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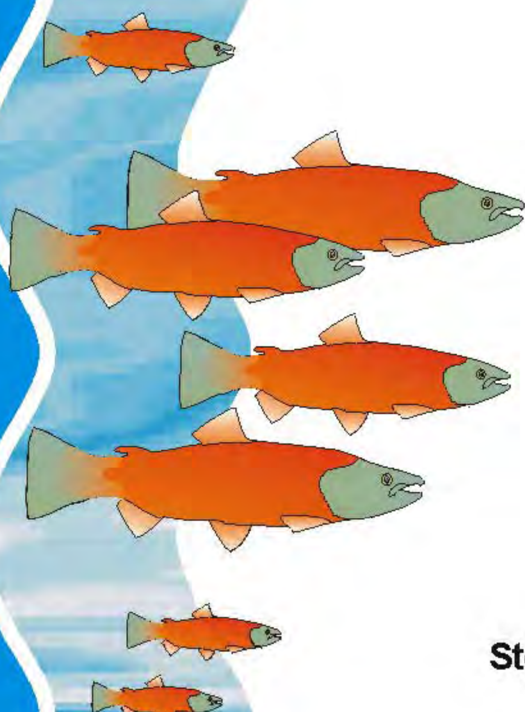

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Stock Management Report No. 17

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EXECUTIVE SUMMARY

All available data on Quesnel Lake kokanee and rainbow trout are summarized to provide an updated assessment of the status of the lakes' populations. Kokanee data suggests there are two distinct populations that may well be reproductively isolated. The stream spawning component historically spawned in reaches of Wasco Creek, the Horsefly River, little Horsefly River and the Mitchell River from mid-September to mid-October. Data from the 1950s and 1960s suggest the stream spawner numbers may have ranged from 50,000 - 100,000 but today there are less than 1000. Shore spawner numbers could not be quantified but they continue to spawn in a few known locations identified in the early 1950s from mid-October to early November. There does not appear to be much difference in size and age at maturity between the stream and shore spawners. Studies on kokanee in the 1950s and 1960s by the International Pacific Salmon Fisheries Commission (IPSFC) focused on the hypothesis that kokanee competed with sockeye juveniles for food and were the cause of cyclical dominance in Quesnel lake sockeye. This work concluded that kokanee did not compete for food, interspecific competition was not a factor causing cyclical dominance and some data indicated that large sockeye numbers could adversely impact kokanee.

There is evidence from the hydroacoustic and trawl survey data that suggests a decline in total numbers of kokanee during the 1990s and early 2000s. The total kokanee population in the 2000s has been estimated at only 1.5-2.2 million compared with 3.5 million in the early 1990s. Based on a large lake kokanee biostandard of 5-7% of the total population size a crude estimate of total spawners ranges from 75,000-150,000. Compared to other similar sized lakes such as Kootenay, Okanagan, Arrow and Shuswap the estimated number of kokanee spawners in Quesnel Lake is exceptionally low. In sharp contrast, the Quesnel Lake sockeye population has increased dramatically during the last decade with annual acoustic estimates ranging from 4-65 million fry. It is speculated that the decline in kokanee is in response to increased competition for food due to significantly increased numbers of sockeye fry. There is no evidence that kokanee spawning habitat has deteriorated to any degree to account for the decline in numbers. It is further speculated that the stream spawning component has declined while the shore spawners have not because stream spawner progeny emerge much later than sockeye fry and shore spawning kokanee fry.

Rainbow trout spawn in the Horsefly and Mitchell rivers with the former system appearing to support the largest numbers. These trout grow to a large size and are the target of a very popular sport fishery. Some crude estimates of escapement numbers place the Horsefly River numbers between 500-800 and the Mitchell River numbers likely less than half of this estimate. While these trout reside in the lake for most of their adult life some also undertake migrations into the two rivers to feed on emerging sockeye fry in the spring and on eggs later in the summer and early fall. These migrations are well known to anglers and some excellent river fishing is experienced throughout the summer and fall.

Quesnel Lake rainbow trout life history is similar to other piscivorous rainbow trout found in Shuswap, Kootenay and Okanagan lakes. They are highly piscivorous, grow to large size (7-10 kg) and generally mature at age 6 or 7. The juvenile fish appear to be highly reliant on stream rearing for one or two years in the Horsefly and Mitchell rivers prior to entering the lake. A decrease in the average size of spawners may have been in part due to some over fishing in the past, however recent age analyses indicates that not only size but rainbow growth rates have declined over the past decade. Stomach sampling confirmed that their primary food source is age 1-3 kokanee which have been declining in numbers over the same period. Diet analysis showed that as the numbers of sockeye fry increased following dominant and subdominant (i.e. high) return years, the numbers of age 1 and 2 kokanee eaten declined and the total biomass of *O. nerka* consumed (per stomach) declined by up to 70%. It follows then that recent increases in the numbers of sockeye and concurrent declines in abundance of kokanee may be the primary cause of declining size and size-at-age of the Quesnel Lake rainbow trout.

Recommendations for further study include continuation of the annual kokanee trawl and acoustics survey in cooperation with DFO. This data provides the best insight into the status of the kokanee population. Improvements to kokanee escapement estimates are required and some index sites for both stream and shore spawners are proposed. The Horsefly River rainbow trout spawning population should continue to be monitored using a resistivity counter. Rainbow trout spawner enumeration work in 2002 and 2003 on the Horsefly system needs to be summarized and incorporated in an updated version of this report. Better biological data for both kokanee and rainbow trout is required, especially in view of the prospect of continued decline in kokanee and lower rainbow trout growth rates. Harvest estimates are required for the large rainbow trout and some consideration should be given to implementing a restricted tag or stamp system similar to those in place on Shuswap and Kootenay lakes.

Concern expressed by fisheries biologists and the public regarding the current status (declining) of the rainbow trout and kokanee populations is supported by biological data in this report.

Finally, it is clear that kokanee are a significant prey item that influences the growth of predator populations in Quesnel Lake and therefore their abundance is of paramount importance. A workshop should be held involving researchers and biologists who work on lakes with similar fish assemblages and problems. The collective experience at the workshop should greatly assist in development of an action plan for future work on Quesnel Lake.

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INTRODUCTION

Quesnel Lake is a 270 km^2 natural (non-regulated) oligotrophic lake located in central British Columbia which supports both recreational and commercially important fish species. The Mitchell River flows into the north arm of the lake while the east arm inflows are quite limited with the exception of Niagara River, a moderate sized stream with an impassable falls at the mouth (**Fig. 1**). The Horsefly River drainage, by far the most important spawning system for salmon and trout, flows north into the central area of the lake. The lake outlet, the Quesnel River, provides access to sockeye salmon via the Fraser River, as well as smaller numbers of chinook and coho.

This natural lake is best known for its production of sockeye salmon and has been the focus of a great deal of research and management effort by the Federal government supported International Pacific Salmon Fisheries Commission (IPSFC) and the Department of Fisheries and Oceans (DFO). The IPSFC was established in 1938 by Treaty between the United States and Canada to monitor and enhance Fraser River salmon, especially sockeye. Assessments of sockeye salmon escapements have been made by the IPSFC for over seventy years and some of the work included data collection on kokanee. In recent years the Quesnel system has produced annual sockeye escapements upward of 3.5 million sockeye salmon. A wealth of literature exists on the life history of sockeye salmon including entire books dedicated to this culturally and economically important species of salmon (see Smith et al 1987; Groot and Margolis 1991). Annual escapements for Quesnel sockeye have been monitored since 1938 (Schubert 1997 and Cone 1999) and juveniles have been monitored since 1977 following dominant years and 1987 following sub-dominant years (Hume and MacLellan 2001). Annual reports are produced by the IPSFC on Quesnel-Horsefly lakes sockeye production and escapements.

Perhaps less known and certainly less understood are resident populations of rainbow trout and kokanee that inhabit Quesnel Lake. These two species are particularly important to local residents for sport fishing and a significant tourist based sport fish industry has developed during the last four decades. Some of the rainbow trout caught in the lake are large-sized piscivores comparable to the Gerrard strain of rainbow trout found in Kootenay Lake. These fish also undergo feeding migrations into major tributaries during summer and fall to take advantage of aquatic invertebrates and eggs from spawning salmon. Quesnel Lake supports at least two indigenous stocks of kokanee with both shoal and stream spawning ecotypes and an enhanced run of sockeye salmon. The majority of sockeye rear for up to a year in Quesnel Lake before migrating to the ocean.

To date most of the focus on Quesnel Lake has been on the sockeye, although some of the earliest studies also included kokanee since they were considered a potential competitor with sockeye. The provincial fisheries program has not spent a great deal of time working on Quesnel Lake therefore the information base for trout and char species is very limited. It wasn't until the mid 1980s that some work began on estimating the extent of the sport fishery (Prest and Ling 1984; Prest 1984) and some rainbow trout radio telemetry work in 1987 (Dolighan 1989). Initial work on juvenile trout production in the Horsefly River also began in 1987 (Sebastian 1990).

Similar to other large lakes in southern British Columbia Quesnel Lake piscivorous trout and char are evidently quite dependent upon kokanee as their primary forage species despite the obvious abundance (i.e., millions) of juvenile sockeye that rear in the lake. Kokanee are the primary food source for Gerrard rainbow trout in Kootenay Lake (Andrusak and Parkinson 1984) and stomach samples of Quesnel Lake rainbow trout indicate a similar reliance on kokanee (Parkinson et al. 1989).

A well established rainbow trout fishery exists on Quesnel Lake with most of the effort directed at the trophy sized fish that can attain a size of 9 kg at maturity (Dolighan 1989). For over a decade anglers have perceived a decrease in the size of trout caught. Coincidentally, kokanee numbers apparently have declined thus leading to the suggestion that the suspected declines in both species are related to significantly increased sockeye numbers over approximately the same time period.

In response to apparent declining size and numbers of piscivorous rainbow trout caught in Quesnel Lake the Ministry of Water Land and Air Protrection (WLAP) undertook a three-year study commencing in 2000. Due to the relative importance of kokanee in the diet of large rainbow demonstrated by Parkinson et al. (1989), it has been suggested that the decline in rainbow size and numbers may be partly a function of recent declines in the kokanee population. A possible cause for the kokanee decline may be increased competition for food and rearing space as a result of increasing numbers of sockeye salmon rearing in the lake. Sockeye dominant year returns to Quesnel Lake tributaries have doubled from 1.9 million fish in 1989 to 3.6 million fish in 2001 (from DFO database), and have increased by 32 times since the early 1950's.

A great deal of information and data on Quesnel Lake fish has been generated over the last half century by the IPSFC and over the past twenty years by the Provincial Fisheries. The purpose of this report was to compile and summarize available, relevant information on Quesnel Lake kokanee and rainbow trout and assess the current status of these stocks. The specific objectives of this initial report are:

- To summarize all available Quesnel Lake rainbow trout and kokanee data;
- To determine the current status of kokanee and rainbow in Quesnel Lake and their possible linkages to sockeye numbers and
- To investigate whether rainbow growth had in fact declined as a result of poorer growth conditions.

Background

Quesnel Lake is located in the south-east central portion of the interior plateau of British Columbia and lies in a general east-west axis between the Cariboo Mountain range and the Quesnel highland of the interior plateau. The lake lies at an elevation of 725 m and is fed by two major rivers and numerous smaller streams. The Mitchell River is the major tributary that flows into the North Arm of the lake while a series of small tributaries contribute to the East Arm. The two arms converge to form the Main Arm which empties into the West Arm near the lake outlet at Likely BC (**Fig. 1**). The Horsefly River flows into the Main Arm approximately 24 km southeast of Likely BC. The lake outlet is the Quesnel River which flows north-west and enters the Fraser River at Quesnel BC.

The lake has a surface area of approximately 270 km^2 with a mean depth of 158 m and maximum of 530 m (Stockner and Shortreed 1989; Hume et al 1996). Stockner and Shortreed (1989) and Nidle et al (1990) describe the lake as being oligotrophic with TDS ranging from 50-70 mg/L. Occasionally the lake freezes over during winter while summer surface water temperature seldom exceeds 18º C. Quesnel Lake has been investigated by the DFO as a candidate lake for lake fertilization and therefore some detailed information on background levels of phosphorus and nitrogen have been described by Stockner and Shortreed (1989). Additional information on Quesnel Lake limnology can be found in Stockner and Shortreed (1989); Nidle et al (1990) and Hume et al (1996).

A brief summary of some physical characteristics of Quesnel Lake are compared with other larger lakes in southern B.C. (Table 1). Compared to Okanagan, Kootenay, Arrow and Shuswap, Quesnel Lake is smaller, has a lower TDS and is considerably deeper. Quesnel Lake is most comparable to Adams Lake in terms of flushing rate, TDS and depth.

Table 1. Comparison of some physical characteristics of large lakes in southern BC.

Lake	TDS	Surface area (ha)	Mean depth (m)	Maximum depth (m)	Water residence time (yr)	Approximate length of lake (km)
Adams	57	13,760	169	457	10	62
Arrow	77	49,800	83	287	<1	240
Kootenay	85	38,900	94	154	1.3	107
Okanagan	165	34,950	75	242	50	110
Quesnel	60	20,700	158	530	10.8	128
Shuswap	80	30,960	62	162	2.1	137

McPhail and Caraveth (1992) described the native species assemblage of the upper Fraser as nearly identical to that of the Upper Columbia except few of the 16 introduced species (into the Columbia) have found their way into the upper Fraser. There are 16 native species found in Quesnel Lake with two species (sturgeon and brassy minnow) possibly present (**Table 2**). The only introduced species (confirmed) in Quesnel Lake are lake trout and lake whitefish.

Table 2. List of fish species in Quesnel Lake (from McPhail and Carveth 1992).

Common name	Scientific name
Sockeye salmon	*Oncorhynchus nerka*
Kokanee	*Oncorhynchus nerka*
Coho salmon	*Oncorhynchus kisutch*
Chinook salmon	*Oncorhynchus tshawytscha*
Rainbow	*Oncorhynchus mykiss*
Bull trout	*Salvelinus confluentus*
Lake trout	*Salvelinus namaycush*
Pygmy whitefish	*Prosopium coulteri*
Mountain whitefish	*Prosopium williamsoni*
Lake whitefish	*Coregonus clupeaformis*
Burbot	*Lota lota*
Northern pikeminnow	*Ptychocheilus oregonensis*
Coarsescale sucker	*Catostomus macrocheilus*
Finescale sucker	*Catostomus catostomus*
Peamouth chub	*Mylocheilus caurinus*
Leopard dace	*Rhinichthys falcatus*
Longnose dace	*Rhinichthys cataractae*
Slimy sculpin	*Cottus cognatus*
Redside shiner	*Richardsonius balteatus*
Lake chub	*Couesius plumbeus*

Many aspects of kokanee (*Oncorhynchus nerka*) life history, the non-anadromous form of Pacific sockeye salmon, have been well documented (Vernon 1957; Northcote and Lorz 1966; Northcote 1973; Sebastian et al 1999; Andrusak and Sebastian *in* Andrusak et al 2000). Most kokanee populations found in the large lakes of British Columbia migrate up tributary streams to spawn usually in September. A few lakes support both stream and shore spawners with large shore spawning populations found in Okanagan and Quesnel lakes.

It is generally believed that kokanee fry move immediately to open waters after emergence from spawning areas be they from tributaries or beach spawning sites. This rapid dispersion of fry to the open water is consistent with many anadromous sockeye populations including those in Quesnel Lake. There are well documented examples of sockeye fry undergoing rapid and intricate dispersion patterns into nursery lakes upon emergence (McCart 1967; McDonald and Hume 1984; Morton and Williams 1990). Babine Lake populations have been studied extensively and McDonald and Hume (1984) demonstrated that fry migrating from tributary streams might remain either on the lakeshore for weeks or move directly into open water. There are also examples of sockeye stocks where the juveniles initially reside on-shore in the littoral area for a period of months (see Burgner 1991). Kokanee fry in the West Arm of Kootenay Lake remain on-shore for two months before moving to the limnetic area (Redfish Consulting Ltd. 1999) but most kokanee fry do seem to move directly to open water (Wilson and Andrusak *in* Andrusak et al. 2003).

In Quesnel Lake, Morton and Williams (1990) showed that sockeye fry from the 1985 brood year migrated from their natal streams (Horsefly and Mitchell rivers) along the shoreline of the lake at a rate of about 2 km/day. They were first observed in the lake near the mouth of the Horsefly river on May 17. Fry from the Horsefly were observed in the vicinity of the junction of the three arms on June 19. Initially no fry were observed in limnetic areas but by June 19 large schools were observed 200 m from shore and by Aug 19 fry were well dispersed in the limnetic zone. They found that the copepod *Leptodiaptomus* was the primary prey item while onshore in May and early June. As *Daphnia* became more abundant it became the primary prey item both on- and off-shore.

Once in the limnetic area both kokanee and sockeye feed primarily on zooplankton, especially copepods and cladocerans. It appears then that kokanee potentially experience intraspecific competition with underyearling sockeye since they prey upon the same macrozooplanktors such as *Daphnia* and *Diaptomus* (Stockner and Shortreed 1989; Hume et al 1996; Thompson 1999 unpublished thesis UBC). In Quesnel Lake under yearling sockeye are found at dusk in the same layers of the lake as juvenile kokanee (Parkinson, research scientist, UBC, pers. com.).

Roos (1991) suggested that the Quesnel Lake sockeye salmon runs may have exceeded ten million fish in the high years prior to 1881. A dam built on the Quesnel River by a mining company in 1896 obstructed fish passage completely in the first few years and partially after a rudimentary fish way was bulit in 1903. J. P. Babcock (Commissioner of Fisheries for British Columbia) estimated an escapement greater than 4 million fish in 1909 (quoted in Roos 1991). The Hell's Gate slide in 1913 and to some extent commercial over-fishing resulted in a further precipitous decline in sockeye spawners to all of the spawning grounds in the Fraser River system (Roos 1991). In 1929 there were only 1,500 sockeye spawners in the Quesnel Lake area from a brood of over 4 million only five generations previously. The IPSFC and the DFO have aimed much of their Fraser River management efforts in the second half of the twentieth century at rebuilding stocks through a combination of fishery regulation and fry/smolt production (Hume et al 1996). As some stocks began to rebuild more effort has been directed at determining optimal escapement levels that will maximize numbers of adult fish. Hume et al (1996) used three approaches to estimate optimal escapement levels of three major Fraser nursery lakes including Quesnel Lake. The three models indicated that fry numbers did not increase significantly beyond escapements ranging from 0.85-1.06 million effective female spawners. A modified model (called the PR model) was developed by Hume et al (1996) that use limnological data (photosynthetic rates) to predict escapements that will maximize smolt output. The premise of this model is based on the knowledge that most sockeye lakes are nutrient limiting (Hyatt and

Stockner 1985). The model also assumes spawning habitat is not limiting and that sockeye fry display density dependent growth. Using this model, phosphorus was identified as the limiting nutrient in Quesnel Lake and for this reason DFO has considered fertilizing Quesnel Lake to increase sockeye production (Shortreed et al. 2001). Additions of nutrients are no longer being considered for Quesnel Lake as a result of recent increases in natural nutrient levels due to record sockeye returns.

Most Fraser River sockeye smolt after 1 year of rearing in the lake and return to spawn in their fourth summer after spending three summers (2+) in the marine environment (Hume et al 1996). The IPSFC work on Quesnel Lake as early as the 1950s identified that there was an obvious single dominant return, a sub-dominant cycle and two significantly weaker non-dominant returns. Much of the IPSFC work involved identifying the cause(s) of the dominance of one brood year over the others but to this day no clear answer is evident (Hume et al.1996). Interestingly, IPSFC scientists in the 1950s believed that kokanee were responsible for the weak cycles because of competition for the same food (zooplankton). As a consequence some of the most comprehensive data on Quesnel Lake kokanee in this report is from the IPSFC files of the 1950s and early 1960s.

DFO undertook an initiative to rebuild the Quesnel Lake sockeye escapements through reduced harvest rates in the late 1980s. As a backup to spawning failure in sub dominant years, a sockeye spawning channel was constructed on the Horsefly River in 1987 and became operational in 1988. This channel is managed for the weak cycle years only and was not intended to operate during the dominant cycle. Some 12,000 females are directed into the channel in the off year cycles in an effort to increase the strength of these cycles. Kokanee do not utilize this channel for spawning. Sockeye salmon escapements have dramatically increased in the 1990s and early 2000s (**Fig. 2**). The dominant year (1997-2001cycle) now exceeds 3.5 million spawners increasing from less than one million only three cycles earlier. The subdominant cycle has doubled to over one million in a short span of twelve years and may have exceeded the highest dominant year in 2002 at an estimated 4 million, although counts were incomplete. The two weak cycles have doubled in the last two decades albeit spawners are still less than one quarter of a million.

Two other sockeye enhancement projects have been undertaken by DFO on the Quesnel Lake system. A weir control structure was built on the outlet of Mitchell Lake in 1988 to increase sockeye fry survival by supplementing winter flows in the Mitchell River. A second project involved development of a cold water siphon in McKinley Lake. The siphon was intended to supply cooler water to McKinley Creek and subsequently the Horsefly River during the peak of sockeye spawning. This project has become problematic for other species that rear in the system.

The decline in kokanee numbers in Arrow and Kootenay lakes has been directly linked to reduced lake productivity as a result of nutrient retention in upstream reservoirs. Cladoceran densities became very low in Kootenay Lake in the 1980s due to reduced lake productivity and or extensive grazing by kokanee and *Mysis relicta* (Ashley et al

1997). Experimental fertilization of both lakes in the 1990s and early 2000s has resulted in dramatic increases in *Daphnia* and kokanee numbers (Wright et al. 2002; Pieters et al 2003). The DFO have fertilized numerous lakes in BC to increase sockeye production (Hyatt and Stockner 1985) with Adams Lake one of the most recent candidate lakes (Hume et al 2003). *Daphnia* in Quesnel Lake are abundant in the non dominant cycle years when sockeye fry densities are comparatively low. However, *Daphnia* densities are low in high fry density years with sockeye fry shifting to smaller prey items and displaying strong density dependent growth and survival (Shortreed et al. 2001). Although Quesnel Lake may be an ideal candidate for increasing smolt production by the application of nutrients, it is not presently being considered for fertilization because of the difficulties that would be encountered in managing an enhanced sockeye stock which migrates through the commercial fishery at the same time as other weaker salmonid stocks, including other sockeye, coho, chinook and steelhead stocks (Stockner et al. 1994).

Recent anecdotal evidence through DFO's annual sockeye monitoring program suggests that Quesnel Lake kokanee may have declined significantly although their spawning habitat remains intact. It appears that while sockeye returns have doubled over the past 20 years kokanee may have been negatively impacted through direct competition for food in the lake.

Apparent recent declines in the size at maturity of rainbow trout spawners in the Horsefly River are also a concern for the Province. Overfishing is one possible reason for the change in trout size but it cannot be discounted that the decline in kokanee numbers may be part of the reason for changes in trout size. This latter possibility would seem unlikely since these trout utilize sockeye fry/smolts whose densities have increased. An up-to-date review of the status of both Quesnel Lake rainbow trout and kokanee is required to understand the impact that restored sockeye runs are having on these and other indigenous freshwater species.

Quesnel Lake supports the largest sport fishery in the Cariboo region with anglers targeting trophy size rainbow trout, lake char, bull trout and in recent years, to a much lesser extent kokanee. Access to the Fraser River enables this system to support an anadromous population of sockeye salmon as well as chinook and coho and recently anglers have also been able to harvest some sockeye. As indicated earlier in this report, Quesnel Lake supports a distinctive stock of wild, late-maturing, piscivorous rainbow similar to the Kootenay Lake Gerrard strain. Unlike the Gerrard trout Quesnel Lake piscivorous rainbows undergo feeding migrations into major tributaries during the summer/fall months to take advantage of aquatic invertebrates and eggs from spawning salmon. These migrations provide an opportunity for unique, high quality catch-and-release river fisheries that have become increasingly popular during the last ten years.

Human impacts on Quesnel Lake fish populations have occurred in many different ways, the most severe attributed to extensive habitat degradation caused by intensive hydraulic mining activities on the Horsefly and Quesnel rivers from 1859 to 1902. Similarly, fish production may have been altered as forest management practices (timber harvesting) appear to have affected seasonal hydrological patterns on select spawning streams (particularly the Horsefly River). Ranching has also impacted the Horsefly River with large sections of riparian vegetation cleared for production of grass and hay.

