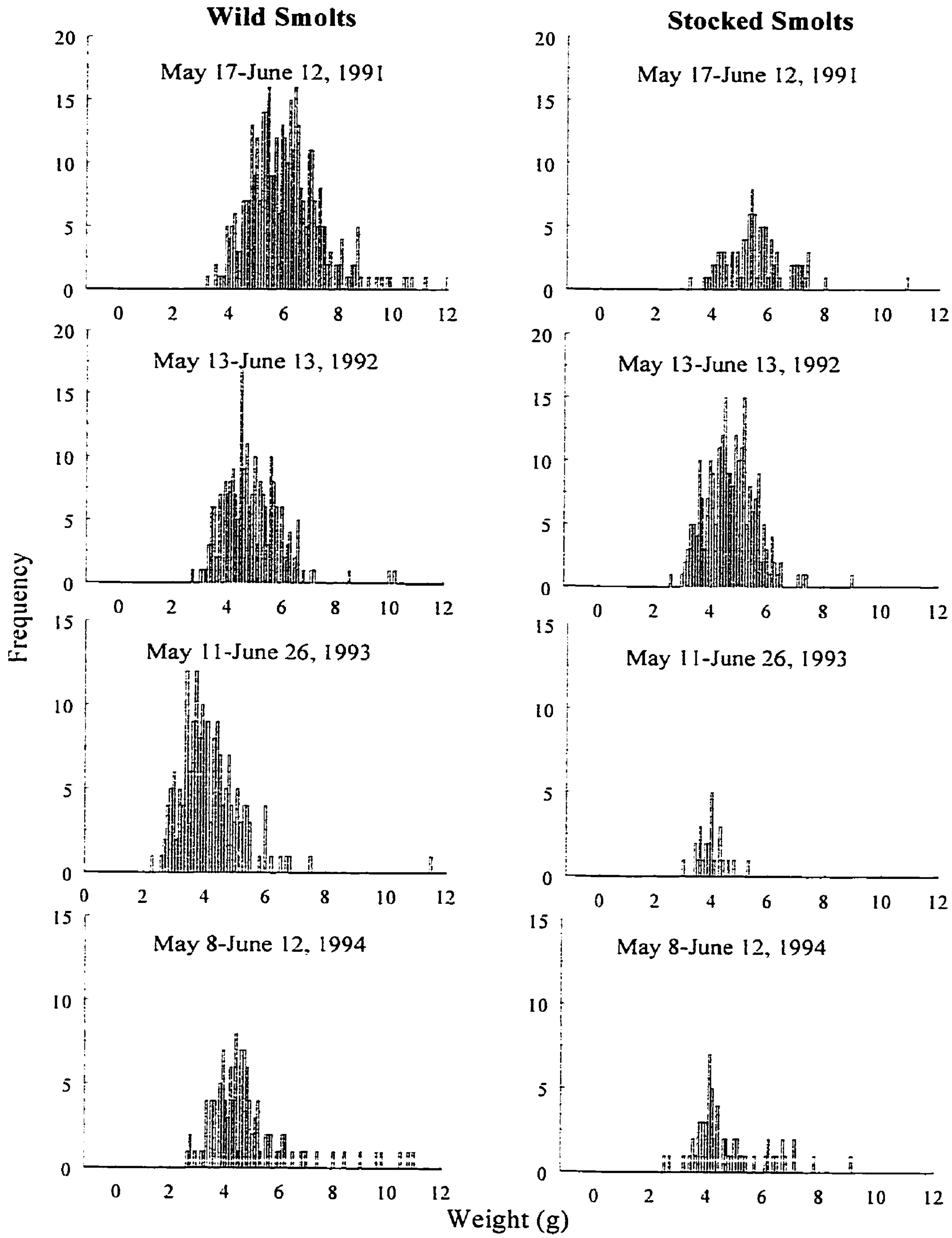


Figure 6.19. Tahltan Lake smolts. Weight-frequency distributions of wild and enhanced smolts captured at the outlet creek weir during smolt outmigration from 1991 to 1999.

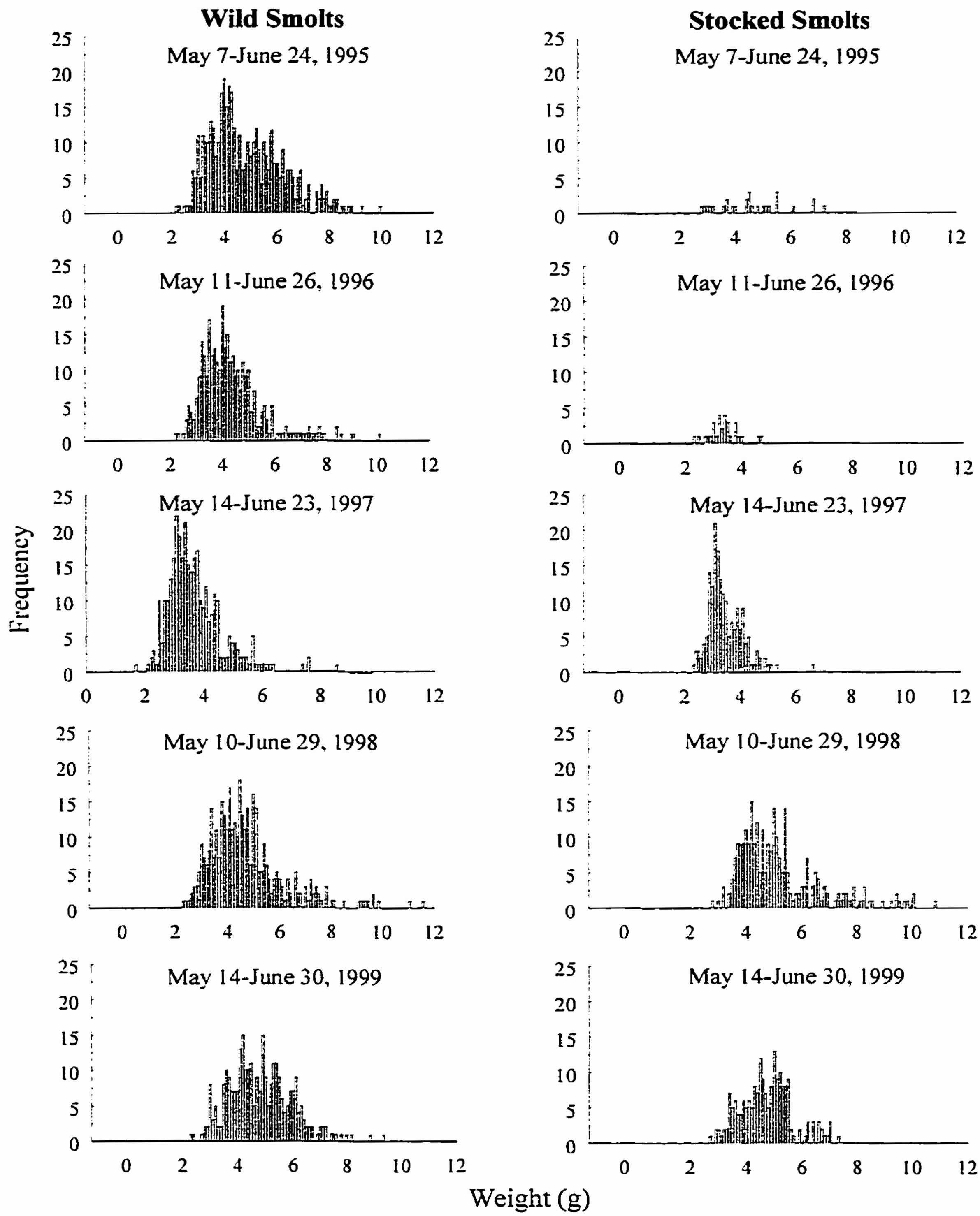


Figure 6.19 continued. Tahltan Lake smolts. Weight-freqruency distributions of wild and enhanced smolts captured at the outlet creek weir during smolt outmigration from 1991 to 1999.

3.3 Weight Frequency Distributions – Tuya Lake

Weight frequency distributions were plotted for enhanced fry captured in each beach seine and trawl sample taken from 1992 to 1999 (Figs. 6.20-6.26). Only enhanced fry were captured since Tuya Lake does not have a wild sockeye population.

Weight frequency distributions were plotted for age 1+ and 2+ enhanced smolts captured by fyke netting the lake outlet during smolt outmigration from 1993 to 1999 (Fig. 6.27). Average total sample size of smolts (1993 to 1999) was 278, ranging from 108 smolts in 1999, to 452 smolts in 1994 (Appendix 6.9). In Tuya Lake, the majority of smolts were age 1+. Age 1+ smolts made up an average of 87% (56% to 98%) of the total smolt population. On average, age 2+ smolts made up 13% (2% to 44%) of the total smolt population. In 1997 and 1999, 1 and 3 age 3+ smolts were captured.

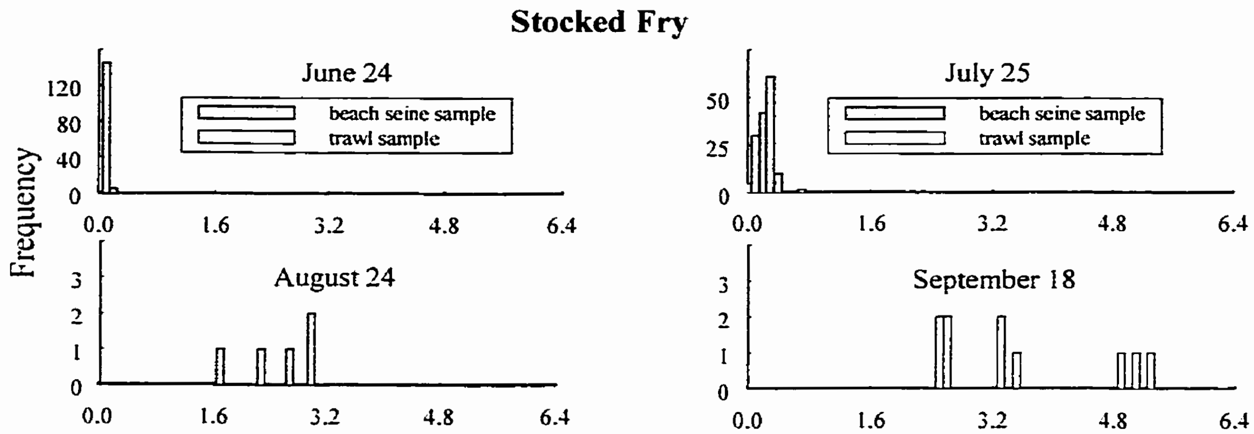


Figure 6.20. Tuya Lake 1992. Weight-frequency distributions of enhanced fry captured in beach seines or trawls.

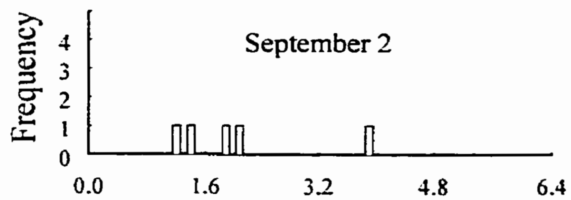


Figure 6.21. Tuya Lake 1993. Weight-frequency distributions of enhanced fry captured in beach seines or trawls.

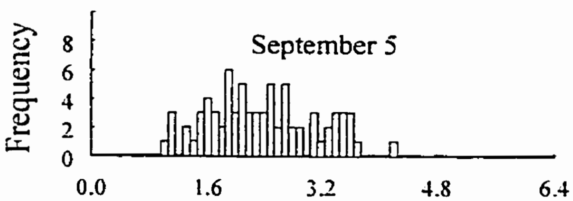


Figure 6.22. Tuya Lake 1994. Weight-frequency distributions of enhanced fry captured in beach seines or trawls.

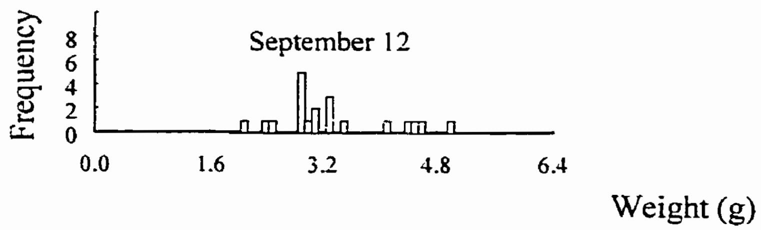


Figure 6.23. Tuya Lake 1995. Weight-frequency distributions of enhanced fry captured in beach seines or trawls.

Stocked Fry

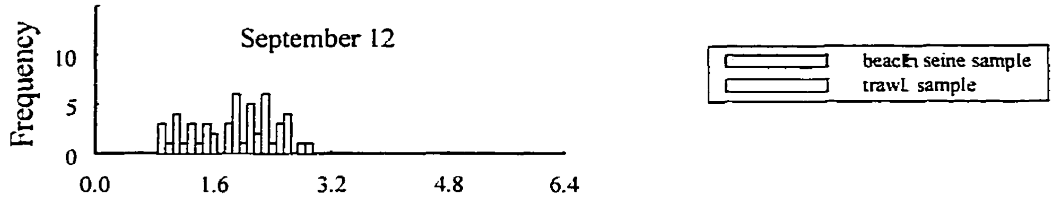


Figure 6.24. Tuya Lake 1996. Weight-frequency distribution of enhanced fry captured in trawls.

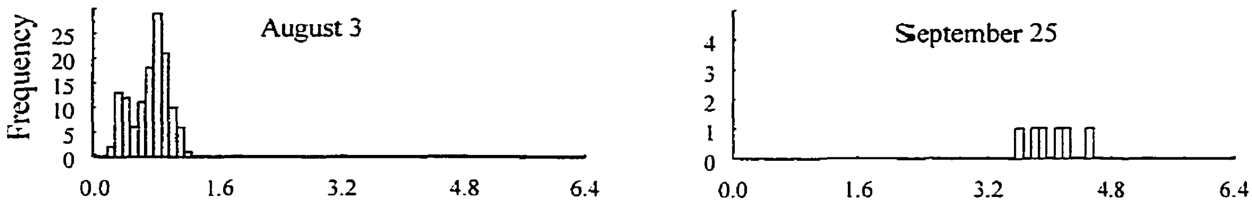


Figure 6.25. Tuya Lake 1997. Weight-frequency distributions of enhanced fry captured in beach seines or trawls.

Fry were not caught in 1998 beach seines and trawls

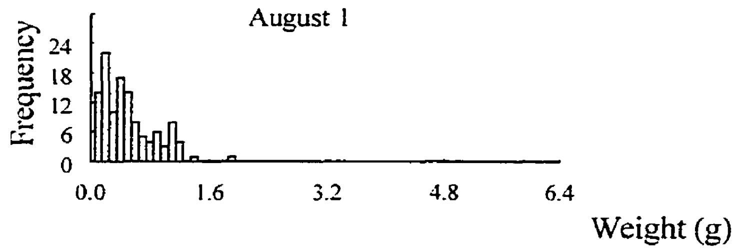


Figure 6.26. Tuya Lake 1999. Weight-frequency distribution of enhanced fry captured in beach seines.

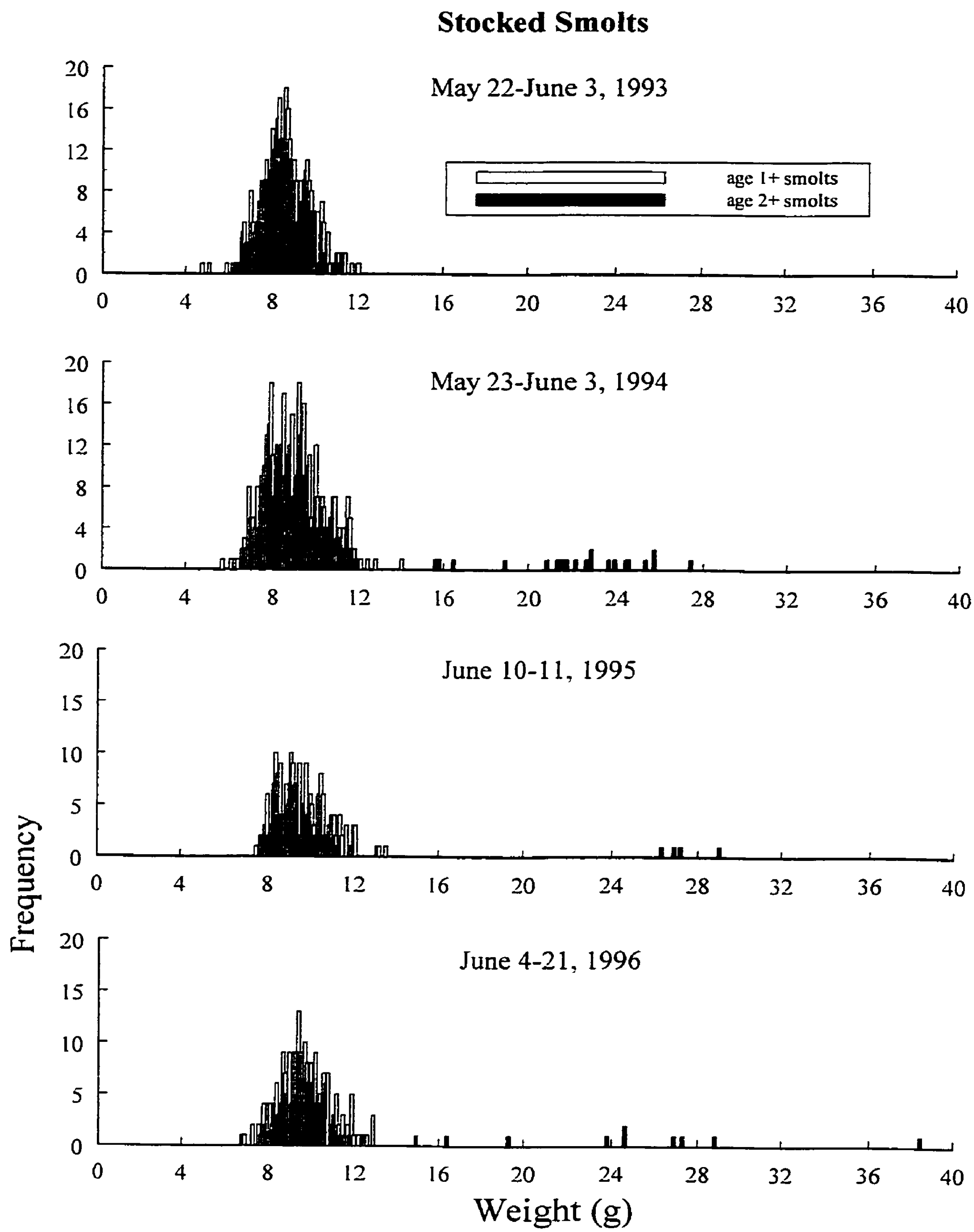


Figure 6.27. Tuya Lake smolts. Weight-frequency distributions of enhanced smolts captured by fyke netting during smolt outmigration from 1993 to 1999.

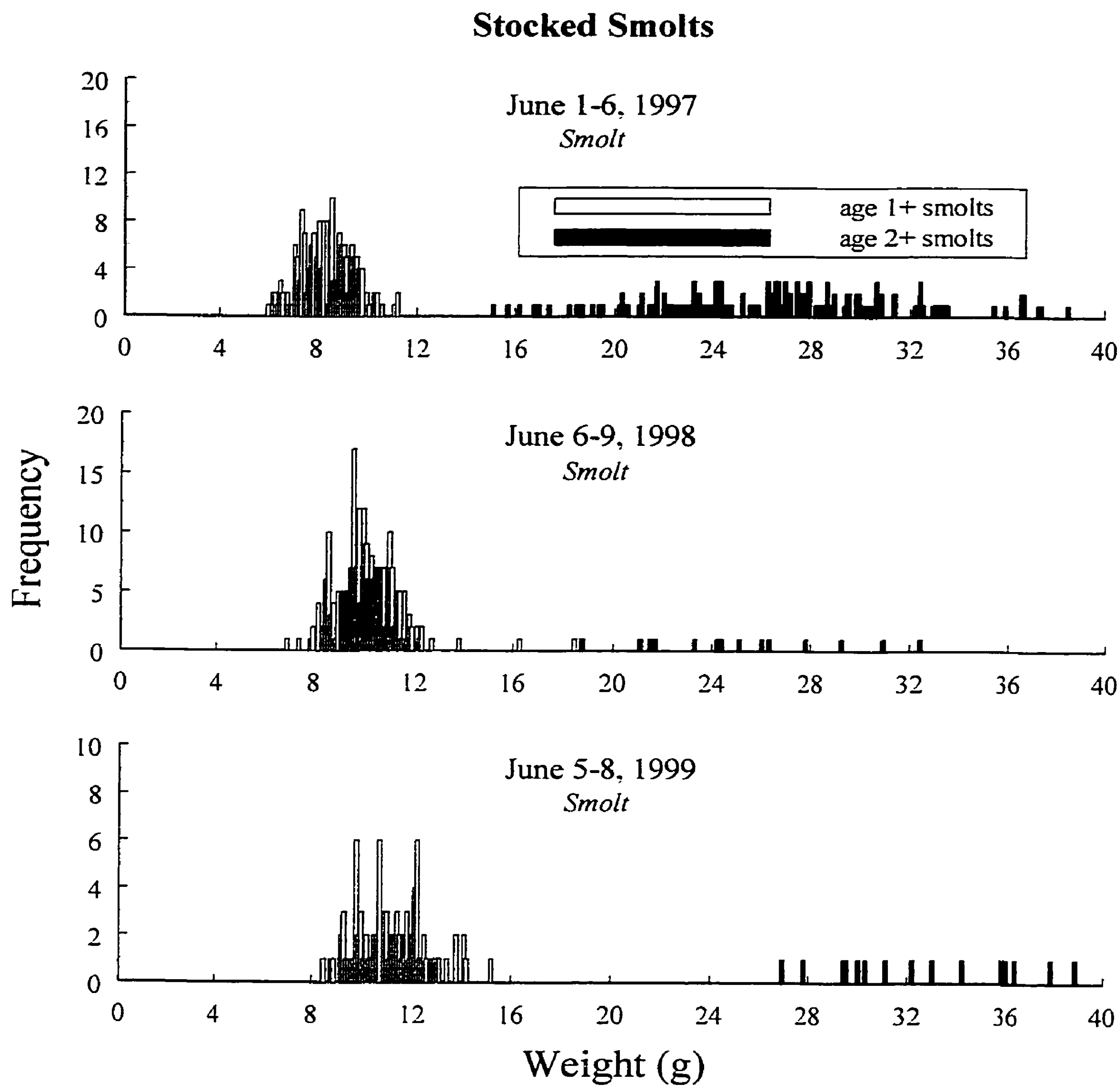


Figure 6.27 continued. Tuya Lake smolts. Weight-frequency distributions of enhanced smolts captured by fyke netting during smolt outmigration from 1993 to 1999.

3.4 Weight Frequency Distributions – Between-lake Comparisons

Analysis of the smolt weight frequency distribution data shows that Tuya Lake smolts were significantly larger after one year in the lake than smolts from Tatsamenie and Tahltan lakes. The average weight of age 1+ enhanced Tuya smolts was 9.5g, compared with average Tatsamenie age 1+ smolt weights of 4.1g (wild) and 3.8g (enhanced), and average Tahltan age 1+ smolt weights of 4.6g (wild) and 4.4g (enhanced) (Appendices C6-C9). For age 2+ smolts, the average weight of enhanced Tuya smolts was 26.8g, compared with average Tatsamenie smolt weights of 13.0g (wild) and 13.9g (enhanced), and average Tahltan smolt weights of 9.7g (wild) and 10.4g (enhanced) (Appendices C6-C9). Thus, the growth of Tuya juveniles in <u>one</u> year of lake residence, approximates the growth of Tatsamenie and Tahltan juveniles in their first <u>two</u> years of lake residence.

3.5 Growth – Tatsamenie Lake

Growth of wild and enhanced fry from Tatsamenie Lake was plotted from 1992 to 1999 (Fig. 6.28).

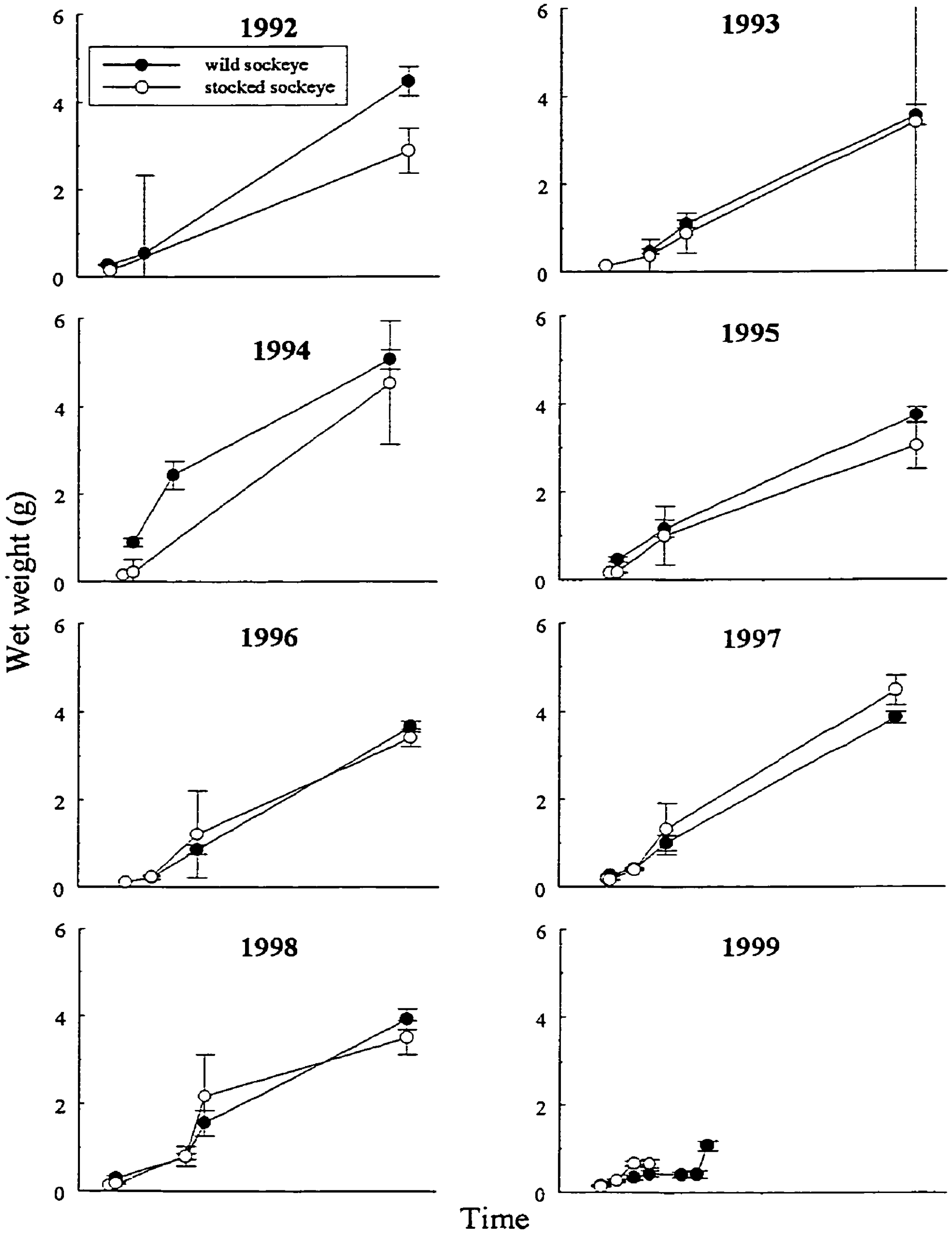


Figure 6.28. Tatsamenie Lake. Growth curves (with 95% confidence intervals) for wild and enhanced juvenile sockeye from the time of enhanced fry stocking (spring) to smolt outmigration (following spring). Year labels (1992 – 1999) refer to the year of stocking and in-lake growth.

Figure 6.28 shows that enhanced fry-to-smolt growth was similar to wild fry-to-smolt growth. In most years, wild smolts were slightly larger than enhanced smolts, but in only one year (1992) was this difference significant (i.e. no overlap of 95% confidence intervals). The exception is 1997, when enhanced smolts were significantly larger than wild fry (i.e. no overlap of confidence intervals).

For each year (1992 to 1998), mean fry weights in the spring, and mean smolt weights the following spring were compared. Kruskal-Wallis tests were used to compare differences between wild and enhanced fry and smolt mean weights, and a one-sample t-test was used to compare wild and enhanced fry mean weights in spring 1992 (Table 6.5).

Table 6.5. Results of Kruskal-Wallis test ($\alpha(2)=0.05$) comparisons between Tatsamenie Lake wild and enhanced fry and smolt mean weights, showing test statistic (bold= one-sample t-test), sample size (N; first value=wild, second value=enhanced), and p-value. Year refers to the stocking year (i.e. fry were stocked in 1992; associated smolt samples were taken the following spring, in 1993). N/a=test not done. The inference for fry: H_o=enhanced mean weights = wild mean weights. The inferenced for smolts: : H_o=enhanced mean weights = wild mean weights.

Year	Inference for fry	Test Stat	N	p-value	Inference for smolts	Test Stat	N	p-value
1992	enhanced smaller	**14**	100, n/a	p<0.01	[a] enhanced smaller	65	79, 6	p<0.01
1993	[a,b] no difference	254	95, 4	p=0.26	[a] no difference	166	137, 3	p=0.57
1994	[a,b] no difference	214	119, 2	p=0.55	[a] no difference	286	167, 4	p=0.63
1995	enhanced smaller	1439	37, 40	p<0.01	[a] no difference	1093	319, 9	p=0.22
1996	[b] no difference	900	186, 13	p=0.12	no difference	7952	330, 45	p=0.44
1997	enhanced smaller	8506	126, 78	p<0.01	enhanced larger	18398	393, 71	p<0.01
1998	enhanced smaller	5293	93, 87	p<0.01	no difference	9523	309, 57	p=0.33
1999	enhanced smaller	1126	57, 24	p<0.01	n/a	n/a	n/a	n/a

[a] these tests had low power because of low sample sizes.
[b] first beach seine sample was taken late (2-4 weeks after stocking) thus sample does not compare initial wild and enhanced fry mean weights.