This report summarizes available biological information on Quesnel Lake kokanee and rainbow trout. Much of the early data has been garnered from old IPSFC reports that focused on the “kokanee problem” when kokanee data was collected in an effort to understand if kokanee were restricting sockeye production. Ironically, the issue today may well be that of understanding if increased sockeye production represents a problem for kokanee! Most of the rainbow trout data stems from BC Fisheries work on the Horsefly River, particularly spawner surveys and some limited tagging results during the 1980s. Since special rainbow trout fishing regulations have been introduced during the last decade a summary of the regulations and possible impacts has been included.

CHAPTER ONE—KOKANEE

INTRODUCTION

Quesnel Lake supports at least two indigenous stocks of kokanee namely those that spawn in tributary streams and those that spawn on beaches or shoals (**Map1**). There has been some genetic analysis done to determine if the two stocks are separate but the results have been inconclusive (Wood and Foote 1996; Wood et al. 1999). Similar genetic analyses for Kootenay Lake stocks are currently underway and some differences between Okanagan Lake shore and stream spawners have been demonstrated (Pollard *in* Andrusak et al. 2000).

Kokanee in Quesnel Lake have been of interest to salmon biologists for decades. IPSFC records show that general observations on spawning kokanee began at least as early as 1940. One report written entitled “An outline of the Kokanee Problem” (C.P Idyll 1944 MS) discusses the possible origin of kokanee with mention of how kokanee may impact sockeye numbers through intraspecific competition. Several other IPSFC reports in the 1940s and 1950s expressed interest and concern about kokanee and their impact on sockeye. A series of annual reports in the 1950s by F. Ward provide some good data on kokanee size, fecundity and stream specific escapements. Ward (1954) noted that when Quesnel Lake kokanee and sockeye spawn in the same stream kokanee spawn about ten days later than sockeye and usually in about 2.2ºC colder water. He also determined the age of spawning Quesnel Lake kokanee as three years (2+) at maturity. Ward (1954) also describes a study that was designed to measure the degree of mixing of kokanee from Quesnel Lake and Horsefly Lake when they spawned in the Little Horsefly River. Using a fish fence located 3 miles downstream of the outlet of Horsefly Lake Ward (1954) tagged kokanee spawners originating from Quesnel and Horsefly lakes. He describes to his dismay that upon removal of the fence kokanee from Quesnel Lake did not move into the river section immediately below Horsefly Lake and intermix with down-streaming Horsefly Lake kokanee. He concluded that there were indeed two separate spawning populations.

Goodman (1958) summarized the 1950s work and concluded that kokanee and sockeye seldom compete for spawning sites and that there was no correlation kokanee abundance and cyclical dominance in the Quesnel Lake sockeye (a theory pursued by the IPSFC for a number of years during the 1950s). Goodman (1971) reported that Quesnel Lake sockeye numbers remained low except for one cycle from 1953-1963 while kokanee numbers consistently remained low (<60,000). Goodman (1971) also discussed the probability of residual sockeye contributing to kokanee numbers in certain sockeye nursery lakes including Quesnel Lake but concluded that sex ratios in kokanee provided no evidence of residual sockeye in Quesnel Lake.

MAP 1 – Stream and shore spawner

location map (available only in hard copy from

regional office in Williams Lake

From the IPSFC files it appears that commencing in the early 1970s attention was shifted from sockeye biology and the “kokanee problem” to rebuilding of sockeye escapements to estimated historical levels. A 1.6 km spawning channel was constructed on the Horsefly system in 1987 in an effort to increase sockeye smolt production. This channel was only operated during the non dominant years in an attempt to even out the four cycles. Research was directed towards limnological work in an attempt to estimate lake carrying capacity in order to maximize sockeye smolt production (Hume et al. 1996). As a consequence there was very little data collected on kokanee during the 1970s and 1980s. Fortunately DFO has been estimating sockeye juvenile production with hydroacoustics and trawl surveys since the late 1970s (Hume et al 1996)*;* they assume the biomass of smolts will be equivalent to the fall biomass of sockeye fry derived from their juvenile estimates (J. Hume, pers.comm.). As a result, some data relevant to kokanee status was collected incidentally and was extracted and interpreted in this report. The provincial government began standardized acoustic and trawl surveys on the lake in 2000, but did conduct some experimental work in 1992.

METHODS

IPSFC data collection

The IPSFC was particularly interested in how kokanee may impact sockeye production. Consequently there was a considerable amount of effort directed at measuring kokanee growth through counts of first year circuli. This work was conducted primarily in the 1950s. The reports are not entirely clear as to method of capture except for those from the little Horsefly River where a fish fence was operated and live fish were sampled. In most cases it appears that dead pitch fish were used for sampling and it is assumed that fish were dip netted as there was no specific mention of beach seining except as part of the little Horsefly River fish fence operation. Kokanee length measurements were recorded but because of concerns about disproportionate male snout growth and worn tails during maturation standard lengths were taken with few fork length measurements recorded (Ward 1953). Standard length is the distance from the hypural plate to the anterior margin of the eye. Fork length (fork in tail to tip of nose) is the standard measurement used by the Provincial Fisheries therefore a regression formula was developed from the 1950s data when both measure-ments were recorded for the same fish (N=1224). In this report standard length measurements have been converted to fork lengths for some years where data was only recorded in standard length. The formula used for this conversion was:

$$FL = 1.0789 \times SL + 5.7791$$

where FL is fork length (mm) and SL is standard length (mm)

Sockeye escapements estimates were often made by direct counting and an index of 1.8 was used to determine total numbers. Peak spawning periods were described by Ward (1954) suggesting that several observations had been made. In some cases on the Horsefly River mark and recapture was used to estimate population size. This involved marking seine-caught live sockeye and recapture of dead fish on the spawning grounds. Information from the mark-recapture estimate was then made for total sockeye numbers for a particular system. Kokanee estimates were then made based on the ratio of kokanee: sockeye carcasses. Goodman (1971) summarized kokanee escapement data from Quesnel Lake from 1953-1957 using a conversion ratio of 2.3 compared to Ward's 1.8. Despite the difference in adjustment values the results are reported according to author since the numbers were relatively small.

BC Fisheries escapement estimates (peak counts) were made by visually estimating numbers in a stream at least three times during the spawning season. Biological samples were collected and fish lengths were measured and recorded as fork length.

The file data revealed only a few reliable fecundity counts (N=11) therefore these were included with known lengths and egg counts from Hill Creek (Arrow Reservoir 1984-2002 data) and Meadow Creek (Kootenay Lake 1987-1992 data) to generate a regression formula. Kokanee data from Hill and Meadow creeks (N=1828) was used because these fish were similar in size and for the years chosen only had one mode (i.e. single age at maturity). The regression formula generated from the data was:

$$\text{Log}_{(10)} Y = 2.2955 (\text{Log}_{(10)} FL) - 3.0068$$

where Y = number of eggs per female and FL = fork length in mm

Very limited contemporary kokanee scale analysis work has been done but some scales have been collected in conjunction with the recent WLAP hydroacoustics and trawl surveys. There was a considerable amount of IPSFC data on age determinations from scale reading often by more than one person so this data was considered reliable. However, all the scales were taken from captured spawners and in retrospect this is considered problematic due to reabsorption of the scales during sexual maturation. IPSFC biologists assigned ages based on date of spawning hence all their ages are age 3 or age 4 which have been changed in this report to ages 2+ and age 3+ respectively. Otoliths were taken from trawl caught fish in 1999 and 2000. These otoliths were sent to Dr. E.C. Volk at the Washington Department of Fish and Wildlife in Olympia, Washington who is acknowledged as an expert in the technique of determining the origin of fish (marine vs. freshwater) by examining the core otolith strontium levels. Details of stock separation techniques are summarized later in this report (see "Sockeye vs. Kokanee Separation" section) and are described more fully in Volk et al. (2000).

Hydroacoustic sampling

Hydroacoustic surveys are an efficient method for monitoring the distribution and densities of pelagic fish (Thorne 1971) including kokanee (Johnson et al. 1987). The strength of acoustic sampling is the ability to sample large volumes of water in a relatively short period of time. The result is a snapshot of the fish population size and density, which is readily repeatable. A downward looking towed transducer is very effective at quantifying fish that are more than 5 meters deep. This method however does not detect fish on or very near to the surface (Sebastian et al. 2003). Thermal stratification in summer and early fall in Quesnel Lake result in nearly ideal conditions for this type of survey, since juvenile sockeye and kokanee tend to reside in cooler water below the thermocline at night and are therefore not near the surface.

Acoustic methods are limited in terms of size separation. They can be used to discriminate reasonably well between fish <10cm which include age 0 nerka (i.e. kokanee and sockeye) and fish >10cm in length which include age 1-3 kokanee and larger fish. This analysis also enables fish greater than about 32 cm to be separated from the 10-32cm group, which includes the large majority of age 1-3 kokanee. The large fish category (i.e. >32cm) in Quesnel Lake most likely consists of rainbow trout but may also include bull trout, lake trout and burbot. For early season sampling, it is possible that this group may also include adult sockeye, particularly during a high return year, and may even have included some of the largest kokanee spawners. Due to the uncertainty of species and relatively small contributions of the large fish (>32cm) group, these results have not been included and discussed in this draft.

Acoustic results presented in this report are primarily based on 70 kHz Simrad single beam data for comparability with other acoustic data for BC lakes. Where possible, comparisons have been made with split-beam data and with dual beam data to take advantage of earlier survey data. Discussions will focus on the “kokanee” results rather than attempt to address the more complex issue of differences in the echosounder results produced by different technologies.

A complicating factor in assessing kokanee with hydroacoustics in Quesnel Lake is that the large majority of pelagic fish are juvenile sockeye (age 0+). To add to the complexity, sockeye runs are on a four year cycle with a high year (referred to as dominant) and moderately high year (referred to as sub-dominant) followed by two low years (referred to as non-dominant). This study, conducted in 2000-2002, was intended to assess juvenile fish populations following two low or non-dominant sockeye return years, 1999 and 2000, and a dominant year in 2001 which saturated the lake with age 0+ sockeye in 2002. Surveys following low return years offer the best likelihood of assessing kokanee numbers. The 1999 sockeye return of 189,000 spawners was however the highest on record for a non-dominant year, so was less than ideal for assessing kokanee abundance in 2000. It is not known if kokanee are cyclical in response to fluctuating sockeye numbers, so a three year study was viewed as minimal to detect this possibility.

Night-time hydroacoustic and trawl surveys of the pelagic habitat were conducted in early fall after the last quarter of the moon, to minimize its effects on vertical distribution. Surveys were conducted September 21-24, 2000, September 13-16 of 2001 and October 1-3, 2002. The survey consisted of 16 standard transects, with 17 additional transects added in 2000 and 3 additional transects added in 2002 (**Fig. 3**).

Acoustic survey data were collected using Simrad models EY200P 70 KHz single beam and EY500 120 KHz splitbeam systems. Transducers were towed on planers alongside the boat at a depth of 1.5 m and data were collected continuously along survey lines at 1-2 pings$\cdot s^{-1}$ while cruising at 2m$\cdot s^{-1}$. Data from both systems were collected and stored on PC computers which provided onsite preliminary data analysis and target verification. Data from the two echosounders were backed up either on Sony Digital Audio Tape (DAT) or writeable CD. The Simrad systems were calibrated in the field at the beginning of the survey on September 23, 2000; specifications and field settings are shown in **Appendix 1**. Field calibrations were conducted by collecting target strength data from solid copper calibration spheres suspended in the center of the echosounder beam at 10-15 m from the transducer. Adjustments were made so that received signals correspond to the empirical strength of the spheres at 70 and 120 KHz. Navigation was by radar, GPS, and mapping provided by the DFO.

The 70 KHz Simrad survey data were digitized and analysed using the Hydroacoustic Data Acquisition System (HADAS) program version 3.98 described by Lindem (1991). The HADAS statistical analysis performed a function similar to manual counting to determine the number of targets per unit area by depth stratum. Habitat was stratified by 4m depth layers and then further stratified into relatively homogeneous zones within each basin using density depth contour plots (**Appendix 2**). Stratum areas for each transect and depth were derived from DFO file data and presented for a 16 transect survey and for the more detailed 33 transect survey that is currently done by DFO (**Appendix 3a and b**). Summaries of fish density by transect for 70 kHz single beam data and for 120 kHz split beam data for 2000-2002 surveys are presented in **Appendix 4a and 4b** respectively.

Two methods were used to extrapolate transect fish density to whole lake population estimates. The first applied fish densities obtained from each transect and 4m depth stratum to the estimated area of pelagic habitat at depth associated with each transect.
The second method used a regression model described by Sebastian et al (1995). The model was developed specifically for enumerating night-time kokanee layers in reservoirs and assumes that fish density will be more similar between consecutive transects at the same depth than between different depths on the same transect. Homogeneous zones were defined for groups of transects having similar vertical distributions of fish (i.e. where fish were concentrated at similar depths). Within each zone the average density for each depth was determined by regression of raw echo counts on the area of esonified habitat. The regression method assumes that the number of echos observed will be directly proportional to the area of habitat surveyed. The regression was forced through origin to ensure a positive slope was attained even at very low density strata on the margins of the fish layer (where the model becomes less reliable). The slope of the regression provided a weighted mean density for each zone and depth layer with standard errors. A Monte Carlo Simulation procedure was then used to combine all strata and expand by the appropriate zone areas to develop maximum likelihood estimates and statistical bounds for each zone and again for the

combined zones using 30,000 iterations per run. Regression statistics and Monte Carlo results are summarized for 2000, 2001 and 2002 surveys in **Appendix 5**.

Fish size distributions were estimated for single beam data with HADAS using a statistical deconvolution algorithm based on Craig and Forbes (1969). The fish densities (i.e., number·ha^{-1}) for each transect and depth strata were binned into 3 decibel (dB) size groups and compiled on a spreadsheet. Each density by depth and size group was then extrapolated or weighted by the estimated area of habitat at depth for each transect to develop a size specific population estimate for the lake. As indicated previously, habitat area estimates by depth and transect were based on data from DFO files to ensure consistency of results.

Split beam data were analyzed using the EP500 version 5.4 software by Lindem (1991). The 120 KHz data was used as a secondary measure of fish density to the 70 KHz data and to conduct a second target strength (TS) analysis. Split-beam target strength measurements are received on four separate transducer quadrants, which enables determination of individual echo location in the beam and therefore direct calculation of target strength. In addition to standard 3dB binning of echoes, a separate analyses of tracked targets was done on split beam data. The acoustic sizes of tracked targets for the entire survey were plotted in length frequencies distributions in 1dB units. The resulting distributions were used to determine more precisely the size cut-off points for split beam data between age 0 fish which were mainly sockeye and age 1-3 kokanee. Acoustic size distributions and estimated cut-off points for separating age 0 and older fish were compared between split beam and single beam methods.

DFO conducted their standard annual Biosonics 420 kHz dual beam survey in September 2000 (Hume and MacLellan 2001), and used a new Biosonics 200kHz split beam sounder in 2002. Both the dual beam and split beam transect data were digitally recorded for later echo integration and *in situ* target strength estimation. Target strength and equipment scaling factors were used to scale the echo integration to provide an estimate of fish density by depth at each transect. Transect densities were then extrapolated by transect habitat areas by 2m depth stratum to estimate total fish abundance in the lake. The DFO conducted two separate population estimates; one based on their original 16 transects and a second based on 33 transects. Acoustic population estimates were proportioned between ages 0+ (assumed to be almost 100% sockeye fry) and larger fish (including age 1-3 kokanee and predators) using acoustic target strength and trawl sampling data.

Trawl Sampling

DFO conducted trawl surveys in September 2000 and October 2002 using methods described in Hume and MacLellan (2001). BC Fisheries conducted some limited sampling in 2001 in the main and east arms as well as some trawling in August 1992 and these results are included. Fish densities and distributions were described as low and patchy in 1992. Trawling was done at two locations: near Plato Island in the main arm and near Deception Point in the north arm. Trawling was described as experimental and non-standard and included some trawling beneath the sockeye layer in the north arm in an attempt to capture kokanee.

Trawling in September 2001 was conducted near Plato Island in the main arm and in the east arm at Lynx and Niagara Creeks. These locations were chosen based on the presence of kokanee sized fish (i.e.>44dB or about >10cm) on the echosounder. Stepped-oblique trawls were used to sample the layers of interest. The net was fished for 20 minutes over three consecutive depth layers where fish had been observed on the echosounder. The trawl net was the same design used by DFO; a 20m long opening and closing trawl with a 3 by 7 m square opening towed at about 0.8 $m \cdot s^{-1}$. The net consisted of graduated mesh panels from 10 cm (stretched mesh) at the head bar to 0.6 cm at the cod end. Net depth was measured using a Notus depth sensor via an acoustic (i.e. wireless) link. A global positioning system (GPS) was used to determine distances travelled and resulting trawl sample volumes. Sampling strategy was to capture some age 1-3 kokanee for size-at-age estimates and to obtain otoliths for strontium analyses.

Trawling strategies employed by DFO involved fishing the most concentrated part of the fish layer in order to obtain samples of at least 30 sockeye fry from seven different zones on the lake. Trawl samples were used to verify sockeye fry size, to estimate acoustic scaling factors, and to collect otolith samples for strontium analyses for determining sockeye and kokanee ratios. Consequently, trawl durations were varied considerably (1 to 120 minutes per trawl) depending on the survey year, location and apparent fish density, and catches of 1-3+ kokanee were very limited.

Captured fish were kept on ice until processed the following morning. The species, fork length, weight and stage of maturity were recorded. Scale samples were collected from all fish >100 mm for age interpretation. Otoliths were taken from all fish for strontium calcium analysis. The trawl data provided species and size information that was used for interpretation of acoustic target strength (TS) distributions.

Sockeye versus kokanee separation

Two different methods were used to separate kokanee from sockeye in order to estimate the kokanee population of Quesnel Lake. The first method used elemental analyses of fish otolith material to verify anadromous parents based on elevated strontium and calcium ratios. DFO trawl samples were used in strontium analyses conducted in 1998 and 1999 prior to this study and again in 2000 as part of this study. The otoliths were dissected from the fish, encased in individual resin blocks, ground and coated with a layer of conducting carbon (Volk 2002). Wavelength dispersive elemental analyses were performed with an electron microprobe just outside the nuclear region of the otoliths (Volk 2002). The resulting ratios of strontium: calcium were displayed as a frequency distribution to determine if fish of non-anadromous origin (i.e. kokanee) could be separated from those with elevated strontium levels indicating an anadromous parent. Some larger kokanee (age 1 and 2) were included in the samples as a test to “validate” the methods. Samples were collected from Quesnel Lake in 2001 and 2002, but at time of writing they had not been analyzed.

The second method for separating sockeye from kokanee was to partition acoustic size distributions into two size groups: fish less than 10 cm which include a mix of age 0+ kokanee and age 0+ sockeye fry, and fish greater than 10 cm most likely to be age 1-3+ kokanee. The total kokanee age 0-3+ population was then reconstructed based on assumed ratios of 60-75% age 0+ to age 1-3 kokanee observed in other kokanee populations in BC lakes. Kokanee spawner numbers were then estimated at 5-7% of the total estimated in-lake population based on kokanee assessments in Kootenay Lake and Arrow Reservoir (Sebastian et al. in Wright et al. 2002; Sebastian et al. in Pieters et al. 2003).

Two different approaches to estimating the appropriate cut-off point were used. The first assumes that lab echosounder calibrations were accurate and that in-lake calibrations (i.e. in-situ calibrations using a standard target) were reliable. The cut-off points were determined using fish length data from trawl catches for each survey. Individual fish lengths were converted to their acoustic equivalent using Love's (1977) dorsal aspect relation and then plotted as a length frequency distribution. A table relating fish lengths to 3dB size bins using Love's relationship is shown in **Appendix 6**. This approach was used to determine the most appropriate acoustic size cut-off from four years of historical DFO dual beam acoustic data. Stables (2001) re-analysed the DFO acoustic data from 1991, 1992, 1998 and 2000 using ESP-TS to generate ASCII files that could be manipulated with Excel, Access and Systat software. The purpose was to determine a suitable size cut-off in decibels to distinguish between sockeye fry and age 1-2 kokanee, and then to estimate the age 1-3 kokanee abundance. The analyses relied on DFO trawl results from the same surveys.

The second approach was to analyze acoustic distributions from each survey separately in order to visually determine the best cut-off point between age 0+ and larger sized fish. The visual criteria were to choose the point of inflection where the declining age 0+ curves rapidly flattens out. This method does not assume field calibrations have been done correctly, but rather relies on the disproportionately large numbers of age 0+ fish to show a distinct inflection point where the very small proportions of larger fish begin. The intent was to exclude all age 0+ fish and assume the remaining fish were most likely to be age 1-3 kokanee.

Sport Fishery Assessments

There has been some limited effort directed towards monitoring of the Quesnel Lake sport fisheries. Lirette (2002) summarized the available data on angler effort and harvest based on two survey methods. A roving survey was conducted in 1982 (Prest and Ling 1984) for the months of August-October. Aerial boat counts have also been conducted periodically (1987, 1990, 1992, 1996, 1997 and 2001) using the provincial based Small Lakes Index Management (SLIM) methods described by Tredger (1992).

RESULTS – kokanee

Stream and shore spawning timing

Kokanee spawn in Quesnel Lake tributary streams in September-October but there has been considerable variation in time of peak spawning. The Horsefly River and Quesnel River kokanee spawning runs are nearly a month earlier than shore spawning kokanee but 10 days later than sockeye (Ward 1954). According to Ward (1954) Mitchell River kokanee spawn as late as one month after the peak of Little Horsefly River spawning**. Table 3** provides a summary of run timing of Quesnel Lake kokanee as reported by various fisheries workers. Generally, the Horsefly and Quesnel River kokanee spawn in late September-early October with other stream spawning kokanee timed for mid October and shore spawning towards the end of October. The wide range in peak spawning times between streams makes reliable indices of kokanee abundance labour intensive.

Escapements

Most of the escapement estimates of Quesnel Lake stream spawning kokanee were made in the 1950s and 1960s with counts made over a number of years on Wasco Creek, Little Horsefly River and the Mitchell River. Most counts conducted by IPSFC were reported as estimates of total numbers based on multiple counts. The estimates made by the Province are peak counts based on a minimum of 3 counts made per season except for 1981 when only one count was made.

J. Goodman (1964) reported that the female equivalent numbers on the Horsefly and Little Horsefly Rivers ranged from 3,000-20,000, suggesting total numbers of 6,000-40,000 for the period of time from 1953-1963. IPSFC file data summarized in Table 4 indicates that in addition to the Little Horsefly River the most important streams were Wasco Creek and Mitchell River. The Mitchell River was not assessed from 2000-2002 but the Little Horsefly River and Wasco and Summit creeks were and almost no fish (< 10 per system) were observed.

In broad terms it appears from the historical data that Wasco Creek total escapement was usually about 2,500; Little Horsefly River numbers appeared to be about 40,000 while the Mitchell River count was about 15,000 (**Table 4**; **Fig. 4**). The historic data suggests that total annual stream escapements were usually around 50,000 with a maximum of 100,000 spawners. For all three systems where there is reliable and comparable data the escapements fluctuated up to the 1980's with no obvious trends but a drastic decline has been occurred in the 2000's, with virtually no kokanee observed in any streams.

The shore spawning estimates garnered from the IPSFC files were inconsistent because no standard beach sites were used for counts hence the data is of little value for comparison purposes. It can be assumed that kokanee shore spawners would have been enumerated where observed since shore spawning sockeye were recorded.

Table 3. Peak kokanee spawning time for major tributaries and shoals in Quesnel Lake reported by various authors.

Stream	Year	Peak spawning period	Reference
Horsefly River	1953	Sept. 16-20	Ward (1954)
	1954	Oct. 1	Goodman (1958)
	1956	Sept 21	Goodman (1958)
	1960	Oct. 8-12	Goodman (1971)
	1961	Sept 23	Goodman (1971)
Lower Little Horsefly R.	1953	Sept. 16-20	Ward (1954)
	1954	Oct. 1-3	
	1955	Oct. 12-14	
	1956	Oct. 6	
	1957	Sept. 21-25	
	1959	Oct. 3-8	
	1960	Oct. 4-6	
	1961	Sept. 20	
	1962	Sept. 20-26	
	1963	Sept. 20-25	
Quesnel River	1954	Oct. 6	Ward (1954)
Mitchell River	1953	Oct. 7-15	Ward (1954)
	1954	Oct. 20-27	Ward (1954)
Wasko Creek	1953	Oct. 7-15	Ward (1954)
	1954	Oct. 20-25	Ward (1954)
	1955	Oct.17-20	Goodman 1971
	1956	Oct.15-20	“
	1957	≈ Oct. 7	“
	1958	Oct. 14-16	“
	1959	Oct. 12-18	“
	1960	Oct. 14-18	“
	1983	Oct. 4-7	Prest (1984)
	1984	Oct. 10-17	Lemp and Englund (1984)
North Arm shore spawners	1954	Oct. 18-20	Ward (1954)
	1979	Oct. 10	Prest and Ling (1983)
	1982	Oct 25-30	Prest and Ling (1983)
	1984	Oct. 25-Nov. 6	Lemp and Englund (1984)
	2000	Nov. 6	Provincial Fisheries files
	2001	Nov. 3-Nov.7	Provincial Fisheries files
	2002	Nov. 5	Provincial Fisheries files

Based on the file data there must have been only few numbers of shore spawning kokanee since single day counts for all beach sites for any particular year in the 1950s and early 1960s was usually less than 2,000. Having said this, some of the file reports mention large numbers of shore spawning kokanee but they were of little interest to the IPSFC. We do have single day counts of shore spawning kokanee at three locations from the 1980's and the past 3 years (Fig 5). The counts are single day estimates therefore have limited value as an index of abundance, i.e. no attempt was made to convert peak counts to total numbers. At least in the case of the shore spawners there have been reasonable numbers present in recent years and somewhat more comparable over time whereas the stream spawners have disappeared.

Table 4. Summary of comparable escapement estimates for Wasco Creek, Little Horsefly River, Summit Creek and Mitchell River.

Year	Wasco Creek	Meth[1]	Little Horsefly River	Meth[1]	Mitchell River	Summit Creek	Meth[1]	Data source
1950	1,194	E	10,000	S				IPSFC files
1952	206	S						IPSFC files
1953	2,339	E	17,500	E	94	1,150	E	IPSFC files
1954	725	E	4,411	E	5,000			IPSFC files
1955	2,208	E	5,060	E	6,900	506	S	IPSFC files
1956	2,339	E	47,840	E	13,204			IPSFC files
1957	2,700	E	8,050	E	18,860	64	S	IPSFC files
1958	2,521	E	0	E	4,000	23	S	IPSFC files
1959	58		40,250	M (5)	6,900			IPSFC files
1960	499	S	34,615	M (5)	8,280			IPSFC files
1961			5543					IPSFC files
1962	529	S	31671					IPSFC files
1963			36,800					IPSFC files
1966			35000					IPSFC files
1981	500	S						B.C. Fisheries
1982						300-500	S	Prest and Ling 1982
1983	200			S				Prest and Ling (1983)
1984	1,500	M	4,818	S		0	M	Lemp and Englund (1984).
2000	<10	M	<10	M		<10	M	BC Fisheries
2001	<10	M	<10	M		<10	M	
2002	<10	M	<10	M		<10	M	

[1] S=single count, M=multiple (number of counts) or E=estimate based on tagging

Length at maturity

Length of spawning kokanee sampled in Quesnel Lake tributaries fall within a very narrow range. Standard length data (n=1224) recorded by the IPSFC has been modified to fork length using the linear regression formula:

$$\text{Fork length} = 1.0789 \times (\text{standard length}) + 5.7791$$ (see **Fig. 6**)

A slight difference in size between the actual measured forks length for the 1950s data (primarily from Wasco Creek kokanee) compared with data derived from standard lengths for the same fish was evident (**Fig. 7**). The difference (< 1cm) is considered insignificant. **Figure 8** shows the length frequency distribution for kokanee stream spawners (Wasco and Summit creeks) for select years in the 1950s and early 1960s. A single mode is evident for all years suggesting one age group. The size of spawners ranged from about 220 to nearly 290 mm over a nine year period.

A comparison of kokanee spawner size range between systems (i.e. Wasco, Summit and Little Horsefly River) and spawner types (stream vs shoal) suggests that size range has remained relatively constant at 215-295 mm over the past 50 years (**Fig. 9**). The average size of spawners was 250mm for Wasko and Summit Creek (1954), 268mm in the Little Horsefly River (1961) and 257mm on shoals near Blue Lead Creek and Deception Point (1992). Quesnel Lake kokanee are slightly larger than those found in Arrow and Kootenay lakes where they are typically 200-230 cm in size but similar in size to Okanagan Lake stream spawners (Mission Creek) where mean size over the last twelve year has been 282 mm (Andrusak *in* Andrusak et al. 2003). However, the Okanagan Lake stream spawners are comprised of multiple age groups and display 2 or 3 distinct modes whereas the Quesnel Lake stream spawners display a single dominant mode with no individual, large sized fish evident.

Okanagan Lake supports two separate populations of kokanee. The majority appears to spawn on the shoreline and they are typically 220-250 mm with virtually no fish sampled > 300 mm. In comparison the stream spawners usually average about 280 mm but a considerable number of fish exceed 300 mm and a few individuals exceed 500 mm (Webster *in* Andrusak et al 2003). A limited number of fork length measurements were made of shore spawning kokanee sampled during 2000-2002. These fish were also between 250-300 mm in length (**Fig. 10**) and appear to be of all one age group.

Fecundity

There was very limited fecundity data found in the IPSFC files. Consequently a regression formula ($Log_{(10)}$ Y = 2.2955 x ($Log_{(10)}$ FL) – 3.0068) was developed from a large sample (N=1839) of lengths and actual egg counts of Hill and Meadow Creek kokanee. This regression formula was used to determine fecundity of Quesnel Lake kokanee from converted length measurements (from SL to FL) from 1813 samples recorded from spawning kokanee by the IPSFC between 1953-1962 (**Table 5**). Small samples of female lengths measured in 1992, 2000 and 2002 were also used to determine fecundity for those years.

Based on the derived data fecundity of Quesnel Lake female kokanee appear to contain between 216-408 eggs with an average of 310 eggs per female. These derived fecundities fall within the known range of kokanee fecundities from Arrow, Okanagan and Kootenay lakes.

Table 5. Mean length and fecundity for Quesnel Lake kokanee and data source.

Year	Sample size	Mean fork length(mm)	Mean fecundity	Source
1953	345	251	317	IPSCF internal reports
1954	192	244	299	IPSCF internal reports
1955	139	244	296	IPSCF internal reports
1956	395	246	302	IPSCF internal reports
1957	214	268	370	IPSCF internal reports
1958	106	260	345	IPSCF internal reports
1959	140	224	245	IPSCF internal reports
1960	115	212	216	IPSCF internal reports
1961	115	262	350	IPSCF internal reports
1962	52	279	405	IPSCF internal reports
1992	67	244	300	Lemp and Englund 1994
2000	14	244	299	BC Fisheries file data
2002	4	280	408	BC Fisheries file data
Overall mean			**311**	

Age composition

There was a considerable amount of work by the IPSFC on age determination of Quesnel Lake kokanee. IPSFC aged virtually all the mature kokanee as 3 year olds (2+). However these ages were based on scales taken from spawning fish and experience suggests that resorption generally occurs as kokanee mature usually leading to the last annulus being obscured. Parkinson et al. (1992) illustrated that trawl caught kokanee captured in August 1987 consisted of three age groups (0-2+) from Quesnel Lake. However, the largest fish were < 22 cm and considerably smaller than observed spawners (see Figs. 6,7). Examination of length frequency distribution of trawl caught kokanee in 1992, 2000-2002 indicate that three age groups (0-2+) are typically captured (**Fig. 11**). When the lengths of the spawners for those same years are superimposed onto the graphs it is clear there are four age groups present for each year. This analysis is supported by the acoustics data described in the next section of this report. In summary, the age at maturity for Quesnel Lake kokanee is age 3+.

Kokanee population estimates

There are no estimates of total kokanee escapements for the lake and the trend information from index spawner counts is mixed, with stream spawner numbers in decline (**Fig. 4**) whereas no trend can be detected for shore spawner numbers (**Fig. 5**). The only data that can provide some insight into population size is the hydro acoustics data from DFO and BC Fisheries.

Stables (2001) determined *Onchorynchus nerka* size frequencies from trawl samples and compared them with target strength (TS) frequencies from the 420 kHz Biosonics dual beam echosounder used by DFO. Aside from the obvious mode for all 0+ fish Stables also identified two other distinct modes (1+, 2+) although there was considerable overlap between 1+ and 2+ fish. Most importantly, Stables (2001) used a very conservative TS (-42 dB) as a cut off for 0+ fish and reasoned that all fish recorded at > -42 TS would be larger kokanee. i.e. a composite of 1+, 2+ and 3+ kokanee. By applying the proportion of larger kokanee from the TS data with the DFO population estimate for all fish in the lake Stables (2001) estimated there were about 3 million age 1+ and 2+ kokanee in 1991 and 1992 but only 100,000-200,000 in 1998 and 2000. Trawl data indicates that over 99% of the fish in the pelagic zone where the acoustics were conducted were *O. nerka.* There are several biases that limit the efficacy of this method such as net avoidance by 1+ fish (Parkinson et al 1994) but for kokanee management purposes it is suffice to know that there are relatively few kokanee in Quesnel Lake compared to Kootenay, Arrow and even Okanagan Lake. Due to high densities of sockeye fry it was impractical to trawl long enough to catch many age 1-3 kokanee (without sacrificing hundreds of sockeye).

Fish distributions

Transects were numbered in order from west to east and south to north beginning near the outlet at the west end of the lake and progressing along the west arm, main arm, north arm and finally east arm (**Figure 3**). The longitudinal distribution of pelagic fish for the three survey years using the original set of 16 transects developed for DFO sockeye surveys are shown in **Figure 12**. Following the two low sockeye years, kokanee densities were variable in the west arm, highest in the main arm and decreased moving north in the north arm and east in the east arm from the junction area. Numbers of fish detected at transect 10 at the north end of the north arm in 2000 and 2001 were an anomaly likely representing a local high density “zone” likely influenced by nutrient inflows from Mitchell River. In 2000, transect fish densities ranged from 115 to 2,852 fish·ha^{-1} between the east and west ends of the lake and averaged nearly 2,300 fish·ha^{-1} in the main arm **(Fig. 12a)**.

In 2001, the densities over the whole lake decreased significantly as would be expected following a low sockeye escapement of only 71,000 spawners. Highest densities were found at transect 10 in the north arm (687 fish·ha^{-1}) and transects 4 and 5 in the main arm (490 and 477 fish·ha^{-1}, respectively). Lowest density (123 fish·ha^{-1}) occurred at transect 7 in the north arm (**Fig. 12b)**. The low numbers of sockeye in the system in 2001 should provide the most accurate estimate of kokanee numbers during the three years of surveys.

In 2002, following a dominant return of nearly 3.6 million sockeye spawners, the highest fish densities were found at transects 8 in the main arm (6,579 fish·ha^{-1}) and 12 in the east arm (6,955 fish·ha^{-1}). The lowest densities were found at transects 2 and 3 in the west arm (139-259 fish·ha^{-1}) and transect 16 in the east arm (347 fish·ha^{-1}) (**Fig. 12c)**.

The variability of pelagic fish densities between surveys and also between transects within a survey was very high in Quesnel Lake compared with kokanee density in non-sockeye lakes. With kokanee populations in Kootenay or Okanagan lakes, transect fish densities typically ranged up to ten times (e.g. 100 to 1000 fish·ha^{-1}) and typically showed gradients of intermediate densities between highest and lowest density transects (Ashley et al, 1999; Andrusak et al., 2003). By contrast, high and low density transects in Quesnel Lake can be adjacent and show differences of more than 60 times (e.g. 60 to 3800 $fish \cdot ha^{-1}$at transects 3.2 and 3.5 respectively in 2000). Apparently juvenile sockeye are more clumped than kokanee. Their high(er) densities may result in zooplankton overgrazing and more mobility as they search for better feeding areas. This may explain the extremely high densities of sockeye fry (i.e. 4,000 - 7,000 $fish \cdot ha^{-1}$) found at Deception Point in the north arm and at transects 11 to14 in the east arm during October 2002. Zooplankton data collected monthly in 2002 may support the overgrazing theory but this information was not available at time of writing. In 2002 it appears juvenile sockeye moved up the east arm to transect 14, but were not found beyond this point while densities remained high (i.e. 2000 – 2500 $fish \cdot ha^{-1}$) throughout the main arm.

In 1994, DFO increased sampling in their annual acoustic surveys from the regular 16 transects (2-3 transects/section) to a more intensive 33 transects (3-7 transects/section) by adding extra transects halfway between the original 16 (Fig. 3). The purpose was to examine the effect on the variability of section and lake acoustic estimates. Comparative data has been collected for 10 summer and fall surveys. On a preliminary examination of the data, the estimates of age-0 *O. nerka* density for lake sections using the intensive design averaged 10% higher but were not significantly different (T test, $P<.05$) from the regular design. The 95% confidence intervals for section estimates were decreased considerably from an average of 203% for the regular survey to only 74% for the intensive survey, due to the increased sample size. Estimates of age-0 *O. nerka* density for the whole lake were also not significantly higher in the intensive survey (mean=12%, $P<0.05$) than in the regular survey. Average confidence levels are much less for the whole lake and were reduced only slightly from a mean of 35% for the regular survey to 30% for the intensive survey.

As the estimates from the intensive surveys are not significantly higher than those from the regular surveys and the differences are well within the confidence limits of both survey types, it was preliminary concluded that the regular 16 transect survey adequately estimated *O. nerka* populations for the whole of Quesnel Lake but were inadequate for section estimates (J Hume pers com). We did a similar comparison on estimates of total fish abundance developed from 16 and then 33 transects of 70 kHz data in 2000, and also concluded that 16 transect surveys in 2001 and 2002 should be adequate for estimating kokanee abundance.

Vertical distribution

Using acoustic data the vertical distribution of kokanee was examined to determine if age 1-3 kokanee were vertically segregated from age 0+ sockeye at night. Observations that the proportion of larger echo targets seemed to increase with depth suggests older fish may have a preference for deeper water at night. This spatial difference might be useful for separating kokanee from sockeye. Preference of larger fish utilizing greater depths was assessed by converting proportions to numbers within each size group and 4m depth stratum and plotting the proportions by depth for each group.

During the first two survey years, it appears that age 0+ fish have a more defined preference for depth than age 1-3 fish. The large majority of age 0+ fish were found between 8 and 20m depth with distinct concentrations at 12-16 m immediately below the thermocline **(Fig. 13a and b).** The larger age 1-3+ fish were found at depths of 8 to 36m and the generally flatter curves indicated no preference for a specific depth.

The October 2002 sampling showed a concentration of both age groups at 12 m but also showed significant numbers from both groups at depths of 4 - 12m (**Fig. 13c**). A closer investigation showed significant numbers of fish above the average thermocline depth (data on file) and near the surface at some transects but not others. The presence of fish near the surface at night suggests that the lake was beginning to de-stratify and that less than ideal conditions for acoustic sampling were found at some sites. Fish too close to the surface (<5m depth) can lead to an underestimate of fish abundance since the viewing area of the transducer becomes very limited and the number of fish echoes sampled is often too small to be statistically valid (Sebastian et al. 2003).

Fish too large to be kokanee (with echo target strengths >-35dB) tended to be deeper than the fry layer during 2000 and 2001, although sample sizes were very small. In 2002, even the larger fish were found near the surface at some stations indicating fall de-stratification had begun and that sampling conditions were less than ideal during this survey **(Fig. 13**).

Size at age

Trawl catch data was useful in comparing kokanee size and growth to other kokanee systems. Length frequency analyses were performed on 4 years of trawl and spawner survey data to compare age structure and size at age. Three years out of four (1992, 2000 and 2001) followed non-dominant sockeye runs and showed similar patterns in size and age. With relatively low numbers of sockeye in the lake, the trawl was able to capture small numbers of age 1+ and age 2+ fish, and a single age 3+ fish in 2001. The frequency distributions **(Fig. 11 a-c**) suggest four age groups: large numbers of age 0+ ranging from 44-99 mm; smaller numbers of age 1+ ranging from 103-176 mm; a few age 2+ fish ranging from 174-237 mm; and stream spawner lengths (same years as the trawl samples) ranging in size from 230-310 mm are almost certain to be age 3+. Compared with other BC lakes, the fry are larger in Quesnel Lake presumably as they are primarily sockeye and not kokanee while age 1+ fish averaging 140-170 mm and age 2+ around 190-230 mm are fairly typical of other kokanee systems.

The length frequency of trawl caught fish in 2002 following a dominant sockeye year was different in that only fry were captured. The range of fry size (i.e. 35-112mm) was much larger than in non-dominant sockeye years (**Table 6)** possibly due to a wider range in emergence time and/or growth rates following emergence. Other investigators have reported that sockeye fry tend to grow faster than kokanee suggesting a possibility of separating them by length at the fry stage (Wood and Foote, 1996; Wood et al 1999). However, the fry length frequencies for Quesnel Lake fry are not bimodal and therefore kokanee fry cannot be separated from sockeye on the basis of length (**Fig 11).** Comparison of kokanee and sockeye length frequency from Quesnel 2000 trawl data based on strontium/calcium identification also confirms this i.e., kokanee fry lengths fell within the same range as sockeye fry lengths **(Fig 14)**.

Table 6. Quesnel Lake nerkid size-at-age data based on trawl and spawner surveys during 1992 and 2000 - 2002.

Year	Parameter	Age 0	Age 1	Age 2	Age 3	Spawners[1]
1992	Average fork length (mm)	60	166	210	265	256
(Sep)	Range (mm)	44-83	150-176	201-220	265	231-288
	Standard Deviation (S.D.)	4.7	10.3	5.2		10.1
	Sample size (n)	229	6	19	1	145
2000	Average fork length (mm)	69	143	190		247
(Sep)	Range (mm)	46-99	103-169	174-199		224-280
	Standard Deviation (S.D.)	8.4	16.5	14.2		12.8
	Sample size (n)	345	35	3		30
2001	Average fork length (mm)	64.5	176	237.5		265
(Oct)	Range (mm)	51-82	157-194	223-252		245-275
	Standard Deviation (S.D.)	5.5	13.3	20.5		6.8
	Sample size (n)	101	5	2	0	25
2002	Average fork length (mm)	65				288
(Oct)	Range (mm)	35-112				275-305
	Standard Deviation (S.D.)	9.0				8.5
	Sample size (n)	959	0	0	0	30

Mean size of shore spawners was 256mm in 1992, 247 mm in 2000, 265 mm in 2001, and 288 mm in 2002. There is some weak evidence that kokanee spawners may be larger following high sockeye return years. It is possible that there may be some density dependent growth response of ages 1+ and 2+ kokanee during the two years of low sockeye fry densities preceding a dominant sockeye year. As well, an increase in nutrients entering the lake from carcasses during a dominant sockeye could also benefit age 1+ and 2+ kokanee growth. While other factors may be at play in determining mature kokanee size this possibility is worthy of some research consideration.

Separation of kokanee and sockeye

To better understand the status of the kokanee population in Quesnel Lake it is imperative that sockeye numbers be distinguished from kokanee numbers in the acoustics and trawl data. Separating kokanee fry from sockeye fry has not been possible using length frequency analysis or segregation based on vertical depth distribution differences. One method that can be used to at least separate fry from larger fish (i.e. 1-3+ kokanee) is through analyses of results of the single beam deconvolution technique used in the surveys. Peak sizes of trawl caught age 0+ fish for all three survey years, converted to acoustic units using Love's (1977) empirical formula were –50 decibels (dB), the same size(s) as the peak size determined by the acoustics surveys (**Fig. 15)**. Confirmation that the sizes are the same provides the opportunity to use the acoustics data to separate fry from larger fish. It should also be noted that these results verify that the acoustic calibration for all three surveys was correct (i.e. the acoustic sizes agree with the actual sizes of fish captured by the trawl). Note in Figure 14 that acoustic sizes were grouped into 3dB size categories or "bins" with the (X-axis) labels representing the lower bin thresholds (i.e., -50dB bin includes fish sizes from –50 to –47.1dB).

Figure 16 shows acoustic size (TS) distributions. The –44dB cut-off which corresponds to a length of 107 mm appeared to be the best cut-off (fit) for 70 kHz data. Sample sizes of trawl caught age 1-3+ kokanee were small, but did appear to agree with the acoustic results when converted to decibels using Love's (1977) equation (**Figure 15).** The derived proportions of age 1-3+ kokanee and larger fish were estimated at approximately 3.4% in 2000, 11.9% in 2001 and 1.0% in 2002 **(Table 7)**. When comparing these proportions with results from the higher frequency echosounder (120hKz), there appeared to be a greater range within the age 0+ frequency distribution. Selecting a theoretical size cut-off of –44dB based on Love's relation and the size of trawled fish resulted in substantial over-estimates in the numbers of larger fish when using higher frequency sounders.

Table 7. Abundance estimates for kokanee based on acoustic size proportions derived from 70 kHz single beam data.

Attribute	Units	Survey year		
		2000	**2001**	**2002**
Total abundance (O. nerka)	Millions	23.1	6.62	59.4
Range (95% C. L.)	Millions	20.5-25.7	6.08-7.30	50.5-68.9
Proportion of age 1-3+ kokanee (10-32cm) [1]	%	3.36%	11.90%	0.99%
Number of age 1-3+ kokanee	Millions	0.78	0.79	0.59
Number of age 0+ kokanee[2]	Millions	1.16	1.18	0.88
Total kokanee all ages	Millions	1.94	1.97	1.47

1. fish from –44dB to –35dB
2. assuming kokanee fry represent 60% of total in-lake kokanee based on other BC lakes

Further data analysis indicated that a more desirable approach was to plot actual target strength (TS) distributions from each survey and choose the cut-off point immediately beyond the first or age 0+ mode. The 120 kHz split beam data was analyzed for tracked targets and their size distributions plotted in 1 dB steps. Because age 0+ fish are by far the largest proportion of total catch, the cut-off should be located at the "tail" of the 0+ distribution curve to ensure all fry are included. **Figure 17** shows the results of this technique applied to the 120 kHz split beam data to estimate proportions of age 1-3+ and larger fish at 4.19% in 2000, 21.3% in 2001 and only 0.83% in 2002 **(Table 8)**.

These percentages were applied to total fish estimates from the split beam sounder to calculate the numbers of age 1-3+ kokanee. **Figure 18** shows the "tail of the distribution" method applied to the 2002 DFO split beam (200kHz) data. The result was a third estimate for age 1-3 kokanee of 437,000, which was comparable to the Province's estimates of 320,000 to 590,000 for age 1-3 kokanee based on split and single beam systems in 2002.

Table 8. Abundance estimates for kokanee based on acoustic size proportions derived from size frequency distributions of tracked fish targets using 120 kHz split beam data.

Attribute	**Units**	**Survey year**		
		2000	**2001**	**2002**
Total abundance (O. nerka)	Millions	19.2	4.12	39.1
Proportion of age 1-3+ kokanee (10-32cm) [1]	%	4.19%	21.3%	0.829%
Number of age 1-3+ kokanee	Millions	0.80	0.88	0.32
Number of age 0+ kokanee[2]	Millions	1.21	1.32	0.49
Total kokanee all ages	Millions	2.01	2.20	0.81

1. – 41dB to –32dB based on visual inspection of tracked fish frequency distributions
2. assuming kokanee fry represent 60% of total in-lake kokanee based on other BC lakes

Kokanee abundance estimates

Using the derived proportions of fry vs. larger fish for each acoustic survey year, the total abundance of fish in pelagic habitat was estimated at 23.1 million (20.5-25.7) in 2000, 6.62 million (6.08-7.30) in 2001 and 59.4 million (50.5-68.9) in 2002 based on standard 70 kHz single beam data **(Table 7).**

The apparent proportions of age 1-3+ kokanee varied considerably (1% to 12%) but this appeared to be primarily due to fluctuations in the number of sockeye fry between study years. The abundance estimates for age 1-3+ kokanee were fairly constant and suggested populations of 600,000-800,000 fish for the three study years **(Table 7)**. Based on a conservative estimate that 60% of in-lake kokanee populations are young-of-the-year, the age 0+ kokanee numbers would be in the order of 900,000 to 1,200,000 during the same period. This suggests that the total in-lake abundance of kokanee (all ages) were in the order of 1.5-2.0 million fish during the study period and up to 2.2 million based on split beam data. Applying a 5-7% bio-standard based on Kootenay and Arrow kokanee data, Quesnel Lake may currently support in the order of 75,000 - 150,000 spawners.