In some years, the tests comparing mean weights between wild and enhanced fish had low power due to low sample sizes of enhanced fish in beach seine or smolt samples. In three years (1993-94 and 1996), the first beach seine sample was taken two to four weeks after enhanced fry were stocked. This does not allow the comparison of initial wild and enhanced fry sizes. It is interesting to note that it is in the three years of late beach seine sampling that no significant differences were found between wild and enhanced fry weights.

The four possible combinations of the mean weight comparison results are: (1) the enhanced fry were smaller than wild fry in spring and at smolt outmigration (1992), (2) the enhanced fry were not smaller in spring and at smolt outmigration (1993-94, 1996; low sample sizes, late initial sampling), (3) the enhanced fry were smaller in spring but not at smolt outmigration (1995, 1997-98), and (4) the enhanced fry were not smaller in spring but were smaller at smolt outmigration (this case did not occur). The results show that when enhanced fry were smaller than wild fry in early spring, the resultant enhanced smolts were either smaller than (1992), similar to (1995, 1998), or larger than (1997), wild smolts. When enhanced fry were similar in size to wild fry in spring, the resultant enhanced smolts were similar in size to wild smolts (1993-94 and 1996). Enhanced fry never started off similar in size to wild fry and then averaged smaller in size at smolt outmigration. The fry and smolt mean weight comparisons will be discussed further in the next chapter.

3.6 Growth - Tahltan Lake

Growth of wild and enhanced fry from Tahltan Lake was plotted from 1990 to 1999 (Fig. 6.29).

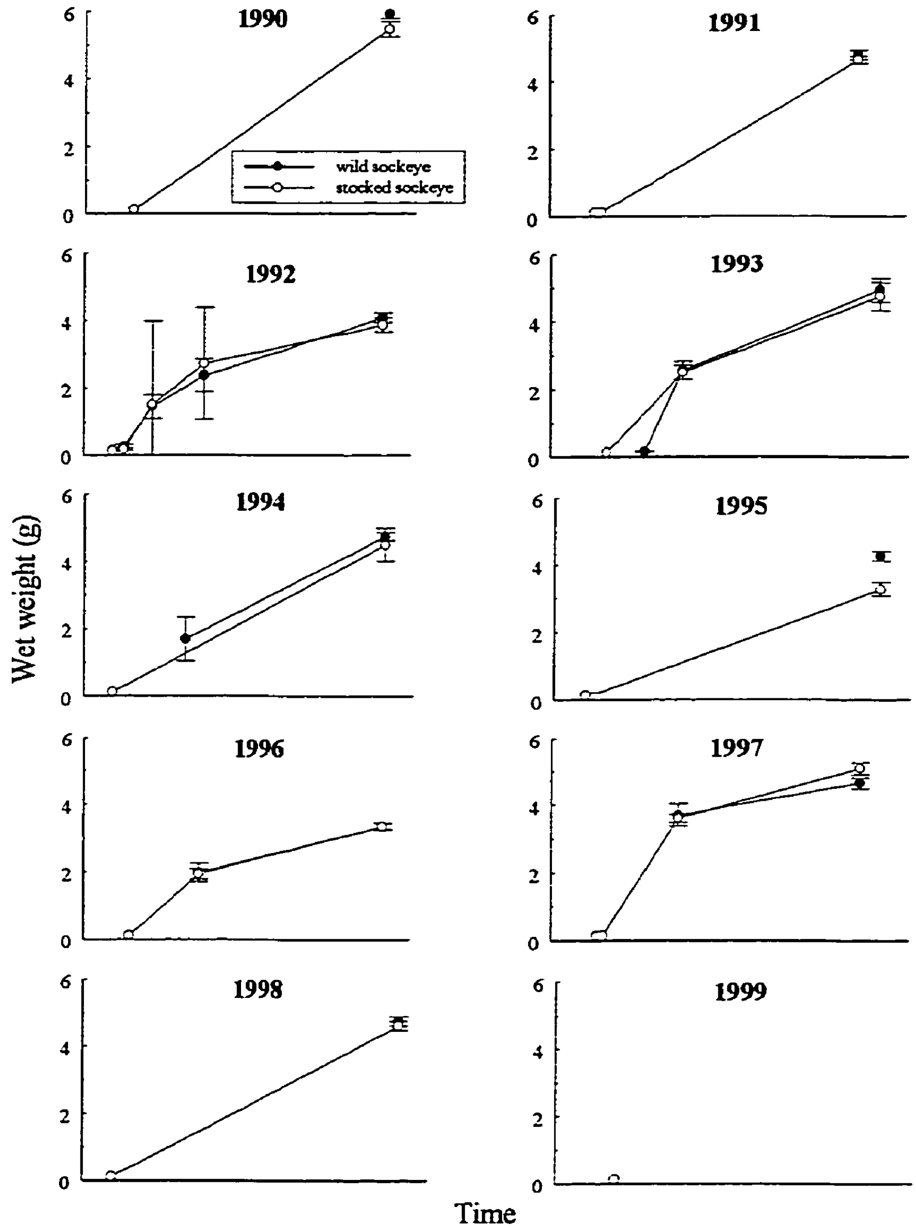


Figure 6.29. Tahltan Lake. Growth curves (with 95% confidence intervals) for wild and enhanced juvenile sockeye from the time of enhanced fry stocking (spring) to smolt outmigration (following spring). Year labels (1990 – 1999) refer to the year of stocking and in-lake growth.

Figure 6.29 shows that enhanced fry-to-smolt growth was similar to wild fry-to-smolt growth. In most years, wild smolts were larger than enhanced smolts, but only in two years (1990, 1995) was this difference significant (due to non-overlap of 95% confidence intervals). The exception is 1997, when enhanced smolts were significantly larger than wild fry (due to non-overlap of confidence intervals).

For each year (1990 to 1998, Fig. 6.29), wild and enhanced mean smolt weights were compared using Kruskal-Wallis tests (Table 6.6).

Table 6.6. Results of Kruskal-Wallis test ($\alpha(2)=0.05$) comparisons between Tahltan Lake wild and enhanced fry and smolt mean weights, showing test statistic, sample size (N; first value=wild, second value=enhanced), and p-value. Year refers to the stocking year (i.e. fry were stocked in 1990; associated smolt samples were taken the following spring, in 1991). N/a indicates the test was not done.
The inference for fry: H_o=enhanced mean weights = wild mean weights.
The inferenced for smolts: : H_o=enhanced mean weights = wild mean weights.

Year	Inference for fry	Test Stat	N	p-value	Inference for smolts	Test Stat	N	p-value
1990	n/a	n/a	n/a	n/a	enhanced smaller	14292	371, 97	p<0.01
1991	n/a	n/a	n/a	n/a	no difference	23807	211, 243	p=0.19
1992	[a, b] no difference	325	72, 8	p=0.55	no difference	2122	185, 25	p=0.50
1993	n/a	n/a	n/a	n/a	no difference	3544	117, 64	p=0.55
1994	n/a	n/a	n/a	n/a	no difference	5218	418, 27	p=0.51
1995	n/a	n/a	n/a	n/a	enhanced smaller	2026	318, 30	p<0.01
1996	n/a	n/a	n/a	n/a	enhanced smaller	33438	323, 180	p<0.01
1997	n/a	n/a	n/a	n/a	enhanced larger	38098	362, 292	p<0.01
1998	n/a	n/a	n/a	n/a	no difference	29756	295, 194	p=0.46
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

[a] sample size was very low, thus the result is questionable.
[b] first beach seine sample was taken 13 days after stocking thus sample does not compare initial wild and enhanced fry mean weights.

Fry weights could not be compared for 1990-1991 and 1993-1999 due to the lack of early season beach seine sampling. The only fry-smolt mean weight comparison (1992, Table 6.6) shows that there was no significant difference between wild and enhanced fry weights close to the time of stocking, and between wild and enhanced smolts the following spring. However, in 1992, the beach seine sample size was low (N_{wild}=72, $N_{enhanced}$=8) and the sample was taken 13 days after stocking, making the size comparison result questionable. Of the nine smolt-year comparisons, enhanced smolts were similar in size to wild smolts in five years (1991-94, 1998), significantly smaller than wild smolts in three years (1990, 1995-96), and significantly larger than wild smolts in one year (1997).

3.7 Growth - Tuya Lake

Growth, for enhanced fry in Tuya Lake, was plotted from 1992 to 1999 (Fig. 6.30). Figure 6.30 shows that enhanced fry had very good growth in their first year, reaching an average mean smolt weight of 9.5g (Appendix C9). This is much higher than the fry-to-smolt growth seen in Tatsamenie and Tahltan lakes, where average mean smolt weights were 3.8g (Appendix C7) and 4.4g (Appendix C8).

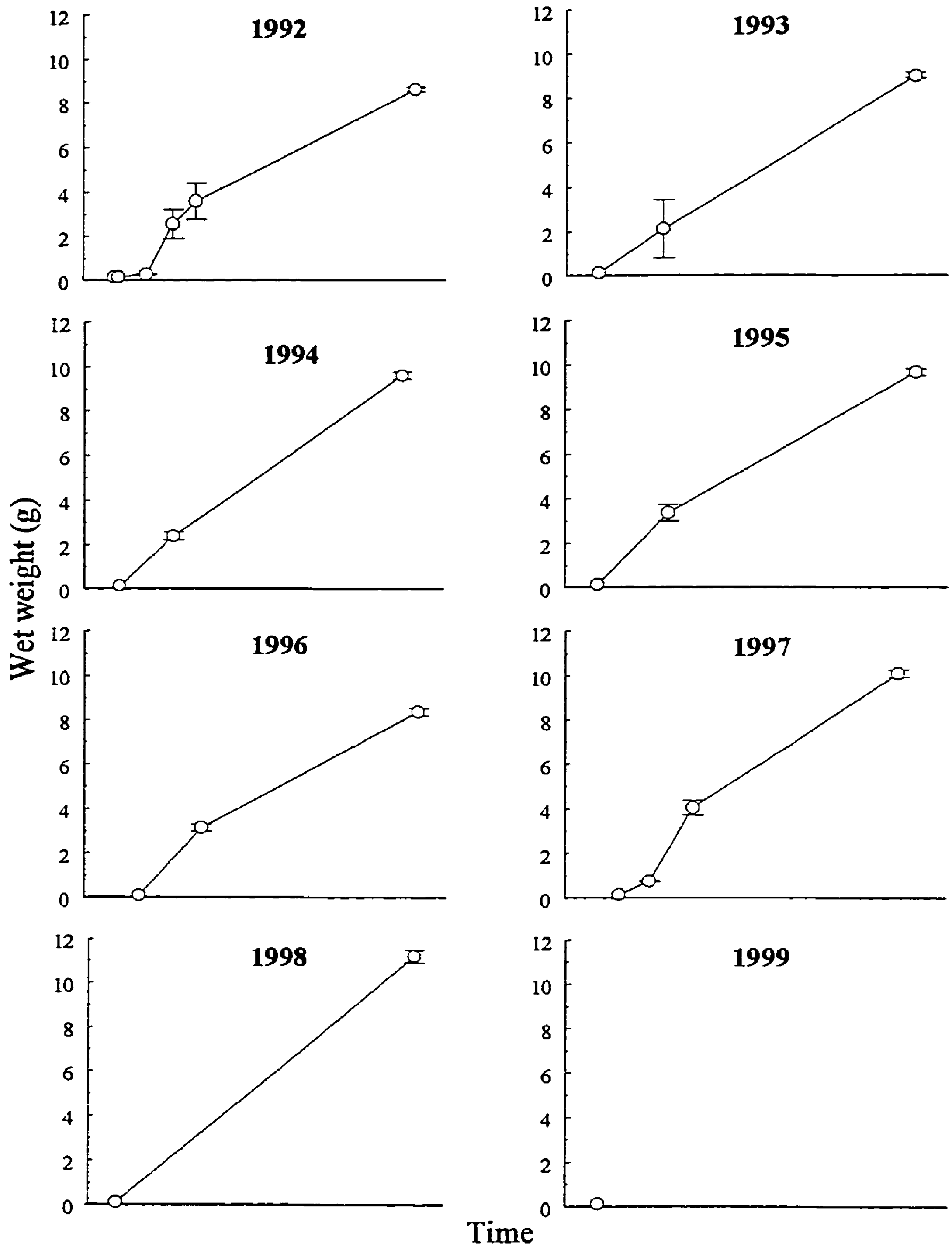


Figure 6.30. Tuya Lake. Growth curves (with 95% confidence interval) for enhanced juvenile sockeye from the time of fry stocking (spring) to smolt outmigration (following spring). Year labels (1992 – 1999) refer to the year of stocking and in-lake growth.

4. Smolt Weight Comparisons

In the previous section, growth analyses compared wild and enhanced sockeye juveniles within lakes and years. This section addresses the comparison (two-factor ANOVA) of enhanced juvenile growth between lakes. The question is: were mean enhanced smolt weights different between Tatsamenie, Tahltan and Tuya lakes? Also addressed is the comparison (three-factor ANOVA) of juvenile growth with respect to origin (wild vs. enhanced), regardless of lake and year. The question is: were mean weights different between wild and enhanced smolts within both Tatsamenie and Tahltan lakes?

4.1 Between-Lake Comparisons of Smolt Weights

The analysis of between-lake growth (Table 6.7) shows that there was a significant lake effect on mean enhanced smolt weights (smolt weights were not similar between lakes). Tuya Lake had the highest average mean smolt weight of 9.5g, more than double the mean smolt weight from Tahltan (4.4g), and Tatsamenie (3.8g) lakes (Fig. 6.31).

Table 6.7. Two-factor ANOVA ($\log_{10}$ transformed data) table summarizing mean enhanced smolt weight comparisons between Tatsamenie, Tahltan and Tuya lakes.

Sources	df	Mean-Square	F-Ratio	p-value
Lake	6	0.484	83.282	0.000
Year	2	21.940	3776.103	0.000
Year*Lake	12	0.130	22.411	0.000
Error	2680	0.006		

There was also a significant year effect on mean enhanced smolt weights (smolt weights are not similar between years), as well as a significant interaction effect. Year effects were included to confirm the expected between-year variation in smolt weight that is related to interannual variations in climatic conditions, with 1996 and 1997 (which correspond to 1995 and 1996 years of fry in-lake growth) being especially unfavorable years (Fig. 6.31). Note that repeated measures were not used because smolt year classes are independent events.

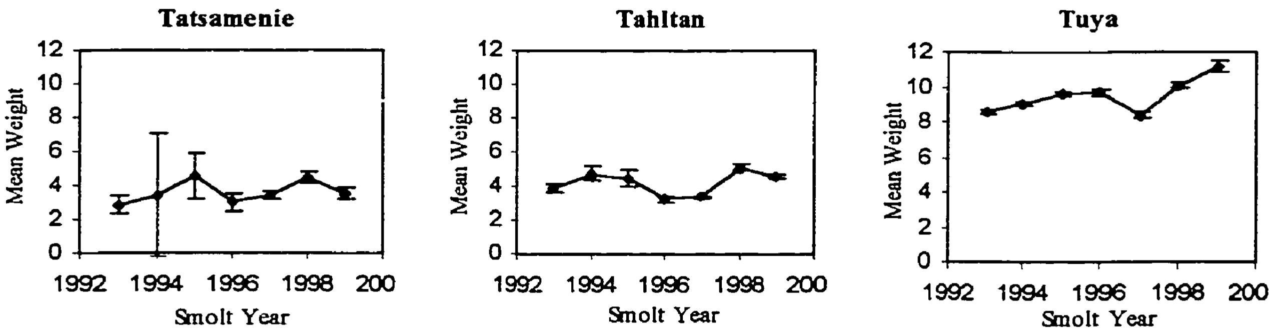


Figure 6.31. Mean enhanced smolt weights from 1993 to 1999 (smolt years) for Tatsamenie, Tahltan and Tuya lakes. Error bars represent 95% confidence intervals.

4.2 Between-Origin (Wild vs. Enhanced) Comparisons of Smolt Weights

The analysis of between-origin (wild vs. enhanced) growth (Table 6.8) shows that there was a significant origin effect on mean smolt weights (mean weights were not the same for wild and enhanced smolts). Combined Tatsamenie and Tahltan wild smolt weights averaged 4.4 g compared to 4.1 g for combined mean enhanced smolt weights (Fig. 6.32). Consistent with the two-factor ANOVA, there were also significant lake and year effects on wild and enhanced mean smolt weights.

Table 6.8. Three-factor ANOVA (log_{10} transformed data) table summarizing mean weight comparisons between wild and enhanced smolts within both Tatsamenie and Tahltan lakes.

Sources	**df**	**Mean-Square**	**F-Ratio**	**p-value**
Year	6	0.564	35.312	0.000
Origin	1	0.154	9.618	0.002
Lake	1	0.638	39.917	0.000
Year*Origin	6	0.162	10.119	0.000
Year*Lake	6	0.194	12.161	0.000
Origin*Lake	1	0.015	0.952	0.329
Year*Origin*Lake	6	0.025	1.575	0.150
Error	4684	0.016		

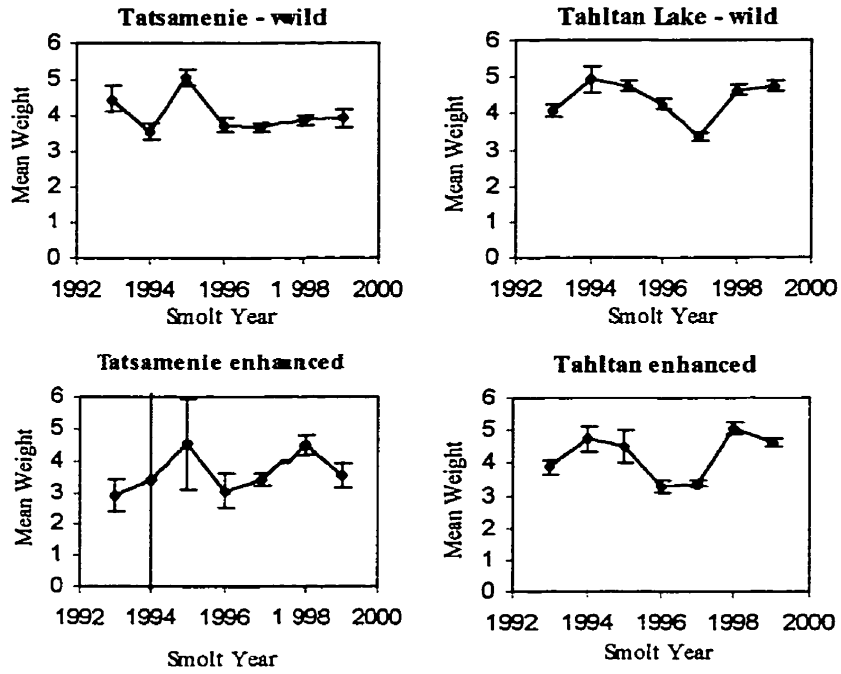


Figure 6.32. Wild (top) and enhanced (bottom) mean smolt weights from 1993 to 1999 for Tatsamenie and Tahltan lakes. Error bars represent 95% confidence intervals.

5. Survival: Wild and Enhanced Juvenile Sockeye

Previous sections have addressed the relationship between juvenile sockeye origin (wild vs. enhanced) and growth by investigating: (1) growth differences between wild and enhanced juveniles in Tatsamenie and Tahltan lakes, and (2) growth differences between enhanced juveniles in Tatsamenie, Tahltan and Tuya lakes. These analyses have shown that: (1) wild and enhanced juvenile growth was generally similar in Tatsamenie and Tahltan lakes, although Tatsamenie Lake enhanced fry were usually smaller than wild fry at stocking, and (2) enhanced juvenile growth in Tuya Lake greatly exceeded enhanced juvenile growth in Tatsamenie and Tahltan lakes.

This section addresses the relationship between origin (wild vs. enhanced) and survival by investigating: (1) survival differences between wild and enhanced juveniles within Tatsamenie and Tahltan lakes (egg-to-age 1+ smolt), and (2) survival differences between wild juveniles from Tatsamenie and Tahltan lakes (egg-to-age 1+ smolt), and between enhanced juveniles from Tatsamenie, Tahltan and Tuya lakes (fry-to-age 1+ smolt).

Enhanced fry were stocked after lake ice-off, 1-2 months after wild fry emerged under the ice, and were often smaller than wild fry in early spring beach seine samples. This section also investigates the effect of stocking date, relative to the ice-off date, on fry-to-smolt survival in Tatsamenie, Tahltan and Tuya lakes.

5.1 Tatsamenie Lake

Tables 6.9 and 6.10 contain estimates of wild and enhanced eggs/fry and smolts, used to calculate egg and fry-to-smolt survivals (Figure 6.33). When wild and enhanced egg-to-smolt survival patterns are compared, the obvious trend is that wild survival is always better than enhanced survival (broodyears 1991 to 1997). Wild egg-to-smolt survival ranged from 3.4% to 16.2% (mean survival=8.7%), and enhanced egg-to-smolt survival ranged from 1.0% to 6.2% (mean survival=2.6%). These trends were found in spite of the fact that enhanced fry were raised in the hatchery and presumably had much higher survivals from the egg-to-fry stages. This leads to the conclusion that enhanced fry experience much higher mortality, from the fry-to-smolt stages, than do wild fry. Enhanced fry-to-smolt survival is always slightly higher than enhanced egg-to-smolt

Table 6.9. Tatsamenie Lake. Relationship between the estimated number of eggs deposited by wild spawners and the estimated number of emigrating age 1+ and 2+ wild smolts for broodyears 1990 to 1999.

Wild Sockeye			
Brood Year	**Number of eggs deposited by wild fish**	**Estimated smolt numbers**	
		Age 1+	**Age 2+**
1990	8,135,115	n/a	141,432
1991	10,808,884	1,117,988	94,553
1992	7,347,795	722,043	100,317
1993	6,278,878	671,415	109,287
1994	3,532,687	571,111	139,759
1995	12,274,366	419,902	22,249
1996	18,812,263	1,237,017	120,895
1997	7,117,629	294,681	n/a
1998	10,461,227	n/a	n/a
1999	4,488,674	n/a	n/a

Table 6.10. Tatsamenie Lake. Relationships between the estimated number of eggs taken from wild broodstock, the number of stocked enhanced fry that were hatchery reared from broodstock eggs, and the estimated number of emigrating age 1+ and 2+ enhanced smolts for broodyears 1990 to 1999.

Enhanced Sockeye				
Brood Year	**Number of eggs taken from broodstock**	**Number of enhanced fry stocked**	**Estimated smolt numbers**	
			Age 1+	**Age 2+**
1990	985,000	673,000	n/a	0
1991	1,360,000	1,232,000	84,859	26,647
1992	1,486,000	909,000	15,472	3,950
1993	1,144,000	521,000	15,798	9,166
1994	1,229,000	898,000	16,217	6,239
1995	2,408,000	1,724,000	57,401	0
1996	5,000,000	3,941,000	223,968	1,889
1997	4,979,935	3,597,000	54,308	n/a
1998	2,557,594	1,769,000	n/a	n/a
1999	496,370	n/a	n/a	n/a

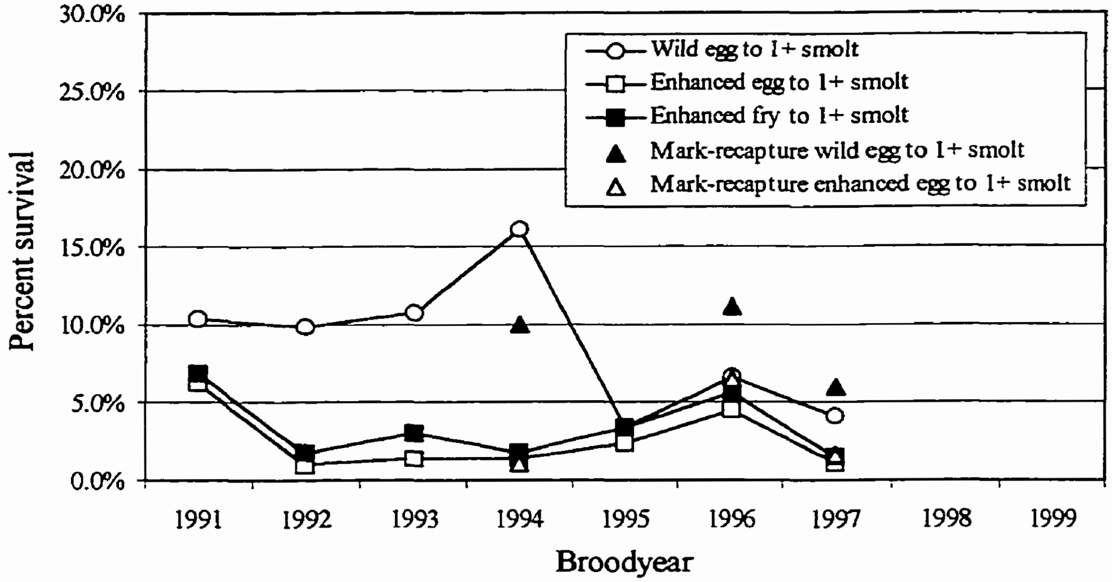


Figure 6.33. Tatsamenie Lake percent survival of wild and enhanced juvenile sockeye for broodyears 1991 to 1997. Mark-recapture program estimates of wild and enhanced egg-to-age 1+ smolt survival are also plotted for broodyears 1994, 1996 and 1997.

survival, since egg-to-fry mortality is not accounted for. The similarity between enhanced egg-to-smolt and enhanced fry-to-smolt survivals indicates how low mortality is from the egg-to-fry stages in the hatchery (which averaged 30%, and ranged from 8% to 55%).

Table 6.11 shows the total estimated escapement to Tatsamenie Lake, the percentage of escapement used for broodstock in each broodyear, and the estimated percentage of enhanced smolts produced from each broodyear. The percentage of total escapement used for Tatsamenie Lake broodstock ranged from 10% to 26%. If survival of enhanced fish was good, then we would expect to see roughly the same percentage of enhanced smolts produced from that broodstock (which ranged from 2% to 14%). Obviously, this is never the case for any broodyear, indicating that the survival of enhanced fry stocked into Tatsamenie Lake has been much below expectations.

Table 6.11. Tatsamenie Lake. Relationship between the total spawner escapement, the percentage of total escapement used for broodstock, and the estimated percentage of enhanced smolts produced from the broodstock, for broodyears 1990 to 1999.

Tatsamenie Lake			
Brood year	**Total spawner escapement**	**% of total escapement used for broodstock**	**% of enhanced smolts in total smolt run**
1990	4,492	12%	n/a
1991	6,570	11%	n/a
1992	4,545	17%	2%
1993	4,022	16%	3%
1994	2,847	25%	3%
1995	5,780	22%	11%
1996	9,381	24%	14%
1997	8,097	26%	n/a
1998	5,997	20%	n/a
1999	2,104	10%	n/a

Because enhanced fry had much lower in-lake survival than wild fry, and because wild fry were known to emerge sooner than the date when enhanced fry were stocked, the timing of stocking was investigated as a factor that might influence enhanced fry survival. Although regression analysis (Fig. 6.34) showed that at least some of the variation in enhanced fry survival (r^2=0.39, p=0.14) might be attributed to the timing of stocking (relative to the ice-off date), the relationship is not significant. Nevertheless, because fry stocked shortly after ice-off tend to survive better than fry stocked later (relative to ice-off), this relationship warrants more detailed analysis in future years.

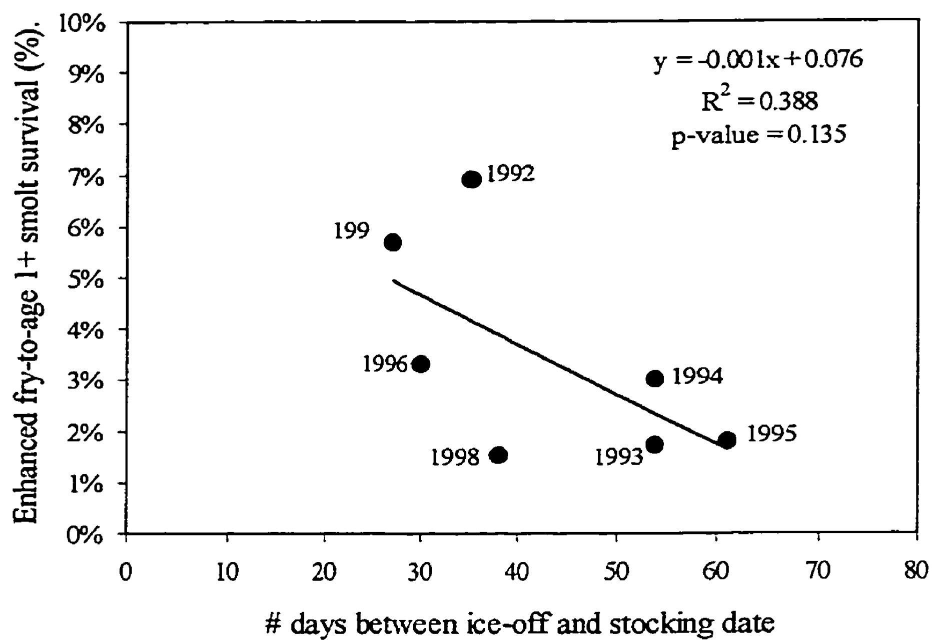


Figure 6.34. Tatsamenie Lake. Relationship between enhanced fry-to-age 1+ smolt survival and the number of days between lake ice-off date and the fry stocking date. Year labels refer to stocking year.

5.2 Tahltan Lake

Tables 6.12 and 6.13 contain estimates of wild and enhanced eggs/fry and smolts, used to calculate egg and fry-to-smolt survivals (Figure 6.35).

Table 6.12. Tahltan Lake. Relationship between the estimated number of eggs deposited by wild spawners and the estimated number of emigrating age 1+ and 2+ wild smolts for broodyears 1989 to 1999.

Wild Sockeye			
Brood Year	Number of eggs deposited by wild fish	Estimated smolt numbers	
		Age 1+	Age 2+
1989	9,980,712	1,120,941	89,405
1990	21,492,560	656,666	55,955
1991	65,245,600	2,799,607	71,731
1992	88,920,601	549,077	23,372
1993	73,313,100	743,668	67,975
1994	57,296,988	1,340,504	29,931
1995	33,410,000	317,850	38,674
1996	32,482,900	287,747	13,496
1997	14,244,800	451,796	n/a
1998	12,061,100	n/a	n/a
1999	10,087,425	n/a	n/a

Wild egg-to-smolt survivals ranged from 0.6% to 11.2% (mean survival=3.1%), and enhanced egg-to-smolt survival ranged from 4.6% to 24.4% (mean survival=11.4%). The obvious trend is that enhanced survivals were almost always higher than wild survivals. This was expected since enhanced sockeye have a higher egg-to-fry survival in the hatchery, than the wild sockeye presumably have in the lake. The 1989 broodyear survival estimate for enhanced egg-to-1+ smolt was low due to the 48% mortality rate from egg fertilization to fry emergence (Pacific Salmon Commission 1991). The mortality was caused by poor water quality problems in the hatchery. The similarity between enhanced egg-to-smolt and enhanced fry-to-smolt survivals indicates how low

Table 6.13. Tahltan Lake. Relationships between the estimated number of eggs taken from wild broodstock, the number of stocked enhanced fry that were hatchery reared from broodstock eggs, and the estimated number of emigrating age 1+ and 2+ enhanced smolts for broodyears 1989 to 1999.

Enhanced Sockeye				
Brood Year	**# of eggs taken from broodstock for Tahltan stocking**	**Number enhanced fry stocked**	**Estimated smolt numbers**	
			Age 1+	**Age 2+**
1989	2,955,000	1,042,000	266,868	31,542
1990	4,511,000	3,585,000	772,782	29,591
1991	1,514,000	1,415,000	369,892	0
1992	2,154,000	1,947,000	294,310	10,624
1993	969,000	904,000	44,620	6,346
1994	1,326,000	1,143,000	144,877	8,259
1995	3,008,000	2,296,000	162,162	4,052
1996	3,100,000	2,248,000	210,393	1,377
1997	2,725,000	1,900,000	292,168	n/a
1998	1,997,918	1,670,600	n/a	n/a
1999	2,496,689	n/a	n/a	n/a

mortality generally is, from the egg-to-fry stages in the hatchery.

The second trend, obvious in all three survival plots, is the decline in percent survival after broodyear 1991. Fry stocked from 1990 to 1992 (1989-1991 broodyears) had very good survivals, averaging 24.4% (fry-to-smolt). Fry stocked from 1993 to 1997 (1992-1997 broodyears) had fairly poor survivals, averaging 10.8%. The decline in survival appears to be affecting both wild and enhanced fry, and may be caused by factors such as increased predation, pathogens, or less favorable environmental conditions, ultimately affecting the quality or quantity of food resources. The reader will recall however, that an examination of the Tahltan Lake zooplankton community, presented in

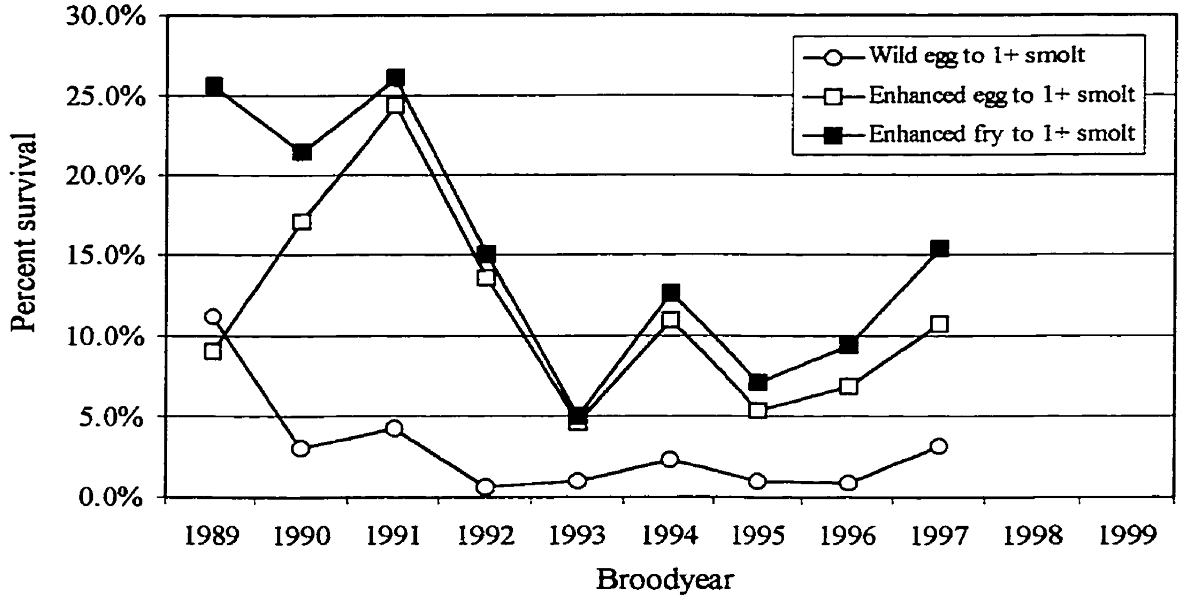


Figure 6.35. Tahltan Lake percent survival of wild and enhanced juvenile sockeye for broodyears 1989 to 1997.

the previous chapter, did not reveal any noticeable changes in the mean size, biomass or density of macrozooplankton groups from 1987 to 1998.

The third trend that is evident from the data (Fig. 6.35) is that the survival of the wild stock in Tahltan Lake appears to be lower (average egg-to-1+ smolt survival of 3.1%) than the wild stock in Tatsamenie Lake (average egg-to-1+ smolt survival of 8.7%). This may be due to low wild egg-to-emergent fry survival in years of high adult escapements to Tahltan Lake. Initial assessments of Tahltan Lake suggested that wild sockeye production was limited by wild fry recruitment, likely due to a limitation of high quality spawning habitat. Because of limited suitable spawning habitat, average wild egg-to-emergent fry survivals likely decrease as spawner abundance increases. In comparison, Tatsamenie Lake has a much larger shoreline and fewer spawners than Tahltan Lake, therefore suitable spawning habitat is likely to be much less limiting to sockeye production in Tatsamenie Lake than it is in Tahltan Lake.

Since the decline in enhanced survival was greater than the decline in wild survival (Fig. 6.35), an attempt was made to explain some of the enhanced survival decline in terms of the timing of stocking. The relationship between enhanced fry-to-smolt percent survival, and the difference between the number of days between lake ice-off and mean stocking date, was investigated (Fig. 6.36). This analysis revealed that at

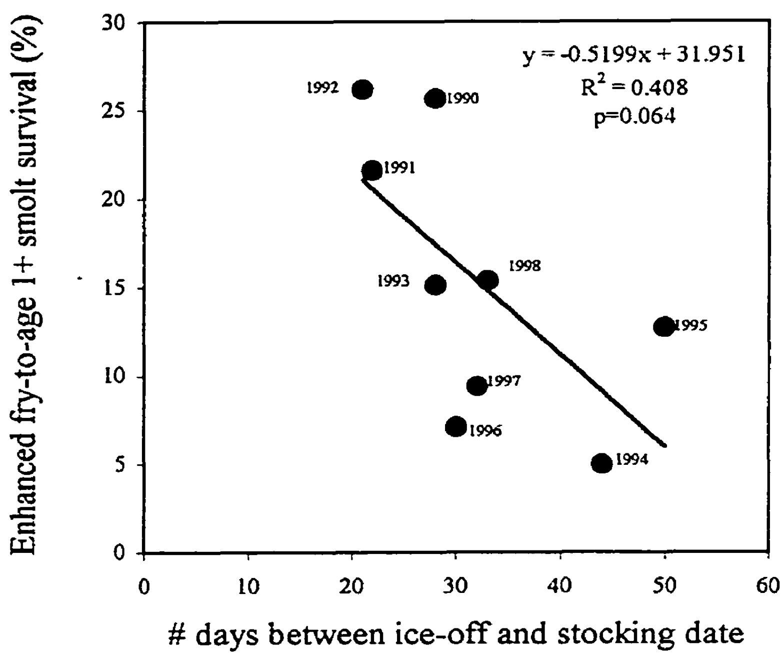


Figure 6.36. Tahltan Lake. Relationship between enhanced fry-to-age 1+ smolt survival and the number of days between lake ice-off date and the fry stocking date. Year labels refer to stocking year.

least some of the variation in enhanced fry-to-smolt survival (r^2=0.41, p=0.06) can be attributed to variations in the timing of stocking (relative to the ice-off date). The conclusion is that fry stocked shortly after ice-off tend to survive better than fry stocked much later (relative to ice-off).

5.3 Tuya Lake

Table 6.14 contains estimates of eggs (taken from Tahltan Lake broodstock to produce enhanced fry for Tuya Lake stocking) and smolts, used to calculate enhanced egg and fry-to-smolt survivals (Figure 6.37).

Table 6.14. Tuya Lake. Relationships between the estimated number of eggs taken from wild Tahltan Lake broodstock, the number of stocked enhanced fry that were hatchery reared from broodstock eggs, and the estimated number of emigrating age 1+ and 2+ enhanced smolts for broodyears 1991 to 1999.

Enhanced Sockeye				
Brood Year	# of eggs taken from Tahltan broodstock for Tuya stocking	Number of enhanced fry stocked	Estimated smolt numbers	
			Age 1+	Age 2+
1991	2,732,000	1,632,000	74,567	11,245
1992	2,747,000	1,990,000	269,879	29,700
* 1993	5,171,000	4,691,000	1,455,303	40,499
1994	2,765,000	2,267,000	971,986	474,182
* 1995	3,883,000	2,474,000	603,504	86,686
* 1996	3,100,000	2,611,000	1,358,077	2,968
1997	462,100	433,000	79,153	n/a
1998	2,302,082	1,603,400	n/a	n/a
1999	1,045,000	n/a	n/a	n/a

* Only broodyear 1993, 1995-96 estimates of smolt numbers were used for survival calculations due to small trawl sample sizes in all other years.

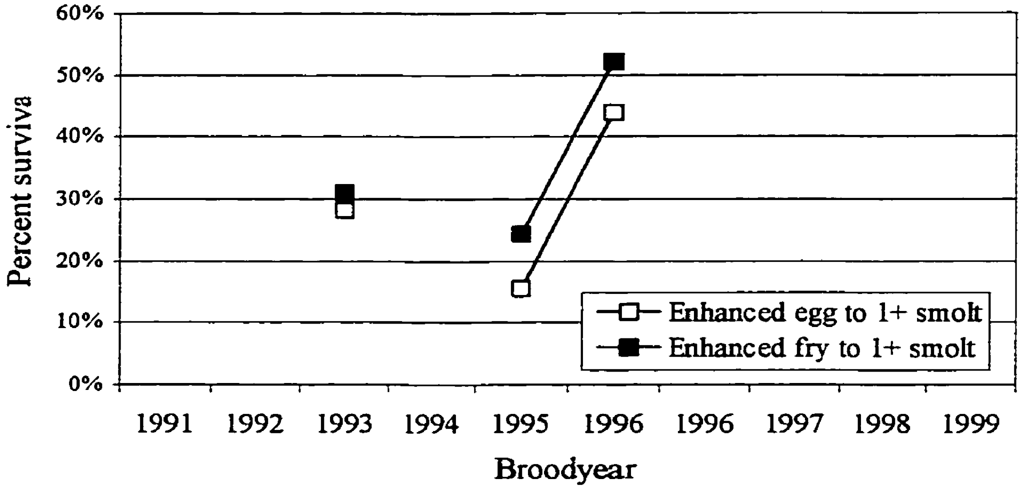


Figure 6.37. Tuya Lake percent survival of enhanced juvenile sockeye for broodyears 1993, and 1995-96.

Estimates of percent enhanced fry-to-smolt survival ranged from 24.4% to 52.0% (mean survival=35.8%). Percent survivals of enhanced egg-to-smolt and fry-to-smolt were very similar, indicating low mortality during the egg-to-fry stage in the hatchery. Tuya Lake enhanced fry apparently had the highest fry-to-smolt survival (35.8%), compared to enhanced fry in Tatsamenie (3.4%) and Tahltan (15.3%) lakes.

The relationship between enhanced fry-to-smolt percent survival, and the difference between the number of days between lake ice-off and mean stocking date, was investigated (Fig. 6.38) using regression analysis. Results (r^2=0.05, p=0.85) from three years of stocking (1994, 1996-97) do not suggest any relationship between fry stocking date (relative to ice-off) and survival.

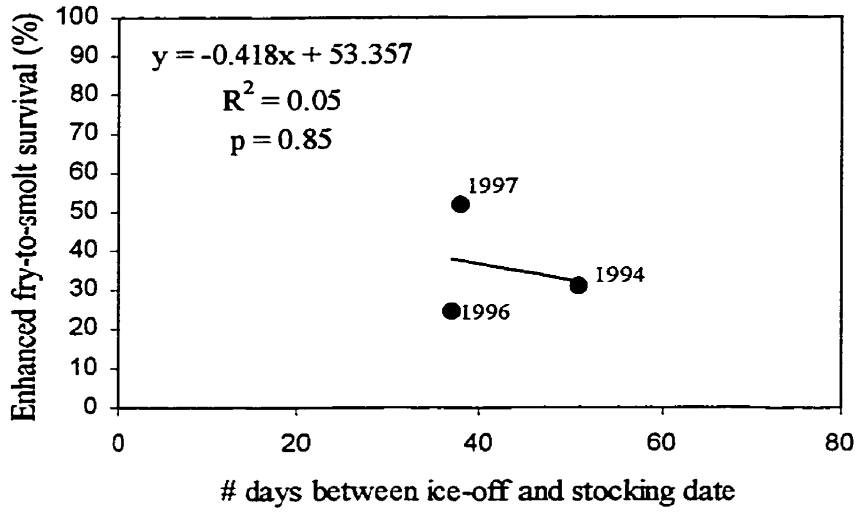


Figure 6.38. Tuya Lake. Relationship between enhanced fry-to-age 1+ smolt survival and the number of days between lake ice-off date and the fry stocking date in 1994 and 1996-97. Year labels refer to stocking year.

6. Timing of Sockeye Fry Mortality

In the last section, it was determined that enhanced fry in Tatsamenie Lake experienced higher in-lake mortality than wild fry. Assuming that wild and enhanced fry moved from inshore to offshore rearing areas at roughly the same time, the ratio of enhanced fry: total fry in beach seine and trawl catches may be used to track the survival of enhanced fry, relative to wild fry. To determine the timing of enhanced fry mortality, the percent of enhanced fry caught in beach seines and trawls was calculated from 1992 to 1999 (Fig. 6.39). The trend in most years, is a decisive mid-summer decline in the percent of enhanced fry in beach seine and trawl catches. From 1992 to 1994 and 1996, it appears that the first fry sampling occurred after the mortality event took place. The

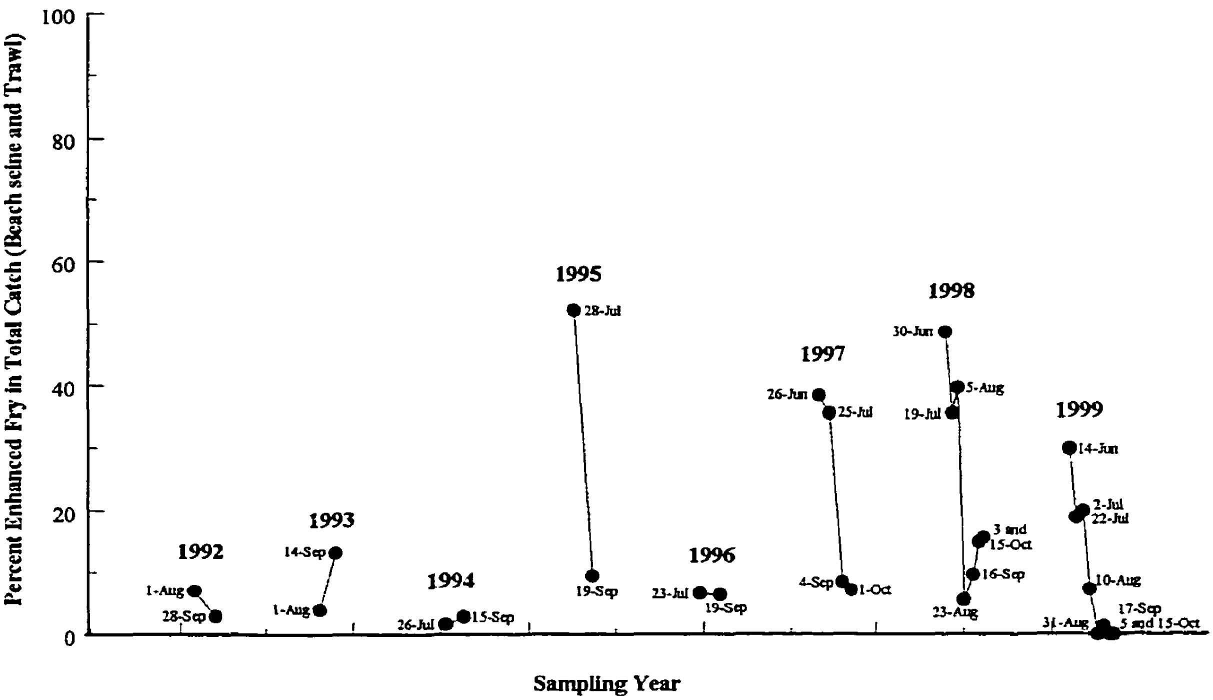


Figure 6.39. Proportion of Tatsamenie Lake enhanced fry in beach seine or trawl catches (combined if sampled on the same day) over time for each sampling year from 1992 to 1999.

earliest sampling in these years was July 23 (1996). In 1995, 1997, 1998 and 1999, substantial fry mortality occurred sometime after July 28th, July 25th, August 5th, and July 22nd. Thus, in most years, it appears that considerable enhanced fry mortality occurred from late July to mid-August. It is known that during this period of time, fry tend to move from inshore to offshore rearing areas, as evidenced by declining total beach seine catches and increasing total trawl catches. Offshore migration may thus play a role in the mortality event experienced by enhanced fry in Tatsamenie Lake.

If the assumption that wild and enhanced fry move offshore at the same time is incorrect, the trends shown in Figure 6.39 require an alternate explanation. Early summer beach seine catches suggest that proportions of wild and enhanced fry were similar in inshore areas. Enhanced fry, which usually started out smaller than wild fry, may have tended to stay inshore longer than wild fry (perhaps to improve their growth rate). It is possible that, because of a longer inshore residence, enhanced fry had high mortality rates due to predation during their first few weeks in the lake, while at the same time, wild fry had begun moving offshore (perhaps as a function of their larger size) at a similar rate. This would account for the similar proportions of wild and enhanced fry in early summer beach seine samples.

Late summer and fall beach seine and trawl catches show lower proportions of enhanced fry compared to wild fry, suggesting a mid-summer decline in enhanced fry numbers. Assuming that the majority of enhanced fry mortality had occurred in early summer, the low proportion of enhanced fry in fall beach seine catches could be accounted for by a greater rate of mortality for enhanced fry (differential mortality) compared to wild fry. The low proportion of enhanced fry in fall trawl catches could be accounted for by the greater numbers of wild fry, compared to enhanced fry, that would have already moved offshore. The high mortality of Tatsamenie Lake enhanced fry is fully discussed in the following chapter.

Insufficient beach seine and trawl catch data exist for similar investigations into the timing of fry mortality in Tahltan and Tuya lakes.

7. Juvenile Sockeye Data Summary

This section presents: (1) results of within-lake correlations between growth, survival, density and time of stocking data, and (2) a summary of between-lake comparisons of juvenile sockeye growth and survival analyses presented earlier in this chapter.

7.1 Within-Lake Growth, Survival, and Density Relationships

Tatsamenie Lake: Correlation analyses were used to investigate a number of relationships between growth rate, percent survival, fry density and time of fry stocking. (1) To investigate density dependent growth and survival, the relationships between growth rate, percent survival, mean smolt weight, and fry density data (Table 6.15) were analysed (columns 1a,b vs. 5,6, columns 2 vs. 5,6 and columns 3a,b vs. 5,6). (2) To investigate the effects of stocking date on growth and survival, the relationships between growth rate, percent survival, and time of stocking (Table 6.15) were analysed (columns 1b vs. 4 and columns 2 vs. 4). (3) To investigate the relationship between growth rate and survival, columns 2 vs. 1b were analysed (Table 6.15). Results of the data set comparisons are summarized in Table 6.16. Growth rates (column 1) were calculated by: (smolt weight – fry weight) / (smolt sample date – fry sample date). Sample dates were converted to day-of-year numbers (1-365 days) to allow subtraction. Total fall fry densities (column 6) were calculated by dividing total fall hydroacoustic population estimates (Table 6.3) by the lake area (1,622 ha).

Table 6.15. Tatsamenie Lake sockeye fry growth rate, survival, mean smolt weight and density data used in correlation analyses.

	1a	1b	2	3a	3b	4	5	6
	Growth rate (g/day) (fry-to-smolt)		Enhanced % survival	Mean smolt weight (g)		# days between ice-off	Number of fry	Total fall fry density
Stocking Year	Wild	Enhanced	(fry-to-smolt)	Wild	Enhanced	and stocking	stocked	(#/ha)
1991	n/a	n/a	n/a	4.87	4.99	32	673,000	493
1992	0.012	0.008	6.9%	4.47	2.88	35	1,232,000	n/a
1993	0.010	0.010	1.7%	3.55	3.40	54	909,000	707
1994	0.013	0.014	3.0%	5.06	4.53	54	521,000	649
1995	0.010	0.009	1.8%	3.74	3.04	61	898,000	580
1996	0.011	0.010	3.3%	3.67	3.42	30	1,724,000	513
1997	0.010	0.012	5.7%	3.87	4.48	27	3,941,000	1,219
1998	0.011	0.010	1.5%	3.93	3.51	38	3,597,000	388
1999	n/a	n/a	n/a	n/a	n/a	12	1,769,000	217

Table 6.16 shows that most of the data relationships were not significant, indicating that: (1) growth and survival of wild and enhanced fry were not density dependent, (2) that growth and survival of enhanced fry were not significantly dependent on time of stocking, and (3) there was no significant relationship between growth and survival of enhanced fry. The exception is the correlation between enhanced fry-to-smolt survival and total fry density (columns 2 vs 6). In this case, the significance of the relationship is influenced by small sample size (n=5), and particularly by one data point (the correlation result without this data point is r^2=0.018, p=0.828). In addition, it would be very unlikely that fry survival would increase significantly with increasing fry densities, due to increased intraspecific competition. Thus, the relationship between survival and density is considered to be insignificant.

Table 6.16. Tatsamenie Lake. Correlation results from analyses between data sets (columns 1a-6) given in Table 6.15. Significant relationships are shown in bold.

Comparison	R value	P value
1a vs 5	-0.450	0.311
1b vs 5	0.093	0.843
1a vs 6	-0.092	0.862
1b vs 6	0.530	0.280
2 vs 4	-0.623	0.135
2 vs 5	0.168	0.719
2 vs 6	**0.837**	**0.038**
3a vs 5	-0.409	0.310
3b vs 5	0.032	0.940
3a vs 6	-0.156	0.740
3b vs 6	0.297	0.520
1b vs 4	0.029	0.951
2 vs 1b	-0.013	0.978

Tahltan Lake: Correlation analyses were done to investigate a number of relationships between growth rate, percent survival, fry density and time of fry stocking. (1) To investigate density dependent growth and survival, the relationships between growth rate, percent survival, mean smolt weight, and fry density data (Table 6.17) were analysed (columns 1a,b vs. 5,6, columns 2 vs. 5,6, and columns 3a,b vs. 5,6). (2) To investigate the effects of stocking date on growth and survival, the relationships between growth rate, percent survival, and time of stocking (Table 6.17) were analysed (columns 1b vs. 4 and columns 2 vs. 4). (3) To investigate the relationship between growth rate and survival, columns 2 vs. 1b were analysed (Table 6.17). Results of the data set comparisons are summarized in Table 6.18. Growth rates (column 1) were calculated by:

(smolt weight – fry weight) / (smolt sample date – fry sample date). Sample dates were converted to day-of-year numbers (1-365 days) to allow subtraction. Total fall fry densities (column 6) were calculated by dividing total fall hydroacoustic population estimates (Table 6.3) by the lake area (492 ha).

Table 6.17. Tahltan Lake sockeye fry growth rate, survival, and density data used in correlation analyses.

	1a	1b	2	3a	3b	4	5	6
Stocking Year	Growth rate (g/day) (fry-to-smolt) Wild	Growth rate (g/day) (fry-to-smolt) Enhanced	Enhanced % survival (fry-to-smolt)	Mean smolt weight (g) Wild	Mean smolt weight (g) Enhanced	# days between ice-off and stocking	Number of fry stocked	Total fall fry density (#/ha)
1990	0.015	0.016	25.6%	5.93	5.47	28	1,042,000	2,460
1991	n/a	0.013	21.6%	4.77	4.62	22	3,585,000	1,448
1992	0.011	0.011	26.1%	4.08	3.87	21	1,415,000	5,836
1993	0.016	0.016	15.1%	4.93	4.74	28	1,947,000	1,164
1994	0.011	0.013	4.9%	4.75	4.50	44	904,000	1,650
1995	n/a	0.009	12.7%	4.26	3.27	50	1,143,000	2,785
1996	0.010	0.010	7.1%	3.63	3.36	30	2,296,000	725
1997	0.004	0.014	9.4%	4.65	5.09	32	2,248,000	612
1998	n/a	0.012	15.4%	4.75	4.62	33	1,900,000	n/a
1999	n/a	n/a	n/a	n/a	n/a	43	1,670,615	n/a

Table 6.18 shows that none of the data relationships were significant, indicating that: (1) growth and survival of wild and enhanced fry were not density dependent, (2) that growth and survival of enhanced fry were not significantly dependent on time of stocking, and (3) there was no significant relationship between growth and survival of enhanced fry.

Table 6.18. Tahltan Lake. Correlation results from analyses between data sets (1a-6) given in Table 6.17. Significant relationships are shown in bold.

Comparison	R value	P value
1a vs 5	-0.454	0.365
1b vs 5	-0.020	0.959
1a vs 6	0.241	0.645
1b vs 6	-0.289	0.487
2 vs 5	0.066	0.866
2 vs 6	0.644	0.085
3a vs 5	-0.192	0.621
3b vs 5	0.061	0.876
3a vs 6	-0.114	0.789
3b vs 6	-0.262	0.530
1b vs 4	-0.283	0.460
2 vs 4	-0.639	0.064
2 vs 1b	0.219	0.572

Tuya Lake: Correlation analyses were done to investigate a number of relationships between growth rate, percent survival, fry density and time of fry stocking: (1) To investigate density dependent growth and survival, the relationships between growth rate, percent survival, mean smolt weight, and fry density data (Table 6.19) were analysed (columns 1 vs. 5,6, columns 2 vs. 5,6, and columns 3 vs. 5,6). (2) To investigate the effects of stocking date on growth and survival, the relationships between growth rate, percent survival, and time of stocking (Table 6.19) were analysed (columns 1 vs. 4 and columns 2 vs. 4). (3) To investigate the relationship between growth rate and survival, columns 2 vs. 1 were analysed (Table 6.19). Results of the data set comparisons are summarized in Table 6.20. Growth rate (column 1) was calculated by:

(smolt weight – fry weight) / (smolt sample date – fry sample date). Sample dates were converted to day-of-year numbers (1-365 days) to allow subtraction. Total fall fry densities (column 6) were calculated by dividing total fall hydroacoustic population estimates (Table 6.4) by the lake area (2,948 ha).

Table 6.19. Tuya Lake sockeye fry growth rate, survival, and density data used in correlation analyses.

	1	2	3	4	5	6
Stocking Year	**Enhanced growth rate (g/day) (fry-to-smolt)**	**Enhanced % survival fry-to-smolt)**	**Enhanced mean smolt weight (g)**	**# days between ice-off and stocking**	**Number of fry stocked**	**Total fall fry density (#/ha)**
1992	0.0247	n/a	8.61	31	1,632,000	n/a
1993	0.0265	n/a	9.02	37	1,990,000	n/a
1994	0.0277	31.0%	9.61	51	4,691,000	672
1995	0.0272	n/a	9.69	48	2,267,000	n/a
1996	0.0242	24.4%	8.36	37	2,474,000	487
1997	0.0289	52.0%	10.10	38	2,611,000	653
1998	0.0308	n/a	11.20	49	433,000	n/a
1999	n/a	n/a	n/a	39	1,603,400	n/a

Table 6.20. Tuya Lake. Correlation results from analyses between data sets (1-6) given in Table 6.19. Significant relationships are shown in bold.

Comparison	R value	P value
1 vs 4	0.653	0.112
1 vs 5	-0.203	0.662
* 1 vs 6	n/a	n/a
* 2 vs 4	n/a	n/a
* 2 vs 5	n/a	n/a
* 2 vs 6	n/a	n/a
3 vs 5	-0.293	0.523
* 3 vs 6	n/a	n/a
* 2 vs 1	n/a	n/a

* Sample size was too low (n=3) to investigate relationships.

Table 6.20 shows that none of the data relationships investigated were significant, indicating that: (1) growth of enhanced fry was not density dependent (survival could not be tested), and (2) that growth of enhanced fry was not dependent on time of stocking (survival could not be tested). The relationship between growth and survival of enhanced fry could not be tested.