Applying the proportions derived from the 120 kHz split beam sounder produced more conservative estimates for total numbers of fish and were only 60-80% of the single beam sounder estimates for total fish. Estimates for age 1-3+ kokanee between the two sounders were quite comparable for 2 of the 3 survey years and lower during the year of highest fry abundance **(Tables 7 and 8).** There were also greater numbers of fish closer to the surface in 2002, where the volume of habitat being sampled by the split beam was lower than for the 70 kHz, which may have lead to an under-representation. This situation underscores the critical nature of determining the cut-off point during high sockeye years and that the analyses are more sensitive to errors when there are disproportionately higher numbers of non-target fish (in this case sockeye) in the system. Both analyses showed an order of magnitude difference in pelagic fish abundance between the lowest (2001) and the highest (2002) density years.

A comparison of the three echosounders for the 2000 survey is shown in **Table 9**. The total pelagic population estimates ranged from 16.5 -23.1 million fish while the range of estimated age 1-3 kokanee ranged from 1.9 – 2.4 million fish.

Table 9. Comparison of kokanee (and sockeye) abundance estimates derived using three different echosounder systems (70 & 120 kHz Simrad and 420 kHz Biosonics dual beam) in September 2000 during low sockeye year.

Attribute	Units	Sounder frequency		
		70 kHz	**120 kHz**	**420 kHz**
Total abundance (O. nerka)	Millions	23.1	19.2	16.5
Proportion of age 1-3+ kokanee (10-32cm) [1]	%	3.36%	4.19%	5.80%
Number of age 1-3+ kokanee	Millions	0.78	0.80	0.956
Number of age 0+ kokanee[2]	Millions	1.16	1.21	1.43
Total kokanee all ages	Millions	1.94	2.01	2.39

1. fish from –44dB to –35dB
2. assuming kokanee fry represent 60% of total in-lake kokanee based on other BC lakes

Strontium calcium ratios found in otoliths were used to separate kokanee from sockeye in trawl caught fish in 2000 (Volk 2002). The proportions of known kokanee fry per station from strontium analyses in 2000 were applied to the acoustic estimate of total abundance in pelagic habitat to produce a crude estimate of the kokanee fry abundance (**Table 10).** When combined with the estimated age 1-3+ kokanee abundance derived from acoustic sizes, it estimates a total kokanee population size (all ages) of approximately 1.7 million fish, which is very comparable to estimates for 2000 derived from the age 1-3+ estimated by size separation using 70 and 120 hKz data (**Tables 10).**

Table 10. Kokanee / sockeye proportions derived from strontium analysis of otoliths 2000 trawl samples and total kokanee estimate based on 70 kHz acoustic data.

Zone	No. of fry analyzed	No. kokanee identified	% kokanee	Total fry Millions[1]	Estimated kokanee fry (millions)	Estimated age 1-3+ (millions)[1]	Total kokanee (millions)
1-3	77	1	1%	18.321	0.238	0.357	0.595
4	38	3	8%	1.954	0.154	0.059	0.213
5	29	2	7%	2.119	0.146	0.181	0.327
6	12	5	42%	0.854	0.356	0.183	0.539
Total	156	11		23.248	0.894	0.780	1.674

1. 70 kHz acoustic data

Large fish component

It is also of interest to note that based on a size of greater than 32cm, the large fish (likely too large to be kokanee) for the three survey years ranged from 0.55-1.54% of total pelagic fish populations and ranged from 13,000 to 172,000 depending on which data is used. The accuracy of developing population estimates based on such small percentages is questionable so these estimates are thought to be very approximate. They are however in the range of what has been estimated for non-kokanee on Kootenay Lake so may be considered reasonable “ball park” estimates. The increased number of large fish targets in 2001 and possibly also in 2002 may have included some sockeye spawners as these were extremely high return years for sockeye and spawners were easily observed along the lakeshore at many locations.

Comparison with DFO estimates

It has been speculated that the numbers of kokanee in Quesnel Lake might have decreased with the increased sockeye returns from 1990 to the present. Some insight into this possibility can be gained by reviewing data summarized by Stables (2001) who analyzed DFO data from two dominant (1991 and 1998) and two non-dominant (1992 and 2000) years. It was assumed that the calibrations were completely accurate every year for water quality conditions, which can vary between arms.

The size of fish caught in the trawl (**Fig. 11**) has not changed significantly from 1992 to 2000-2002, therefore the cut-off used should remain similar to –44dB (**Fig. 15**). However, Biosonics 420 kHz dual beam data obtained from DFO showed quite different ranges and peaks of fry sized fish over the four years (1991, 1992, 1998 and 2000) **(Fig. 19)**. A fixed cut-off of –42dB for all years was initially used to determine the numbers of larger fish, but this did not seem to accurately represent the true proportion since the inflection of the distribution curve varied from year to year. When the cut-off values from Stables (2001) are compared with the data generated in this study, it appears that the size frequency distribution determined by Stables (2001) were inconsistent with known fish size, probably due to a calibration problem with earlier DFO data.

If the declining cut-off method is applied, potential problems with echosounder calibration are removed and more consistent estimates of non-fry sized fish are provided. The same data was converted to the standard 3 dB bins and cut-off’s were based solely on where the curve dropped sharply and began to flatten out (**Fig. 20).** This results in a more reasonable estimate of the proportions and numbers of age 1-3 kokanee **(Table 11)**. A best estimate of kokanee abundance (all ages) in the early 1990s for Quesnel Lake is 3.5 million (3.3-3.6) and suggests spawning populations of 175,000-250,000. These revised kokanee estimates suggest a 37-57% decline in kokanee numbers over the past decade.

Table 11. Abundance estimates for kokanee based on acoustic size proportions derived from 420 kHz DFO dual beam data with size cut-off adjusted by curve inflection method.

Attribute	**Units**	**Survey year**			
		1991	**1992**	**1998**	**2000**
Total abundance (O. nerka)	Millions	65.1	28.9	56.3	16.5
Proportion of age 1-3+ kokanee (10-32cm)[1]	%	2.03%	4.98%	1.15%	5.80%
Number of age 1-3+ kokanee	Millions	1.33	1.44	0.644	0.956
Number of age 0+ kokanee[2]	Millions	1.99	2.16	0.966	1.43
Total kokanee all ages	Millions	3.32	3.6	1.61	2.39

1. fish from –44dB to –35dB
2. assuming kokanee fry represent 60% of total in-lake kokanee based on other BC lakes

Angler catch

There has not been any census of Quesnel Lake kokanee catch during scheduled creel census programs that were directed at determining the rainbow trout catch and effort. Prest and Ling (1984) reported a total estimated catch of about 1700 kokanee in 1982 but much of the summer months were not included, the time when the majority of kokanee are caught. Lirette (2002) estimated that total angler effort on Quesnel Lake was slightly over 20,000 angler days in 2001 with most of this directed towards rainbow trout and very little directed towards kokanee. Informed estimates from experienced WLAP fisheries staff places the probable annual catch at around 10,000 during 1970s, <5,000 in the 1990s and <1000 in the early 2000s.

DISCUSSION – kokanee

This summary of available data on kokanee in Quesnel Lake provides a reasonable portrayal of the status of the population. By all accounts the biology and life history of Quesnel Lake kokanee are similar and comparable to those populations found in other large lakes in southern BC. The majority of these fish grow to a comparatively large size at maturity (23-30 cm). It appears that mean size in the 1990s and 2000s may have increased slightly compared to the 1950s and 1960s data (Fig. 6) but sample sizes for the recent years are quite small. These kokanee are larger than those in Arrow Reservoir and Kootenay Lake but similar to kokanee found in Adams and Shuswap lakes (Redfish Consulting Ltd. 2003). Quesnel Lake kokanee spawn in the streams nearly a month later than those in Okanagan, Kootenay and Arrow but their timing is similar to those in Adams and Shuswap lakes. Age at maturity is most likely 3+ with little evidence that multiple year classes contribute to the spawning population.

While the biology of Quesnel Lake kokanee is similar to most other large lake populations there is a considerable difference regarding population size. The review of historic escapement data suggests that the total stream spawning component was probably 50,000-100,000 with no estimate available for the shore spawner numbers. The small amount of IPSFC file data on shore spawners suggests the magnitude of shore spawners some 40-50 years ago was probably about the same as today. This does not appear to be the case for stream spawners. In the early 2000s virtually no kokanee spawn in the primary streams (Little Horsefly River, Mitchell River, Wasco Creek) despite good habitat. These same systems supported documented numbers in the 10,000s in the 1950s and 1960s (Table 3). Analysis of the DFO acoustics data also suggests a decline in numbers between the 1990s and early 2000s. The decline in stream escapements in recent years cannot be explained from the data presented in this report but some possible causes are discussed below.

The best information available on Quesnel Lake kokanee is found in the series of WLAP trawl and acoustic surveys. This data includes size-at-age information that provides evidence that the age-at-maturity is 3+ since little reliable ageing work through scale or otoliths have been done. The acoustics data has been critically important in determining the probable population size. Analysis of the data indicates that the total population size ranged from 1.5-2.2 million during 2000-2002 based on the assumption that approximately 60% of these are fry (Table 7). The application of a biostandard of 5-7% to the total population estimates results in a crude estimate of 75,000-150,000 spawners; the large majority of these fish are currently shore spawning. There is no suggestion from the IPSFC file data or BC Fisheries data that escapements were any larger than these estimates notwithstanding the poor account of shore spawning numbers.

Stream escapements have been monitored on a number of lakes similar in size to Quesnel Lake. Some of these lakes, particularly Kootenay and Okanagan lakes have stream and shore spawner counts dating back to the early 1970s (Wright et al. 2002;

Andrusak et al. 2003). Escapement data from these and a few other lakes are summarized in **Table 12**. The Adams Lake data (Redfish Consulting Ltd. 2003) is sparse but is shown since currently it appears to be the only large lake other than Quesnel that appears to support so few kokanee spawners. Even Okanagan Lake that is known to have reduced carrying capacity (compared to the 1970s) due to mysid competitive interaction and or nutrient imbalance (Andrusak et al. 2003) currently supports more kokanee than Quesnel Lake. Arrow, Kootenay, Shuswap and Okanagan (in the 1970s) lakes support an order of magnitude more kokanee than what Quesnel Lake is estimated to support.

Table 12. Comparison of large lakes in southern BC that support abundant kokanee populations.

Lake	TDS	Surface area (ha)	Mean depth (m)	Escapement estimates (millions)	Sock-eye present	Spawner type		Mysids
						stream	shore	
Adams	57	13,760	169	< 0.15	Y	Y	Y	N
Arrow	77	49,800	83	0.5-1.0	N	Y	N	Y
Kootenay	85	38,900	94	0.2-4.0	N	Y	N	Y
Okanagan	165	34,950	75	0.05-0.75	N	Y	Y	Y
Quesnel	60	20,700	158	< 0.20	Y	Y	Y	N
Shuswap	80	30,960	62	0.5-1.5	Y	Y	N	N

Adams and Quesnel lakes do have some common characteristics: both support large numbers of sockeye; both lakes are deep and relatively unproductive yet neither of them contains *Mysis relicta* (**Table 12**). It does appear to be more than coincidence that kokanee numbers have declined concurrent with large increases in the numbers of sockeye (**Fig. 2**) in both lakes. Kokanee stream spawners spawn at least ten days later than sockeye in Quesnel Lake tributaries and are subject to the same incubation temperatures. It is therefore likely that the kokanee fry emerge slightly later than sockeye fry and enter the lake well after huge numbers of sockeye fry have dispersed in the lake and gained a competitive advantage. The shore spawners are known to spawn at least a month later than sockeye stream spawners, but may not necessarily emerge later as a result of the warmer incubation temperatures in the lake. It is more likely that the shore spawning kokanee emerge at the same time or earlier than the sockeye fry since the trawl data suggests kokanee and sockeye fry sizes are indistinguishable by late summer. The actual mechanisms that currently limit Quesnel Lake kokanee are not well understood and require further study that would include some analysis of trophic levels and the relationship(s) between them.

CHAPTER TWO---RAINBOW TROUT

INTRODUCTION

Until this current study was undertaken starting in 2000 the biology of rainbow trout that inhabit Quesnel Lake was not well understood and much of their life history had been inferred from research results on other comparable stocks. Even now it is unknown how many stocks or strains of rainbow trout reside in Quesnel Lake and its tributaries. Analogous large lakes such as Okanagan, Shuswap, Arrow and Kootenay lakes support at least one non piscivorous form as well as a piscivorous strain of trout and this is most likely the case in Quesnel Lake. It is known that very large trout live in the lake and that they are highly piscivorous (Parkinson et al. 1989). These fish can grow to a size comparable to the Gerrard rainbow trout in Kootenay Lake (10-13 kg) and are targeted not only in the lake but also in the rivers during the late summer and fall where they can be observed feeding on sockeye eggs and decomposing carcasses. As well, these trout stage off the primary sockeye rivers during the spring and prey on the abundance of newly emerged sockeye fry that are out-migrating. It is also known that these trout spawn primarily in the Horsefly and Mitchell rivers which support rearing juveniles for at least one and possibly two winters (Tredger 1989; Sebastian 1990). They exhibit similar early life histories to most steelhead populations (e.g. Keogh River see Ward and Slaney 1992) and the juveniles are found rearing in the rivers similar to Okanagan Lake rainbow trout that rear in Mission Creek (Sebastian 1979) and Kootenay Lake rainbows that rear in the Lardeau River (Irvine 1978; Redfish Consulting Ltd. 2002; Slaney and Andrusak 2003).

The sport fishery in the lake is conducted by anglers trolling a variety of terminal gear from recreational boats that tend to be fairly large (5-8 m) suitable for a lake that can be subject to high winds and waves at any time of the year. The majority of fishing occurs from May-October (Lirette 2002). Fishing gear that mimic kokanee swimming along the surface waters such as buck tails, plugs and apex lures are commonly used. Rainbow trout > 9kg are caught and these 'trophy" sized fish attract anglers from around the world. There are also lesser fisheries for kokanee, lake char and bull trout and more recently a very limited opening for returning sockeye. The lake has eight well developed resorts that are very dependent upon the fishery. These resorts cater largely to European and American clientele.

The Quesnel Lake rainbow trout fishery is somewhat distinctive from most other large lake fisheries since it offers not only superb lake fishing but also excellent river fisheries on the Horsefly, Mitchell and Quesnel rivers. The Quesnel River fishery targets river resident rainbow trout whereas the Horsefly and Mitchell river fisheries target non-spawning Quesnel Lake rainbow that migrate up these rivers in the summer and fall to feed on aquatic invertebrates and salmon eggs that are in abundance most years. The river fisheries are immensely popular and catch and release regulations have necessarily been maintained since 1988 to ensure conservation levels are met while still providing angling opportunities.

Rainbow trout that grow to a large size (>50cm) such as those in Shuswap, Okanagan and Kootenay lakes rely heavily on kokanee as their primary food source (Andrusak and Parkinson 1984; Parkinson et al 1989; Hebden draft report 1993). They are also quite vulnerable in the sport fishery(s) and despite the size of these lakes over fishing can occur (Redfish Consulting 2003). This study commenced in 2000 with objectives to obtain better information on the life history of these large trout and their relationship with the kokanee population that was suspected of being in decline and with increasing numbers of sockeye.

Background

The Quesnel Lake sport fishery was enjoyed primarily by local residents until the 1960s when road access to the area began to improve. The primary focus of the fishery was on rainbow trout and char and to a much lesser extent kokanee. Resort and cottage development grew considerably in the 1970s and the proportion of non resident anglers increased. During the early 1980s anglers and resort owners began expressing concern over the steady increase in angling effort and apparent decrease in angling success for trophy size rainbow trout. In response to these concerns, and to the need for more intensive management of key large lake fisheries on a provincial scale, some focussed Quesnel Lake rainbow trout research projects were initiated in 1986. As mentioned the major rainbow trout spawning systems were known or suspected to be the Horsefly and Mitchell rivers although smaller tributaries probably do support some trout that contribute to the fishery.

Due to the size and turbidity of the main spawning streams during spring it was not possible to directly enumerate rainbow spawners during earlier studies. As an alternate, an indirect strategy was adopted in the 1980s to assess the status of rainbow trout through a combination of juvenile sampling (electrofishing) and application of a theoretical habitat capability model developed for steelhead by provincial biologists. Juvenile assessment of rainbow trout was conducted from 1987-89 on the Horsefly River and estimates of theoretical carrying capacity were developed. From three years of results it was concluded that rainbow trout fry habitat was under-recruited during two of the three years of study (Sebastian 1990). A first cut estimate of potential rainbow production was 53,000 age 2 migrants or 550-2600 adults for the Horsefly River system before harvest (Sebastian 1990). Tredger (1989) used a similar approach to estimate parr production (i.e. migrants) from the Mitchell River at 2,400 -10,000 or about 20% of that estimated for the Horsefly River.

While the stream assessment work in the late 1980s provided some good insight into the dynamics of the juvenile trout populations in the major rivers the question(s) of exactly where the adults spawned and how many fish there were remained unanswered. A radio telemetry study was initiated in 1987 to determine where migrant trout spawned in the Horsefly River. Dolighan (1989) confirmed that the majority of tagged fish spawned in the mainstem river but also identified McKinley Creek as an important spawning area. The majority of 21 mature fish captured in 1987 were aged as seven year old maiden fish, reaffirming that these trout are late maturing. It was also confirmed by angling that large mature trout were in the Mitchell River during the spring months. During the summers of 1986 to 1988 rainbow trout > 20 cm from the Horsefly, Mitchell and Quesnel rivers were captured by electroshocking or angling, sampled for biological information and floy tags were attached to monitor their movement.

In response to concerns that rainbow trout size had decreased in recent years some effort has been made to capture mature fish in the Horsefly and Mitchell rivers. This data is summarized in this report. Also, in 2002 and again in 2003 a resistivity counter was operated in McKinley Creek in an attempt to directly enumerate rainbow spawners (McCubbing 2002).

During the 1980s and early 1990s there was little interest or concern over the status of the kokanee population in Quesnel Lake although some qualitative work was done on vertical migration and feeding behavior by Eric Parkinson (Provincial Research Scientist, UBC). This work included some trawling for kokanee and sockeye. It was known from the early work of the Pacific Salmon Fisheries Commission (IPSFC) that kokanee spawned in the Horsefly River, Lower Little Horsefly River, Wasco Creek, Summit Creek and the Mitchell River as well as various beaches, particularly on the North Arm. Although summarized in Chapter One, mention is made here of Quesnel Lake kokanee since they are an important component of rainbow diet. The importance of kokanee as a primary food source for piscivorous rainbow is evident in many other large lakes in BC including Okanagan, Arrow and Kootenay (Andrusak and Parkinson 1984; Parkinson et al 1989). Some further collection and analyses of Quesnel Lake rainbow diet data not previously reported has been included in this report as a follow-up to work reported by Parkinson et al (1989). Studies in Kootenay Lake suggest a dramatic decline in Kootenay lake kokanee numbers was believed to have negatively impacted Gerrard rainbow trout numbers in the early 1990s (Redfish Consulting Ltd 2003). The main concern on Quesnel Lake is the reason for apparent declines in the growth of rainbow trout.

METHODS

With the exception of direct adult counts, some recent scale age interpretation and a re-analyses of 1990s diet data, there was very little new information presented in this chapter. The majority of rainbow data has been summarized from project reports and from data on file in the regional Ministry of Water Land and Air Protection (WLAP) office in Williams Lake. All juvenile rainbow trout data and analyses have been quoted from habitat assessment reports on work carried out in the late 1980s by Tredger (1989) and Sebastian (1990). This work involved electrofishing at representative index sites using the two catch removal method described by Seber and LeCren (1967). Fish densities and biomass were adjusted according to habitat suitability based on depths and velocities using a modified PHABSIM approach (Milhous et al, 1984). Adjusted densities were then compared with estimates of theoretical maximum densities based on an alkalinity model by Ptolemy (1989). Estimates of actual (i.e., measured) densities and theoretical maximum density for fry were expanded to the estimated total area of suitable fry habitat in order to assess levels relative to habitat capacity. Provincial biostandards for rainbow survival were then applied to predict potential migrant yields and theoretical adult production for the Horsefly system.

The mature fish data were summarized from biological samples collected during floy tagging studies that involved spring time angling in the Horsefly and Mitchell rivers and some limited radio telemetry work carried out by Dolighan (1989). During the spring of 1987 fifteen adult rainbow trout were captured by angling, equipped with external radio transmitters and tracked as they moved up the Horsefly River. More detail on the methods and fish movements are described in the 1987 study by Dolighan (1989) although the results were not as informative as hoped since the fish were caught too late in the spawning run and did not exhibit much movement once tagged. Floy tagging studies in the early 1980s also provided length, weight and age information on the non-spawning rainbow that entered Horsefly and Mitchell rivers during the spring summer and fall periods. The Quesnel Lake sport fishery provided some length and age data, especially that summarized by Prest and Ling (1982) and Prest (1984) although the data may include rainbow stocks that are not originating from the main streams.

Direct enumeration of rainbow spawners was first conducted on McKinley Creek in 2002 as part of this study. The method employed a Logie electronic fish counter which uses resistivity to count and size migrating fish and a “target activiated” video system to record events and provide size calibration and species validation. The resistivity counter was installed using four 2.5m by 1.5m vinyl electrode pads placed directly on the streambed to monitor the entire width of McKinley Creek. The first year was used to examine the feasibility of operating an automated counter on McKinley Creek and more detailed methods and results are documented in McCubbing (2002). At the time of writing there was new information forthcoming from a second year of investigation on McKinley Creek spawners using the resistivity counter. A tagging component was added to McKinley project to enable a mark/recovery population estimate to be carried out on the Horsefly River rainbow spawning population.

Some data on the diet of Quesnel Lake rainbow trout was found in a report by Parkinson et al (1989) while other Provincial Fisheries files contained more recent data on rainbow trout food habits from stomach collections conducted during the early to mid 1990s. All available raw diet data has been summarized and presented in this report.

RESULTS – Rainbow trout

Escapements

The known spawning areas for large rainbow trout from Quesnel Lake include the Horsefly and Mitchell rivers. Dolighan (1989) tracked fifteen radio tagged trout that had been captured in the Horsefly River. Some of these trout spawned in the mainstem river while spawning was also observed in McKinley Creek. Tredger (1989) identified the area below the falls near the outlet area of Mitchell Lake as the primary spawning area for rainbow trout and large pre-spawning rainbow trout captured in the Mitchell River in 2000 were confirmed as Quesnel Lake fish.

There has not been a rainbow trout adult enumeration conducted of either the Horsefly or Mitchell river populations owing to the size of these systems. However, Tredger (1989) and Sebastian (1990) did conduct juvenile trout assessments in the Mitchell and Horsefly rivers. Assuming rainbow to have similar habitat requirements to juvenile steelhead, a first cut estimate of habitat capacity for the Horsefly system was 237,000 fry and 54,000 yearling migrants (Sebastian 1990). Applying a 5% migrant to adult survival estimated a range for annual escapement to the Horsefly system of up to 2,700 fish with no harvest. Applying the same biostandard to Tredger's juvenile migrant estimate of 2,400-10,000 suggests about 120-500 adults for the Mitchell River.

Initial back-calculations were based on a 13% egg-to-fry survival and an estimated average fecundity of 6000 eggs/female and suggested a minimum escapement of 550 spawners would be required to fully seed the available fry habitat in the Horsefly River and tributaries. A more recent estimate of average fecundity (4900 eggs/female) derived from data in this report suggests a slightly higher minimum required escapement of 744 adults for the Horsefly River.

In the spring 2002 a resistivity counter was installed on McKinley Creek to enumerate migrating Quesnel Lake rainbow trout (McCubbing and Burroughs 2002). This study was very much a research and development project initially aimed at evaluating relatively new technology. Despite some equipment problems the counter estimated between 144 -191 upstream migrants in McKinley Creek. The equipment was used again in 2003 and much larger numbers of fish were counted but at the time of writing the data analyses had not been completed. Since it is known from the radio telemetry work (Dolighan 1989) that most rainbow trout likely spawn in the mainstem Horsefly River, the 2002 estimate by McCubbing and Burroughs (2002) for McKinley Creek provides a valuable reference point for estimating numbers in the entire system. If McKinley Creek supported greater than 200 spawners then the Horsefly River probably supports an order of magnitude more, and would be similar to early estimates of potential adult production based on juvenile assessment (Sebastian 1990).