7.2 Between-Lake Comparisons of Growth and Survival

Tatsamenie, Tahltan, and Tuya lakes were selected for sockeye enhancement because they: (1) were thought to be limited by fry recruitment into the lake, and (2) had unused rearing capacity. Tatsamenie Lake was recruitment-limited due to low escapement (low numbers of spawners result in low numbers of fry). Tahltan Lake was recruitment-limited due to a shortage of spawning sites (escapement was high but the amount of spawning area limited wild production). Tuya Lake was recruitment-limited due to a barrier downstream of the lake, preventing sockeye access into the lake. Using the summary of growth, density and survival data (Table 6.21), conclusions about the success of the sockeye enhancement program in each lake, and recommendations about future stocking, will be made in the final chapter.

Escapement and Density: Mean adult spawner escapement (Table 6.21) to Tatsamenie Lake (5,384 spawners) was considerably lower than the mean escapement to Tahltan Lake (33,092 spawners). As expected, the mean number of eggs deposited by wild spawners was considerably lower in Tatsamenie Lake (8,926,000 eggs), compared to

Tahltan Lake (38,049,000 eggs). Mean stocking density was highest in Tahltan Lake (3,689 ha^{-1}), compared to Tatsamenie (1,046 ha^{-1}) and Tuya (751 ha^{-1}; 1992-99) lakes. This is due in part to the availability of broodstock at Tahltan Lake, in comparison with Tatsamenie Lake. Accordingly, mean density of the fall total limnetic fry population was highest at Tahltan Lake (1,214 ha^{-1}), compared to Tatsamenie (596 ha^{-1}) and Tuya (698 ha^{-1}; 1994, 1996-7) lakes.

Growth: Weight frequency distributions (Table 6.21) of fry in both Tatsamenie and Tahltan lakes showed that enhanced fry were usually smaller than wild fry, but that enhanced fry weights fell within the range of wild fry weights. Weight frequency distributions of smolts in both Tatsamenie and Tahltan lakes showed that enhanced smolt weights fell within the range of wild smolt weights. Tuya Lake weight frequency distributions showed that enhanced fry and smolt weights greatly exceeded the weights of both wild and enhanced fry and smolts in Tatsamenie and Tahltan lakes. Mean growth rate (enhanced fry-to-age 1+ smolt) was twice as high in Tuya Lake (0.027 g/day), as it was in Tatsamenie (0.010 g/day) and Tahltan (0.013 g/day) lakes. Mean enhanced smolt weight (age 1+) was twice as high in Tuya Lake (9.5g), as it was in Tatsamenie (3.8g) and Tahltan (4.4g) lakes.

Table 6.21. Summary of major trends in juvenile sockeye growth and survival in Tatsamenie, Tahltan and Tuya lakes.

	Tatsamenie Lake		Tahltan Lake		Tuya Lake
	Wild	Enhanced	Wild	Enhanced	Enhanced
Mean annual adult spawner escapement	5,384 (range 2,104 – 9,381)		33,092 (range 8,316 – 59,907)		n/a
Mean annual wild sockeye egg deposition	8,926,000 (range 3,533,000 – 18,812,000)	n/a	38,049,000 (range 9,981,000 – 88,921,000)	n/a	n/a
Mean annual enhanced fry stocking number	n/a	1,696,000 (range 521,000 – 3,941,000 over 9 years)	n/a	1,815,060 (range 904,000 - 3,585,000 over 10 years)	2,212,675 (range 433,000 – 4,691,000 over 8 years)
Mean annual enhanced fry stocking density	n/a	1,046 ha^{-1} (range 321 – 2,430) lake area = 1,622 ha	n/a	3689 ha^{-1} (range 1,837 – 7,287) lake area = 492 ha	751 ha^{-1} (range 147 – 1,591) lake area = 2,948 ha
Mean annual fall fry density (hydroacoustics)	546 ha^{-1} (range 198 – 1,094) lake area = 1,622 ha	50 ha^{-1} (range 12 – 126) lake area = 1,622 ha	723 ha^{-1} (range 196 – 1,044) lake area = 492 ha	491 ha^{-1} (range 45 – 980) lake area = 492 ha	604 ha^{-1} (range 487 – 672) lake area = 2,948 ha
	596 ha^{-1} (wild and enhanced combined)		1,214 ha^{-1} (wild and enhanced combined)		698 ha^{-1} (including sculpin)

Table 6.21 continued. Summary of major trends in juvenile sockeye growth and survival in Tatsamenie, Tahltan and Tuya lakes.

	Tatsamenie Lake		Tahltan Lake		Tuya Lake
	Wild	**Enhanced**	**Wild**	**Enhanced**	**Enhanced**
Weight frequency distributions – **fry**	Enhanced fry were usually smaller than wild fry but enhanced fry weights always fell within the range of wild fry weights.		Enhanced fry were usually smaller than wild fry but enhanced fry weights always fell within the range of wild fry weights.		Enhanced fry weights exceeded enhanced and wild fry weights found in Tatsamenie and Tahltan lakes.
Weight frequency distributions – **smolts**	Enhanced smolt sample sizes were much lower than wild smolt sample sizes but the data show that enhanced smolts fall within the weight range of wild smolts.		Enhanced smolts fall within the weight range of wild smolts.		Enhanced smolt weights exceeded enhanced and wild smolt weights found in Tatsamenie and Tahltan lakes.
Mean growth rate (g/day) (fry to smolt)	0.011 g/day (range 0.010 – 1.013)	0.010 g/day (range 0.008 – 0.014)	0.013 g/day (range 0.010 – 0.016)	0.013 g/day (range 0.009 – 0.016)	0.027 g/day (range 0.024 – 0.031)
Mean age 1+ smolt weight (g)	4.1g (range 3.55g – 5.06g)	3.8g (range 2.88g – 4.99g)	4.6g (range 3.36g – 5.93g)	4.4g (range 3.27g – 5.47g)	9.5g (range 8.36g – 11.20g) Smolts are significantly larger than those from Tatsamenie or Tahltan lakes.
Mean total smolt numbers produced	795,688 (range 264,000 – 1,483,234)		1,202,881 (range 480,012 – 3,169,499)		1,182,346 (range 690,190 – 1,495,803)

Table 6.21 continued. Summary of major trends in juvenile sockeye growth and survival in Tatsamenie, Tahltan and Tuya lakes.

	Tatsamenie Lake		Tahltan Lake		Tuya Lake
	Wild	**Enhanced**	**Wild**	**Enhanced**	**Enhanced**
Mean annual smolt densities produced	532 ha^{-1} (range 163 ha^{-1} – 914 ha^{-1}) lake area = 1,622 ha		2684 ha^{-1} (range 1043 ha^{-1} – 6,588 ha^{-1}) lake area = 492 ha		401 ha^{-1} (range 234 ha^{-1} – 507 ha^{-1}) lake area = 2,948 ha
Mean egg-to-age 1+ smolt survival (%)	8.7% (range 3.4% – 16.2%)	2.6% (range 1.0% – 6.2%)	3.1% (range 0.6% – 11.2%)	11.4% (range 4.6% – 24.4%)	29.2% (range 15.5% – 43.8%)
Mean fry-to-age 1+ smolt survival (%)	n/a	3.4% (range 1.5% - 6.9%)	n/a	15.3% (range 4.9% - 26.1%)	35.8% (range 24.4% – 52.0%)
Correlation results of fry-to-age 1+ smolt survival vs. # days between stocking and ice-out dates	n/a	$r^2 = 0.39$ $p = 0.14$ The relationship is not significant but data suggest that fry stocked earlier survive better.	n/a	$r^2 = 0.41$ $p = 0.06$ The relationship is not significant but data suggest that fry stocked earlier survive better.	$r^2 = 0.05$ $p = 0.85$ Sample size was too low to make conclusions.
Possible timing of fry mortality	n/a	late July to mid-August	n/a	Insufficient fry sampling to make conclusions.	Insufficient fry sampling to make conclusions.

Survival: Mean enhanced egg-to-age 1+ smolt survival (Table 6.21) was substantially higher in Tuya Lake (29.2%), compared to Tatsamenie (2.6%) and Tahltan (11.4%) lakes. A comparison of the wild and enhanced mean egg-to-smolt survivals in Tatsamenie and Tahltan lakes, shows that the within-lake survival trends are quite different between lakes. In Tatsamenie Lake, wild survival was much higher (8.7%) than enhanced survival (2.6%). Potential causes for the lower survival of enhanced fry are discussed in detail in the next chapter. In Tahltan Lake, wild survival was much lower (3.1%) than enhanced survival (11.4%). This may be due to low wild egg-to-fry survival in years of high escapement (due to a shortage of suitable spawning sites). In both Tatsamenie and Tahltan lakes, data suggest that fry stocked earlier in the spring (and closer to the time that wild fry emerge), survive better (r^2=0.39, p=0.14 and r^2=0.41, p=0.06). It is well known that wild fry emerge at a time (usually the month of May) that is optimal for feeding and survival (Groot and Margolis 1991). Enhanced fry were usually stocked into Tatsamenie and Tahltan lakes in mid-June. It is possible that enhanced fry missed an important period of rapid growth that resulted in wild fry having a competitive advantage (for food and protective, inshore habitats) over enhanced fry. When fry are stocked a month or so after wild fry emergence, they are usually smaller and may be more susceptible to predation. Insufficient data exist to determine the importance of stocking date on Tuya Lake enhanced fry survival, but since the mean stocking date (Chapter 4) is quite early, relative to ice-off, and since the data suggest survival is excellent, the stocking date should remain unchanged. In Tatsamenie Lake, the percentage of enhanced fry captured in beach seines and trawls (Fig 6.40), declines significantly usually after late-July to mid-August, perhaps indicating a mid-summer mortality event. Identification and discussion of possible mechanisms of enhanced fry mortality follow in the next chapter.

Summary: A between-lake comparison of fry density trends suggest that: (1) fry densities were highest at Tahltan Lake, and (2) fry densities have been comparable between Tatsamenie and Tuya lakes. Between-lake trends in fry growth suggest: (1) that the growth of Tuya Lake fry has been double the growth of Tatsamenie and Tahltan lake fry, and (2) that the growth of wild and enhanced fry in Tatsamenie and Tahltan lakes has been comparable. A between-lake comparison of egg-to-smolt survival trends suggest that: (1) enhanced survivals appear to have been highest at Tuya Lake, and (2) within-lake wild and enhanced survival trends were opposite in Tatsamenie and Tahltan lakes.

Chapter 7 - Tatsamenie Lake Fry Survival Problem

INTRODUCTION

In the previous chapter, it was determined that the survival of Tatsamenie Lake enhanced fry was much lower than the survival of wild fry (stocking years 1991-1997). This chapter addresses the potential causes of the low enhanced fry survival. Since preliminary analyses of wild and enhanced fry sizes indicated that enhanced fry may be at a size disadvantage, compared to wild fry at the time of stocking, the initial hypothesis was one of size-selective mortality (smaller fry experience higher mortality than larger fry). To confirm that enhanced fry were at a size disadvantage at the time of stocking, the last chapter presented a comparison of the mean weights (1992-1998) of wild and enhanced fry at the time of stocking, and the mean weights of wild and enhanced smolts a year after stocking (Table 6.5). This chapter uses these comparisons to test the hypothesis that enhanced fry mortality is size-selective. Three mechanisms of size-selective mortality are identified, investigated and discussed.

SIZE-SELECTIVE MORTALITY

In general, experimental studies have shown that larger, or faster growing fish have a survival advantage over smaller, or slower growing fish from the same population. This is due to their lower vulnerability to starvation, pathogens or parasites, environmental extremes, and predation (Sogard 1997). Wahl and Stein (1989), Svasand and Kristiansen (1990), Johnson and Margenau (1993) and Willis *et al.* (1995) found that when hatchery fish were marked and released into natural environments, larger fish had better survival than smaller fish. Leber (1995) and Leber *et al.* (1995) found differences in mortality patterns between wild and hatchery juvenile striped mullet: hatchery fish experienced size-selective mortality to a greater degree than the wild fish. Size-selective mortality has also been shown to occur in salmon. Healey (1982) found that juvenile chum salmon experience size-selective mortality in early marine life, and Parker (1971) suggested that early marine mortality of chum salmon (*Oncorhynchus keta*) and pink salmon (*Oncorhynchus gorbuscha*) was caused by size-selective predation by juvenile coho (biased towards smaller individuals). West and Larkin (1987) found evidence of size-selective mortality in juvenile sockeye of Babine Lake, BC.

Absolute size is very important when examining causes of mortality that have threshold effects, such as mortality due to predators that are limited by gape size. Perhaps more important when considering the Tatsamenie Lake enhanced fry survival problem, is relative size compared to other members of the young-of-the-year population. If enhanced fry are smaller relative to wild fry, they may be less able to compete with wild fry for food and protective inshore habitat, and may be more susceptible to predators. Stocking enhanced fry that are smaller than wild fry may reduce predation on wild fry by suddenly providing predators with prey that are more vulnerable and abundant.

SIZE-SELECTIVE HYPOTHESIS TESTING

The mean weights of wild and enhanced fry (at the time of stocking), and smolts (a year after stocking) were compared (Table 6.5) for seven years (1992-1998). This was done to determine if: (1) enhanced fry were smaller than wild fry at the time of stocking, and (2) if the initial size difference (or similarity) was maintained through the year to the smolt stage. Of the seven years of mean weight comparisons, only two years (1997 and 1998) have data strong enough to allow us to test our size-selective mortality hypothesis. Data in all other years (1992-96) could not be used for one or more of the following reasons: (1) low initial beach seine sample size, (2) low smolt sample size, or (3) late initial beach seine sampling (Appendix C1). Critical assumptions that must be met when comparing mean sizes obtained from cross-sectional sampling of a population include: collecting unbiased and successive samples from the same population, and collecting samples before and after a period of suspected high mortality (Sogard 1997). Since initial mortality (first few days to weeks) of enhanced fry in Tatsamenie Lake is likely substantial, it was important to use data only from years when initial beach seine sampling was done near the end of the stocking period.

In 1997, stocking of enhanced fry took place from June 15-27. The first beach seine sample (N_{wild}=126, $N_{enh.}$=78) was taken the day before the final group (of seven groups) of fry was stocked. In this sample, enhanced fry were significantly smaller than wild fry (mean $weight_{wild}$=0.27±0.02, mean $weight_{enh.}$=0.16±0.01, $p<0.01$). The associated smolt sample (N_{wild}=393, $N_{enh.}$=71), taken a year later in spring 1998, suggested that enhanced smolts were significantly larger than wild smolts (mean $weight_{wild}$=3.87±0.13, mean $weight_{enh.}$=4.48±0.33, p<0.01).

In 1998, stocking of enhanced fry took place from June 15-29. The first beach seine sample (N_{wild}=93, $N_{enh.}$=87) was taken the day after the final group (of seven groups) of fry was stocked. In this sample, enhanced fry were significantly smaller than wild fry (mean $weight_{wild}$=0.29±0.05, mean $weight_{enh.}$=0.17±0.02, p<0.01). The associated smolt sample (N_{wild}=309, $N_{enh.}$=40), taken a year later in spring 1999, suggested that enhanced smolts were not significantly different in size from wild smolts (mean $weight_{wild}$=3.93±0.24, mean $weight_{enh.}$=3.51±0.38, p<0.33).

In 1997 and 1998, enhanced fish were smaller than wild fish as fry, but they were not smaller as smolts. This suggests that enhanced fry mortality was size-selective. In 1997, wild and enhanced egg-to-smolt survivals were 6.6% and 4.5%. In 1998, wild and enhanced egg-to-smolt survivals were 4.1% and 1.1%. Hence, enhanced egg-to-smolt survivals were lower than wild survivals in spite of the fact that enhanced egg-to-fry survivals were likely considerably higher (hatchery incubation) than wild egg-to-fry survivals (lake incubation). This suggests that the enhanced fry population experienced a greater degree of size-selective mortality, from the fry-to-smolt stages, than the wild fry population. The smallest, enhanced fry would have experienced higher mortality than larger enhanced fry, thus removing fry in the lower end of the weight-frequency distribution, resulting in enhanced smolts having mean weights similar to, or higher than wild smolts. The patterns of wild and enhanced survival that occurred may look similar to those shown in Figure 7.1. An alternate explanation for the observed enhanced mortality and changes in mean weight from fry-to-smolt, is that enhanced fry experienced

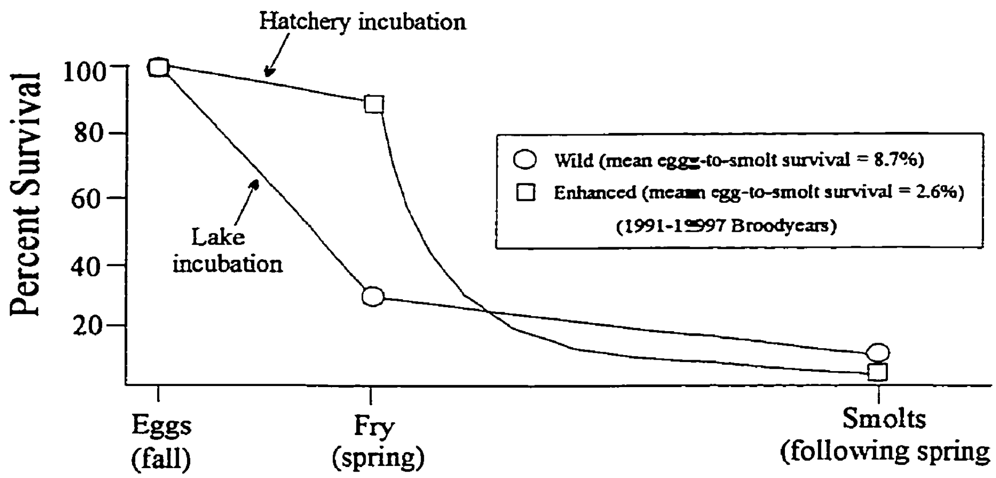


Figure 7.1. Theoretical patterns of wild and enhanced percent survival from the egg to smolt stages in Tatsamenie Lake.

non-size selective (random) mortality, and grew at a faster rate than wild fry, thus catching up to wild fish by the smolt stage. However, mean instantaneous daily growth rates for wild (0.011 g/day) and enhanced (0.010 g/day) fish from stocking to smolt outmigration, suggest that enhanced fry did not grow faster than wild fry.

Mechanisms identified to explain the low survival of enhanced fry, with respect to the size-selective mortality hypothesis include: (1) feeding: smaller fry had lower success acquiring food compared to larger fry, (2) pathogens or parasites: smaller fry were more susceptible than larger fry, or (3) predation: smaller fry were more susceptible than larger fry. The remainder of this chapter examines wild and enhanced fry diets, disease testing, and net pen feeding experiment data, to identify which of the mechanisms of size-selective mortality was responsible for the low survival of enhanced fry.

MECHANISMS OF SIZE-SELECTIVE MORTALITY

1. Feeding: Sockeye Fry Diet Analyses

1.1 Methods

Diets were analysed and compared for wild and enhanced fry captured by beach seining on July 19, 1998 (site 5, Fig. 3.2) and July 2, 1999 (sites 2-5, Fig. 3.2). Stomach contents were analysed to determine if differences existed between wild and enhanced fry prey selection (qualitative) and stomach content weights (quantitative). Diet analysis methods were developed by K. Mathias.

Stomach processing was done by cutting the esophagus just above the cardiac stomach, and removing both the cardiac and pyloric portions of the stomach. With a scalpel and dissecting microscope, the complete stomach was sliced open and the contents teased out with forceps. The fry carcass and empty stomach were placed back into their labeled vial containing 70% denatured alcohol (ethanol/methanol mix) for storage. The major prey groups found in each stomach were recorded in decreasing order of abundance, and it was noted whether insect prey were found intact, as heads only, or in bits (zooplankton were almost always whole). Stomach contents were then put into individual, labeled vials with 70% denatured alcohol (ethanol/methanol mix) for storage until they were weighed. A vacuum pump and filter apparatus was used to filter the stomach contents onto a pre-washed (with 20 ml of 70% alcohol), pre-weighed 2.5 mm Whatman filter. In order to standardize the amount of alcohol saturating the filter, vacuum pump suction was applied to the filters for precisely 5 seconds after the alcohol had been filtered through. The filters and stomach contents were weighed using a Cahn electrobalance with 0.001g precision, then placed back into the labeled vial with 70% alcohol for storage.

Stomach content weight was calculated by subtracting the pre-washed filter weight from the weight of the filter plus stomach contents. Processing of stomach content weight data involved calculating the stomach content weight as a percentage of fry wet weight by:

$$\frac{\text{stomach content weight (g)}}{\text{fry wet weight (g)}} \times 100\%$$

Percent stomach content weights were arcsine transformed to normalize the distribution of the data ($p' = \text{arcsine}\sqrt{p}$). A Fulton-type condition factor (Anderson and Gutreuter 1983) for each fry was calculated as:

$$\frac{\text{weight (g)}}{\text{length (mm)}^3} \times 100{,}000 \text{ (an arbitrary scaling constant)}$$

Condition factors (indices of well-being) were calculated to determine if significant differences in body condition existed between wild and enhanced fry.

1.2 Results

Results of the stomach content analyses showed no observable differences between wild and enhanced fry prey selection. Major prey groups eaten included:

(1) zooplankton
- *Daphnia* sp.
- *Bosmina* sp.
- cyclopoid copepods

(2) insects
- Diptera larvae, pupae and adults
- Hemiptera nymphs and adults
- Thysanoptera adults (thrips)

Less common prey groups eaten included Trichoptera adults (caddisflies), Hymenoptera adults, Odonata adults (damselflies), and Araneida (mites). In the July 19, 1998 sample (n_{wild}=30, $n_{enhanced}$=10 fry), the most common prey eaten were cyclopoid copepods, *Daphnia*, and Diptera pupae. In the July 2, 1999 sample (n_{wild}=26, $n_{enhanced}$=26 fry), the most common prey eaten were Diptera larvae and pupae, and Thysanoptera adults. Differences in prey selection between the two samples are likely due to temporal and spatial variations in available prey between years and habitats.

Mean stomach content weights as percentages of fry weights (arcsine transformed) were compared for wild and enhanced fry in July 19, 1998 and July 2, 1999 beach seine samples. Although mean percent stomach content weight was lower for enhanced fry compared to wild fry (Fig. 7.2), two-sample Student's *t* tests showed no significant differences between wild and enhanced mean percent stomach content weights in 1998 ($t_{0.05(2),38}$ = 1.42, 0.20>p>0.10) and 1999 ($t_{0.05(2),50}$ =1.67, p=0.1) samples.

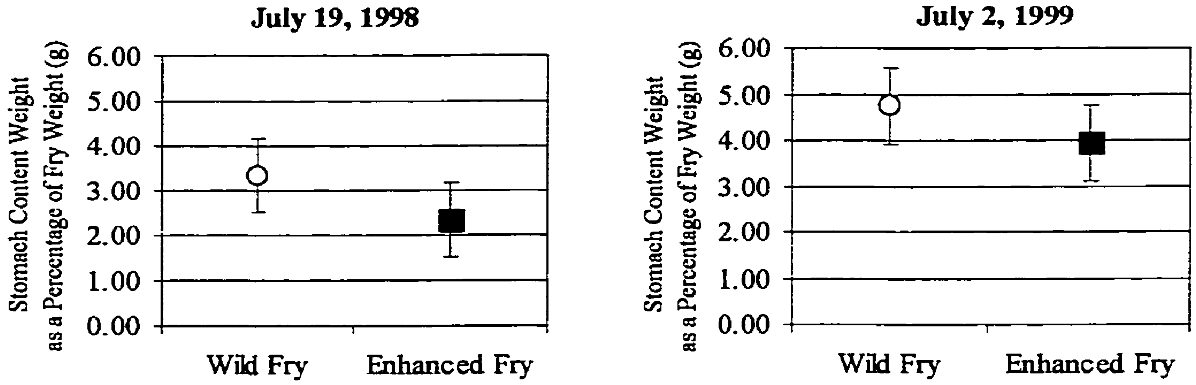


Figure 7.2. Mean percent stomach content weights (arcsine transformed) and 95% confidence intervals for wild and enhanced fry captured in July 19, 1998 and July 2, 1999 beach seines.

Linear regression analyses between percent stomach content weight (arcsine transformed) and fry weight were compared for wild and enhanced fry samples collected from July 19, 1998 and July 2, 1999 beach seines (Fig. 7.3).

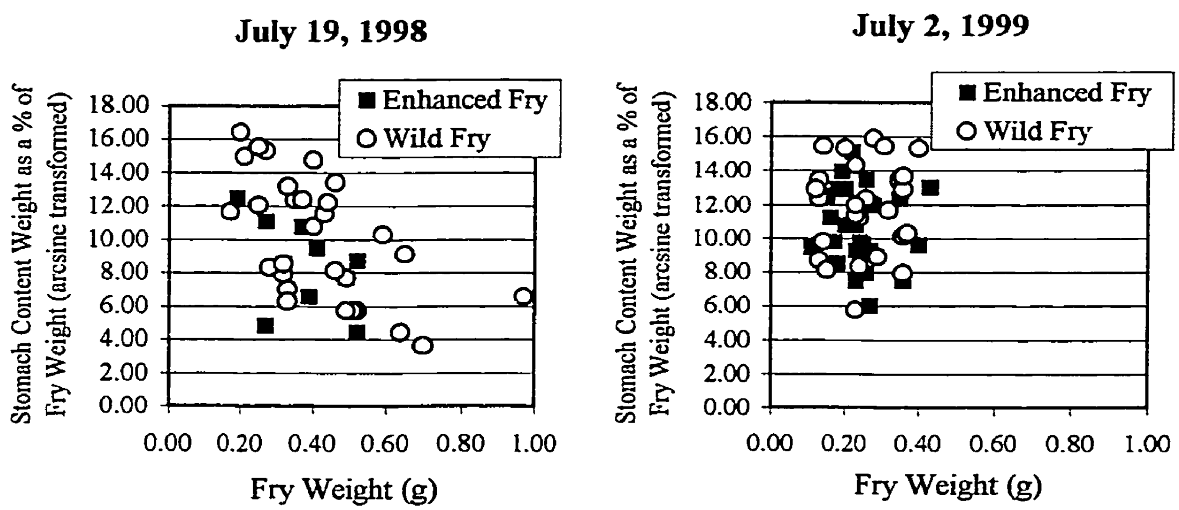


Figure 7.3. Relationship between percent stomach content weight (arcsine transformed) and fry weight, for fry captured in July 19, 1998 and July 2, 1999 beach seines.

In the 1998 sample, a significant relationship was found for wild fry (r^2=0.22, p=0.01), but not for enhanced fry (r^2=0.22, p=0.17). When wild and enhanced regression lines were compared using ANCOVA, it was found that they were not significantly different in slope ($t_{0.05(2),36}$=1.03, 0.50>p>0.20) and elevation ($t_{0.05(2),37}$=0.08 < =2.03, p>0.50). In the 1999 sample, no significant relationships were found for wild fry (r^2=0.01, p=0.67) and enhanced fry (r^2=0.00, p=0.74). When wild and enhanced regression lines were compared using ANCOVA, it was found that they were not significantly different in slope ($t_{0.05(2),48}$=0.44, p>0.50) and elevation ($t_{0.05(2),49}$=0.66, p>0.50).

Mean condition factors were compared for wild and enhanced fry in July 19, 1998 and July 2, 1999 beach seine samples. Although mean condition factor was lower for enhanced fry, compared to wild fry, in both 1998 (0.68±0.04 compared to 0.70±0.03) and 1999 (0.55±0.03 compared to 0.57±0.04), two-sample Student's *t* tests showed no significant differences between wild and enhanced condition factors in either 1998 ($t_{0.05(2),38}$=1.42, 0.20>p>0.10) or 1999 ($t_{0.05(2),50}$=1.67, p=0.1) samples.

Linear regression analyses between condition factor and percent stomach content weight (arcsine transformed) were compared for wild and enhanced fry samples collected from July 19, 1998 and July 2, 1999 beach seines (Fig. 7.4). In the 1998 sample, a significant relationship was found for wild fry (r^2=0.15, p=0.03), but not for enhanced fry (r^2=0.18, p=0.22). When wild and enhanced regression lines were compared using ANCOVA, it was found that they were not significantly different in slope ($t_{0.05(2),36}$=1.08, p>0.20) and elevation ($t_{0.05(2),37}$=0.75, 0.50>p>0.20). In the 1999 sample, no significant relationships were found for wild fry (r^2=0.00, p=0.90), and enhanced fry (r^2=0.01, p=0.58). When wild and enhanced regression lines were compared using ANCOVA, it was found that they were not significantly different in slope ($t_{0.05(2),48}$=1.01, 0.50>p>0.20) and elevation ($t_{0.05(2),49}$=0.86, 0.50>p>0.20).