Size

Prest & Ling (1982) and Prest (1984) show the size frequency of all rainbow trout caught in the sport fishery. Their original data has been reproduced but includes sport caught fish from May-September (only) to compare with data recorded from the fishery for the periods of 1987-89 and 1990-1994 (**Fig. 21**). Although the frequency plots shown in Figure 21 probably represent more than one strain of trout, it is quite evident that some very large fish (> 60 cm) contribute to the fishery. The plots also show no major change in size frequency from the 1980s to 1990s. Of interest however, is the size frequency plot of rainbow trout caught in the 2000-2001 sport fishery (**Fig. 21**). Based on a large sample size, the percent frequency occurrence of larger trout is considerably less than the histograms shown for the 1980s and 1990s. The decrease in larger and presumably older trout suggests either a reduction in growth and or loss of larger fish due to over fishing. Similarly, a comparison of data collected from spawning rainbow trout sampled in the Horsefly River in the late 1980s and in 1999 to 2002 also suggests a decrease in size (**Fig. 22**). The size of Horsefly River rainbow trout spawners captured in 2003 (**Fig. 23**) adds further support to the possibility that a size reduction has occurred even when compared to the 1999-2002 data (**Fig. 22**). It appears that size of spawners in the Horsefly and Mitchell rivers are similar as indicated from samples collected in 2000 (**Fig. 24**).

Size at age and age at maturity

In order to compare size-at-age and size at maturity scale samples were analysed from Quesnel Lake rainbow collected from the Horsefly River at the onset of the spawning period in 1986 -1988 and 1999 -2003. An apparent difference in the size-at-age can be seen in the growth curves between the late 1980s and early 2000s (**Figure 25a and b)**. Although sample sizes are small, error bars (95% confidence limits) suggest that differences in length at age are statistically significant between the two time periods (**Fig. 25c**). The large majority of fish were age 5 or older and a surprising number were as old as age 10, particularly in the more recent samples (Table 13). Age analysis of rainbow spawners captured in the Horsefly and Mitchell rivers in 2000 suggests these fish are similar in size and age (**Fig. 26**) ranging from 5-10 years old.

Table 13. Comparison of mean length at age for spawning rainbow sampled during two time periods in the Horsefly River.

	1986-1987		**1999-2002**	
Age	**Mean length (mm)**	**Sample (n)**	**Mean length (mm)**	**Sample (n)**
4	394	10	353	2
5	531	10	432	12
6	606	6	492	14
7	704	14	532	18
8	784	1	570	16
9	900	3	601	13
10			619	14
Total		**44**		**89**

The majority of Quesnel Lake rainbow trout (>50%) spawn for the first time at six or seven years of age (Dolighan 1989). The fact that these trout are very late maturing implies they would be quite vulnerable to any intensive fishing effort. A change in the sport fish regulations in 2002-03 requiring release of all rainbow trout > 50 cm reflects a growing concern about the harvest rate of these larger trout.

Combining the juvenile (n=494) data from Sebastian (1990) and recent adult data from 1999-2002 provides reasonable certainty as to the age structure of this population (**Fig. 27**). Of note is that age 3+ fish are not represented since they were not captured during the juvenile trout survey work by Sebastian (1990) nor were they captured by angling for spawners in the river (**Fig.26**) as it is most likely that they remain in the lake as immature fish. This age group appears to be represented in the summer sport fishery (**Fig. 21**) ranging in size from about 250-350 mm.

An unusual feature of Quesnel Lake rainbow trout is their migration into the main rivers during the early summer and fall to feed on sockeye fry, aquatic invertebrates and salmon eggs and flesh from decaying carcasses. It is most likely some of these are resident trout but the majority were believed to be from Quesnel Lake. The size frequency histograms for these non-spawning rainbow caught in the two rivers were very similar with nearly all fish less than 60 cm (**Fig. 28**). There was little overlap in lengths between the spring spawners and the non-spawning fish captured in the Horsefly River during summer and fall suggesting the two groups of fish are distinctly different in both size and most likely in age (Fig. 29).

The spawners that were sampled from 1999-2002 and then aged through scale reading were virtually all age 5 or older. On the other hand, few of the non-spawners sampled from 1986-1988 were older than five years with the majority ages 3 and 4 (**Fig. 30**). Mitchell River non-spawners were all aged as 2-5 years old (**Fig. 31**).

Fecundity

There is no information on Quesnel lake rainbow trout fecundity except for one fish that was 59.0 cm in length, weighed 2.9 kg and had 4,900 eggs. Quesnel lake rainbow trout are similar in size to the Gerrard rainbow trout found in Kootenay Lake. Gerrard rainbow trout are believed to have an average of about 7,268 eggs / female (Irvine 1978). Irvine (1978) developed a regression formula for determining Gerrard rainbow trout fecundity from fork length:

$$\text{Log } F = 1.94 \log L + \log 1.81$$

Where F= fecundity (no. of eggs) and L = Fork Length in centimeters

This formula was applied to length data from 77 mature trout caught in the Horsefly River (1999-2002) and a mean fecundity of 4867 with a range of 2792-7858 was derived. This results seems reasonable since similar sized steelhead (mean FL = 75.9

cm) in the Bella Coola River have a mean fecundity of 5786 eggs (Nelson et al. 1998). Thompson River steelhead are also similar in size but are known to have a very small egg size and high mean fecundity of 12, 614 (Ian McGregor Provincial Fisheries Biologist Kamloops BC pers. com.)

Juvenile rainbow trout production

Sebastian (1990) assessed juvenile rainbow trout production in the Horsefly system during 1987-1989 and compared measured densities from three survey years to theoretical maximum densities suggested by a draft model (alkalinity vs fish density) that was published in 1993 (Ptolemy 1993). The average summer alkalinity of $41 mg \cdot l^{-1}$ suggested a maximum fry biomass of $2\ g \cdot m^{-2}$ and predicted fry densities of $0.51\text{-}1.06\ fry \cdot m^2$ based on observed fry size (1.8-4.0g). Once adjusted for habitat suitability, the measured fry densities ranged from $0.03\text{-}1.05\ fry \cdot m^2$. Based on average adjusted densities of 0.54, 0.55 and 0.89 $fry \cdot m^2$ in 1987, 88 and 89 respectively, it was concluded that habitat was at approximately 50% of estimated capacity during 1987 and 1988, and at 85% in 1989 (**Table 14**). The total area of suitable fry habitat was estimated at 29.5 ha (13% of stream habitat area) and potential fry production at 237,000. Limited scale analyses and observed age structure suggested a likelihood of age 2 migrants (Sebastian 1990). A fry survival biostandard developed for Atlantic Salmon by Symons (1979) and modified for steelhead by Tredger (1990 in prep.) suggested 22% fry-to-migrant survival for the Horsefly River and an overall potential migrant yield of 54,000 when tributary production was included. It was estimated that 2700 adults (1600-4000) could potentially be produced before harvest (Sebastian 1990). Tredger's (1989) juvenile assessment of the Mitchell River suggests its production capability is likely in the order of 20% of the Horsefly system. Initial estimates of the minimum required escapement to seed fry habitat in the Horsefly River of 550 adults were based on an average fecundity of 6,600 eggs per female. With the smaller average size of rainbow in the early 2000s (and lower fecundity) the estimated number of rainbow spawners required to fully seed fry habitat has been increased to 750 fish.

Table 14. Rainbow trout fry densities for the Horsefly River and accessible tributaries from electrofishing surveys during 1987-89. Source: Sebastian (1990).

Survey year	No. of sample sites	Fry Density ($fish \cdot m^2$)	Adjusted Fry Density ($fish \cdot m^2$)	Mean Adjusted Density ($fish \cdot m^2$)
1987	11	0.03 - 0.87	0.03 – 0.93	0.54
1988	6	0.16 – 0.53	0.22 – 0.73	0.55
1989	5	0.27 – 0.99	0.38 – 1.05	0.89
Estimated capacity				1.05

Repetitive juvenile sampling of established fry sites has been conducted in most years since 1989 and results will be included in an updated version of this report in 2004.

Rainbow trout movements

The movements of mature rainbow trout to and from the Horsefly and Mitchell rivers were documented during the course of radio tagging work in 1987 (Dolighan 1989) and floy tagging work primarily from 1986-88. In both rivers trout were captured as they migrated upstream to spawn. In 1987 fifteen rainbow spawners in the Horsefly River were radio tagged and tracked to identify spawning locations. Most appeared to spawn in the mainstem river but evidence from floy tagging suggested there was also spawning in McKinley Creek. In 1987 spawning occurred over a six week period from April 10 to May 25. Post spawned fish moved into the lake and seemed to concentrate in the central "Junction" area of the lake. One third of these tagged fish were captured in the fishery providing some indication of exploitation rates.

A file data report summarized the river floy tagging results. The tagging effort was of varying magnitude with some initially directed on the Quesnel River during 1984 and on the Horsefly, Quesnel and Mitchell Rivers from 1986 to 1988. A total of 740 rainbows were tagged during these years, with the majority (579) tagged in 1986/87. A summary of tagging dates, locations and relevant biological information for all tagged fish is presented in Appendix 8.

Horsefly River

Lengths weights and scale samples were randomly collected from 48% (n=211) of 440 rainbow trout tagged in the Horsefly River during 1986-1987. Length and weight data were summarized age group after scale analyses (**Table 15)**.

Table 15. Mean fork length (cm) and weight (kg) by age from 211 floy tagged rainbow trout randomly sampled in Horsefly River during 1986 – 1987.

Age	n	% of Total Sample	Mean Length (cm) and Range	Mean Weight (kg) and Range
2+	65	30.8	27.3 (22.8 - 33.6)	.20 (.12 - .57)
3+	54	25.6	37.2 (31.0 - 45.7)	.76 (.32 - 1.3)
4+	52	24.6	42.1 (37.0 - 51.5)	1.09 (.59 - 1.81)
4.S+	4	1.9	48.4 (43.2 - 52.0)	1.39 (.92 - 1.83)
5+	30	14.2	52.1 (47.0 - 59.0)	1.91 (1.2 - 2.8)
5.S+	3	1.4	58.8 (52.0 - 65.3)	2.8 (2.3 - 3.4)
6+	1	.5	61.6 (-)	3.0 (-)
6.S+	2	.9	70.0 (66.3 - 73.6)	4.9 (4.3 - 5.5)

Rainbows at ages 2, 3, 4 and 5 comprised the greater portion of sampled tagged fish and respectively accounted for 30.8%, 25.7%, 24.6% and 14.2% of the total sample. The average length and weight for all floy tagged trout sampled from the Horsefly River was 40 cm and 1.09 kg. The majority of these fish were captured during the summer and fall months while they were feeding insect drift and sockeye eggs and the large majority (i.e., 96%) were immature fish.

Mitchell River

In the Mitchell River trout were captured during the summer months only from 1986-88 (**Table 16**). Random sampling for length, weight and age was conducted on 44% (n=56) of the total fish tagged (n=126). Similar to the Horsefly River, trout at ages 2, 3, and 4 were the most common age groups encountered while tagging and comprised 34.0%, 28.6% and 23.2% (respectively) of the total fish sampled. The average length and weight for all age classes of rainbow sampled from the Mitchell River was 39.9 cm and 1.03 kg.

Table 16. Mean fork length (cm) and weight (kg) by age for 56 floy tagged rainbow trout randomly sampled in Mitchell River during 1986 to 1988.

Age	n	% of Total Sample	Mean Length (cm) and Range	Mean Weight (kg) and Range
2+	19	34	28.1 (22.8 – 33.4)	.26 (0.13 -0 .57)
3+	16	28.6	38.1 (35.6 – 40.6)	.86 (0.68 - 1.02)
4+	13	23.2	46.5 (40.6 – 52.5)	1.30 (0.79 - 1.79)
5+	6	10.7	55.2 (50.4 – 60.0)	2.27 (1.59 - 2.95
6+	2	3.5	67.1 (66.0 – 68.2)	4.3 (4.0 - 4.6)

Quesnel River

During 1984 and 1988 a total of 186 rainbow trout were floy tagged in the Quesnel River. Of these fish 20% or 38 fish were randomly sampled for biological information (**Table 17)**.

Table 17. Mean fork length (cm) and weight (kg) by age for 38 rainbow trout sampled in Quesnel River during fall, 1988.

Age	n	% of Total Sample	Mean Length and Range (cm)	Mean Weight and Range (kg)
2+	1	2.6	34.5 ( )	
3+	3	7.9	26.3 (26.1 – 27.0)	
3.S+	2	5.2	31.0 (27.0 – 31.0)	
4+	15	39.5	32.3 (29.0 – 38.0)	.33 (.20 - .50)
4.S+	5	13.2	39.8 (36.0 – 44.5)	.56 (.48 - .65)
4.S+	1	2.6	46.5 (-)	1.0 (-)
5+	5	13.2	42.7 (38.5 – 47.0)	.60 (.49 - .70)
5.S+	6	15.8	44.9 (42.2 – 49.0)	.80 (.58 - 1.13)

Recapture data for trout from all three rivers has been summarized (**Table 18)**. The Horsefly and Mitchell River trout were either recaptured in the river or they were subsequently caught in the lake fishery. By contrast the Quesnel River trout were all recaptured in the river and none were caught in the lake. Based on the numbers of mature trout captured in each system, their size at age and the location of recaptures it was concluded that the Quesnel River rainbow trout are a river resident stock.

Table 18. Mark recapture data for Horsefly, Mitchell and Quesnel rivers during 1984 and 1986-1988.

Tagging location	Total No. tagged	Recapture location	Total No. of recaptures	% of total fish tagged
Horsefly River	440	Quesnel Lake – N – Arm	7	1.6
		Quesnel Lake – M – Arm	16	3.7
		Quesnel Lake – E – Arm	3	0.7
		Horsefly River	38	8.5
		Horsefly Lake	1	0.2
		Total of Horsefly R. recaps.	65	14.6
Mitchell River	127	Quesnel Lake – N – Arm	5	3.9
		Quesnel Lake – M – Arm	1	0.8
		Mitchell River	7	5.5
		Total of Mitchell R. recaps.	13	10.2
		Quesnel Lake – but tag no. or color not reported	11	
Quesnel River	174	Quesnel River	43	25

Angler catch and the sport fishery

The following information on the Quesnel Lake rainbow trout fishery has been summarized from internal management reports by R. Dolighan, Wunderlich (2002) and M. Lirette (2003). Excerpts from these reports have been reproduced with some minor editing to conform to this report.

Sportfish values in the Quesnel Lake drainage were first realized in the early 1900s and by 1950 were gaining international recognition as a producer of trophy size rainbow trout, Dolly Varden char (now bull trout) and lake trout. By 1960, increased resource use and angling demand was such that several lakeside recreational facilities such as fishing resorts, private cottages, recreation sites and campgrounds were developed. In response to the growing angler demand for the lake's large size rainbow trout, preliminary life history information was collected and it was determined that similar to the famous Gerrard trout of Kootenay Lake (Cartwright,1961), Quesnel Lake rainbows were a unique late maturing strain. It was not however, until 1981 that the first fisheries management programs were conducted. Partial creel censuses were conducted in 1982 and 1983 (Prest 1984). The creel was designed as a “roving” survey and only captured a portion of the sport fishery with the peak fishing months of July-mid August not surveyed. The estimated angler effort for a portion the fishery surveyed was just over 2,000 angler days. A best guess estimate of total (annual) angler effort would be about 8,000 angler days. Approximately 70% of the effort was directed at rainbow trout with some effort recorded for kokanee, bull trout and lake char.

Commencing in 1987 and periodically thereafter aerial boat counts following methods of Tredger (1991) were conducted on Quesnel Lake in an attempt to improved estimates of angler effort. Again these surveys covered only a portion of the lake and only from May to September. Estimates of angler effort for the central part of the lake have ranged upward of 12,000 angler days in 1992. However in 1996 and 2001 complete boat counts for the entire lake were conducted and total effort was estimated at 17,676 angler days in1996 and 20,546 in 2001 (Wunderlich 2002). These estimates are thought to be conservative by local fisheries staff and actual angler days currently may exceed 30,000. Angling guide days issued to licensed angling guides have steadily increased since the early 1990's. In the 1990/1991 angling season, four angling guides were issued 175 guide days. By comparison 15 angling guides were issued 3,715 guide days in 2003.

Accurate measurements of the total annual harvest of each species in Quesnel Lake has not been possible as most creel census programs were either incomplete (1982, 1983) or designed to randomly sample for general harvest trend information. Extrapolated results from the 1983 creel census suggest that approximately 8,000 angler days were expended to capture 5,000 rainbow trout, 3200 kokanee, 700 lake char and 300 bull trout. Of the 5000 rainbow harvested approximately 1400 were fish larger than 50cms.

No measure of rainbow trout catch rates are available for Quesnel Lake other than in 1982 when it was 0.37 trout/angler day during August and September 1982 (Prest and Ling 1984). Angler success rates for Kootenay Lake rainbow trout over the entire year determined by a mail questionnaire average approximately 0.65 trout per day (Redfish Consulting Ltd 2003). Creel census on Okanagan Lake in the 1980s and early 1990s indicated that rainbow trout success rates were approximately 0.6 per day (Shepherd 1994). Arrow Reservoir creel census from 1976 to 2002 suggested average catch rates of about 0.28 to 0.42 trout/angler day assuming an angler day averages 4.3 hours (Sebastian, 2000, Arnt 2002).

Applying a daily success rate of 0.5 fish/angler day suggests the current total catch on Quesnel Lake is most likely about 10,000-15,000. There is no indication from the Quesnel Lake data what percentage of the catch is harvested but it is unlikely to exceed 50%. Therefore the annual harvest could potentially be up to 7,500 rainbow trout. In Kootenay Lake the release rate exceeds 50% (Redfish Consulting Ltd. 2003). The current harvest rate is almost certainly lower than 50% as a result of the increasingly restrictive harvest regulations that have been imposed on Quesnel Lake over the last two decades as quoted from Lirette (2003):

"Prior to 1985 the fish species daily limits on Quesnel Lake were the same as region wide regulations. This included a trout/char daily limit of 8 fish (two of which could be over 50 cm in length). In 1982/83 Quesnel lake was designated as a *special lake* requiring that alien anglers pay an additional $15 to fish the lake. This added licence was removed in subsequent years. In 1985/86 the daily limit for trout/char was reduced by half to 4 fish (again 2 could be over 50 cm and none could be under 30 cm). A further limitation was imposed in 1988/89 where only two rainbow trout could be harvested a day with a size restriction of one rainbow between 30-50 cm and one over 50 cm. At the same time a single hook and bait ban gear restriction was imposed to reduce mortalities of released rainbow trout. The bait ban had a significant impact on the ability of anglers to catch and harvest kokanee. Also in 1988/89 the Horsefly River sport fishery targeted rearing rainbow trout from Quesnel Lake went to a release of all trout captured during the open season of July 1 to October 30th. In 1994/95 the trout/char combined daily limit on Quesnel Lake was reduced to 2 fish (1 fish 30-50 cm and 1 fish over 50 cm). And, finally in 2002/03 the trout/char daily limit stayed at two fish but only one could be a lake char, none could be a bull trout and all rainbow trout over 50 cm must be released. Quesnel Lake has one of the most restrictive daily catch limits of any large lake in the province aimed specifically at protecting large rainbow trout and sensitive lake char and bull trout populations. During the summer of 2002 the retention of sockeye salmon caught by sport anglers fishing Quesnel Lake (in Horsefly Bay) was allowed for the first time by Fisheries and Oceans Canada."

Food habits

O. nerka are a critically important component of the diet of Quesnel Lake rainbow trout (**Table 19**). While insects and zooplankton were a large component of the diet in the spring and summer (35%) they were virtually absent from the diet in the fall and winter (1%). On average, the diet of angler caught rainbow trout changed from 90% insects and zooplankton to >60% *O. nerka* as rainbow length increased.

Parkinson et al. (1989) compared the diet of fish captured from Quesnel Lake in 1987 (the year after a small subdominant sockeye escapement) to the diet of Gerrard rainbow trout in Kootenay Lake (Andrusak and Parkinson 1984). They found the diet was similar in both lakes, consisting mainly of kokanee >80 mm (mostly age 1 and 2+ kokanee). O. nerka in the diet of Kootenay Lake rainbow trout were larger than in Quesnel Lake but they related this difference to the larger size of rainbow trout in Kootenay Lake compared with Quesnel Lake.

Table 19. Prey type composition of the diet of rainbow trout caught in Quesnel Lake from 1987 to 1991.

a) Diet by size class			
	Number of	**Proportion (% volume)**	
Rainbow size class (cm)	**Stomachs (n)**	**O. nerka**	**Insects & Zooplankton**
< 30	4	10	90
30 - 60	142	40	60
> 60 - 90	95	64	36
b) Diet by season			
Season			
Fall / Winter	76	99	1
Spring / Summer	159	65	35

An additional seven years of diet data have been collected from angler caught rainbow trout since the Parkinson et al. (1989) report. The data set now includes 297 fish >30 cm in fork length from four nondominant years (88,89,92,93), two subdominant years (87, 91) and two dominant years (90, 94). Effective female sockeye spawners (EFS) varied from 8,900 to 2.6 million during this time. All fish from the rainbow trout stomachs were measured to fork length (or estimated from body parts overly digested). Ages were estimated from known size at age data (from trawling) and on the length frequency of all *O. nerka* found in the stomachs **(Fig. 32**). Biomass of *O. nerka* found in the stomachs was estimated from the length weight regression of all trawl caught fish in 2000 to 2002 **(**Fig**. 33).** The estimated average weight of *O. nerka* in the rainbow trout diet was 2.1, 25.8 and 95.7g for the age 0, 1 and 2 fish respectively.

Age 1 and older kokanee formed the highest proportion of the diet in the years following non and subdominant sockeye escapements (EFS <300,000, **Fig. 34a)** while in the years following dominant escapements (EFS>0.9 million) age-0 *O. nerka* (presumably mostly sockeye) were by far the largest numerous component of the diet. The large increase in body mass as the *O. nerka* age results in the age 1 and 2 kokanee being a much more important component of the diet than is apparent from the numerical data. Mean total biomass of *O. nerka* eaten by a Quesnel Lake rainbow trout decreases from 71g in the non-dominant years to 28g in the subdominant and 21g in the dominant years **(Fig. 34b**). This decrease in biomass eaten is a direct result of the decrease of older kokanee in the diet of rainbow trout as the abundance of sockeye fry in the lake increases.

There were only a few differences between the diet of medium (30-60cm) and large (60 – 90cm) rainbow trout **(Fig. 35).** Age-0 sockeye were increasingly common in the diet of both size groups as sockeye escapement increased although but were slightly more common in diet of medium sized rainbow trout in the lower escapement years. The pattern of decreasing biomass in the diet of rainbow trout as sockeye escapement increases was seen in both classes of rainbow trout **(Fig. 36**).

DISCUSSION – Rainbow trout

Recent data on Quesnel Lake piscivorous rainbow trout summarized in this report is sufficient to provide an overview of their current status. Good data is available on their early life history and current work on adult spawner enumeration is providing magnitude of escapements in the Horsefly River. The fishery data is poor and harvest estimates have been based on data from other similar fisheries. These trout provide excellent fishing opportunities for anglers who want to catch large sized trout in both lake and stream environments and are willing to spend the time to do so. There are only a few trout populations in British Columbia that grow to such an exceptional size and therefore require good data and more intensive management to ensure their conservation.

Life history information summarized in this report indicates that the biology of these trout is very similar to Okanagan lake rainbow trout (Sebastian 1979), piscivorous rainbow trout in Shuswap Lake (Sebastian 1989; Bison 1991) and Gerrard rainbow trout in Kootenay Lake (Irvine 1978; Slaney and Andrusak 2003). Quesnel Lake rainbow trout grow to a very large size (7-10 kg) and reach maturity at age 6 or 7. These fish are highly piscivorous utilizing both sockeye fry and kokanee (Parkinson et al. 1989). These trout also exhibit a similar early life history strategy to Gerrard and Mission Creek rainbow trout with juveniles very dependent on good rearing habitat in the primary spawning rivers.