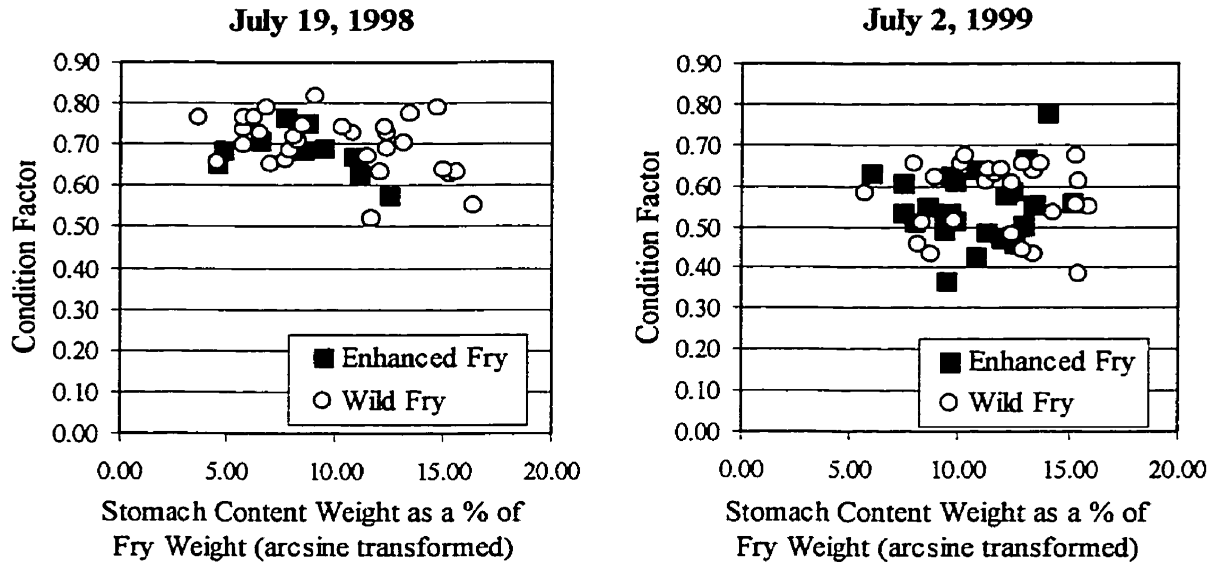


Figure 7.4. Relationship between condition factor (Fulton-type; Anderson and Gutreuter 1983) and percent stomach content weight (arcsine transformed) for fry captured in July 19, 1998 and July 2, 1999 beach seines.

Taken together, all of these data suggest a trend for enhanced fry to contain somewhat less food and to exhibit somewhat lower condition factors than wild fry. However, the differences are small and it is reasonable to assume that enhanced fry did not experience higher mortality than wild fry because they had difficulty obtaining a sufficient quantity or quality of food. This leads us to test the hypotheses that the high rate of observed enhanced fry mortality is due to pathogens/parasites, or predation.

2. Pathogens or Parasites: Sockeye Disease Testing

Small fish size, slow growth rate, and poor condition have been found to influence susceptibility to disease and parasites (Sogard 1997). West and Larkin (1987) suggested that smaller, slower growing juvenile sockeye salmon can experience higher mortality due to disease or parasitism, than larger, faster growing juveniles. Boyce (1974) found that parasitism by the cestode *Eubothrium salvelini*, could cause size-selective mortality in Babine Lake sockeye fry. Smaller and slower growing fry are more susceptible to infection by the parasite than larger (greater than 35-45 mm) and faster growing fry. Although parasitized fry can survive to the smolt stage, they demonstrate reduced growth, survival and swimming performance (Boyce and Behrans Yamada 1977; Boyce 1979, 1982; Boyce and Clarke 1983) and are likely more susceptible to predation in the lake (Smith 1973).

Infectious hematopoietic necrosis virus (IHNV) and bacterial kidney disease (BKD) are the most common and serious diseases of sockeye salmon. IHNV is pathogenic to all life stages from eggs to adults, and results in acute mortality (Mulcahy and Pascho 1985). In general, smaller fish are more susceptible to the virus, with fry mortality rates that can reach 100% over a two to three week period. IHNV is most commonly transmitted directly from fish to fish, but can be transmitted indirectly through the water by urine, feces and mucus shed by infected fish. The virus survives for several days in fresh water, and very low levels of virus can cause infection. Fortunately, IHNV is destroyed by iodiphore disinfectants, which can be very effective in preventing transmission on the outside of eggs. To avoid transmission of IHNV, eggs must come only from inspected and certified IHNV free broodstock sources. BKD is caused by the bacterium *Renibacterium salmoninarum*, and is believed to be transmitted through direct contact with infected fish (Roberts 1989). BKD develops slowly in the infected fish and signs of the disease may not be present until the fish reaches the adult stage. External signs of the disease include protruding eyes, skin darkening, hemorrhaging at the base of the fins, and cutaneous ulcers. Internal signs of BKD include granulomas in the kidney, and often in the spleen, heart and liver.

Annual disease sampling of the Transboundary sockeye stocks, for IHNV and BKD, has been done since 1989. Of approximately 100 kidney and ovarian fluid samples from Tatsamenie Lake broodstock tested annually (1990 to 1999), an average of 24% of samples tested positively for IHNV. Of these samples, an average of 38% had titers greater than, or equal to 10^4 plaque forming units (pfu), which is the point at which the probability of parent to offspring transmission of IHNV is believed to greatly increase (Pacific Salmon Commission 1991). This rate of adult spawner infection is considered to be normal for sockeye populations. Indigenous fish species caught during initial surveys at each lake were examined externally and internally at the Fish Disease Diagnostics Laboratory, PBS, Nanaimo, BC. Fish were tested for bacterial pathogens in kidney tissue, and viral pathogens in kidney, gill, spleen, and pyloric caeca tissues. Internal organs were examined by parasitology experts. The parasitic cestode *Eubothrium salvelini*, which caused size-selective mortality of sockeye fry in Babine Lake, was found to be absent in fish examined from the Transboundary lakes.

Canadian and Alaskan (Fish Pathology Section of the ADF&G) fish health approvals were required to transport eggs of Canadian origin to the Snettisham Hatchery near Juneau, AK, and to transport the resultant fry back to Canadian lakes. Canadian fish health transport approval conditions (Pacific Salmon Commission 1991, Appendix A) that were required to be met included:

- All eggs collected in BC must be surface disinfected immediately after fertilization. Care must be taken to avoid re-contamination of the disinfected eggs by water which is not from a fish-free source.
- The sockeye eggs must be incubated and hatched, and the resulting fry reared in strict isolation from all other fish or eggs on the Port Snettisham Hatchery site.
- All shipments of fry returned to BC will be tested for IHNV at a 95% probability of detecting a 2% disease incidence, according to protocols outlined in the manual of compliance to the Canadian Fish Health Protection Regulations.

It was concluded that pathogens or parasites were unlikely to be responsible for the consistent low survival of enhanced fry in Tatsamenie Lake for the following reasons: (1) disease testing of broodstock was conducted annually, (2) Canadian and Alaskan fish health transport protocols were strictly adhered to, and (3) it is unlikely that enhanced fry would suffer from a pathogen or parasite that did not affect wild fry to a similar degree. This leaves predation as the best explanation for the low survival of enhanced fry. This mechanism of mortality is examined in the following section.

3. Predation: Net Pen Feeding Experiment

In June 1998, a net pen feeding experiment was conducted using 394,000 of the 3,600,000 enhanced fry to be stocked into Tatsamenie Lake. The purpose of this study was to determine if feeding enhanced fry (held in net pens located in the lake), would improve survival relative to the unfed enhanced fry. It was expected that the survival of fed enhanced fry would meet or exceed wild fry survival.

Unfed enhanced fry (3,206,000 fry) were transported to Tatsamenie Lake in six shipments from June 15-27. To assess their short-term mortality, the unfed enhanced fry were held in net pens within the lake for an average of 38 hours (23-72 hours). Average mortality was 2.3% (1.0% - 3.8%). One shipment of enhanced fry (394,000 fry) was held in net pens in the lake and fed commercial fish food for 15 days from June 25 to July 9. Mortality of the fed enhanced fry during this time was 5%. Daily records were kept of surface water temperatures, which averaged 14.4°C (12.0 – 16.0), and of the amount of food fed. Fed fry weights, which ranged from 0.11g (day 1) to 0.32 (day 14), were measured every 1-4 days (average N=36 fry). On July 15, approximately 388,000 fed enhanced fry were passively released onshore throughout the day.

Table 7.1 shows the weight comparisons of wild, fed enhanced, and unfed enhanced fish: (1) shortly after stocking (June 30), (2) at the time of fed enhanced fry release (July 9), and (3) at smolt outmigration a year later (June 1999). The first important thing to note from Table 7.1 is the significant weight difference between wild and unfed enhanced fry shortly after stocking (June 30, Kruskal-Wallis $p<0.01$), making it likely that unfed enhanced fry were at a survival disadvantage in terms of size-selective predation and intraspecific competition with wild fry. Fed enhanced fry weight was mid-way between wild and unfed enhanced fry weights, indicating that fed fry had much higher growth rates than unfed fry. It is possible that Tatsamenie Lake fry are food-limited to some degree. Several studies of juvenile fish (Post and Prankevicius 1987; Holtby *et al.* 1990; Blom *et al.* 1994) have shown an interesting relationship between food limitation and size-selective mortality. When food was limiting, mean growth and survival rates were lower, and size-selective mortality was apparent. When food was not limiting, mean growth and survival rates were higher, but size-selective mortality was absent or too subtle to be detected.

Table 7.1. Comparisons between wild, fed enhanced, and unfed enhanced fish weights (with 95% confidence intervals and sample size (N)) shortly after stocking (30-June-98), at the time of fed enhanced fry release (9-July-98), and at smolt outmigration the following spring (June 1999).

	30-Jun-98 beach seine			**9-Jul-98 (fed fry release)**			**Smolt sample (June 1999)**		
	Mean weight (g)	95% CI	N	Mean weight (g)	95% CI	N	Mean weight (g)	95% CI	N
Wild	0.29	0.05	93	** 0.36	n/a	n/a	3.93	0.24	309
Fed enhanced	* 0.21	n/a	68	0.32	n/a	42	3.85	0.57	17
Unfed enhanced	0.16	0.01	37	n/a	n/a	n/a	3.51	0.38	40

* mean weight of fed enhanced fry in net pens on 1-July-98

** mean weight was extrapolated using wild fry instantaneous daily growth rate (0.00842 g/day), calculated from growth between 30-June-98 to 19-July-98 beach seines.

The second thing to note from Table 7.1 is that wild and fed enhanced fry weights, on the day fed fry were released, were not substantially different. The wild fry mean weight is an estimate derived from multiplying 9 days (the number of days between the first beach seine sample (June 30) and the date of fed fry release (July 9)) by the daily growth rate (0.00842 g/day). Daily growth rate was calculated by dividing the difference in wild fry weights (0.45g – 0.29g = 0.16g; Appendix C1) between the first two beach seine samples (June 30 and July 19), by the number of days between the first two beach seine samples (19 days). If wild fry experienced substantial size-selective mortality between the first two beach seine samples, it is likely that the wild daily growth rate (and therefore the mean weight estimate) is over-estimated. In that case, the mean weights of wild and fed enhanced fry would be even more similar, which raises the expectation that wild and fed enhanced fry would have similar survival rates (if size-selective predation is significantly responsible for low enhanced fry survival).

The final thing to note in Table 7.1 is that the mean smolt weights for wild, fed enhanced, and unfed enhanced fry were not significantly different from each other (Kruskal-Wallis p=0.299). This suggests that unfed enhanced fry, which started out significantly smaller than wild fry, experienced substantial size-selective mortality.

From these results we would expect wild and fed enhanced fry to have similar survival rates, and unfed enhanced fry to have much lower survival rates compared to wild and fed fry. Table 7.2 shows egg-to-age 1+ smolt survival estimates for wild, fed enhanced, and unfed enhanced fish, calculated using two independent methods. The first method for estimating egg-to-smolt survival used the fall hydroacoustic population estimate of limnetic fry (1998) to estimate the emigrating smolt population the following spring (1999). Total fall acoustic estimates were multiplied by 0.75 to account for 25% overwinter mortality and age 1+ holdovers (fry that spend two years in the lake instead of only one). In Tatsamenie Lake, an average of 15% of the fish in each broodyear emigrate as age 2+ smolts. The total smolt estimate was broken down into age and origin classes (wild, enhanced, age 1+, age 2+) using the relative proportions of each found in the smolt

Table 7.2. Comparison of egg-to-age 1+ smolt survival between wild, fed enhanced, and unfed enhanced fish (1998 stocking year) using two independent estimates of age 1+ smolt numbers.

	Hydroacoustic Estimate			
	# eggs	# fry stocked	# age 1+ smolts	Egg-to-smolt survival
Wild	7,117,629	n/a	294,681	4.1%
Fed enhanced	549,287	388,000	16,184	2.9%
Unfed enhanced	4,430,648	3,130,000	38,124	0.9%
	Total:	388,000	348,989	

	Mark-recapture Estimate			
	# eggs	# fry stocked	# age 1+ smolts	Egg-to-smolt survival
Wild	7,117,629	n/a	455,240	6.4%
Fed enhanced	549,287	388,000	30,272	5.5%
Unfed enhanced	4,430,648	3,130,000	51,272	1.2%
	Total:	388,000	536,784	

sub-sample obtained by fyke netting the lake outlet during outmigration. Egg-to-age 1+ smolt survival was calculated by dividing the number of smolts by the number of eggs. The number of enhanced eggs was calculated by multiplying the number of female spawners used for broodstock, by the average fecundity (measured during the egg-take). The number of wild eggs was calculated by multiplying the number of female spawners counted at the Tatsamenie Lake weir, by the average fecundity found for broodstock females.

The second method for estimating egg-to-smolt survival (Table 7.2) used smolt estimates derived from a mark-recapture survey. Smolts, captured using a fyke net (with an attached "live box") deployed in the lake outlet, were tagged using color coded staple tags (unique tags for each day), and released along an established transect across the lake, 4 km from the outlet. Smolts were continually captured day and night, and daily records were kept of the number of tagged smolts that were tagged that day, the number of tagged smolts that had any tag, and the total number of smolts captured that day. From these data, total smolt emigration was then calculated using the Maximum Likelihood Darroch estimator in the Stratified Population Analysis System (SPAS) computer program. SPAS, which was developed to analyse stratified mark-recapture data (Arnason *et al.* 1995), allows pooling of strata and performs several tests for goodness of fit.

To give an idea of samples sizes, in 1998, a total of 147,754 smolts were captured from May 16 to June 30. Of these smolts, 7,789 were tagged and released, and 373 were recovered. Concurrent with the mark-recapture program, a total of approximately 500 smolts were retained from daily smolt sub-sampling to provide length, weight and age (scale samples) data, and wild:enhanced ratios (otolith samples) from which daily run estimates of each could be calculated. The total smolt estimate was broken down into age and origin classes (wild, enhanced, age 1+, age 2+) using the relative proportions of each found in daily smolt sub-samples, weighted by week. Egg-to-age 1+ smolt survival was calculated by dividing the number of smolts by the number of eggs. Detailed methods and results of the 1996, 1998 and 1999 Tatsamenie Lake mark-recapture programs are reported in Mercer & Associates Ltd. (1998, 1999, in prep.).

The egg-to-smolt survival estimates derived by the two methods are fairly consistent. Although actual survival estimates are slightly different, the relative differences between wild, fed enhanced and unfed enhanced fry are similar. Fed enhanced fry survival was 3.2 times (hydroacoustic method) to 4.6 times (mark-recapture method) greater than the unfed enhanced fry survival. However, although feeding enhanced fry improved their survival, wild survival was still 1.4 times (hydroacoustic method) to 1.2 times (mark-recapture method) higher. This may have been due to fed enhanced fry being slightly (but not significantly) smaller than wild fry, even after feeding (Table 7.1). Alternately, fed enhanced fry may have had lower survival than wild fry because of differences in feeding or migration (from littoral to limnetic areas) behaviours that made enhanced fry more susceptible to predation than wild fry (not tested).

What do the net pen feeding experiment results mean? Feeding caused enhanced fry to grow faster, so that they caught up to the weight of wild fry by the time they were released. Growing enhanced fry bigger increased their survival either by: (1) making them better able to compete for food with the smaller, unfed, enhanced fry, and with wild fry, (2) protecting them from predators (net pen enclosure) during a vulnerable period of acclimation to the lake environment, or (3) improving their ability to avoid predators after they were released. Since we know that unfed enhanced and wild fry ate similar amounts and types of food, it follows that we would expect fed enhanced and wild fry to have similar diets. This rules out the first possibility, leaving predators as the most likely cause of mortality for the hatchery fry that are stocked into Tatsamenie Lake.

FUTURE TEST OF SIZE-SELECTIVE MORTALITY

West and Larkin (1987) used otolith-body length relationships and back-calculation of size-at-age procedures to show that mortality of sockeye fry in Babine Lake was size-selective. The daily growth rings visible in sagitta otoliths have been commonly used to determine fish size (Jonsson and Stenseth 1977; Marshall and Parker 1982; Neilson and Geen 1982; Wilson and Larkin 1982). West and Larkin (1987) compared the length frequency distributions of recently emerged fry (original population) with the back-calculated length-at-emergence of summer to fall fry and smolts of the same year class (the survivors). They found that the survivors of the original population had lengths-at-emergence that were above the mean length of the original population. This indicates that there was early selection against fry of small lengths.

To investigate if size-selective mortality could be detected for Tatsamenie Lake enhanced fry from 1997 to 1999, we attempted to use the back calculation of size-at-age procedures outlined by West and Larkin (1987). The idea was to take total otolith length (T.O.L.; Fig. 7.5) measurements from recently emerged enhanced fry just prior to stocking. These otolith samples, called voucher samples, were collected from fry in each hatchery incubator to provide references for later otolith thermal mark identification. Ideally, fry length and weight measurements should be taken when voucher otolith samples are taken, in order to test the relationship between T.O.L. and length-at-emergence. T.O.L measurements would also be taken from fry in the fall trawl samples, approximately 3-4 months after stocking, and be used to back calculate the size of fry at emergence. If length-at-emergence of the voucher fry was similar to the that of the fall

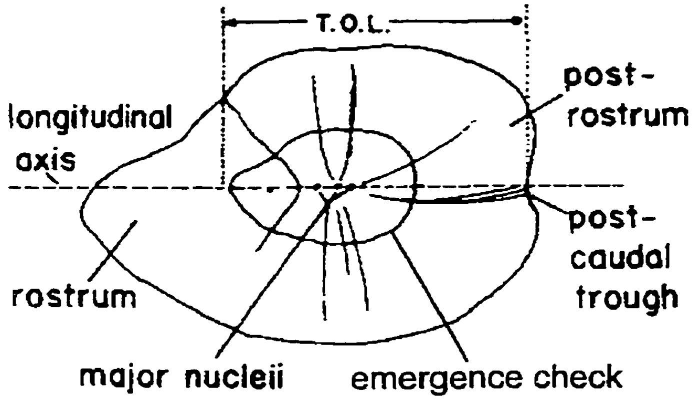


Figure 7.5. Diagram of a juvenile sockeye otolith viewed from the distal side indicating the locations of the emergence check and the total otolith length (T.O.L.) measurement. Taken from West and Larkin (1987).

trawl fry, the conclusion would be that size-selective mortality was absent or undetectable. If length-at-emergence of fall trawl fry was larger than that of the voucher fry, the conclusion would be that size-selective mortality did occur since fry that survived to the fall would have been among the largest fry to emerge. Unfortunately, this investigation had not been planned for spring 1999, and therefore samples were not collected with otolith measurements in mind. The ADF&G Otolith Lab in Juneau, AK attempted to look at existing 1997-99 voucher and fall trawl samples, but it was not possible to carry out this investigation due to the following reasons: (1) the sample sizes of 1997-99 voucher fry were too low (approximately 10 fry) to allow unambiguous validation of the emergence check location, (2) length and weight measurements were not taken from fry when their otoliths were removed for voucher samples, and (3) the Otolith

Lab had limited budgeted time for the processing and validation of otolith measurements. It is unknown whether this work will be carried out in future stocking years.

SUMMARY

It was determined in the last chapter that Tatsamenie Lake enhanced fry had much lower egg-to-smolt survival rates than wild fry, despite being raised in a thermally stable, predator-free, hatchery environment from the egg-to-fry stages. Since preliminary analyses indicated that enhanced fry were at a size disadvantage compared to wild fry at the time of stocking, it was hypothesized that enhanced fry experienced size-selective mortality to a greater degree than wild fry. Many studies have shown that smaller, slower growing juvenile fish experience higher rates of mortality than larger, faster growing fish, because of the greater vulnerability to starvation, disease, environmental extremes, and predation (Sogard 1997). When considering size-selective intraspecific competition and predation, the size of an individual fish relative to other fish in the same year class is likely more important than the fish's absolute size.

Mean weight comparisons of wild and enhanced fry and smolts in 1997 and 1998 suggested that enhanced fry in Tatsamenie Lake experienced a higher degree of size-selective mortality than wild fry. Possible mechanisms of size-selective mortality of the enhanced fry include: (1) feeding: small fry lacked success in acquiring a sufficient quantity and quality of food than larger fry, (2) disease: small fry were more susceptible to pathogens or parasites than larger fry, or (3) predation: small fry were more susceptible to predators than larger fry. Analyses of fry diets suggested that wild and enhanced fry in

1998 and 1999 early summer beach seines ate similar amounts and types of prey. I concluded that enhanced fry were not likely to have had difficulties feeding (compared to wild fry), and that enhanced fry mortality was likely due either to disease or predation. Close inspection of disease testing procedures revealed that sockeye broodstock underwent stringent annual tests for IHNV and BKD, indigenous fish underwent internal and external examinations for pathogens and parasites, and Canadian and Alaskan fish health transport protocols were strictly adhered to. Based on these findings, it was concluded that disease was not responsible for the consistent low survival of enhanced fry, leaving predation as the most likely cause of enhanced fry mortality.

In spring of 1998, a net pen (enclosure) feeding experiment was conducted to determine if feeding the smaller enhanced fry to a size similar to the larger wild fry would improve survival. The results showed that enhanced fry feeding improved their survival over unfed enhanced fry by an average of 3.9 times. However, wild fry survival rates were still an average of 1.3 times higher than fed enhanced fry survival rates. The reason why feeding improved survival is not clear since this experiment was confounded. The feeding experiment could have improved the survival of enhanced fry either by: (1) growing the enhanced fry larger before stocking, improving their ability to avoid predators, or (2) by simply protecting the enhanced fry from predators for their first two weeks in the lake, allowing them to acclimate to the lake environment prior to contact with predators. Improved enhanced fry survival was likely a combination of both factors, but since we have evidence of size-selective mortality of enhanced fry, it is most reasonable to assume that it was the increase in enhanced fry size that was most responsible for their improved survival by enabling them to better avoid predators. Therefore it was concluded that size-selective predation was the most likely mechanism responsible for the consistent low survival of enhanced fry in Tatsamenie Lake.

Whatever the mechanism, the most important result is that enhanced fry suffered high rates of mortality, compared to wild fry, despite being raised in a hatchery environment. Considerable costs are associated with the egg-takes from broodstock, hatchery operations, stocking, and monitoring. Although feeding enhanced fry (which is also costly) did improve their survival, wild fry survival was still superior. The fact is, that despite many attempts to improve enhanced fry survival, the eggs taken to the hatchery would have had better survival if simply left in the lake to develop naturally. Therefore, the overall conclusion is that the enhancement program at Tatsamenie Lake has been unsuccessful to date.

Chapter 8 - Discussion and Conclusions

OVERVIEW

Tatsamenie, Tahltan, and Tuya lakes were selected for sockeye stock enhancement because the fish production models (EV model and Zooplankton Density model) that the TTC used to assess the lakes, suggested that they had unused juvenile sockeye rearing capacities (Chapter 1). Tuya Lake was determined to have the highest carrying capacity (284 EV units), compared to Tatsamenie (162 EV units) and Tahltan (94 EV units) lakes.

In Chapter 3, we learned that all three lakes have very different physical, chemical, and biological characteristics. Nevertheless, with one exception, trophic level biomass relationships were about what were expected (Table 8.1). Tatsamenie Lake had the lowest phytoplankton (chlorophyll *a*) and zooplankton standing stocks, and sockeye production. Tahltan Lake had the highest zooplankton standing crop and sockeye production (per hectare), although only the second highest phytoplankton standing stock.

Table 8.1. Ranking of the Tatsamenie, Tahltan, and Tuya lakes with regard to phytoplankton and zooplankton standing stocks, and total sockeye production (a rank of 1 indicates highest abundance, and a rank of 3 indicates lowest).

	Wild Sockeye	**Enhanced Sockeye**	**Phytoplankton (chlorophyll *a*) Standing Stock**	**Zooplankton Standing Stock**	**Sockeye Production (per hectare)**
Tatsamenie Lake	✓	✓	3	3	3
Tahltan Lake	✓	✓	2	1	1
Tuya Lake		✓	1	2	2

Tuya Lake had the highest phytoplankton standing stock, and intermediate abundances of zooplankton and sockeye.

In Chapter 5, we learned that in general, stocking Tatsamenie, Tahltan, and Tuya lakes with juvenile sockeye did not cause noticeable changes in crustacean zooplankton biomasses or species composition. The notable exception was in Tuya Lake where stocked fry were associated with changes in the three largest-bodied zooplankton groups, *Epischura* (eliminated by fry stocking), *Heterocope* (eliminated by fry stocking), and *Daphnia* (fry stocking caused decreased mean sizes and increased abundances). However, even in Tuya Lake, additional taxa composition changes were not observed after 1994. These trends are supported by the observation that there were no relationships found between enhanced fry stocking densities and mean annual zooplankton biomass in the three lakes (Figs. 8.1 - 8.3). Nor were there any relationships between total spring fry densities (wild and enhanced) and mean annual zooplankton biomass in Tatsamenie (Fig. 8.4), Tahltan (Fig. 8.5), or Tuya (Fig. 8.6) lakes.

The primary objective of this thesis was to evaluate the success of the sockeye enhancement program in Tatsamenie, Tahltan, and Tuya lakes by comparing the growth and survival of wild and enhanced sockeye fry in each lake. In Chapter 6, we learned that fry densities, growth, and survival rates differed between the three lakes. The following three sections summarize these trends.

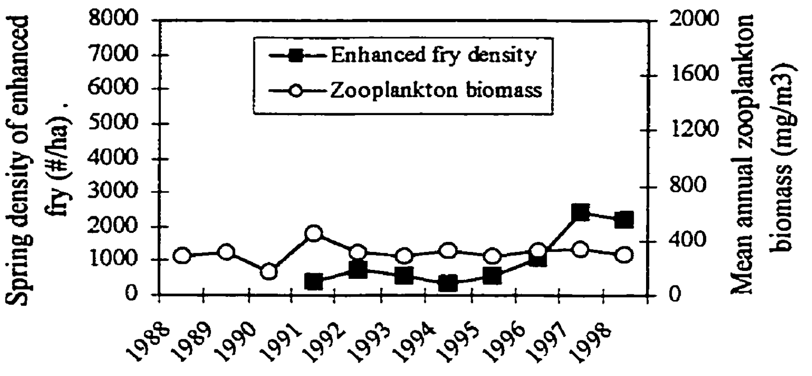


Figure 8.1. Tatsamenie Lake. Relationship between density of stocked fry and mean annual zooplankton biomass. Year labels refer to stocking year.

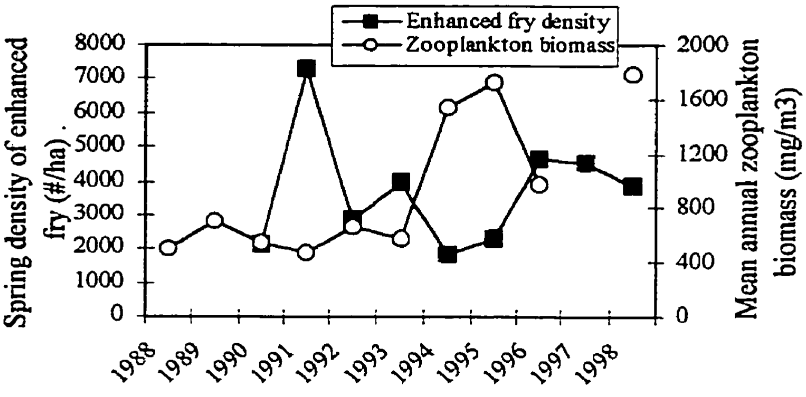


Figure 8.2. Tahltan Lake. Relationship between density of stocked fry and mean annual zooplankton biomass. Year labels refer to stocking year.

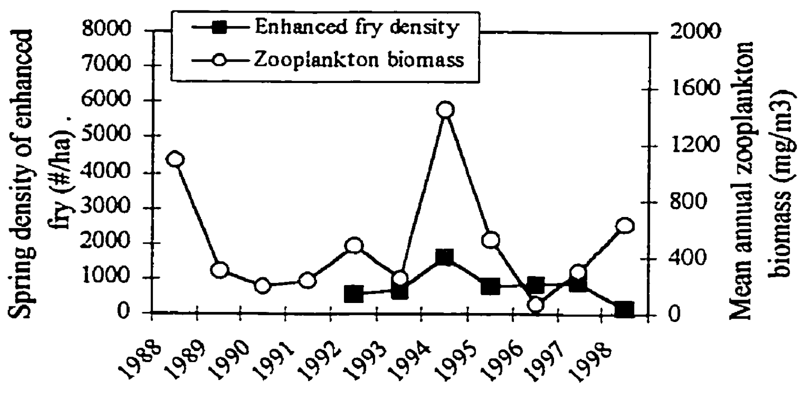


Figure 8.3. Tuya Lake. Relationship between density of stocked fry and mean annual zooplankton biomass. Year labels refer to stocking year.

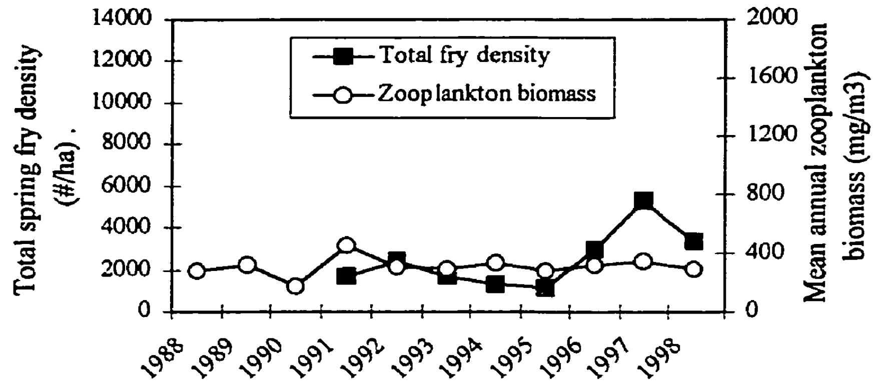


Figure 8.4. Tatsamenie Lake. Relationship between total spring density of fry (wild and enhanced) and mean annual zooplankton biomass. Years refer to stocking year.

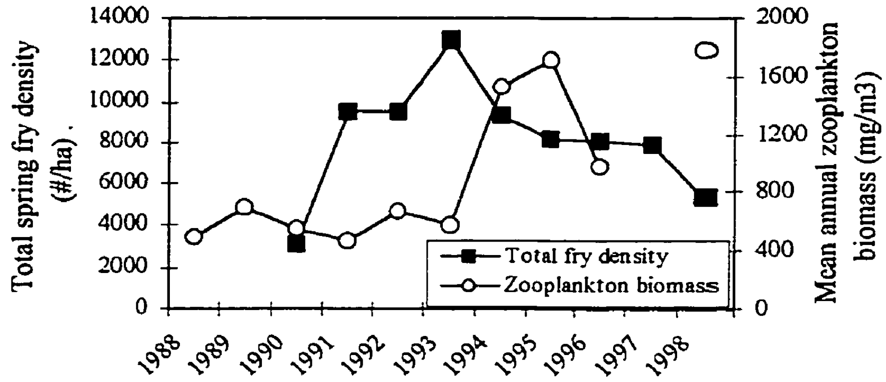


Figure 8.5. Tahltan Lake. Relationship between total spring density of fry (wild and enhanced) and mean annual zooplankton biomass. Years refer to stocking year.

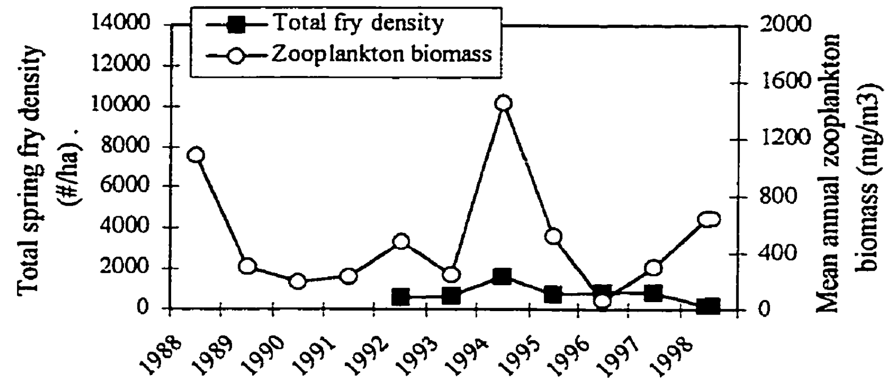


Figure 8.6. Tuya Lake. Relationship between density of total spring fry (enhanced fry only) and mean annual zooplankton biomass. Year labels refer to stocking year.

1. Sockeye Density

The goal of the enhancement program was to stock Tatsamenie, Tahltan, and Tuya lakes at approximately half of the predicted carrying capacity to ensure that stocked fry would use the zooplankton community without drastically changing its structure. Koenings and Burkett (1987a) established that a lake at carrying capacity could produce 23,000 smolts/EV unit. Table 8.2 shows that Tahltan Lake produced a total (wild and enhanced) mean annual smolt density of 12,797/EV unit, indicating that the conservative upper limit of enhanced fry stocking had been reached. Mean annual total smolt densities in both Tatsamenie and Tuya lakes were still far below half of the predicted carrying capacity.

Mean annual numbers of enhanced fry stocked were quite similar for Tatsamenie (1,700,000 fry), Tahltan (1,815,000 fry) and Tuya (2,212,700 fry) lakes, although mean annual densities stocked were quite different (Table 8.2). Highest densities of fry were stocked into Tahltan Lake (19,309 EV^{-1}), followed by Tatsamenie (10,469 EV^{-1}), and Tuya (7,791 EV^{-1}) lakes. The question we need to answer in order to evaluate the success of the enhancement program is: which lake produced the most enhanced smolts (and therefore adults)? Since stocking densities (per EV unit) were highest in Tahltan Lake, we would expect Tahltan Lake (followed by Tatsamenie Lake) to also have the highest enhanced smolt densities (per EV unit). However, Table 8.2 shows that in fact Tuya Lake had the highest mean annual enhanced smolt density (4,163 EV^{-1}), compared to Tahltan (3,261 EV^{-1}) and Tatsamenie (475 EV^{-1}) lakes. This means that annual enhanced smolt production averaged 1,182,000 from Tuya Lake, 306,500 from Tahltan Lake, and 77,000

Table 8.2. Mean annual densities of fry stocked, of total smolts (age 1+ and 2+ wild and enhanced), of enhanced smolts (age 1+ and 2+), and the estimated numbers of adults produced by Tatsamenie, Tahltan and Tuya lakes. Bold indicates highest values.

	Tatsamenie Lake	Tahltan Lake	Tuya Lake
Mean annual stocking density (EV^{-1})	10,469 EV^{-1} (range 3,216 EV^{-1} – 24,327 EV^{-1}) euphotic volume units = 162	**19,309** EV^{-1} (range 9,617 EV^{-1} – 38,138 EV^{-1}) euphotic volume units = 94	7,791 EV^{-1} (range 1,525 EV^{-1} – 16,518 EV^{-1}) euphotic volume units = 284
Mean annual total smolt density (EV^{-1}) (wild + enhanced)	5,322 EV^{-1} (range 1,630 EV^{-1} – 9,156 EV^{-1}) euphotic volume units = 162	**12,797** EV^{-1} (range 5,107 EV^{-1} – 33,718 EV^{-1}) euphotic volume units = 94	4,163 EV^{-1} (range 2,430 EV^{-1} – 5,267 EV^{-1}) euphotic volume units = 284
Mean annual enhanced smolt density (EV^{-1})	475 EV^{-1} (range 120 EV^{-1} – 1,394 EV^{-1}) euphotic volume units = 162	3,261 EV^{-1} (range 542 EV^{-1} – 8,536 EV^{-1}) euphotic volume units = 94	**4,163** EV^{-1} (range 2,430 EV^{-1} – 5,267 EV^{-1}) euphotic volume units = 284
Mean annual enhanced smolt production	76,950 smolts	306,534 smolts	**1,182,292 smolts**
*Estimated mean annual enhanced adult production	8,364 adults	33,276 adults	**128,368 adults**

*Adult numbers were estimated using the relationship between smolt and adult production (23,000 smolts produce 2,500 adults) determined by Koenings and Burkett (1987a).

from Tatsamenie Lake. Using the relationship between smolt and adult production determined by Koenings and Burkett (1987a) (23,000 smolts/EV unit will result in 2,500 adults/EV unit), it was estimated that an annual average of 128,400 enhanced adults would theoretically be produced from stocking Tuya Lake. An annual average of 33,300 enhanced adults would in theory be produced from stocking Tahltan Lake, and an annual average of 8,400 enhanced adults would be produced from stocking Tatsamenie Lake.

2. Sockeye Growth

The rearing capacity of a sockeye nursery lake is thought to be reached when less than 85% of smolts are age 1+ (Koenings and Burkett 1987a), and when threshold-sized smolts (2.0 g or 60-65 mm) are produced in one growing season (Geiger and Koenings 1991). Smolt sizes from Tatsamenie, Tahltan, and Tuya lakes indicated that the three lakes have not been pushed to the limits of their carrying capacities. The Tatsamenie Lake smolt population (wild and enhanced combined) consisted of 85% age 1+ smolts, and had a mean weight of 4.0 g. The Tahltan Lake smolt population (wild and enhanced combined) consisted of 93% age 1+ smolts, and had a mean weight of 4.5 g. The Tuya Lake smolt population (enhanced only) consisted of 87% age 1+ smolts, and had a mean weight of 9.5 g. In capacity limited (or rearing limited) lakes, studies have shown that fry growth rate declines with increasing sockeye densities (Burgner 1964; Johnson 1965; Mathisen and Kerns 1964; Mathisen 1972; Hyatt and Stockner 1985; Koenings and Burkett 1987a). Smolt sizes in the three lakes did not decrease with higher stocking densities (Chapter 6), providing further support for the conclusion that the lakes are not at rearing capacity.

In order for the enhancement program to be successful at each lake, it was important that enhanced fry-to-smolt growth be similar to wild fry-to-smolt growth. I found that wild and enhanced fry-to-smolt growth rates were similar in Tatsamenie (0.011

g/day and 0.010 g/day) and Tahltan (0.013 g/day for both) lakes, but wild smolts were significantly larger than enhanced smolts (in both Tatsamenie and Tahltan lakes combined). This was likely due to the smaller size of enhanced fry (compared to wild fry) at the time of stocking. Although there were no wild sockeye in Tuya Lake for comparison, the average growth rate of enhanced smolts (0.027 g/day) was two times higher than the growth rates of enhanced fry in the other lakes. These differences in growth rate meant that although enhanced fry were stocked at the same weight (~0.1-0.2 g), Tuya Lake age 1+ enhanced smolt weights were significantly greater (9.5 g) than Tatsamenie (3.8 g) and Tahltan (4.4 g) enhanced smolt weights. Thus, Tuya Lake produced the largest, fastest growing sockeye, and as expected, Tatsamenie Lake produced the smallest, slowest growing sockeye.

3. Sockeye Survival

In Tahltan Lake, enhanced egg-to-smolt survival was better (11%) than wild egg-to-smolt survival (3%). It is probable that hatchery incubation improved enhanced egg-to-fry survival over wild survival, but that in-lake fry-to-smolt survival rates were similar for both wild and enhanced fish. In Tatsamenie Lake, enhanced egg-to-smolt survival was lower (3%) than wild egg-to-smolt survival (9%). Although it is probable that hatchery incubation improved enhanced egg-to-fry survival over wild survival, it appears that in-lake enhanced fry-to-smolt survival was much lower than for wild fry. The data suggested that Tuya Lake enhanced fry egg-to-smolt survival averaged 29%. Of the three lakes, it was expected that fry in Tatsamenie Lake would experience greater top-down predation because of the greater number of piscivorous fish species (Meehan 1966) thought to be present in the lake, and the preceding summary, combined with the detailed analysis provided in Chapter 7, supports this conclusion.

CONCLUSIONS AND RECOMMENDATIONS

Sockeye fry stocked into Tuya Lake had considerably better growth and survival than fry stocked into the other lakes, and as a result, it appears that the enhancement program at Tuya Lake produced the most smolts (estimated 1,182,000 smolts annually). Thus, it seems reasonable to conclude that the sockeye stock enhancement program has been very successful at Tuya Lake, and it is recommended that the program continue. Also, since Tuya Lake stocking has produced smolt densities that average far below (4,163 EV^{-1}) half of the estimated carrying capacity (11,500 EV^{-1}), it is likely that Tuya Lake could support modest increases in stocking densities.

Fry stocked into Tahltan Lake had growth comparable to wild fry, but egg-to-smolt survival rates were almost four times higher than wild fry egg-to-smolt survival. As a result, the enhancement program at Tahltan Lake produced an estimated additional 306,500 smolts, and potentially 33,300 returning adults annually. Given that the costs associated with the production of these additional smolts was quite high, it is recommended that a cost-benefit analysis of the Tahltan Lake enhancement program be done to assess whether the benefits of producing about 33,300 new adults outweighs the program costs. Since Tahltan Lake stocking produced smolt densities that average slightly above (12,797 EV^{-1}) half of the estimated carrying capacity (11,500 EV^{-1}), it is recommended that stocking levels not be increased.

Fry stocked into Tatsamenie Lake had growth comparable to the wild fry, but egg-to-smolt survival rates were almost three times lower. As a result, the enhancement program at Tatsamenie Lake produced only an estimated additional 77,000 smolts annually. This means that the enhancement program has been producing fewer fry and smolts, than would have been produced if the eggs taken from broodstock had been left to develop in the lake. Therefore, it is recommended that stocking of enhanced fry be cancelled at Tatsamenie Lake, and higher escapements of wild spawners be allowed to return to Tatsamenie Lake to reproduce naturally.

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Appendix A

Appendix A. Summary of samples collected from Tatsamenie, Tahltan, and Tuya lakes from 1987 to 1999. Y indicates that a sample was collected; N indicates that a sample was not collected.

Lake	Year	Sampling Date	Hydro-acoustics	Midwater Trawl	Zoo-plankton	Phyto-plankton	Water Chemistry	Secchi Depth	Beach Seine	Temperature Profile	Dissolved Oxygen
Tatsamenie	1987	31-Aug	Y	Y	Y	Y	Y	Y	N	Y	N
Tatsamenie	1988	22-Jul	N	N	Y	N	N	N	N	N	N
		22-Aug	N	N	Y	N	N	N	N	N	N
		24-Sep	N	N	Y	N	N	N	N	N	N
Tatsamenie	1989	8-Jun	N	N	Y	N	N	N	N	N	N
		13-Jul	N	N	Y	N	N	N	N	N	N
		30-Aug	N	N	Y	N	N	N	N	N	N
		4-Oct	N	N	Y	N	N	N	N	N	N
Tatsamenie	1990	8-Jun	N	N	Y	N	N	Y	N	N	N
		15-Jul	N	N	Y	N	N	Y	N	N	N
		8-Sep	N	N	Y	N	N	Y	N	N	N
		2-Oct	N	N	Y	N	N	Y	N	N	N
Tatsamenie	1991	19-24-Jun	N	N	Y	Y	Y	Y	Y	Y	Y
		9-19-Jul	Y	Y	Y	Y	Y	Y	Y	Y	Y
		14-19-Aug	N	N	Y	Y	Y	Y	Y	Y	Y
		9-20-Sep	Y	Y	Y	Y	Y	Y	Y	Y	Y
Tatsamenie	1992	18-25-Jun	N	N	Y	Y	Y	Y	Y	Y	Y
		24-Jul-5-Aug	Y	Y	Y	Y	Y	Y	Y	Y	Y
		20-25-Aug	N	N	Y	Y	Y	Y	Y	Y	Y
		17-Sep-4-Oct	Y	Y	Y	Y	Y	Y	Y	Y	Y
Tatsamenie	1993	19-Jun	N	N	Y	N	N	Y	N	Y	N
		1-2-Aug	N	N	Y	Y	Y	Y	Y	Y	Y
		13-17-Sep	Y	Y	Y	Y	Y	Y	Y	Y	Y
Tatsamenie	1994	16-18-Jun	N	N	Y	N	N	Y	N	Y	N
		23-29-Jul	N	N	Y	N	Y	Y	Y	Y	Y
		2-22-Sep	Y	Y	Y	Y?	Y	Y	Y	Y	Y
Tatsamenie	1995	28-Jul	N	N	Y	N	Y	Y	Y	Y	N
		18-19-Sep	Y	Y	Y	N	Y	Y	Y	Y	N

Lake	Year	Sampling Date	Hydro-acoustics	Midwater Trawl	Zoo-plankton	Phyto-plankton	Water Chemistry	Secchi Depth	Beach Seine	Temperature Profile	Dissolved Oxygen
Tatsamenie	1996	23/24-Jul	N	N	Y	N	Y	Y	Y	Y	N
		16/17-Sep	Y	Y	Y	N	Y	Y	Y	Y	N
Tatsamenie	1997	20-Jun	N	N	Y	N	N	N	N	N	N
		25-30-Jun	Y	Y	Y	N	Y	Y	Y	Y	N
		25-26-Jul	N	N	Y	N	Y	Y	Y	Y	N
		6/7-Aug	Y	Y	N	N	N	Y	N	N	N
		2-5-Sep	Y	Y	Y	N	Y	Y	Y	Y	N
		30-Sep/1-Oct	Y	Y	Y (night)	N	N	N	Y	Y	N
		6-Oct	N	N	Y (day)	N	Y	Y	N	Y	N
Tatsamenie	1998	19-Jul	Y	Y	Y	Y	Y	Y	Y	N	N
		5-Aug	Y	Y	Y	Y	Y	Y	Y	Y	N
		23-Aug	N	N	Y	Y	Y	Y	Y	Y	N
		3-4-Sep	Y	Y	N	N	N	N	N	N	N
		13-Sep	N	Y	Y	Y	Y	Y	Y	Y	N
		22-24-Sep	Y	Y	N	N	N	N	N	N	N
		3-Oct	N	N	Y	Y	Y	Y	Y	Y	N
		12-15-Oct	Y	Y	Y	N	N	Y	Y	Y	N
Tatsamenie	1999	14-Jun	N	N	Y	Y	Y	Y	Y	Y	N
		2-Jul	N	N	Y	Y	Y	Y	Y	Y	N
		22-Jul	N	N	Y	Y	Y	Y	Y	Y	N
		10-Aug	N	N	Y	Y	Y	Y	Y	Y	N
		31-Aug	N	N	Y	Y	Y	Y	Y	Y	N
		17-Sep	N	N	Y	Y	Y	Y	Y	Y	N
		5-Oct	N	N	Y	Y	Y	Y	Y	Y	N
		14-Oct	Y	Y	N	N	N	N	N	N	N
Tahltan	1985	June	N	N	Y	Y	Y	Y	N	Y	N
		July	N	N	Y	Y	Y	Y	N	N	N
		Aug	N	N	Y	Y	Y	Y	N	N	N
		Sept	N	N	Y	Y	Y	Y	N	Y	N
Tahltan	1986	None	.	.	.	.	.	.	.	.	.
Tahltan	1987	25/26-Aug	Y	Y	Y	Y?	Y	Y	N	Y	N
Tahltan	1988	28-Aug	Y	Y	Y	Y?	Y	Y	N	Y	N

Lake	Year	Sampling Date	Hydro-acoustics	Midwater Trawl	Zoo-plankton	Phyto-plankton	Water Chemistry	Secchi Depth	Beach Seine	Temperature Profile	Dissolved Oxygen
Tahltan	1989	8-Jun	N	N	Y	N	N	N	N	N	N
		13-Jul	N	N	Y	N	N	N	N	N	N
		30-Aug	N	N	Y	N	N	N	N	N	N
		4-Oct	N	N	Y	N	N	N	N	N	N
Tahltan	1990	10-Jun	N	N	Y	Y	Y	Y	Y	Y	Y
		14-17-Jul	Y	Y	Y	Y	Y	Y	Y	Y	Y
		25-Aug	N	N	Y	Y	Y	Y	Y	Y	Y
		1-3-Oct	Y	Y	Y	Y	Y	Y	Y	Y	Y
Tahltan	1991	19-24-Jun	N	N	Y	Y	Y	Y	Y	Y	Y
		9-19-Jul	Y	Y	Y	Y	Y	Y	Y	Y	Y
		14-19-Aug	N	N	Y	Y	Y	Y	Y	Y	Y
		9-20-Sep	Y	Y	Y	Y	Y	Y	Y	Y	Y
Tahltan	1992	18-25-Jun	N	N	Y	Y	Y	Y	Y	Y	Y
		24-Jul-5-Aug	Y	Y	Y	Y	Y	Y	Y	Y	Y
		20-25-Aug	N	N	Y	Y	Y	Y	Y	Y	Y
		17-Sep-4-Oct	Y	Y	Y	Y	Y	Y	Y	Y	Y
Tahltan	1993	17-Jun	N	N	Y	N	N	Y	N	Y	N
		3-4-Aug	N	N	Y	Y	Y	Y	Y	Y	Y
		17-21-Sep	Y	Y	Y	Y	Y	Y	Y	Y	Y
Tahltan	1994	16-18-Jun	N	N	Y	N	N	Y	N	Y	N
		23-29-Jul	N	N	Y	N	Y	Y	Y	Y	Y
		2-22-Sep	Y	Y	Y	N	Y	Y	Y	Y	Y
Tahltan	1995	30-Jul	N	N	Y	N	Y	Y	N	Y	N
Tahltan	1996	25-Jul	N	N	Y	N	Y	Y	Y	Y	N
		13-14-Sep	Y	Y	Y	N	Y	Y	Y	Y	N
Tahltan	1997	21-Jun	N	N	Y	N	N	N	N	N	N
		1-Aug	N	N	Y	N	Y	Y	Y	Y	N
		15-Aug	N	N	Y	N	N	N	N	N	N
		27-29-Sep	Y	Y	Y	N	Y	Y	Y	Y	N
Tahltan	1998	4-Oct	N	N	Y	N	N	Y	N	Y	N

Lake	Year	Sampling Date	Hydro-acoustics	Midwater Trawl	Zoo-plankton	Phyto-plankton	Water Chemistry	Secchi Depth	Beach Seine	Temperature Profile	Dissolved Oxygen
Tahltan	1999	19-May	N	N	Y	Y	Y	Y	N	Y	N
		3-Jun	N	N	Y	Y	Y	Y	N	Y	N
		20-Jun	N	N	Y	Y	Y	Y	N	Y	N
		13-Jul	N	N	Y	Y	Y	Y	N	Y	N
		27-Jul	N	N	Y	Y	Y	Y	N	Y	N
		11-Aug	N	N	Y	Y	Y	Y	N	Y	N
		26-Aug	N	N	Y	Y	Y	Y	N	Y	N
		11-Oct	Y	Y	Y	Y	Y	Y	Y	Y	N
Tuya	1987	9-Sep	Y	Y	Y	Y?	Y	Y	N	Y	N
Tuya	1988	21-Jul	N	N	Y	N	N	N	N	N	N
		24-27-Aug	Y	Y	Y	Y?	Y	Y	N	Y	N
		23-Sep	N	N	Y	N	N	N	N	N	N
Tuya	1989	10-Jun	N	N	Y	N	Y	Y	Y	Y	Y
		20-Jun	N	N	Y	N	Y	Y	Y	Y	Y
		15-Jul	N	N	Y	N	Y	Y	Y	Y	Y
		28-Aug	N	N	Y	N	Y	Y	Y	Y	Y
		1-Oct	N	N	Y	N	Y	Y	Y	Y	Y
Tuya	1990	6-Jun	N	N	Y	N	N	Y	N	N	N
		16-Jul	N	N	Y	N	N	Y	N	N	N
		29/30-Aug	?	?	Y	?	?	Y	?	?	?
		7-Oct	N	N	Y	N	N	Y	N	N	N
Tuya	1991	18-Jun	N	N	Y	N	N	Y	N	N	N
		23-Jul	N	N	Y	N	N	Y	N	N	N
		4-Sep	?	?	Y	?	?	?	?	?	?
		10-Oct	N	N	Y	N	N	Y	N	N	N
Tuya	1992	18-25-Jun	N	N	Y	Y	Y	Y	Y	Y	Y
		24-Jul-5-Aug	Y	Y	Y	Y	Y	Y	Y	Y	Y
		20-25-Aug	N	N	Y	Y	Y	Y	Y	Y	Y
		17-Sep-4-Oct	Y	Y	Y	Y	Y	Y	Y	Y	Y
Tuya	1993	16-Jun	N	N	Y	N	N	Y	N	Y	N
		4-5-Aug	N	N	Y	Y	Y	Y	Y	Y	Y
		30-Aug-5-Sep	Y	Y	Y	Y	Y	Y	Y	Y	Y

Lake	Year	Sampling Date	Hydro-acoustics	Midwater Trawl	Zoo-plankton	Phyto-plankton	Water Chemistry	Secchi Depth	Beach Seine	Temperature Profile	Dissolved Oxygen
Tuya	1994	16-18-Jun	N	N	Y	N	N	Y	N	Y	N
		23-29-Jul	N	N	Y	N	Y	Y	Y	Y	Y
		2-22-Sep	Y	Y	Y	N	Y	Y	Y	Y	Y
Tuya	1995	1-Aug	N	N	Y	N	Y	Y	Y	Y	N
		9-13-Sep	Y	Y	Y	N	Y	Y	Y	Y	N
Tuya	1996	26-27-Jul	N	N	Y	N	Y	Y	Y	Y	N
		9-Sep	Y	Y	Y	N	Y	Y	Y	Y	N
Tuya	1997	24-Jun	N	N	Y	N	N	N	N	N	N
		1-Jul	N	N	Y	N	N	N	N	N	N
		3/4-Aug	N	N	Y	N	Y	Y	Y	Y	N
		24-26-Sep	Y	Y	Y	N	Y	Y	Y	Y	N
Tuya	1998	2-Aug	N	N	Y	Y	Y	Y	Y	N	N
		18-20-Sep	Y	Y	Y	Y	Y	Y	Y	Y	N
Tuya	1999	1-Aug	N	N	Y	Y	Y	Y	Y	Y	N
		14-Sep	Y	Y	Y	Y	Y	Y	Y	Y	N

Appendix B

Appendix B Key. Summary of zooplankton sampling at Tatsamenie, Tahltan, and Tuya Lakes from 1987-1998.

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments

Lake = Tatsamenie, Tahltan and Tuya lakes
Year = year in which the sample was taken
Date = date of sample collection
Site = sampling site; U=unknown site
Sample Time (h) = time of day sample was taken
Haul Depth (m) = water depth from which sample was taken from
Thermocline depth (m) = water depth at which water temperature changes most rapidly with depth
Net Type; Net area (m2) = net type used to collect the sample (standard net = S.C.O.R. net, 0.25m2 mouth area)
Net Mesh Size = standard mesh size = 100 microns
Sampler = field crew or agency that collected the sample

- Triton=Triton Environmental Consultants Ltd.
- Mercer=B.Mercer and Associates
- PBS=Pacific Biological Station staff
- BH=B.Hanslit
- KM=K.Mathias
- DB=D.Barto
- AR=A.Reimer
- BM=B.Morley
- JC=J.Candy
- PE=P.Etherton
- Nidle/Short.=Nidle and Shortreed (DFO, Cultis Lake)
- Cook=ADF&G staff

Comments = information relevant to the sample

Zooplankton sample data were eliminated from analyses if they did not meet the following criteria:

1) Depth: haul depth must be standard (25 m with the exception of 15m for Tuya site 2 and Tahltan site 1) and be deeper than the thermocline depth (if known). Data from 4 samples taken at 20m have been retained.
2) Site: sample site must be a standard site 1 or site 2.
3) Net type: sample must have been collected with a SCOR, 100um mesh, 0.25m2 mouth area haul net.
4) Time: sample must have been taken during daylight hours (early June twilight samples were retained).

Appendix B. Summary of zooplankton sampling at Tatsamenie, Tahltan, and Tuya Lakes from 1987-1998.