Size and age data suggests that there has been a change in growth in recent years with some evidence of fewer large, older trout possibly due in part to over fishing. Considering the popularity of these trout to anglers and their vulnerability due to their highly predacious nature it should not be surprising that these trout could be over-exploited. Not only are these trout intensively fished in the lake, they have also been actively fished while in the Horsefly River where they prey on sockeye eggs and fry. The long list of increasing restrictive regulation changes summarized in this report reflects a growing concern by fisheries managers about this stock and the possibility of over fishing.

Despite the large size of Quesnel Lake these trout are subjected to ever more efficient lake fishing techniques that include improved technology (e.g. down riggers, echo sounders, planer boards) and fishing lures. As well, Quesnel Lake rainbow trout exhibit the same migratory feeding movements into the primary rivers for sockeye eggs and fry as do the Shuswap Lake rainbow trout into Adams River (Bison 1991). When in the rivers or feeding off the river mouths these trout are highly vulnerable to anglers. Catch and release of these trout in the lower Adams River (Shuswap Lake) and Horsefly River has been applied to ensure conservation of these populations.

The early life history of Quesnel Lake rainbow trout has been documented by Tredger (1989) for the Mitchell River and by Sebastian (1990) for the Horsefly River system. From assessment of fry habitat and fish density information collected over a three year period it was concluded that the Horsefly River was most likely under recruited during two of the three years suggesting that escapement levels were relatively low (Sebastian 1990). The effect of regulation changes made at that time to increase escapement levels have been monitored and will be included in an updated version of this report in 2004. A habitat based capacity model provided initial estimates of potential fry production at 237,000 for the Horsefly River and accessible tributaries. A first cut estimate of potential migrant production of 54,000 yearling rainbow was based on a steelhead fry to smolt model rather than on the amount or quality of parr habitat. As a result, these early estimates may be high but do provide an upper limit for trout production for this system. Using steelhead biostandards for survival a best estimate of 2700 (1600-4000) adult rainbow (before harvest) could potentially be produced from the Horsefly migrants. A minimum escapement required to fully seed fry habitat was estimated initially estimated at 550 fish, but has been revised upward to 750 in this report based on new fecundity information and the smaller size of rainbow returning to the Horsefly River. Applying the same biostandards to Mitchell River juvenile estimates reported in Tredger (1989) suggests a theoretical escapement level of 120-500 spawners for Mitchell River.

It is believed that all Quesnel Lake piscivorous trout production originates from the Horsefly and Mitchell rivers. Earlier work by Tredger (1989) and Sebastian (1990) on the two main spawning and rearing streams, although highly theoretical, was useful in providing some bounds on the probable size of this trout population. The on-going resistivity counter work on the Horsefly-McKinley Creek system by McCubbing and Burroughs (2002) is providing some corroborative data that supports earlier habitat based estimates. Less than two hundred adults were counted in McKinley Creek in 2002 with an unknown number in the mainstem river. Although the data has not been summarized for 2003, initial mark and recapture information derived from the McKinley Creek counter suggests a total spawning escapement of about 800 fish for the Horsefly River. The documentation of spawners utilizing McKinley Creek by McCubbing (2002) was especially informative for run timing and size of spawners.

How many large adult size piscivorous rainbow trout should there be in Quesnel Lake? While the data on Quesnel Lake rainbow trout is insufficient to answer this question it is worth reviewing rainbow trout population data from three similar size lakes to get a sense of what is possible. The work of Irvine (1978) on the Gerrard trout population and recent work on Lardeau River habitat assessment and trout production capability modeling by Slaney and Andrusak (2003) provide some useful insights into this trout population. The juvenile survey work by Sebastian (1979) on Mission Creek, the only known spawning stream for piscivorous rainbow in Okanagan Lake, and some Mission Creek spawner counts offer some information on the size of this population. Shuswap Lake piscivorous rainbow trout spawn primarily in the Eagle and Adams rivers and Scotch Creek. Some file data on Eagle River spawner counts and juvenile assessment work by Sebastian (1988) and Bison (1991) on the main spawning systems contribute to a partial picture of Shuswap Lake rainbow population size. These data are summarized in **Table 20** but must be considered as "best guess" estimates and are shown simply to illustrate probable magnitude of adult numbers.

The most significant points to be made from **Table 20** are: a) estimates of fry and parr for all the lakes and production systems are all less than one million fry and less than 100,000 parr; b) despite differences in size of lakes and small differences in productivity (Table 1) annual number of spawners, except for Shuswap Lake, is probably less than 1000. The salient point is that despite the size of these lakes the piscivorous trout populations are quite small and therefore vulnerable to fishing effort. Fishing mortality undoubtedly plays a large role in the state of the rainbow populations in each of these lakes as evidenced in the Kootenay Lake fishery where over fishing was implicated in the decline of Gerrard spawner numbers in the late 1990s (Redfish Consulting Ltd 2002). Data summarized in this report for the Quesnel Lake rainbow population also suggests that over fishing may have played a part since the recent decrease in rainbow size (Fig. 25) is indicative of over fishing. However, growth rates also appear to have declined so these trout may have been impacted not only from over fishing but also from a changing food supply.

Table 20. Summary estimates of juvenile and spawner numbers for piscivorous rainbow trout in Kootenay, Okanagan, Shuswap and Quesnel lakes.

Lake	**Data source**	**Estimated fry no.**	**Estimated parr no.**	**Estimated adult spawners and method of estimation**	
Kootenay (Lardeau)	Irvine (1978)	97,500	65,000	574	Mean number 1967-1976
	Slaney and Andrusak (2003)		50,000		
	Redfish Conslt. Ltd. (2002)			864	47 yr ave. peak counts x 3
Okanagan (Mission)	Wightman and Sebastian (1979)	83,000	13,000	445	Direct fence counts-4 year average
Shuswap (Eagle, Scotch, Adams)	Bison (1991)	600,000	97,000*	6000	
Eagle	File data			471-699	Direct peak count for 2 years x 3
Mitchell River	Tredger (1989)	7550	5000		
Horsefly	Sebastian (1990)	237,000	54,000	2,700 (before harvest)	
Horsefly River	McCubbing and Burroughs (2002)			500-700	

* discussed with R. Bison BC Fisheries biologist Kamloops BC

The status of the kokanee numbers in some of these lakes has also been clearly demonstrated as a driving variable in the status of these rainbow populations. The best documented example of kokanee abundance influencing trout numbers is from Kootenay Lake. As the numbers increased due to initial lake fertilization the rainbow trout population appears to have increased with a lag time of 3-4 years (Redfish Consulting Ltd. 2003). When the fertilizer loading was deliberately decreased the kokanee numbers declined by 65-75% and the rainbow trout numbers also appeared to decline 3-4 years later. This decline appears to have been exacerbated by some short term over fishing when the trout population was at near record high levels. In 2000 the fertilizer loading was increased to the original level and the year afterward the kokanee numbers again increased sharply according to hydroacoustic monitoring. Three years later the rainbow trout data suggests an increase in numbers of younger trout.

There is ample evidence that these piscivorous rainbow trout populations are highly reliant upon kokanee as a primary food source. The recent decline in Quesnel Lake kokanee stream spawners, as well as the indicators that the lake populations of juveniles may also have declined, is therefore worrisome. Although the increased sockeye fry abundance in years following dominant sockeye spawning runs provide the rainbow trout with an increased food supply, the diet analysis indicates that the trout are actually obtaining less biomass in these dominant years. Due to the cyclic nature of the sockeye runs older kokanee are still the dominant food source in the non-dominant years but there are indications that the sockeye runs in these years are also building due to decreased harvest rates (Fig. 2). In addition, the last two sockeye brood years (2001 & 2002) are the largest ever observed to Quesnel Lake and may be at pre-fishery levels. These escapements have conflicting effects on the lake's ecosystem and kokanee in particular. They have increased primary production (Ken Shortreed, DFO Cultus Lake, pers. com.) but have also increased the abundance of juvenile sockeye salmon and thus could potentially enhance kokanee production via lake enrichment and inhibit kokanee production through increased competition. Depending on how these influences balance out there may be net detrimental or beneficial effects on kokanee growth and survival, however all indications to date are that the effect on kokanee is negative. Increases in sockeye abundance up until the 1997 dominant brood year did not cause a measurable increase in primary productivity and information to date indicates they had a negative effect on kokanee production. The 2001 and 2002 escapements are nearly double those encountered in this study and have increased primary production by 1.5 times. At the same time juvenile sockeye populations to date have not exceeded 65 million fall fry, indicating that there may be no further increases in competition from sockeye fry. Limnological and pelagic fish data collected in 2003 and 2004 may provide insights into the interactions of these bottom-up and top-down processes and their effects on sockeye and kokanee survival as well as rainbow trout diet and growth.

CONCLUSIONS

Kokanee

1. Two separate and apparently reproductively isolated stocks of kokanee inhabit Quesnel Lake. Stream spawning stocks utilized lower reaches of the Horsefly, Mitchell and Little Horsefly rivers, Wasco Creek and many smaller streams. They typically spawn during September and early October. Shore spawners spawn much later during late October through November and utilize very specific shoal areas in the North and East Arms of Quesnel Lake.

2. Considerable work was carried out on Quesnel Lake kokanee by the International Pacific Salmon Fisheries Commission throughout the 1950s and 60s. For this early period spawner abundance estimates have been pieced together for stream but not shore spawning stocks. Spawner counts have been very limited since this time.

3. Information on shoal spawning kokanee is intermittent and subjective although it appears these fish were numerous in the 1950s and 60’s, 80s and early 2000s. There is no information to suggest that shore spawner abundance has changed.

4. Kokanee stream spawners are easier to enumerate and therefore are more reliable than shore spawner estimates. Although data is limited, stream spawners probably numbered in the order of 50,000 - 100,000 from the 1950’s through the 80s. In the last two decades stream spawners have virtually disappeared and habitat degradation does not appear to be the cause.

5. Biological information from trawl surveys from the late 1980s to the present time suggests kokanee size and size-at-age in Quesnel Lake is similar to other large lakes. There are three or four age groups rearing in the lake and the majority of fish spawn at age 3+.

6. Acoustic surveys were useful in estimating the total pelagic fish population in Quesnel Lake. Concurrent trawling verifies that the large majority of fish found in pelagic habitat at night are *O. Nerka* (either juvenile sockeye or kokanee).

7. In-lake nerkid population estimates since the early 1990s have ranged from 4-65 million late summer. The vast majority are sockeye fry, especially following the dominant and subdominant sockeye cycle.

8. Acoustic size distributions were used for separating age 1-3 kokanee from age 0+ sockeye and kokanee. Disproportionately high numbers of age 0+ fish provide a visible cut-off point (by eye) for separating fry from older fish using acoustic

size distributions. The proportion of age 1-3 kokanee ranged from 1-12% during the three consecutive years of survey, largely a result of changes in the number of sockeye fry.

9. Age 1-3 kokanee abundance was estimated at 600,000 - 800,000 during 1999-2002. The numbers of age 0+ kokanee required to support these numbers were estimated at 900,000 – 1,200,000 based on a typical age structure for kokanee of 60% age 0 to older fish observed in other lakes.

10. Strontium analyses appears feasible for separating kokanee from sockeye in Quesnel Lake at the juvenile stage, however, the technique is fairly costly and remains developmental at this time. Despite a very small sample size, the ratio of non-anadromous to total *O. nerka* in 2000 suggested a kokanee fry population of 0.9 million for Quesnel Lake. This was similar to the 0.9-1.2 million kokanee fry estimated by applying a 60% fry "biostandard" to the acoustic age 1-3+ kokanee estimates.

11. The total kokanee population appeared to be relatively stable at 1.5 – 2.2 million during 1998 -2002 despite large fluctuations in the numbers of juvenile sockeye (e.g. 4-65 million) over the same period. These estimates are appreciably lower than similar sized lakes such as Arrow Lakes Reservoir, Kootenay Lake and even Okanagan Lake where kokanee numbers are severely depressed.

12. The current spawning population of kokanee is estimated at 75,000 - 150,000 using biostandards of survival developed on Kootenay Lake and Arrow Reservoir. In the absence of any observed numbers of stream spawners it is apparent that the majority are shore spawners.

13. Acoustic data from the early 1990s suggested in-lake kokanee numbers were in the order of 3.5 million and a spawning population of about 175,000 - 245,000 fish. Declines in kokanee appear to be in the order of 37-57% over the past decade suggesting a decline in spawner numbers of 65,000 – 140,000.

14. Recent anecdotal information from anglers supports the notion that kokanee numbers have declined significantly. In contrast, kokanee were the dominant sport fish species captured in the early 1980's but now very few kokanee are caught by anglers. There is no evidence that kokanee size and therefore vulnerability to angling has declined in Quesnel Lake.

15. Sockeye spawner and juvenile populations have increased dramatically over the past two decades concurrent with the decline of stream spawning kokanee. Since kokanee spawning habitat has not deteriorated to any extent it is speculated that kokanee declines must be due to increased competition for food with juvenile sockeye. The most likely explanation for why only stream spawners have declined is related to timing of fry migration to the lake. Stream spawning kokanee spawn later than sockeye and therefore their fry emerge later in the

spring. Quesnel Lake shore spawning kokanee spawn even later than the stream spawners, but their eggs probably experience much warmer incubation temperatures and the fry emerge as early if not earlier than the sockeye fry. This earlier fry emergence may eliminate the size advantage that emergent sockeye fry typically have over stream spawning kokanee.

Rainbow

15. The Horsefly River is the most important tributary for spawning and rearing of Quesnel Lake rainbow followed by the Mitchell River. The Quesnel River also supports a population of rainbow although they appear to be river resident fish and therefore do not appreciably contribute to the Quesnel Lake fishery. Smaller non piscivorous stock(s) most likely exist in Quesnel Lake similar to Kootenay, Arrow and Shuswap lakes.

16. Rainbow trout spawners in the Horsefly and Mitchell rivers currently range from 40 – 80cm fork length and are from five to ten years of age. Age at maturity is typically 6 or 7 years. Spawner size and size-at-age appears to be similar in the Horsefly and Mitchell rivers.

17. There are two migrations of rainbow from Quesnel Lake into the Horsefly and Mitchell rivers each year. The spawning run occurs during April and May. At this time pre-spawners and non spawners stage off the mouths of the rivers feeding on newly emerged sockeye fry. A second "feeding" migration occurs during July to September and includes a large component of smaller immature fish (age 3+ to 5+) and small numbers of larger fish seeking aquatic vertebrates, sockeye eggs and flesh from sockeye carcasses.

18. The average size of rainbow caught in Quesnel Lake has declined over the past decade. Limited data indicates the growth rate has also declined significantly during this period.

19. The importance of O. nerka in Quesnel Lake rainbow diet was confirmed through analysis of stomach samples (1988-94). Age 1 and 2 kokanee were clearly the most important component in rainbow diet following non-dominant and sub-dominant sockeye runs. Sockeye fry were by far the most numerous in rainbow stomachs following a dominant sockeye run, however the biomass of age 1-2 kokanee was still significant. The most interesting result was that the mean total biomass of *O. nerka* eaten actually declined as sockeye fry numbers in the lake increased. The lower biomass was due almost entirely to the lower numbers of age 1-2 kokanee eaten during dominant sockeye years. This appears to explain how rainbow growth can decline while the number of *O. nerka* in the lake continues to increase. Declining numbers of kokanee appear to be responsible for the observed decline in rainbow trout growth rates

20. Overfishing in the 1990s may also have contributed to decreases in the size of rainbow trout. In light of the recent diet analyses, it appears unlikely that restrictive fishing regulations alone will prevent or reverse the trend of declining rainbow size and growth, although more restrictive regulations for large trout may result in more fish surviving to maturity. This trend may be a new reality in the face of restored sockeye runs which appear to have returned to pre-1896 levels (i.e., before mining activities blocked returning sockeye).

21. Evidence from a combination of indirect (juvenile) and direct (adult counting) assessments in Horsefly River suggest the current spawning population is most likely in the order of 500-1000 spawners. Low fry density estimates some years suggest that run-size was likely below 500 fish during the late eighties and early 1990s. The Mitchell River probably supports less than half these numbers.

22. Adult enumeration in 2002 supports the notion that McKinley Creek is an important spawning area for the Horsefly River. It appears to support a large enough proportion of the total run to be a reliable index stream for estimating total annual escapement.

RECOMMENDATIONS

Kokanee

1. Continue on an annual basis with acoustics surveys and conduct trawl surveys following non-dominant sockeye years to improve size at age information on kokanee. Recommend that WLAP conduct acoustic and trawl surveys following low sockeye years and DFO collect the same data using the same methods following the higher return years.

2. Establish the Lower Little Horsefly River and Wasco Creek as index streams for annual kokanee escapement estimates.

3. Establish a minimum of three index sites for shore spawner counts, preferably at those locations that have some historical information (see **Map 1**). Suggest two sites in North Arm and one site in East Arm.

4. Collect stream and lake temperature data at spawning locations to see if peak spawning time can be modeled-this will assist in planning further spawner assessments.

5. Obtain an annual sample of 100 fish for length, fecundity and age data.

6. Conduct a workshop involving researchers who work on other large lakes to identify strategic objectives that would guide future kokanee and rainbow trout assessments.

7. Review the literature and summarize the limnological, phytoplankton and zooplankton data that exists on Quesnel Lake prior to the workshop.

8. The shore spawners should be investigated in greater detail to define where they spawn, depth of spawning and when fry emerge. The work on Okanagan Lake shore spawners (Wilson and Andrusak *in* Andrusak et al. 2003) should be used as a guide.

9. Update this technical report with data obtained in 2003 including additional year of strontium analyses from samples collected in 2001.

Rainbow

16. Continue to monitor Horsefly River escapements using the resistivity counter to enumerate fish in McKinley Creek. Continue the use of external visible tags in order to estimate the proportion of Horsefly River fish which spawn in McKinley Creek.

17. Obtain more growth and age data from spawners entering Horsefly and Mitchell rivers to monitor growth (i.e., size-at-age). The intent is to verify recent findings of reduced size-at-age for rainbow and determine if their size continues to decline.

18. Obtain fecundity data directly from the fishery by collecting female gonads, length, weight and scales from the sport fishery during September—May.

19. Design and conduct a complete creel census in order to determine current catch and harvest rates on Quesnel Lake rainbow (and other species). The creel census should employ local guides to assist in collecting reliable size and age information on released fish.

20. Conduct a more thorough assessment of juvenile habitat and fish density in the Horsefly River and accessible tributaries in 2004 aimed at assessing parr habitat and its level of utilization following a strong fry year in 2003. The intent is to refine estimates of migrant yield presented in Sebastian (1992) by including a parr model which may produce more reliable estimates of migrant capacity.

21. Using Horsefly pre-spawners, conduct some scale analyses directed at determining the dominant age and size of rainbow at the time of lake entry. This

information will help determine whether future juvenile assessments should focus on fry or parr capacity.

22. Consider repeating the diet study conducted by Parkinson et al.(1989) on large piscivorous rainbows if it is determined that the stock can withstand a limited harvest of larger fish. Consider using a non-lethal technique such as stomach pumping to collect further diet data from large rainbow trout.

23. Consider instituting a tag or limited entry draw in future to control the total numbers of large rainbow that will be harvested each year.i.e. KLRT/SLST stamp system. If this system were to be initiated then the creel census should be used to calibrate the survey results.

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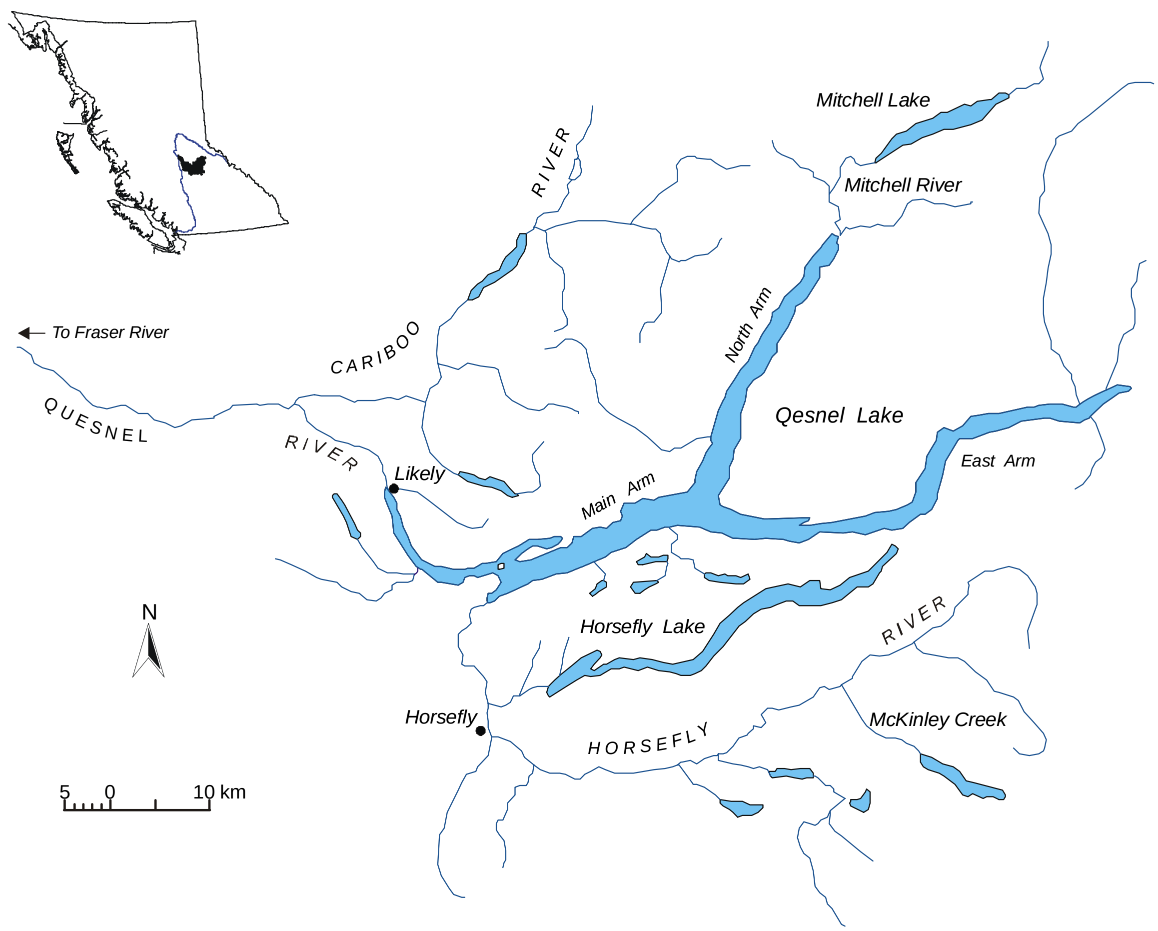


Figure 1. General Location map showing Quesnel Lake and major tributaries.

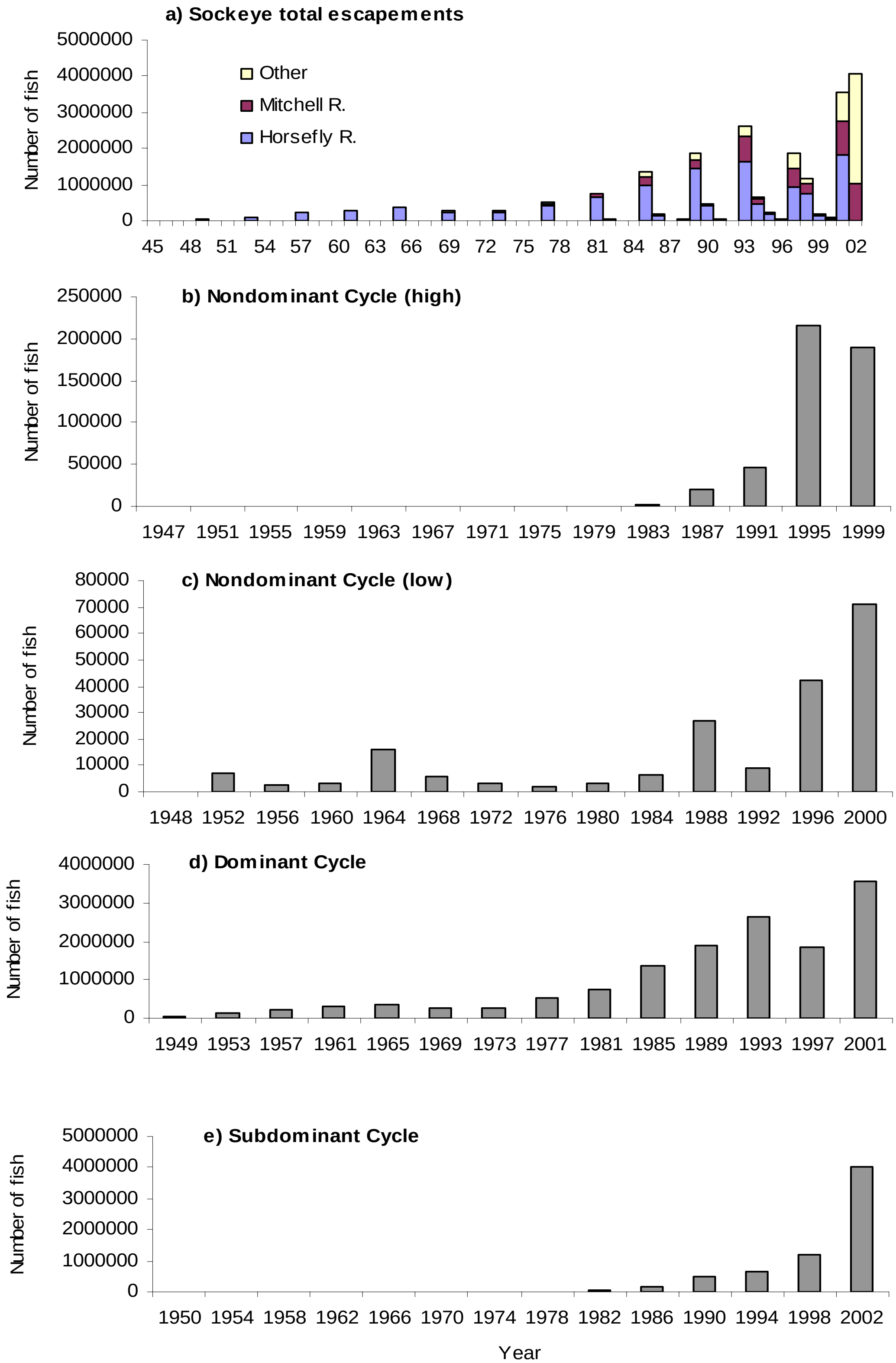


Figure 2. Sockeye escapement to Quesnel Lake system showing annual estimates and trends by four year cycles.

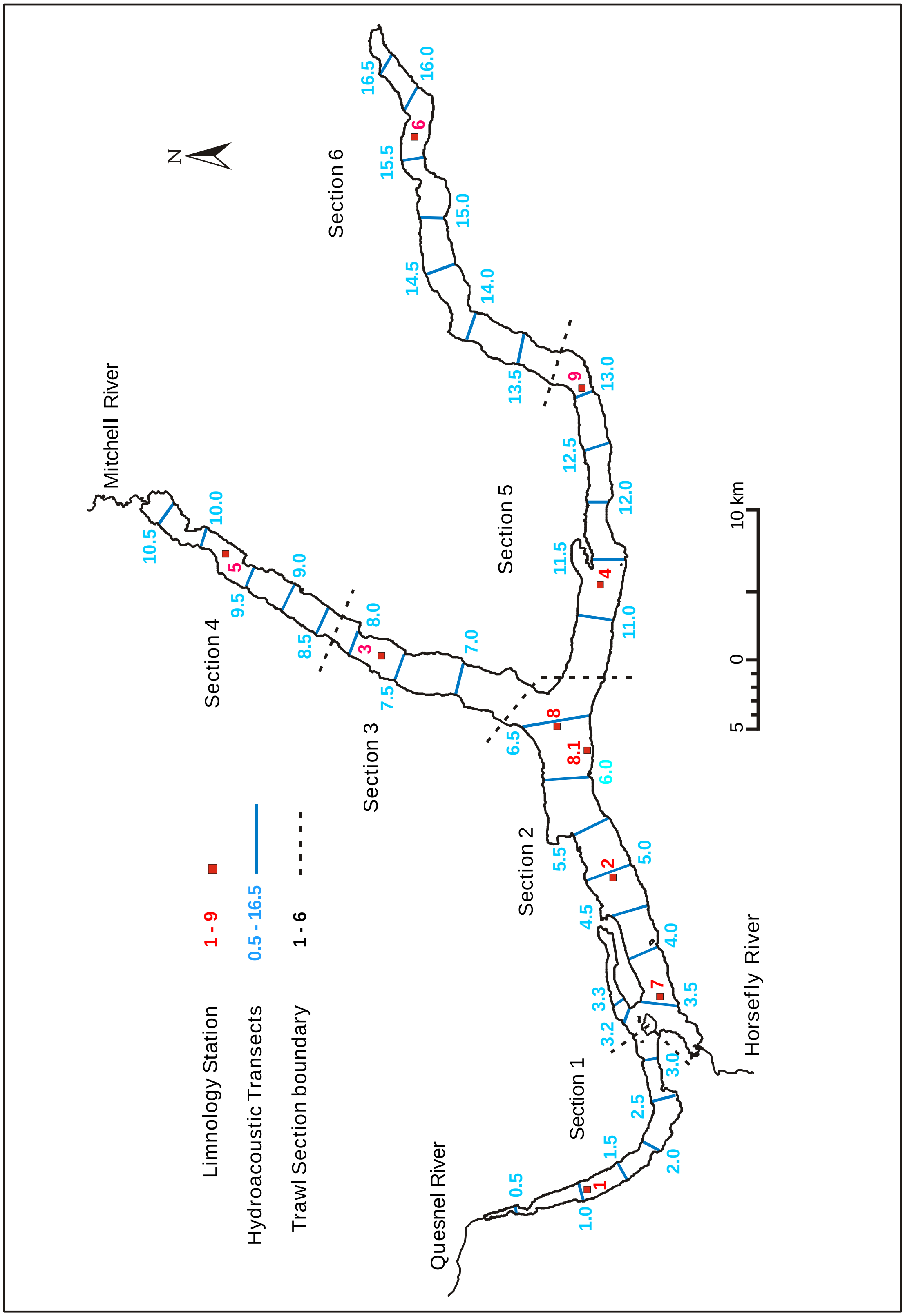


Figure 3. Map of Quesnel Lake showing hydroacoustic transects and DFO section boundaries. Source: J. Hume, DFO.

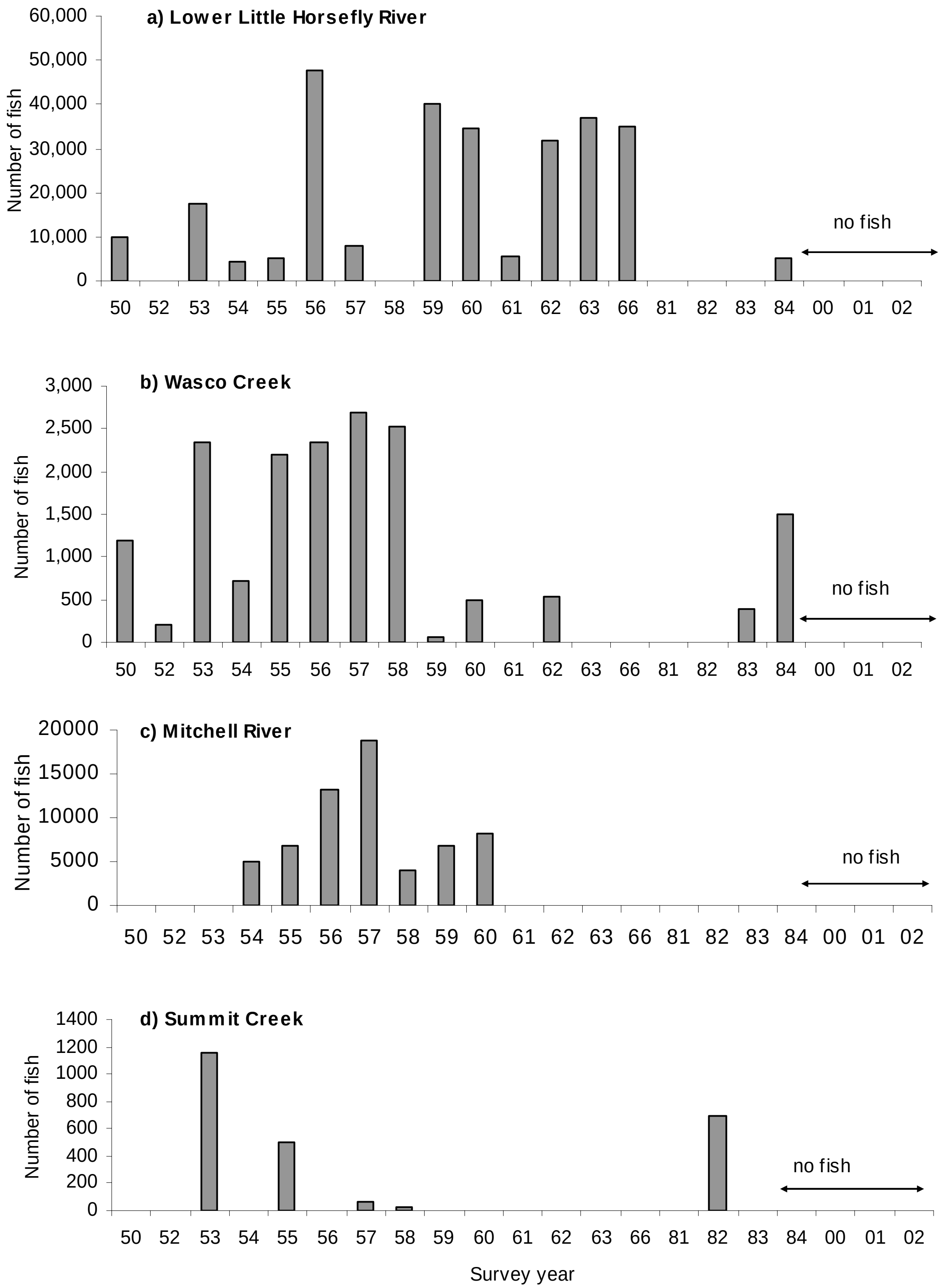


Figure 4. Kokanee peak counts from a) Wasco Creek, b) Lower Little Horsefly River, c) Summit Creek and d) Mitchell River. Data for 2000-2002 that indicates no fish is based on multiple counts of <10 fish in each system each year.

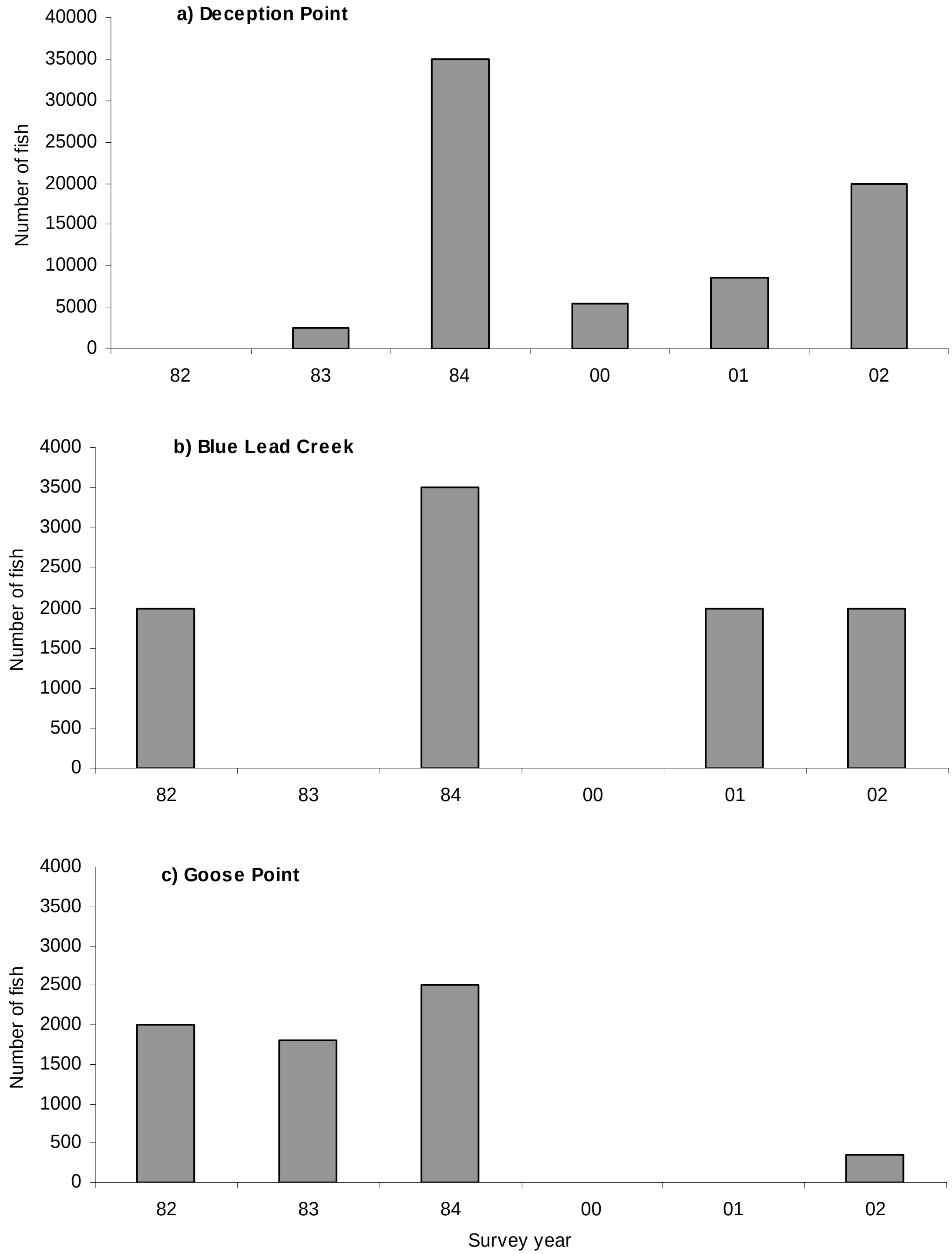


Figure 5. Shore spawning kokanee peak counts for a) Deception Point, b) Blue Lead Creek, and c) Goose Point. Source: Prest (1983), Lemp and Englund (1984) and Provincial fisheries file data (2002).

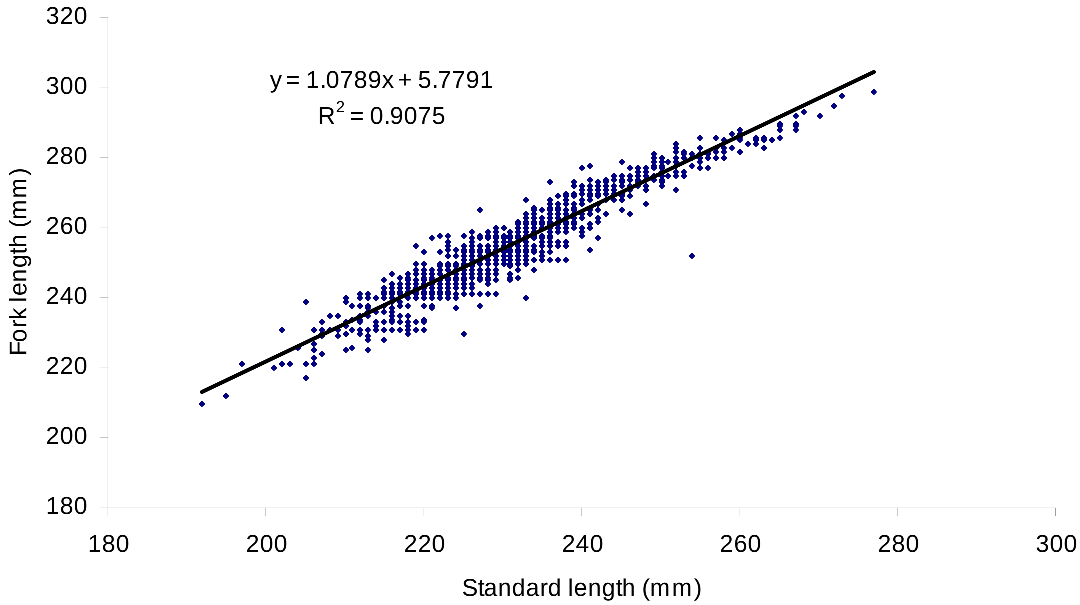


Figure 6. Regression of fork length on standard lengths for Quesnel Lake stream spawning kokanee. N=1224. Source: IPSC file data for 1946, 1953, 1954 and 1956.

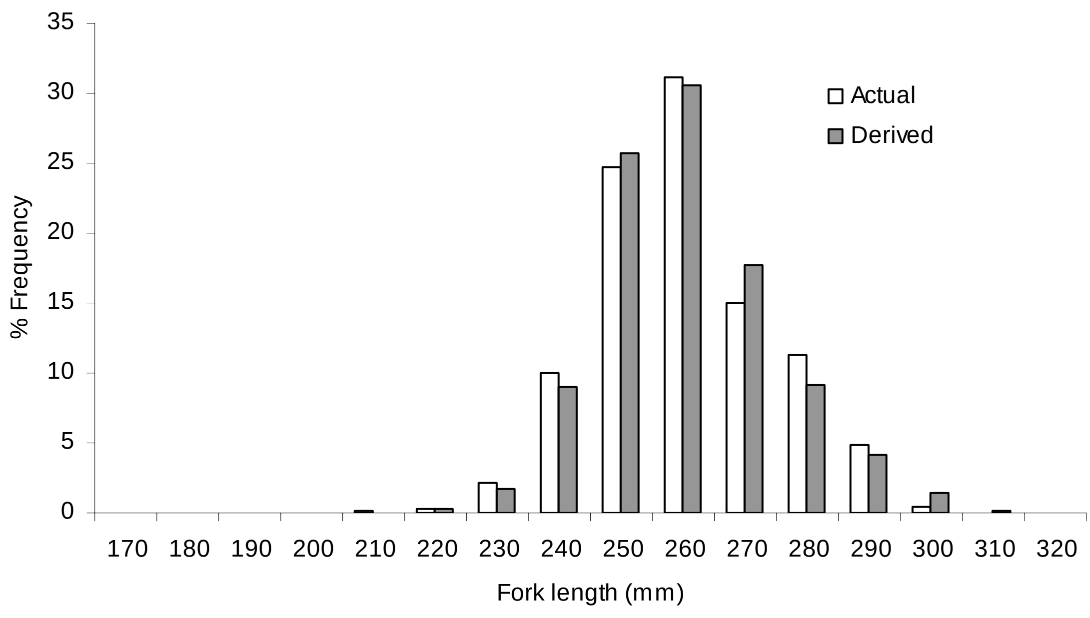


Figure 7. Comparison of actual and derived fork lengths for 1224 Quesnel Lake kokanee sampled from tributary streams.

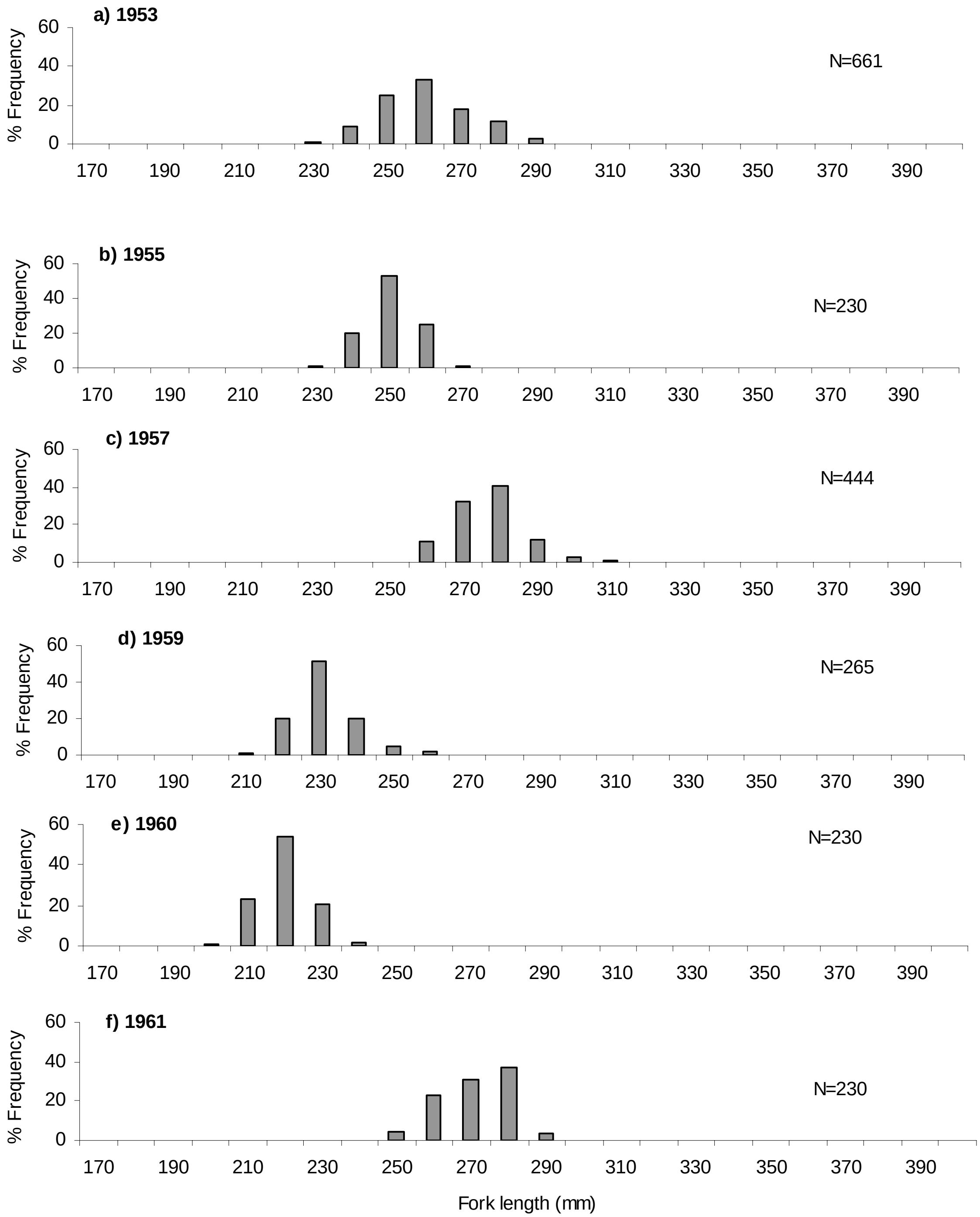


Figure 8. Length frequency plots of kokanee spawners from Quesnel Lake streams (primarily Wasco and Summit Creeks) during the 1950s and early 1960s.