(shaded box) indicates samples that do not meet criteria for use in zooplankton analysis graphs (see Appendix B Key)

(empty box) indicates sample replicates that have not been processed

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
Tatsamenie	1987	31-Aug	2	10:30	50	5-10	SCOR; 0.25m2	100	BM/JC	Depth criterion not met
			2	10:30	50	5-10	SCOR; 0.25m2	100	BM/JC	"
			1	13:10	50	10-20	SCOR; 0.25m2	100	BM/JC	"
			1	13:10	50	10-20	SCOR; 0.25m2	100	BM/JC	"
Tatsamenie	1988	22-Jul	1	9:30	25		SCOR; 0.25m2	100	Mercer	
			1	9:30	25	.	SCOR; 0.25m2	100	Mercer	
			2	10:30	25	.	SCOR; 0.25m2	100	Mercer	
			2	10:30	25	.	SCOR; 0.25m2	100	Mercer	
		22-Aug	1	12:20	25	.	SCOR; 0.25m2	100	Mercer	
			1	12:20	25	.	SCOR; 0.25m2	100	Mercer	
			2	11:30	25	.	SCOR; 0.25m2	100	Mercer	
			2	11:30	25	.	SCOR; 0.25m2	100	Mercer	
		24-Sep	1	19:00	25	.	SCOR; 0.25m2	100	Mercer	
			1	19:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	.	25	.	SCOR; 0.25m2	100	Mercer	
			2	.	25	.	SCOR; 0.25m2	100	Mercer	
Tatsamenie	1989	8-Jun	1	11:00	25	.	SCOR; 0.25m2	100	Mercer	
			1	11:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	11:30	25	.	SCOR; 0.25m2	100	Mercer	
			2	11:30	25	.	SCOR; 0.25m2	100	Mercer	
		13-Jul	1	11:40	25	.	SCOR; 0.25m2	100	Mercer	
			1	11:40	25	.	SCOR; 0.25m2	100	Mercer	
			2	11:20	25	.	SCOR; 0.25m2	100	Mercer	
			2	11:20	25	.	SCOR; 0.25m2	100	Mercer	
		30-Aug	1	11:50	25	.	SCOR; 0.25m2	100	Mercer	
			1	11:50	25	.	SCOR; 0.25m2	100	Mercer	

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			2	11:20	25	.	SCOR; 0.25m2	100	Mercer	
			2	11:20	25	.	SCOR; 0.25m2	100	Mercer	
		4-Oct	1	15:00	25	.	SCOR; 0.25m2	100	Mercer	
			1	15:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	14:45	25	.	SCOR; 0.25m2	100	Mercer	
			2	14:45	25	.	SCOR; 0.25m2	100	Mercer	
Tatsamenie	1990	8-Jun	1	11:50	25	.	SCOR; 0.25m2	100	Mercer	
			1	11:50	25	.	SCOR; 0.25m2	100	Mercer	
			2	13:30	25	.	SCOR; 0.25m2	100	Mercer	
			2	13:30	25	.	SCOR; 0.25m2	100	Mercer	
		15-Jul	1	11:50	25	.	SCOR; 0.25m2	100	Mercer	
			1	11:50	25	.	SCOR; 0.25m2	100	Mercer	
			2	13:30	25	.	SCOR; 0.25m2	100	Mercer	
			2	13:30	25	.	SCOR; 0.25m2	100	Mercer	
		8-Sep	2	14:15	25	.	SCOR; 0.25m2	100	Mercer	Site #1 not sampled due to weather
			2	14:15	25	.	SCOR; 0.25m2	100	Mercer	"
		2-Oct	1	12:40	25	.	SCOR; 0.25m2	100	Mercer	Site #2 not sampled due to weather
			1	12:40	25	.	SCOR; 0.25m2	100	Mercer	"
Tatsamenie	1991	22-Jun	1	day	25	4	SCOR; 0.25m2	100	Triton	
			1	day	25	4	SCOR; 0.25m2	100	Triton	
			2	day	25	4	SCOR; 0.25m2	100	Triton	
			2	day	25	4	SCOR; 0.25m2	100	Triton	
		15-Jul	1	day	25	5?	SCOR; 0.25m2	100	Triton	Thermocline not well defined
			1	day	25	5?	SCOR; 0.25m2	100	Triton	"
			2	day	25	none	SCOR; 0.25m2	100	Triton	
			2	day	25	none	SCOR; 0.25m2	100	Triton	
		17-Aug	1	17:00	25	11	SCOR; 0.25m2	100	Triton	
			1	day	25	11	SCOR; 0.25m2	100	Triton	
			2	day	25	12-14	SCOR; 0.25m2	100	Triton	
			2	day	25	12-14	SCOR; 0.25m2	100	Triton	
		15-Sep	1	day	25	none	SCOR; 0.25m2	100	Triton	
			1	day	25	none	SCOR; 0.25m2	100	Triton	

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			2	day	25	15-20	SCOR; 0.25m2	100	Triton	Thermocline not well defined
			2	day	25	15-20	SCOR; 0.25m2	100	Triton	"
Tatsamenie	1992	22-Jun	1	day	25	none	SCOR; 0.25m2	100	Triton	
			1	day	25	none	SCOR; 0.25m2	100	Triton	
			2	day	25	none	SCOR; 0.25m2	100	Triton	
			2	day	25	none	SCOR; 0.25m2	100	Triton	
		2-Aug	1	day	25	15-20	SCOR; 0.25m2	100	Triton	
			1	day	25	15-20	SCOR; 0.25m2	100	Triton	
			2	day	25	15-20	SCOR; 0.25m2	100	Triton	
			2	day	25	15-20	SCOR; 0.25m2	100	Triton	
		22-Aug	1	day	25	5	SCOR; 0.25m2	100	Triton	Thermocline not well defined
			1	day	25	5	SCOR; 0.25m2	100	Triton	"
			2	day	25	7	SCOR; 0.25m2	100	Triton	"
			2	day	25	7	SCOR; 0.25m2	100	Triton	"
		28-Sep	1	day	25	none	SCOR; 0.25m2	100	Triton	
			1	day	25	none	SCOR; 0.25m2	100	Triton	
			2	day	25	15-20	SCOR; 0.25m2	100	Triton	Thermocline not well defined
			2	day	25	15-20	SCOR; 0.25m2	100	Triton	"
Tatsamenie	1993	19-Jun	2	21:30	25	16-20	SCOR; 0.25m2	100	Mercer	Site #1 not sampled due to weather;
			2	21:30	25	16-20	SCOR; 0.25m2	100	Mercer	enough light to read and record
		2-Aug	1	day	25	10	SCOR; 0.25m2	100	Triton	Thermocline not well defined
			1	day	25	10	SCOR; 0.25m2	100	Triton	"
			2	day	25	5	SCOR; 0.25m2	100	Triton	"
			2	day	25	5	SCOR; 0.25m2	100	Triton	"
		15-Sep	1	day	25	9	SCOR; 0.25m2	100	Triton	"
			1	day	25	9	SCOR; 0.25m2	100	Triton	"
			2	day	25	7	SCOR; 0.25m2	100	Triton	"
			2	day	25	7	SCOR; 0.25m2	100	Triton	"
Tatsamenie	1994	17-Jun	2	10:00	25	none	SCOR; 0.25m2	100	Mercer	Site #1 not sampled due to weather
			2	10:00	25	none	SCOR; 0.25m2	100	Mercer	
		26-Jul	1	16:20	25	10	SCOR; 0.25m2	100	Mercer	
			1	16:20	25	10	SCOR; 0.25m2	100	Mercer	

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			2	18:00	25	10-15	SCOR; 0.25m2	100	Mercer	
			2	18:00	25	10-15	SCOR; 0.25m2	100	Mercer	
		14-Sep	1	12:30	25	17	SCOR; 0.25m2	100	Triton	
			1	12:30	25	17	SCOR; 0.25m2	100	Triton	
			2	13:25	25	15	SCOR; 0.25m2	100	Triton	
			2	13:25	25	15	SCOR; 0.25m2	100	Triton	
Tatsamenie	1995	28-Jul	1	17:00	25	17	SCOR; 0.25m2	100	Mercer	
			1	17:00	25	17	SCOR; 0.25m2	100	Mercer	
			2	19:00	25	12	SCOR; 0.25m2	100	Mercer	
			2	19:00	25	12	SCOR; 0.25m2	100	Mercer	
		19-Sep	2	11:49	25	8-10	SCOR; 0.25m2	100	AR/ZP	Thermocline not well defined
			2	11:49	25	8-10	SCOR; 0.25m2	100	AR/ZP	"
			1	14:10	25	16-18	SCOR; 0.25m2	100	AR/ZP	"
			1	14:10	25	16-18	SCOR; 0.25m2	100	AR/ZP	"
Tatsamenie	1996	23-Jul	1	14:20	25	5-7	SCOR; 0.25m2	100	Mercer	"
			1	14:30	25	5-7	SCOR; 0.25m2	100	Mercer	"
			2	15:10	25	10	SCOR; 0.25m2	100	Mercer	"
			2	15:30	25	10	SCOR; 0.25m2	100	Mercer	"
		17-Sep	1	13:50	25	18	SCOR; 0.25m2	100	BH/AR	"
			1	14:00	25	18	SCOR; 0.25m2	100	BH/AR	"
			2	14:35	25	18	SCOR; 0.25m2	100	BH/AR	"
			2	14:45	25	18	SCOR; 0.25m2	100	BH/AR	"
Tatsamenie	1997	20-Jun	U	late pm	25	.	:1 conical; 0.5m di	153	Snettisham	Net type/site criteria not met
			U	late pm	25	.	:1 conical; 0.5m di	153	Snettisham	Sample frozen as well as preserved
		26-Jun	1	13:35	25	17	SCOR; 0.25m2	100	BH/Mercer	
			1	13:35	25	17	SCOR; 0.25m2	100	BH/Mercer	
			2	14:20	25	13	SCOR; 0.25m2	100	BH/Mercer	
			2	14:20	25	13	SCOR; 0.25m2	100	BH/Mercer	
		25-Jul	1	16:00	25	15	SCOR; 0.25m2	100	Mercer	
			1	16:00	25	15	SCOR; 0.25m2	100	Mercer	
			2	18:30	25	12	SCOR; 0.25m2	100	Mercer	
			2	18:30	25	12	SCOR; 0.25m2	100	Mercer	

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
		2-Sep	1	14:00	25	15	SCOR; 0.25m2	100	Mercer	
			1	14:00	25	15	SCOR; 0.25m2	100	Mercer	
			2	16:00	25	12	SCOR; 0.25m2	100	Mercer	
			2	16:00	25	12	SCOR; 0.25m2	100	Mercer	
		1-Oct	2	1:51	25	15	SCOR; 0.25m2	100	BH/KM	Sample time criterion not met
			2	1:56	25	15	SCOR; 0.25m2	100	BH/KM	"
			1	2:17	25	16	SCOR; 0.25m2	100	BH/KM	"
			1	2:19	25	16	SCOR; 0.25m2	100	BH/KM	"
		6-Oct	1	11:45	25	20-23	SCOR; 0.25m2	100	Mercer	
			1	11:55	25	20-23	SCOR; 0.25m2	100	Mercer	
			2	13:30	25	20-25	SCOR; 0.25m2	100	Mercer	
			2	13:45	25	20-25	SCOR; 0.25m2	100	Mercer	
Tatsamenie	1998	1-Jul	1	20:00	25	.	SCOR; 0.25m2	100	Mercer	
			1	20:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	?	25	.	SCOR; 0.25m2	100	Mercer	
			2	?	25	.	SCOR; 0.25m2	100	Mercer	
		19-Jul	1	15:30	25	.	SCOR; 0.25m2	100	Mercer	
			1	15:30	25	.	SCOR; 0.25m2	100	Mercer	
			2	17:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	17:00	25	.	SCOR; 0.25m2	100	Mercer	
		6-Aug	1	22:40	25	6-8	SCOR; 0.25m2	100	Mercer	
			1	22:40	25	6-8	SCOR; 0.25m2	100	Mercer	
			2	21:00	25	5-6	SCOR; 0.25m2	100	Mercer	
			2	21:00	25	5-6	SCOR; 0.25m2	100	Mercer	
		24-Aug	1	11:10	25	2-4	SCOR; 0.25m2	100	Mercer	Thermocline not well defined
			1	11:00	25	2-4	SCOR; 0.25m2	100	Mercer	"
			2	11:50	25	2	SCOR; 0.25m2	100	Mercer	"
			2	12:00	25	2	SCOR; 0.25m2	100	Mercer	"
		13-Sep	1	18:45	25	10-11	SCOR; 0.25m2	100	Mercer	Thermocline not well defined
			1	18:30	25	10-11	SCOR; 0.25m2	100	Mercer	"
			2	19:45	25	8-9	SCOR; 0.25m2	100	Mercer	"
			2	19:30	25	8-9	SCOR; 0.25m2	100	Mercer	"

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
		3-Oct	1	16:20	25	none	SCOR; 0.25m2	100	Mercer	
			1	16:30	25	none	SCOR; 0.25m2	100	Mercer	
			2	18:00	25	none	SCOR; 0.25m2	100	Mercer	
			2	18:10	25	none	SCOR; 0.25m2	100	Mercer	
		14-Oct	1	17:00	25	none	SCOR; 0.25m2	100	Mercer	
			1	17:10	25	none	SCOR; 0.25m2	100	Mercer	
			2	11:00	25	none	SCOR; 0.25m2	100	Mercer	
			2	11:15	25	none	SCOR; 0.25m2	100	Mercer	
Tahltan	**1985**	**18-Jun**	**2**	**10:20**	**40**		**SCOR; 0.25m2**	**100**	**Nidle/Short**	**Lake fertilization initiated**
		16-Jul	**2**	**10:40**	**40**		**SCOR; 0.25m2**	**100**	**Nidle/Short**	**Depth criterion not met**
		13-Aug	**2**	**14:15**	**10**		**SCOR; 0.25m2**	**100**	**Nidle/Short**	"
		10-Sep	**2**	**12:30**	**40**		**SCOR; 0.25m2**	**100**	**Nidle/Short**	"
Tahltan	**1986**	**None**	.	.	.	.	.	.		
Tahltan	**1987**	**26-Aug**	**1**	**9:00**	**25?**	**12**	**SCOR; 0.25m2**	**100**	**BM/JC**	**Lake fertilization concluded**
			1	**9:00**	**25?**	**12**	**SCOR; 0.25m2**	**100**	**BM/JC**	**Samples lost**
			2	**8:00**	**25**	**12**	**SCOR; 0.25m2**	**100**	**BM/JC**	"
			2	**8:00**	**25**	**12**	**SCOR; 0.25m2**	**100**	**BM/JC**	"
Tahltan	1988	28-Aug	1	18:00	25	8	SCOR; 0.25m2	100	PBS	
			1	18:00	25	8	SCOR; 0.25m2	100	PBS	
			2	19:13	25	14	SCOR; 0.25m2	100	PBS	
			2	19:13	25	14	SCOR; 0.25m2	100	PBS	
Tahltan	1989	8-Jun	2	14:10	25	.	SCOR; 0.25m2	100	Mercer	
			2	14:10	25	.	SCOR; 0.25m2	100	Mercer	
			1	13:30	15	.	SCOR; 0.25m2	100	Mercer	
			1	13:30	15	.	SCOR; 0.25m2	100	Mercer	
		13-Jul	2	12:40	25	.	SCOR; 0.25m2	100	Mercer	
			2	12:40	25	.	SCOR; 0.25m2	100	Mercer	
			1	13:00	15	.	SCOR; 0.25m2	100	Mercer	
			1	13:00	15	.	SCOR; 0.25m2	100	Mercer	
		30-Aug	2	14:30	25	.	SCOR; 0.25m2	100	Mercer	
			2	14:30	25	.	SCOR; 0.25m2	100	Mercer	
			1	15:50	15	.	SCOR; 0.25m2	100	Mercer	

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			1	15:50	15	.	SCOR; 0.25m2	100	Mercer	
		4-Oct	2	16:30	25	.	SCOR; 0.25m2	100	Mercer	
			2	16:30	25	.	SCOR; 0.25m2	100	Mercer	
			1	16:45	15	.	SCOR; 0.25m2	100	Mercer	
			1	16:45	15	.	SCOR; 0.25m2	100	Mercer	
Tahltan	1990	10-Jun	1	day	25	5-15	SCOR; 0.25m2	100	Triton	Thermocline not well defined
			1	day	25	5-15	SCOR; 0.25m2	100	Triton	"
			2	day	25	3-7	SCOR; 0.25m2	100	Triton	"
			2	day	25	3-7	SCOR; 0.25m2	100	Triton	"
		17-Jul	1	day	25	5-15	SCOR; 0.25m2	100	Triton	"
			1	day	25	5-15	SCOR; 0.25m2	100	Triton	"
			2	day	25	10-15	SCOR; 0.25m2	100	Triton	"
			2	day	25	10-15	SCOR; 0.25m2	100	Triton	"
		25-Aug	1	day	25	9	SCOR; 0.25m2	100	Triton	
			1	day	25	9	SCOR; 0.25m2	100	Triton	
			2	day	25	9-15	SCOR; 0.25m2	100	Triton	Thermocline not well developed
			2	day	25	9-15	SCOR; 0.25m2	100	Triton	"
		1-Oct	1	day	25	15	SCOR; 0.25m2	100	Triton	"
			1	day	25	15	SCOR; 0.25m2	100	Triton	"
			2	day	25	15	SCOR; 0.25m2	100	Triton	"
			2	day	25	15	SCOR; 0.25m2	100	Triton	"
Tahltan	1991	24-Jun	1	10:00	15	5	SCOR; 0.25m2	100	Triton	
			1	day	15	5	SCOR; 0.25m2	100	Triton	
			2	12:15	25	5	SCOR; 0.25m2	100	Triton	
			2	day	25	5	SCOR; 0.25m2	100	Triton	
		12-Jul	1	day	15	7-10	SCOR; 0.25m2	100	Triton	
			1	day	15	7-10	SCOR; 0.25m2	100	Triton	
			2	day	25	10-20	SCOR; 0.25m2	100	Triton	
			2	day	25	10-20	SCOR; 0.25m2	100	Triton	
		18-Aug	1	20:00	15	.	SCOR; 0.25m2	100	Triton	
			1	day	15	.	SCOR; 0.25m2	100	Triton	
			2	day	25	12	SCOR; 0.25m2	100	Triton	

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			2	day	25	12	SCOR; 0.25m2	100	Triton	
		11-Sep	1	day	25	15-20	SCOR; 0.25m2	100	Triton	
			1	day	25	15-20	SCOR; 0.25m2	100	Triton	
			2	day	25	15-20	SCOR; 0.25m2	100	Triton	
			2	day	25	15-20	SCOR; 0.25m2	100	Triton	
Tahltan	1992	23-Jun	1	day	15	7	SCOR; 0.25m2	100	Triton	
			1	day	15	7	SCOR; 0.25m2	100	Triton	
			2	day	25	10	SCOR; 0.25m2	100	Triton	
			2	day	25	10	SCOR; 0.25m2	100	Triton	
		29-Jul	1	day	25	11	SCOR; 0.25m2	100	Triton	
			1	day	25	11	SCOR; 0.25m2	100	Triton	
			2	day	25	11	SCOR; 0.25m2	100	Triton	
			2	day	25	11	SCOR; 0.25m2	100	Triton	
		20/21-Aug	1	day	15	10	SCOR; 0.25m2	100	Triton	
			1	day	15	10	SCOR; 0.25m2	100	Triton	
			2	day	25	14	SCOR; 0.25m2	100	Triton	
			2	day	25	14	SCOR; 0.25m2	100	Triton	
		3-Oct	1	day	15	none	SCOR; 0.25m2	100	Triton	
			1	day	15	none	SCOR; 0.25m2	100	Triton	
			2	day	25	none	SCOR; 0.25m2	100	Triton	
			2	day	25	none	SCOR; 0.25m2	100	Triton	
Tahltan	1993	17-Jun	1	12:00	15	7	SCOR; 0.25m2	100	Mercer	
			1	12:00	15	7	SCOR; 0.25m2	100	Mercer	
			2	13:50	25	7	SCOR; 0.25m2	100	Mercer	
			2	13:50	25	7	SCOR; 0.25m2	100	Mercer	
		3/4-Aug	1	19:30	15	5	SCOR; 0.25m2	100	Triton	
			1	day	15	5	SCOR; 0.25m2	100	Triton	
			2	day	25	9	SCOR; 0.25m2	100	Triton	
			2	day	25	9	SCOR; 0.25m2	100	Triton	
		19-Sep	1	day	25	16	SCOR; 0.25m2	100	Triton	
			1	day	25	16	SCOR; 0.25m2	100	Triton	
			2	day	25	13	SCOR; 0.25m2	100	Triton	

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			2	day	25	13	SCOR; 0.25m2	100	Triton	
Tahltan	1994	17-Jun	2	11:30	25	5-10	SCOR; 0.25m2	100	Mercer	
			2	11:30	25	5-10	SCOR; 0.25m2	100	Mercer	
			1	12:30	15	5-10	SCOR; 0.25m2	100	Mercer	
			1	12:30	15	5-10	SCOR; 0.25m2	100	Mercer	
		27-Jul	2	17:00	25	8-10	SCOR; 0.25m2	100	Mercer	
			2	17:00	25	8-10	SCOR; 0.25m2	100	Mercer	
			1	15:30	15	8-10	SCOR; 0.25m2	100	Mercer	
			1	15:30	15	8-10	SCOR; 0.25m2	100	Mercer	
		18-Sep	2	11:20	25	14	SCOR; 0.25m2	100	Triton	
			2	11:20	25	14	SCOR; 0.25m2	100	Triton	
			1	13:15	25	16	SCOR; 0.25m2	100	Triton	
			1	13:15	25	16	SCOR; 0.25m2	100	Triton	
Tahltan	1995	30-Jul	1	14:30	15	13	SCOR; 0.25m2	100	Mercer	
			1	14:30	15	13	SCOR; 0.25m2	100	Mercer	
			2	13:00	25	11	SCOR; 0.25m2	100	Mercer	
			2	13:00	25	11	SCOR; 0.25m2	100	Mercer	
Tahltan	1996	25-Jul	1	18:30	15	15	SCOR; 0.25m2	100	Mercer	
			1	18:30	15	15	SCOR; 0.25m2	100	Mercer	
			2	15:15	25	10	SCOR; 0.25m2	100	Mercer	
			2	15:15	25	10	SCOR; 0.25m2	100	Mercer	
		14-Sep	2	14:20	25	16	SCOR; 0.25m2	100	BH/AR	
			2	14:20	25	16	SCOR; 0.25m2	100	BH/AR	
			1	16:39	20	18	SCOR; 0.25m2	100	BH/AR	
			1	16:39	21	18	SCOR; 0.25m2	100	BH/AR	
Tahltan	1997	21-Jun	U	day	25	.	:1 conical; 0.5m di	153	Snettisham	Sampled from plane during outplant
			U	day	25	.	:1 conical; 0.5m di	153	Snettisham	Sample frozen as well as preserved
		15-Aug	1	.	20	.	:1 conical; 0.5m di	153	Cook	Net/site criteria not met
			3	.	40	.	:1 conical; 0.5m di	153	Cook	
		29-Sep	1	17:00	25	16	SCOR; 0.25m2	100	BH/KM	
			1	17:10	25	16	SCOR; 0.25m2	100	BH/KM	
			2	15:30	25	15	SCOR; 0.25m2	100	BH/KM	

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			2	15:40	25	15	SCOR; 0.25m2	100	BH/KM	
			2	1:00	25	15	SCOR; 0.25m2	100	BH/KM	
			2	1:09	25	15	SCOR; 0.25m2	100	BH/KM	
			1	1:35	20	16	SCOR; 0.25m2	100	BH/KM	
			1	1:39	20	16	SCOR; 0.25m2	100	BH/KM	
	1998	1-Jun	1	12:45	15	.	SCOR; 0.25m2	100	BH/KM	
			1	12:55	15	.	SCOR; 0.25m2	100	BH/KM	
			2	13:55	25	.	SCOR; 0.25m2	100	BH/KM	
			2	13:45	25	.	SCOR; 0.25m2	100	BH/KM	
		11-Jun	1?	14:30	15	.	SCOR; 0.25m2	100	BH/KM	
			1?	16:00	15	.	SCOR; 0.25m2	100	BH/KM	
		14-Jul	1	15:49	15	.	SCOR; 0.25m2	100	BH/KM	
			1	16:02	15	.	SCOR; 0.25m2	100	BH/KM	
			2	17:36	25	.	SCOR; 0.25m2	100	BH/KM	
			2	17:20	25	.	SCOR; 0.25m2	100	BH/KM	
		29-Jul	1	13:50	15	.	SCOR; 0.25m2	100	BH/KM	
			1	13:36	15	.	SCOR; 0.25m2	100	BH/KM	
			2	14:29	25	.	SCOR; 0.25m2	100	BH/KM	
			2	14:45	25	.	SCOR; 0.25m2	100	BH/KM	
		21-Aug	1	12:02	15	.	SCOR; 0.25m2	100	BH/KM	
			1	12:10	15	.	SCOR; 0.25m2	100	BH/KM	
			2	11:16	25	.	SCOR; 0.25m2	100	BH/KM	
			2	11:04	25	.	SCOR; 0.25m2	100	BH/KM	
		9-Oct	1	16:10	15	none	SCOR; 0.25m2	100	BH/KM	
			1	16:00	15	none	SCOR; 0.25m2	100	BH/KM	
			2	16:45	25	none	SCOR; 0.25m2	100	BH/KM	
			2	16:30	25	none	SCOR; 0.25m2	100	BH/KM	
Tuya Lake	1987	9-Sep	1	13:57	<25	none	SCOR; 0.25m2	100	BM/JC	Rough water due to wind
			1	13:57	<25	none	SCOR; 0.25m2	100	BM/JC	"
			2	20:46	15	none	SCOR; 0.25m2	100	BM/JC	
			2	20:46	15	none	SCOR; 0.25m2	100	BM/JC	
Tuya Lake	1988	21-Jul	1	8:30	<25	.	SCOR; 0.25m2	100	Mercer	Rough water due to wind

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			1	8:30	<25	.	SCOR; 0.25m2	100	Mercer	"
			2	9:30	15	.	SCOR; 0.25m2	100	Mercer	Rippled water conditions
			2	9:30	15	.	SCOR; 0.25m2	100	Mercer	"
		24-Aug	1	12:30	25	13	SCOR; 0.25m2	100	Mercer	Temperature profile site =
			1	12:30	25	13	SCOR; 0.25m2	100	Mercer	mid lake trans #2 (done by BM/JC)
			2	1:00	15	none	SCOR; 0.25m2	100	Mercer	"
			2	1:00	15	none	SCOR; 0.25m2	100	Mercer	"
		23-Sep	1	12:45	25	.	SCOR; 0.25m2	100	Mercer	
			1	12:45	25	.	SCOR; 0.25m2	100	Mercer	
			2	12:00	15	.	SCOR; 0.25m2	100	Mercer	
			2	12:00	15	.	SCOR; 0.25m2	100	Mercer	
Tuya Lake	1989	10-Jun	2	9:30	<15	.	SCOR; 0.25m2	100	Mercer	Rough water due to wind
			2	9:30	<15	.	SCOR; 0.25m2	100	Mercer	Site #1 not sampled due to ice
		20-Jun	1	12:00	25	.	SCOR; 0.25m2	100	Mercer	
			1	12:00	25	.	SCOR; 0.25m2	100	Mercer	
		15-Jul	1	10:00	<25	.	SCOR; 0.25m2	100	Mercer	Rough water due to wind
			1	10:00	<25	.	SCOR; 0.25m2	100	Mercer	"
		28-Aug	1	14:00	25	.	SCOR; 0.25m2	100	Mercer	
			1	14:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	13:00	15	.	SCOR; 0.25m2	100	Mercer	
			2	13:00	15	.	SCOR; 0.25m2	100	Mercer	
		1-Oct	1	12:00	25	.	SCOR; 0.25m2	100	Mercer	
			1	12:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	12:30	15	.	SCOR; 0.25m2	100	Mercer	
			2	12:30	15	.	SCOR; 0.25m2	100	Mercer	
Tuya Lake	1990	6-Jun	1	11:00	25	.	SCOR; 0.25m2	100	Mercer	
			1	11:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	11:30	15	.	SCOR; 0.25m2	100	Mercer	
			2	11:30	15	.	SCOR; 0.25m2	100	Mercer	
		16-Jul	1	10:30	25	.	SCOR; 0.25m2	100	Mercer	
			1	10:30	25	.	SCOR; 0.25m2	100	Mercer	
			2	9:50	15	.	SCOR; 0.25m2	100	Mercer	

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			2	9:50	15	.	SCOR; 0.25m2	100	Mercer	
		29-Aug	n/a	day	24	.	SCOR; 0.25m2	100	PBS	Site criterion not met
			n/a	day	24	.	SCOR; 0.25m2	100	PBS	
		7-Oct	1	15:00	25	.	SCOR; 0.25m2	100	Mercer	
			1	15:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	16:00	15	.	SCOR; 0.25m2	100	Mercer	
			2	16:00	15	.	SCOR; 0.25m2	100	Mercer	
Tuya Lake	1991	18-Jun	1	8:00	25	.	SCOR; 0.25m2	100	Mercer	
			1	8:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	7:30	15	.	SCOR; 0.25m2	100	Mercer	
			2	7:30	15	.	SCOR; 0.25m2	100	Mercer	
		23-Jul	2	9:00	<15	.	SCOR; 0.25m2	100	Mercer	Rough water due to wind
			2	9:00	<15	.	SCOR; 0.25m2	100	Mercer	"
		4-Sep	1	.	25	.	SCOR; 0.25m2	100	BM/PE	
			1	.	25	.	SCOR; 0.25m2	100	BM/PE	
		10-Oct	1	10:30	<25	.	SCOR; 0.25m2	100	Mercer	Rough water due to wind
			1	10:30	<25	.	SCOR; 0.25m2	100	Mercer	"
			2	10:00	<15	.	SCOR; 0.25m2	100	Mercer	"
			2	10:00	<15	.	SCOR; 0.25m2	100	Mercer	"
Tuya Lake	1992	25-Jun	1	day	25	2	SCOR; 0.25m2	100	Triton	Thermocline not well developed
			1	day	25	2	SCOR; 0.25m2	100	Triton	"
			2	day	15	2	SCOR; 0.25m2	100	Triton	"
			2	day	15	2	SCOR; 0.25m2	100	Triton	"
		26-Jul	1	day	25	14	SCOR; 0.25m2	100	Triton	
			1	day	25	14	SCOR; 0.25m2	100	Triton	
			2	day	20	11	SCOR; 0.25m2	100	Triton	
			2	day	20	11	SCOR; 0.25m2	100	Triton	
		24-Aug	1	day	25	15-20	SCOR; 0.25m2	100	Triton	
			1	day	25	15-20	SCOR; 0.25m2	100	Triton	
			2	day	15	15-20	SCOR; 0.25m2	100	Triton	
			2	day	15	15-20	SCOR; 0.25m2	100	Triton	
		18-Sep	1	day	25	none	SCOR; 0.25m2	100	Triton	

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			1	day	25	none	SCOR; 0.25m2	100	Triton	
			2	day	15	none	SCOR; 0.25m2	100	Triton	
			2	day	15	none	SCOR; 0.25m2	100	Triton	
Tuya Lake	1993	16-Jun	1	22:00	25	7	SCOR; 0.25m2	100	Mercer	Enough light to read and record
			1	22:00	25	7	SCOR; 0.25m2	100	Mercer	"
			2	23:00	15	7	SCOR; 0.25m2	100	Mercer	"
			2	23:00	15	7	SCOR; 0.25m2	100	Mercer	"
		4/5-Aug	1	day	25	12-14	SCOR; 0.25m2	100	Triton	
			1	day	25	12-14	SCOR; 0.25m2	100	Triton	
			2	day	15	5	SCOR; 0.25m2	100	Triton	
			2	day	15	5	SCOR; 0.25m2	100	Triton	
		1-Sep	1	day	25	14	SCOR; 0.25m2	100	Triton	
			1	day	25	14	SCOR; 0.25m2	100	Triton	
			2	day	25	9	SCOR; 0.25m2	100	Triton	
			2	day	25	9	SCOR; 0.25m2	100	Triton	
Tuya Lake	1994	18-Jun	1	22:00	25	.	SCOR; 0.25m2	100	Mercer	Enough light to read and record
			1	22:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	19:00	<15	.	SCOR; 0.25m2	100	Mercer	Rough water due to wind
			2	19:00	<15	.	SCOR; 0.25m2	100	Mercer	"
		28-Jul	1	15:30	<25	8-10	SCOR; 0.25m2	100	Mercer	Rough water due to wind
			1	15:30	<25	8-10	SCOR; 0.25m2	100	Mercer	"
			2	18:00	<15	10-12	SCOR; 0.25m2	100	Mercer	"
			2	18:00	<15	10-12	SCOR; 0.25m2	100	Mercer	"
		4-Sep	1	13:30	25	12	SCOR; 0.25m2	100	Triton	
			1	13:30	25	12	SCOR; 0.25m2	100	Triton	
			2	15:00	15	11	SCOR; 0.25m2	100	Triton	
			2	15:00	15	11	SCOR; 0.25m2	100	Triton	
Tuya Lake	1995	1-Aug	1	14:00	25	15	SCOR; 0.25m2	100	Mercer	
			1	14:00	25	15	SCOR; 0.25m2	100	Mercer	
			2	18:45	15	10	SCOR; 0.25m2	100	Mercer	
			2	18:45	15	10	SCOR; 0.25m2	100	Mercer	
		11-Sep	2	11:00	<20	16-18	SCOR; 0.25m2	100	Mercer	Rough water due to wind

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			2	11:00	<20	16-18	SCOR; 0.25m2	100	Mercer	"
			1	12:30	<25	22-24	SCOR; 0.25m2	100	Mercer	"
			1	12:30	<25	22-24	SCOR; 0.25m2	100	Mercer	"
Tuya Lake	1996	26-Jul	1	19:40	25	4	SCOR; 0.25m2	100	Mercer	
			1	19:40	25	4	SCOR; 0.25m2	100	Mercer	
			2	16:30	15	6	SCOR; 0.25m2	100	Mercer	
			2	16:30	15	6	SCOR; 0.25m2	100	Mercer	
		10-Sep	1	10:30	20	none	SCOR; 0.25m2	100	BH/AR	
			1	10:30	25	none	SCOR; 0.25m2	100	BH/AR	
			2	12:45	<20	none	SCOR; 0.25m2	100	BH/AR	Rough water due to wind
			2	12:45	20-25	none	SCOR; 0.25m2	100	BH/AR	Net line 20 degrees from vertical
Tuya Lake	1997	24-Jun	U	day	<25	.	;1 conical; 0.5m di	153	Snettisham	Net/site criteria not met
			U	day	<25	.	;1 conical; 0.5m di	153	Snettisham	Sample frozen as well as preserved
		1-Jul	U	day	10	.	;1 conical; 0.5m di	153	Snettisham	Net/site criteria not met
			U	day	10	.	;1 conical; 0.5m di	153	Snettisham	Sample frozen as well as preserved
		3/4-Aug	1	10:00	25	12-13	SCOR; 0.25m2	100	Mercer	
			1	10:00	25	12-13	SCOR; 0.25m2	100	Mercer	
			2	19:50	15	10-11	SCOR; 0.25m2	100	Mercer	
			2	19:50	15	10-11	SCOR; 0.25m2	100	Mercer	
		24-Sep	1	13:45	20	none	SCOR; 0.25m2	100	BH/KM	
			1	14:00	20	none	SCOR; 0.25m2	100	BH/KM	
			2	15:30	20	none	SCOR; 0.25m2	100	BH/KM	
			2	15:45	20	none	SCOR; 0.25m2	100	BH/KM	
			2	0:13	25	none	SCOR; 0.25m2	100	BH/KM	
			2	0:22	25	none	SCOR; 0.25m2	100	BH/KM	
			1	0:46	25	none	SCOR; 0.25m2	100	BH/KM	
			1	0:52	25	none	SCOR; 0.25m2	100	BH/KM	
	1998	1-Aug	1	10:30	25	.	SCOR; 0.25m2	100	Mercer	
			1	10:40	25	.	SCOR; 0.25m2	100	Mercer	
			2	16:35	15	.	SCOR; 0.25m2	100	Mercer	
			2	16:30	15	.	SCOR; 0.25m2	100	Mercer	
		19-Sep	1	15:30	25	.	SCOR; 0.25m2	100	Mercer	

Lake	Year	Date	Site	Sample Time (h)	Haul Depth (m)	Thermocline Depth (m)	Net Type; Net Area	Net Mesh Size (um)	Sampler	Comments
			1	16:00	25	.	SCOR; 0.25m2	100	Mercer	
			2	18:20	15	.	SCOR; 0.25m2	100	Mercer	
			2	18:30	15	.	SCOR; 0.25m2	100	Mercer	

Appendix C

Appendix C1. Tatsamenie Lake. Summary of sockeye fry and smolt mean lengths, weights, 95% confidence intervals (CI) and sample sizes of fry caught in beach seines and trawls from 1992 to 1999. Beach seine and trawl samples have been corrected for preservative shrinkage (99% denatured alcohol). Trawl sample means have been corrected for trawl net avoidance (except for mean length < 40 mm).

		Wild fry					*Enhanced fry*				
Sampling date	Capture method	Mean length (mm)	95% CI	Mean weight (g)	95% CI	# wild fish captured	Mean length (mm)	95% CI	Mean weight (g)	95% CI	# enhanced fish captured
21-Jun-92	beach seine	33.4	0.4	0.28	0.02	100	.	.	.	.	0
24-Jun-92	stocking	.	.	.	.	.	.	.	0.15	.	.
1-Aug-92	beach seine	36.0	0.7	0.29	0.02	116	33.4	1.9	0.20	0.04	9
1-Aug-92	trawl	36.0	32.3	0.54	1.78	3	.	.	.	.	0
21-Aug-92	beach seine	50.2	2.0	1.33	0.19	89	48.5	57.2	1.14	5.14	2
28-Sep-92	beach seine	35.3	2.7	0.36	0.11	32	30.0	.	0.19	.	1
25-May-93	smolt	75.9	2.0	4.47	0.34	79	65.2	4.4	2.88	0.51	6
10-Jul-93	stocking	.	.	.	.	.	.	.	0.13	.	.
1-Aug-93	beach seine	37.4	1.2	0.47	0.05	95	34.3	11.1	0.36	0.39	4
14-Sep-93	beach seine	33.5	2.8	0.28	0.09	10	41.0	.	0.49	.	1
14-Sep-93	trawl	55.5	1.2	1.56	0.08	102	49.9	4.1	1.21	0.45	16
30-May-94	smolt	75.9	1.5	3.55	0.23	137	73.0	30.5	3.40	3.68	3
14-Jul-94	stocking	.	.	.	.	.	.	.	0.15	.	.
26-Jul-94	beach seine	44.3	1.5	0.89	0.09	119	31.5	6.4	0.21	0.30	2
15-Sep-94	beach seine	38.4	4.8	0.55	0.22	16	55.0	.	1.46	.	1
15-Sep-94	trawl	72.7	2.6	4.23	0.32	50	65.5	.	3.16	.	1
2-Jun-95	smolt	81.9	1.1	5.06	0.22	167	79.8	8.3	4.53	1.41	4
20-Jul-95	stocking	.	.	.	.	.	.	.	0.15	.	.
28-Jul-95	beach seine	36.7	1.4	0.46	0.06	37	29.1	0.7	0.17	0.01	40
19-Sep-95	trawl	56.2	2.5	1.68	0.19	39	53.6	10.3	1.40	0.67	4
11-Jun-96	smolt	75.0	1.2	3.74	0.18	319	69.9	3.9	3.04	0.54	9
20-Jun-96	stocking	.	.	.	.	.	.	.	0.11	.	.
23-Jul-96	beach seine	31.4	0.5	0.21	0.02	186	31.4	1.4	0.23	0.05	13
19-Sep-96	beach seine	38.9	1.8	0.54	0.14	52	47.5	16.8	0.98	1.08	4
19-Sep-96	trawl	51.8	1.4	1.51	0.11	51	58.9	16.9	1.77	0.99	3
10-Jun-97	smolt	75.2	0.9	3.67	0.12	330	73.0	1.7	3.42	0.20	45

Sampling date	Capture method	*Wild fry* Mean length (mm)	95% CI	Mean weight (g)	95% CI	# wild fish captured	*Enhanced fry* Mean length (mm)	95% CI	Mean weight (g)	95% CI	# enhanced fish captured
22-Jun-97	stocking	.	.	.	.	.	.	.	0.17	.	.
26-Jun-97	beach seine	33.1	0.6	0.27	0.02	126	29.8	0.3	0.16	0.01	78
25-Jul-97	beach seine	36.0	0.6	0.41	0.03	228	35.8	0.5	0.39	0.02	125
4-Sep-97	beach seine	45.5	1.4	0.96	0.13	124	48.6	7.6	1.23	0.83	9
4-Sep-97	trawl	51.4	1.8	1.39	0.17	85	57.7	6.0	1.98	0.59	10
1-Oct-97	beach seine	38.0	2.3	0.55	0.20	42	.	.	.	.	0
6-Jun-98	smolt	76.7	0.9	3.87	0.13	393	81.8	1.9	4.48	0.33	71
14-Jun-98	beach seine	.	.	0.41	.	50	.	.	.	.	.
22-Jun-98	stocking	.	.	.	.	.	.	.	0.14	.	.
30-Jun-98	beach seine	33.9	1.4	0.29	0.05	93	30.2	0.6	0.17	0.02	87
19-Jul-98	beach seine	36.7	1.4	0.45	0.08	82	36.2	0.9	0.39	0.04	45
5-Aug-98	beach seine	38.8	4.4	0.58	0.28	23	46.1	3.5	0.88	0.17	15
23-Aug-98	beach seine	31.3	1.0	0.22	0.03	52	45.0	7.5	0.74	0.58	3
13-Sep-98	beach seine	48.3	1.8	0.98	0.12	47	51.4	2.9	1.20	0.20	8
23-Sep-98	trawl	49.8	1.0	1.06	0.07	134	50.4	4.5	1.07	0.23	11
3-Oct-98	beach seine	45.0	4.7	1.23	0.44	48	54.2	8.8	1.51	0.66	9
15-Oct-98	trawl	64.2	2.2	2.38	0.27	79	68.7	5.2	2.87	0.77	10
11-Jun-99	smolt	75.2	1.5	3.93	0.24	309	74.3	2.8	3.51	0.38	40
4-Jun-99	stocking	.	.	.	.	.	.	.	0.15	.	.
14-Jun-99	beach seine	31.6	0.4	0.17	0.01	57	29.9	0.5	0.13	0.01	24
2-Jul-99	beach seine	34.2	0.8	0.27	0.03	74	35.3	0.8	0.27	0.04	45
22-Jul-99	beach seine	34.7	1.1	0.35	0.05	65	42.2	1.1	0.66	0.06	17
10-Aug-99	beach seine	37.9	1.6	0.43	0.07	91	44.0	1.7	0.66	0.10	9
31-Aug-99	beach seine	42.6	5.4	0.77	0.35	16	.	.	.	.	0
17-Sep-99	beach seine	37.8	1.5	0.41	0.06	72	50.0	.	0.88	.	1
5-Oct-99	beach seine	37.7	2.2	0.42	0.08	27	.	.	.	.	0
15-17-Oct-99	trawl	55.6	1.8	1.08	0.11	25	.	.	.	.	0
spring 2000	smolt										

Note: Tatsamenie Lake was first stocked in 1991. In-lake data from 1991 and smolt data from 1992 could not be located.

Appendix C2. Tahltan Lake. Summary of sockeye fry and smolt mean lengths, weights, 95% confidence intervals (CI) and sample sizes of fry caught in beach seines and trawls from 1990 to 1999. Beach seine and trawl samples have been corrected for preservative shrinkage (99% denatured alcohol). Trawl sample means have been corrected for trawl net avoidance (except for mean length < 40 mm).

		Wild fry					*Enhanced fry*				
Sampling date	Capture method	Mean length (mm)	95% CI	Mean weight (g)	95% CI	# wild fish captured	Mean length (mm)	95% CI	Mean weight (g)	95% CI	# enhanced fish captured
15-Jun-90	stocking	.	.	.	.	.	.	.	0.13	0.00	.
in-lake 1990	data could not be located										
15-Jul-90	bs	50.4	.	1.30	.	76	39.0	.	0.56	.	89
25-May-91	smolt	91.1	0.7	5.93	0.13	371	88.9	1.2	5.47	0.23	97
12-Jun-91	stocking	.	.	.	.	.	.	.	0.13	0.00	.
in-lake 1991	data could not be located										
25-May-92	smolt	84.8	0.8	4.77	0.14	211	84.2	0.6	4.62	0.11	243
9-Jun-92	stocking	.	.	.	.	.	.	.	0.13	0.00	.
23-Jun-92	beach seine	31.7	1.2	0.26	0.05	72	29.6	1.8	0.17	0.04	8
29-Jul-92	beach seine	30.7	1.3	0.22	0.06	71	33.3	5.9	0.31	0.25	4
29-Jul-92	trawl	60.3	3.8	2.21	0.35	21	62.7	28.7	2.34	2.47	3
20-Aug-92	beach seine	27.6	0.6	0.11	0.01	12	.	.	.	.	0
3-Oct-92	trawl	73.7	4.0	4.10	0.48	32	76.2	17.2	4.88	1.65	5
25-May-93	smolt	80.6	0.8	4.08	0.15	185	79.7	1.5	3.87	0.20	25
17-Jun-93	stocking	.	.	.	.	.	.	.	0.13	0.00	.
3-Aug-93	beach seine	29.2	0.3	0.15	0.01	95	28.0	.	0.14	.	1
19-Sep-93	trawl	74.2	2.2	4.54	0.27	93	75.0	1.6	4.38	0.21	68
25-May-94	smolt	84.1	1.6	4.93	0.35	117	83.4	1.9	4.74	0.40	64
26-Jun-94	stocking	.	.	.	.	.	.	.	0.13	0.00	.
19-Sep-94	beach seine	54.6	15.7	2.10	1.42	8	.	.	.	.	0
19-Sep-94	trawl	63.1	6.2	2.68	0.65	16	77.1	.	4.66	.	1
18-May-95	smolt	83.5	0.7	4.75	0.13	418	82.0	2.6	4.50	0.48	27

		Wild fry					Enhanced fry				
Sampling date	Capture method	Mean length (mm)	95% CI	Mean weight (g)	95% CI	# wild fish captured	Mean length (mm)	95% CI	Mean weight (g)	95% CI	# enhanced fish captured
29-Jun-95	stocking	.	.	.	.	.	.	.	0.13	0.00	.
1995	no fry sampling conducted in 1995										
25-May-96	smolt	80.1	0.8	4.26	0.14	318	74.5	1.6	3.27	0.20	30
20-Jun-96	stocking	.	.	.	.	.	.	.	0.12	0.00	.
19-Sep-96	beach seine	43.4	3.6	0.95	0.23	59	58.5	2.3	1.79	0.33	10
19-Sep-96	trawl	68.3	2.3	3.30	0.26	56	70.6	1.6	3.21	0.16	31
25-May-97	smolt	77.4	0.7	3.63	0.10	323	76.1	0.7	3.36	0.09	180
21-Jun-97	stocking	.	.	.	.	.	.	.	0.14	0.00	.
* 29-Sep-97	trawl	82.7	1.7	3.70	0.32	58	83.8	0.7	3.60	0.13	100
1-Jun-98	smolt	83.4	0.8	4.65	0.16	362	85.8	0.8	5.09	0.18	262
10-Jun-98	stocking	.	.	.	.	.	.	.	0.12	0.00	.
1998	no fry sampling conducted in 1998										
6-Jun-99	smolt	83.8	0.7	4.75	0.14	295	83.4	0.7	4.62	0.13	194
31-May-99	stocking	.	.	.	.	.	.	.	0.13	0.00	.
in-lake 1999	no beach seines were conducted; no fry were caught in trawls										
2000	smolt										

* trawl avoidance correction was not applied to mean weight since the correction is incongruent with the mean smolt weight the following spring.

Appendix C3. Tuya Lake. Summary of sockeye fry and smolt mean lengths, weights, 95% confidence intervals (CI) and sample sizes of fry caught in beach seines and trawls from 1992 to 1999. Beach seine and trawl samples have been corrected for preservative shrinkage (99% denatured alcohol). Trawl sample means have been corrected for trawl net avoidance (except for mean lengths < 40 mm).

		Enhanced fry				
date	**capture method**	**mean length (mm)**	**95 % CI**	**mean weight (g)**	**95 % CI**	**enhanced N**
19-Jun-92	stocking	.	.	0.13	0.00	.
24-Jun-92	beach seine	27.7	0.2	0.14	0.00	150
25-Jul-92	beach seine	32.3	0.6	0.27	0.02	150
24-Aug-92	beach seine	63.2	4.8	2.57	0.66	5
18-Sep-92	beach seine	no fry caught in beach seines				
18-Sep-92	trawl	87.6	4.3	6.90	0.81	10
28-May-93	smolt	99.4	0.5	8.61	0.11	370
27-Jun-93	stocking	.	.	0.13	0.00	.
2-Sep-93	beach seine	no fry caught in beach seines				
2-Sep-93	trawl	69.5	10.5	3.62	1.32	5
28-May-94	smolt	98.7	0.5	9.02	0.13	432
3-Jul-94	stocking	.	.	0.13	0.00	.
5-Sep-94	beach seine	no fry caught in beach seines				
5-Sep-94	trawl	73.4	1.3	4.17	0.17	75
10-Jun-95	smolt	95.5	0.6	9.61	0.16	208
27-Jun-95	stocking	.	.	0.13	0.00	.
1-Aug-95	beach seine	no fry caught in beach seines				
12-Sep-95	beach seine	no fry caught in beach seines				
12-Sep-95	trawl	83.8	2.2	6.40	0.37	20
12-Jun-96	smolt	99.5	0.6	9.69	0.15	236

		Enhanced fry				
date	**capture method**	**mean length (mm)**	**95 % CI**	**mean weight (g)**	**95 % CI**	**enhanced N**
27-Jun-96	stocking	.	.	0.11	0.00	.
26-Jul-96	beach seine	only 7 fry caught in beach seines (not processed)				
12-Sep-96	beach seine	no fry caught in beach seines				
12-Sep-96	trawl	69.0	1.6	3.14	0.16	51
3-Jun-97	smolt	93.7	0.6	8.36	0.16	178
27-Jun-97	stocking	.	.	0.14	0.00	.
3-Aug-97	beach seine	42.2	0.7	0.75	0.04	129
25-Sep-97	beach seine	no fry caught in beach seines				
25-Sep-97	trawl	90.4	2.5	7.99	0.32	6
7-Jun-98	smolt	103.4	0.5	10.10	0.16	228
26-Jun-98	stocking	.	.	0.12	0.00	.
2-Aug-98	beach seine	no fry caught in beach seines				
19-Sep-98	beach seine	no fry caught in beach seines				
19-Sep-98	trawl	only one fry caught in 8 trawls			.	.
21-Jun-99	smolt	104.1	0.9	11.20	0.29	89
26-Jun-99	stocking	.	.	0.12	0.00	.
1-Aug-99	beach seine	41.5	1.6	0.69	0.09	71
14-Sep-99	trawl	no fry caught in 5 trawls		.	.	.
spring 2000	smolt	.	.	.	.	.

Appendix C4. Tatsamenie Lake sockeye fry mean lengths, weights, 95% confidence intervals (CI) and sample sizes (N) from trawl samples, before and after trawl net avoidance correction:

corrected mean length=(0.5419)(trawl length)^1.1965

corrected mean weight=(1.3922)(trawl weight)^1.2512

Note: only original mean lengths over 40 mm, and associated weights, were corrected.

	Wild fry						
date	original mean length (mm)	corrected mean length (mm)	95 % CI	original mean weight (g)	corrected mean weight (g)	95 % CI	wild N
1-Aug-92	36.0	36.0	32.3	0.54	0.54	1.78	3
28-Sep-92	otolith thermal mark data not found						
14-Sep-93	47.9	55.5	1.2	1.10	1.56	0.08	102
15-Sep-94	60.0	72.7	2.6	2.43	4.23	0.32	50
19-Sep-95	48.4	56.2	2.5	1.16	1.68	0.19	39
19-Sep-96	45.2	51.8	1.4	0.86	1.51	0.11	51
4-Sep-97	44.9	51.4	1.8	1.00	1.39	0.17	85.00
13-23-Sep-98	43.8	49.8	1.0	0.80	1.06	0.07	134
15-Oct-98	54.1	64.2	2.2	1.54	2.38	0.27	79
15-17-Oct-99	48.0	55.6	1.8	0.82	1.08	0.11	25

	Enhanced fry						
date	original mean length (mm)	corrected mean length (mm)	95 % CI	original mean weight (g)	corrected mean weight (g)	95 % CI	enhanced N
1-Aug-92	.	.	.	.	.	.	0
28-Sep-92	otolith thermal mark data not found						
14-Sep-93	43.8	49.9	4.1	0.89	1.21	0.45	16
15-Sep-94	55.0	65.5	.	1.93	3.16	.	1
19-Sep-95	46.5	53.6	10.3	1.00	1.40	0.67	4
19-Sep-96	50.3	58.9	16.9	1.21	1.77	0.99	3
4-Sep-97	49.5	57.7	6.0	1.32	1.98	0.59	10
13-23-Sep-98	44.2	50.4	4.5	0.81	1.07	0.23	11
15-Oct-98	57.2	68.7	5.2	1.78	2.87	0.77	10
15-17-Oct-99	.	.	.	.	.	.	0

Appendix C5. Tahltan Lake sockeye fry mean lengths, weights, 95% confidence intervals (CI) and sample size (N) from trawl samples, before and after trawl net avoidance correction:

corrected mean length=(0.5419)(trawl length)^1.1965

corrected mean weight=(1.3922)(trawl weight)^1.2512

	Wild fry						
date	original mean length (mm)	corrected mean length (mm)	95 % CI	original mean weight (g)	corrected mean weigh t(g)	95 % CI	wild N
29-Jul-92	51.3	60.3	3.8	1.45	2.21	0.35	21
3-Oct-92	60.7	73.7	4.0	2.37	4.10	0.48	32
19-Sep-93	61.0	74.2	2.2	2.57	4.54	0.27	93
19-Sep-94	53.3	63.1	6.2	1.69	2.68	0.65	16
1995	no fry sampling conducted in 1995						
19-Sep-96	57.0	68.3	2.3	1.99	3.30	0.26	56
29-Sep-97	66.8	82.7	1.7	3.70	7.16	0.32	58.00
1998	no fry sampling conducted in 1998						
1999	no beach seines conducted in 1999; only 1 fry caught in trawls						

	Enhanced fry						
date	original mean length (mm)	corrected mean length (mm)	95 % CI	original mean weight (g)	corrected mean weight (g)	95 % CI	enhanced N
29-Jul-92	53.0	62.7	28.7	1.51	2.34	2.34	3
3-Oct-92	62.4	76.2	17.2	2.72	4.88	1.65	5
19-Sep-93	61.6	75.0	1.6	2.50	4.38	0.21	68
19-Sep-94	63.0	77.1	.	2.63	4.66	.	1
1995	no fry sampling conducted in 1995						
19-Sep-96	58.6	70.6	31.0	1.95	3.21	0.16	31
29-Sep-97	67.6	83.8	0.7	3.60	6.93	0.13	100
1998	no fry sampling conducted in 1998						
1999	no beach seines conducted in 1999; only 1 fry caught in trawls						

Appendix C6. Tuya Lake sockeye fry mean lengths, weights, 95% confidence intervals (CI) and sample sizes (N) from trawl samples, before and after trawl net avoidance correction:

corrected mean length=(0.5419)(trawl length)^1.1965

corrected mean weight=(1.3922)(trawl weight)^1.2512

	Enhanced fry							
date	**original mean length (mm)**	**corrected mean length (mm)**	**95 % CI**	**original mean weight (g)**	**corrected mean weight (g)**	**95 % CI**	**enhanced N**
18-Sep-92	70.1	87.6	4.3	3.60	6.90	0.81	10
2-Sep-93	57.8	69.5	10.5	2.15	3.62	1.32	5
5-Sep-94	60.5	73.4	1.3	2.40	4.17	0.17	75
12-Sep-95	67.6	83.8	2.2	3.38	6.40	0.37	20
12-Sep-96	57.4	69.0	1.6	1.91	3.14	0.16	51
25-Sep-97	72.0	90.4	2.5	4.04	7.99	0.32	6
1998	no fry were caught in fall trawls						
1999	no fry were caught in fall trawls						

Appendix C7. Tatsamenie Lake sockeye smolt (age 1+ and age 2+) mean lengths, weights, 95% confidence intervals (CI) and sample size (N). Length and weight measurements were taken from fresh (unpreserved) smolts.

date	*Wild smolts - age 1+*					*Enhanced smolts - age 1+*				
	mean length (mm)	95 % CI	mean weight (g)	95 % CI	wild N	mean length (mm)	95 % CI	mean weight (g)	95 % CI	enhanced N
May 20-29, 1992	81.0	.	4.87	.	147	81.6	.	4.99	.	14
May 20-31, 1993	75.9	2.0	4.47	0.34	79	65.2	4.4	2.88	0.51	6
May 22-June 6, 1994	75.9	1.5	3.55	0.23	137	73.0	30.5	3.40	3.68	3
May 20-June 15, 1995	81.8	1.1	5.06	0.22	167	79.8	8.3	4.53	1.41	4
May 28-June 26, 1996	75.0	1.2	3.74	0.18	319	69.9	3.9	3.04	0.54	9
May 23-June 28, 1997	75.2	0.9	3.67	0.12	330	73.0	1.7	3.42	0.20	45
May 15-June 30, 1998	76.7	0.9	3.87	0.13	393	81.8	1.9	4.48	0.33	71
May 22-July 1, 1999	75.2	1.5	3.93	0.24	309	74.3	2.8	3.51	0.38	40
Mean:	**77.1**		**4.1**			**74.8**		**3.8**		

date	*Wild smolts - age 2+*					*Enhanced smolts - age 2+*				
	mean length (mm)	95 % CI	mean weight (g)	95 % CI	wild N	mean length (mm)	95 % CI	mean weight (g)	95 % CI	enhanced N
May 20-29, 1992	117.5	.	14.10	.	78	.	.	.	.	0
May 20-31, 1993	103.5	6.4	9.77	1.74	10	.	.	.	.	0
May 22-June 6, 1994	114.7	4.2	13.34	1.54	18	111.4	8.4	11.52	2.86	5
May 20-June 15, 1995	119.3	1.8	16.12	0.75	25	117.0	.	15.20	.	1
May 28-June 26, 1996	124.3	2.5	16.29	1.07	61	126.8	11.4	16.90	4.19	5
May 23-June 28, 1997	106.5	1.9	9.57	0.53	110	107.0	5.6	9.48	1.59	5
May 15-June 30, 1998	112.9	5.0	11.96	1.26	7	.	.	.	.	0
May 22-July 1, 1999	114.8	1.8	12.95	0.54	127	129.0	12.7	16.20	3.81	2
Mean:	**114.2**		**13.0**			**118.2**		**13.9**		

Appendix C8. Tahltan Lake sockeye smolt (age 1+ and age 2+) mean lengths, weights, 95% confidence intervals (CI) and sample size (N). Length and weight measurements were taken from fresh (unpreserved) smolts.

date	*Wild smolts - age 1+*					*Enhanced smolts - age 1+*				
	mean length (mm)	95 % CI	mean weight (g)	95 % CI	wild N	mean length (mm)	95 % CI	mean weight (g)	95 % CI	enhanced N
May 17-June 12, 1991	91.1	0.7	5.93	0.13	371	88.9	1.2	5.47	0.23	97
May 13-June 13, 1992	84.8	0.8	4.77	0.14	211	84.2	0.6	4.62	0.11	243
May 11-June 26, 1993	80.6	0.8	4.08	0.15	185	79.7	1.5	3.87	0.20	25
May 8-June 12, 1994	84.1	1.6	4.93	0.35	117	83.4	1.9	4.74	0.40	64
May 7-June 24, 1995	83.5	0.7	4.75	0.13	418	82.0	2.6	4.50	0.48	27
May 11-June 26, 1996	80.1	0.8	4.26	0.14	318	74.5	1.6	3.27	0.20	30
May 14-June 23, 1997	77.4	0.7	3.63	0.10	323	76.1	0.7	3.36	0.09	180
May 10-June 29, 1998	83.4	0.8	4.65	0.16	362	85.8	0.8	5.09	0.18	262
May 14-June 30, 1999	83.8	0.7	4.75	0.14	295	83.4	0.7	4.62	0.13	194
Mean:	**83.2**		**4.6**			**82.0**		**4.4**		

date	*Wild smolts - age 2+*					*Enhanced smolts - age 2+*				
	mean length (mm)	95 % CI	mean weight (g)	95 % CI	wild N	mean length (mm)	95 % CI	mean weight (g)	95 % CI	enhanced N
May 17-June 12, 1991	112.3	3.8	11.63	1.19	38	.	.	.	.	0
May 13-June 13, 1992	110.1	2.9	10.18	0.77	20	115.2	6.0	11.99	1.93	10
May 11-June 26, 1993	105.6	8.5	10.33	2.42	7	116.5	108.0	12.85	46.38	2
May 8-June 12, 1994	102.5	3.0	8.63	0.85	18	.	.	.	.	0
May 7-June 24, 1995	114.5	4.1	12.43	1.42	28	116.0	8.4	13.08	3.05	9
May 11-June 26, 1996	103.5	5.6	9.57	1.70	22	105.5	6.4	9.20	10.16	2
May 14-June 23, 1997	95.2	2.2	6.57	0.48	39	93.3	6.1	6.16	1.45	8
May 10-June 29, 1998	103.2	2.7	8.58	0.66	46	103.3	10.9	8.87	2.66	7
May 14-June 30, 1999	107.8	10.7	9.99	3.00	9	95.0	.	6.50	.	1
Mean:	**106.1**		**9.8**			**106.4**		**9.8**		

Appendix C9. Tuya Lake sockeye smolt (age 1+ and age 2+) mean lengths, weights, 95% confidence intervals (CI) and sample size (N). Length and weight measurements were taken from fresh (unpreserved) smolts.

	Enhanced smolts - age 1+				
date	**mean length (mm)**	**95 % CI**	**mean weight (g)**	**95 % CI**	**enhanced N**
28-May-93	99.4	0.5	8.61	0.11	370
28-May-94	98.7	0.5	9.02	0.13	432
10-Jun-95	95.5	0.6	9.61	0.16	208
12-Jun-96	99.5	0.6	9.69	0.15	236
3-Jun-97	93.7	0.6	8.36	0.16	178
7-Jun-98	103.4	0.5	10.10	0.16	228
21-Jun-99	104.1	0.9	11.20	0.29	89
Mean:	**98.4**		**9.5**		

	Enhanced smolts - age 2+				
date	**mean length (mm)**	**95 % CI**	**mean weight (g)**	**95 % CI**	**enhanced N**
28-May-93	.	.	.	.	.
28-May-94	134.5	4.0	22.15	1.55	20
10-Jun-95	137.0	6.2	27.35	1.85	4
12-Jun-96	133.1	9.0	24.50	4.83	10
3-Jun-97	136.1	1.4	26.40	0.80	139
7-Jun-98	140.7	3.9	25.21	2.26	14
21-Jun-99	158.2	6.9	35.09	2.90	19
Mean:	**136.3**		**26.8**		