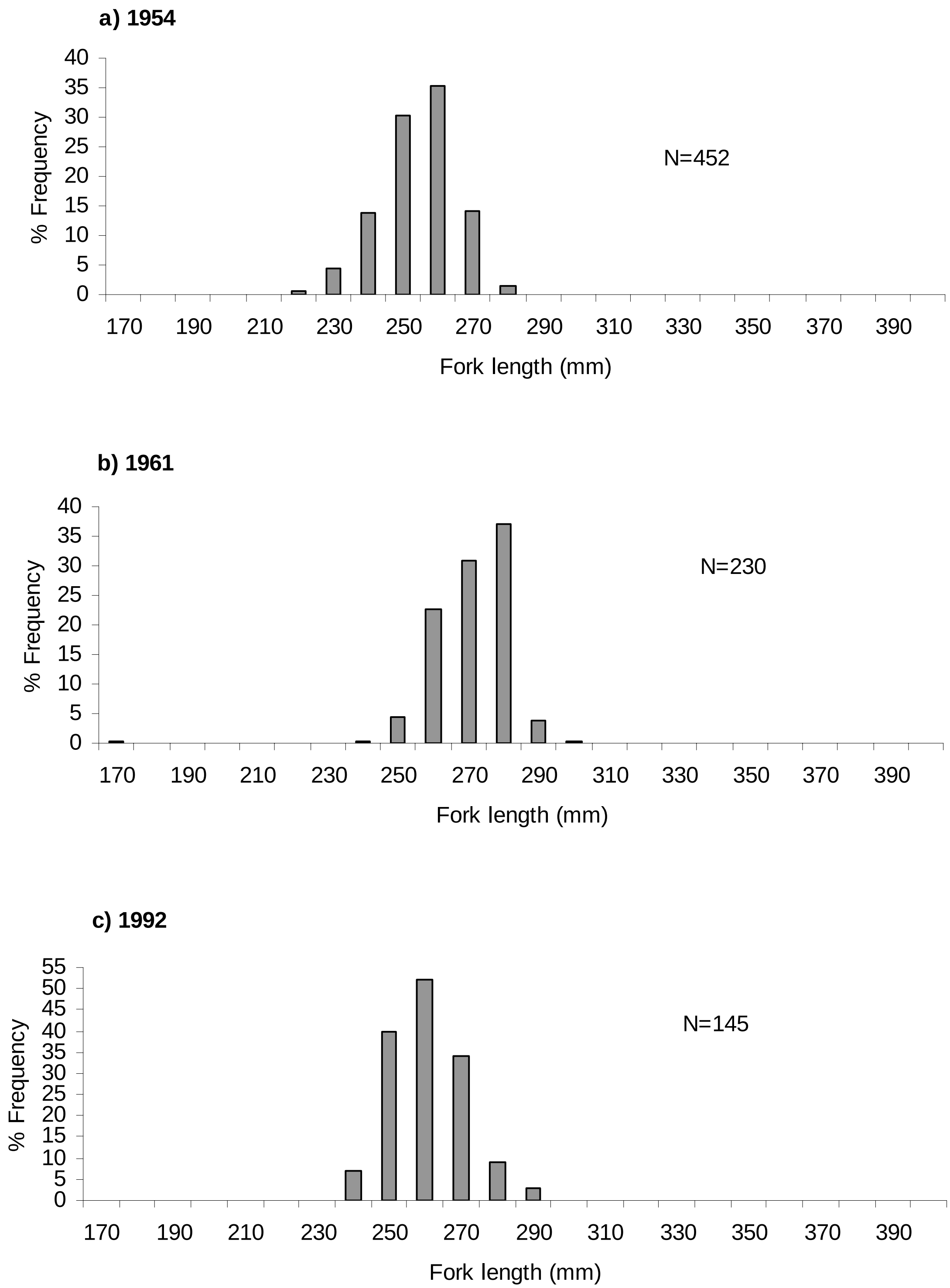


Figure 9. Length frequency plots of kokanee spawners from Quesnel Lake streams (primarily Wasco and Summit Creeks for 1954); data from Lower Little Horsefly River in 1961 and shore spawners (Blue Lead Creek and Deception Point) in 1992.

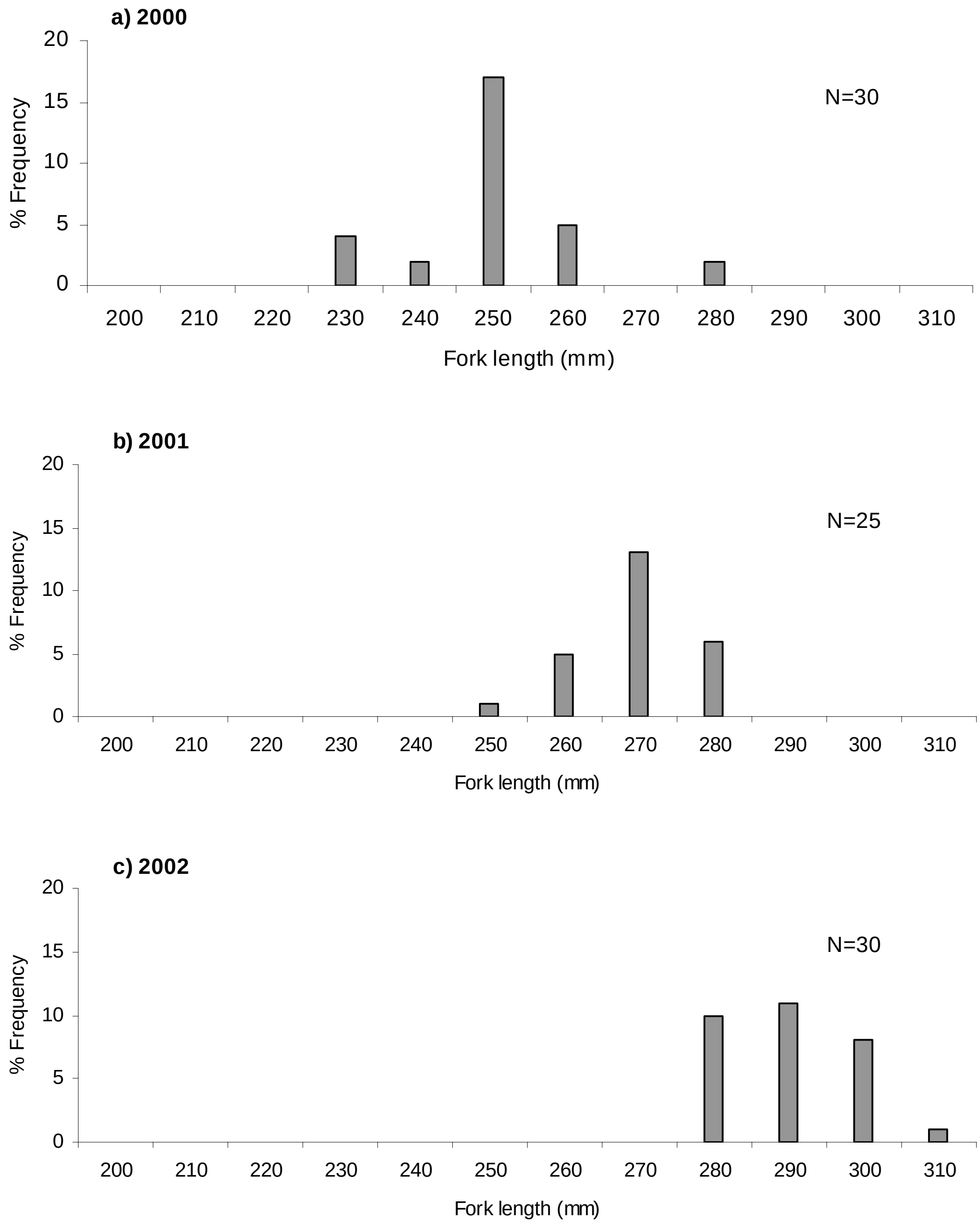


Figure 10. Length frequency plots of Quesnel Lake shore spawning kokanee during 2000-2002.

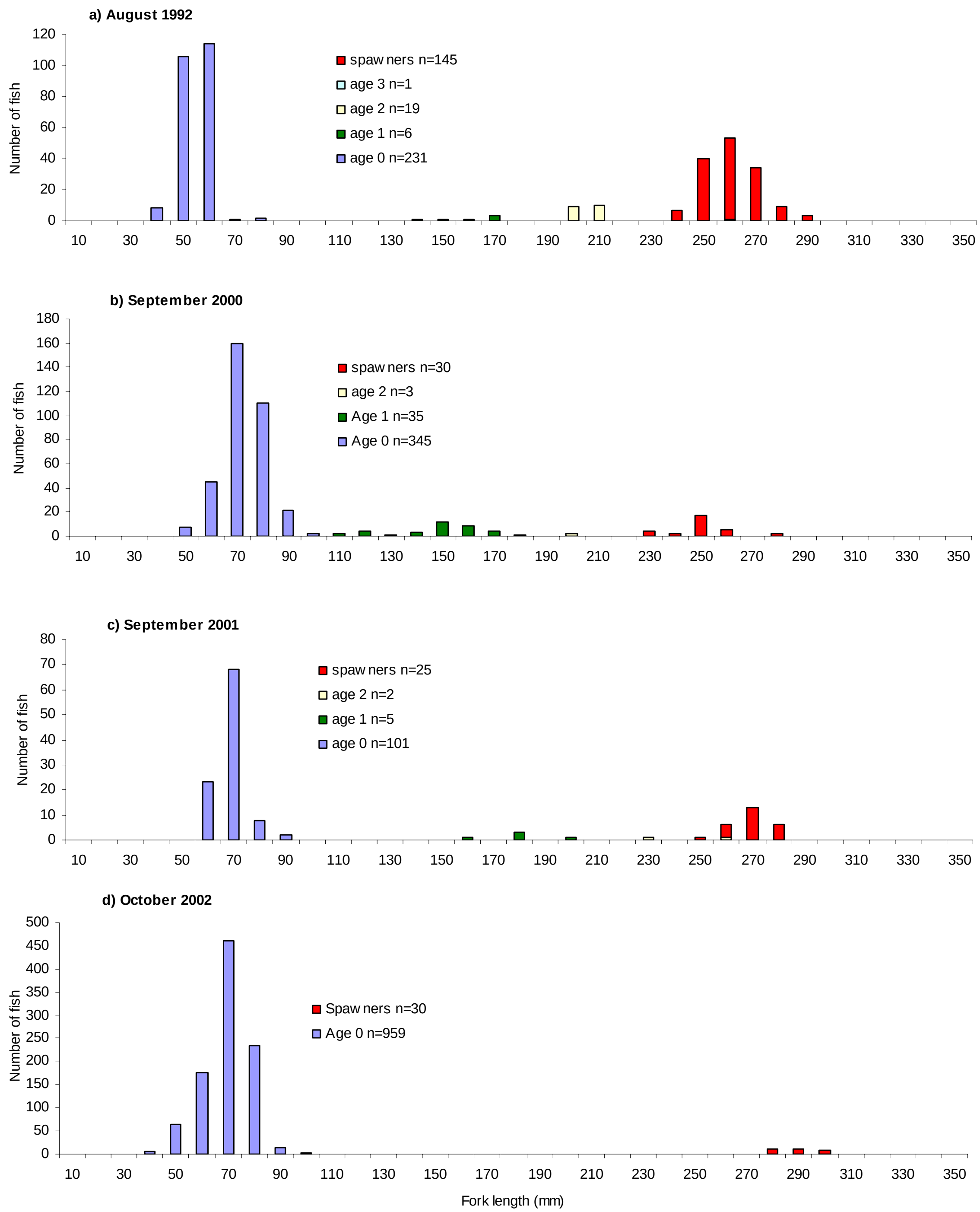


Figure 11. Length frequency distribution of trawl caught sockeye and kokanee and shore spawning kokanee from Quesnel Lake during 1992 and 2000-02.

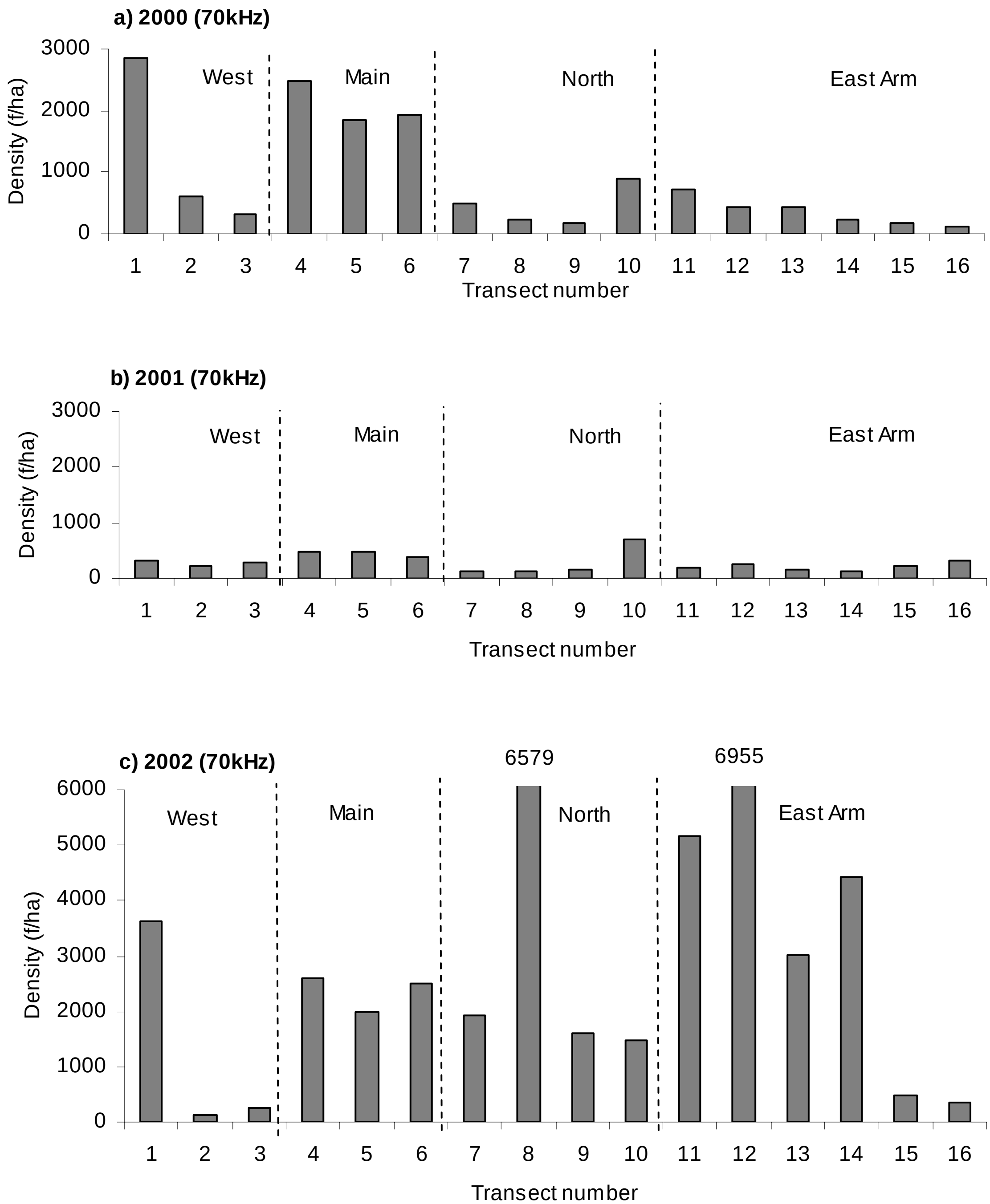
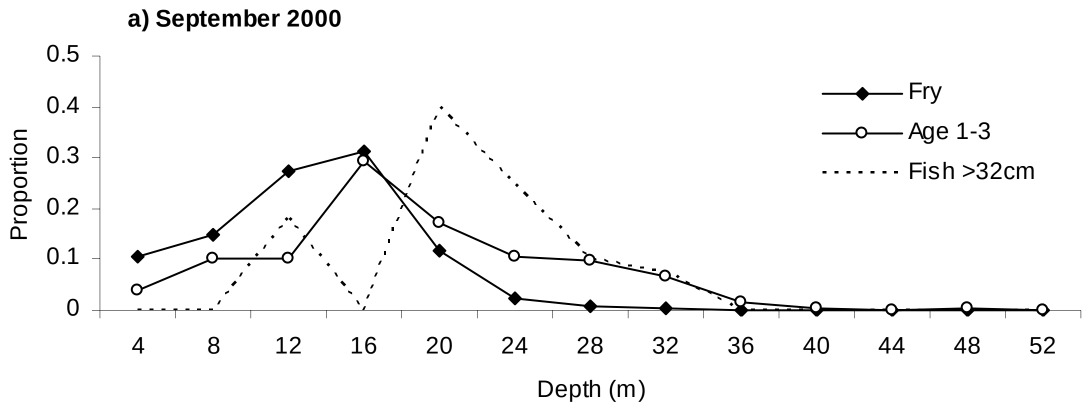
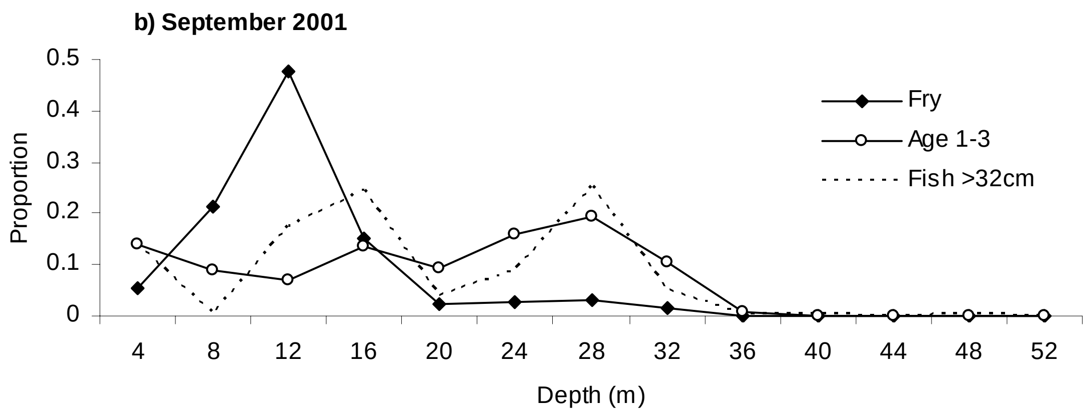


Figure 12. Longitudinal density distributions of sockeye and kokanee determined by 70kHz hydroacoustic sampling in Quesnel Lake 2000-2002. Note the difference in y axis scale between the non-dominant years (2000, 2001) and dominant year (2002).





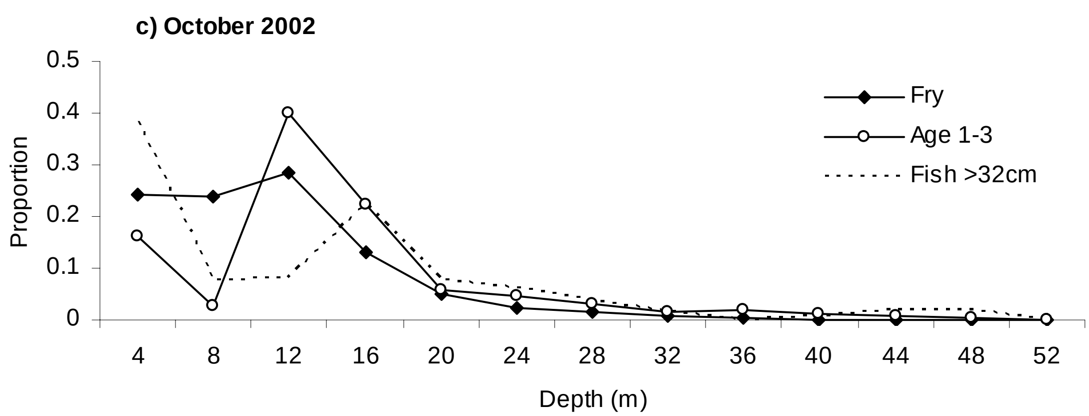


Figure 13. Proportion by size (age) by depth of nerkids and other large fish in Quesnel Lake 2000-2002.

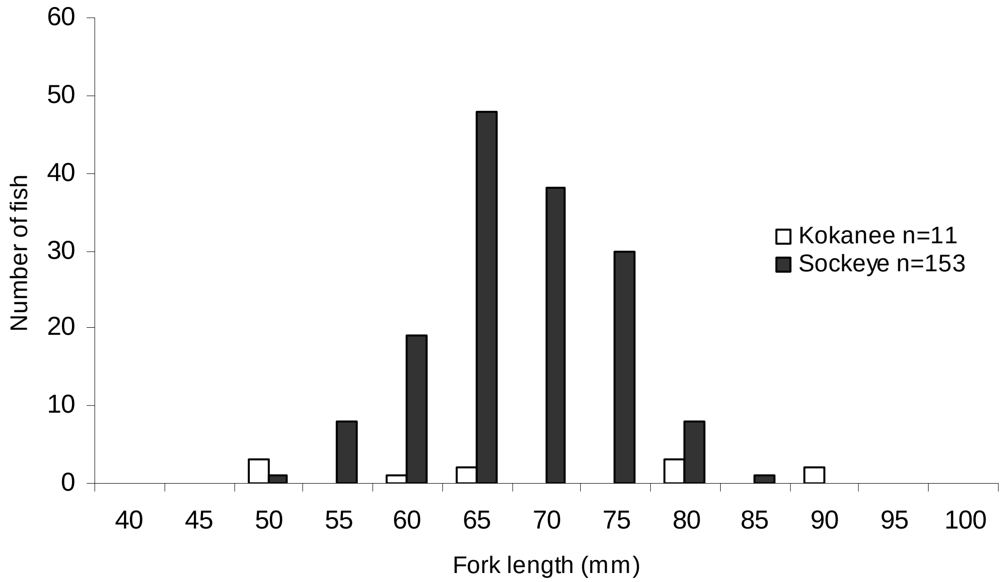


Figure 14. Length frequency distribution of Quesnel Lake trawl caught age 0 kokanee and sockeye in September 2000 based on strontium analyses. Source: Volk (2002).

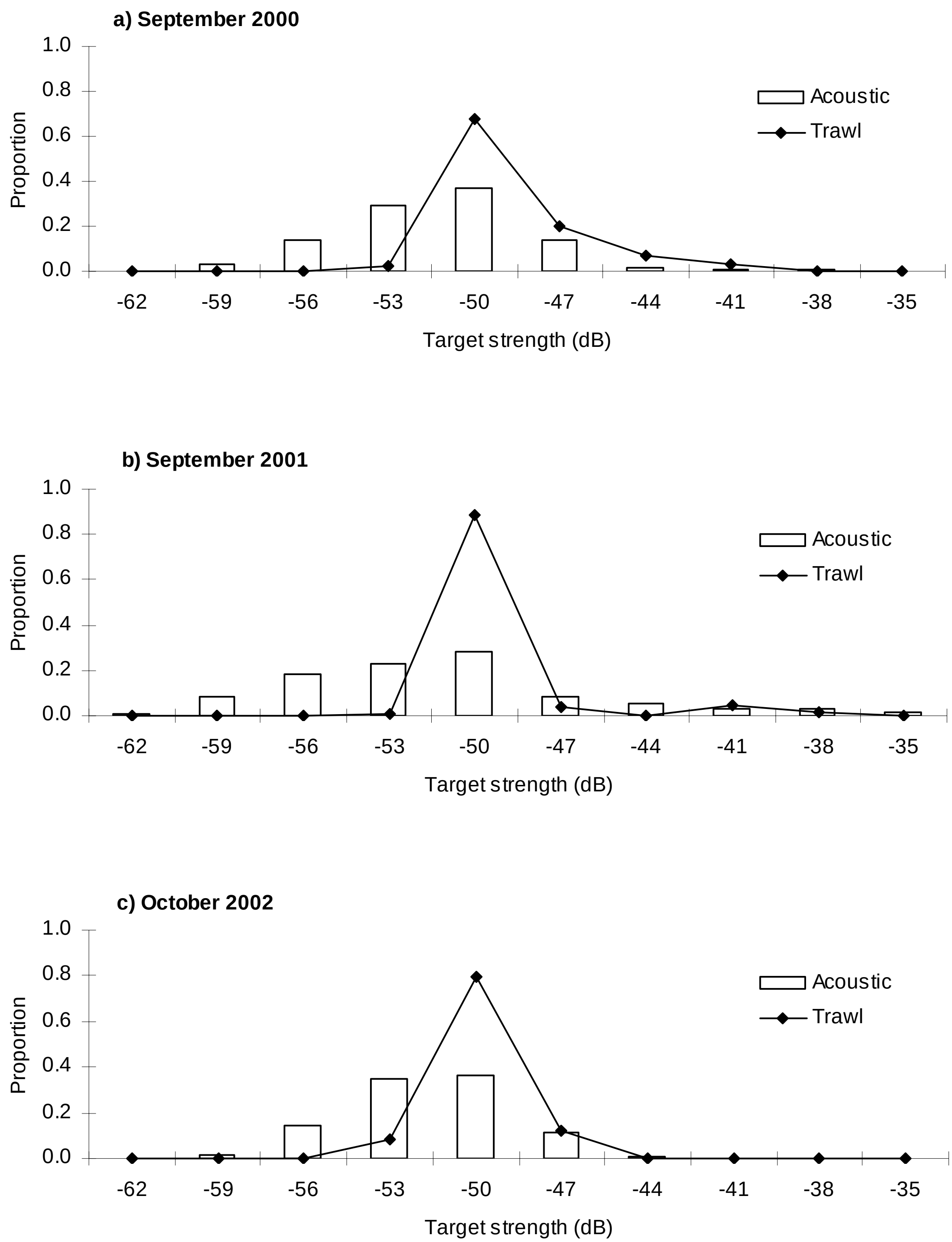


Figure 15. Comparison of fish size distributions from 70 kHz acoustic analyses and trawl surveys on Quesnel Lake from 2000-2002. Note: Love's (1977) dorsal-aspect formula was used to convert fish size in millimeters to the acoustic scale (decibels).

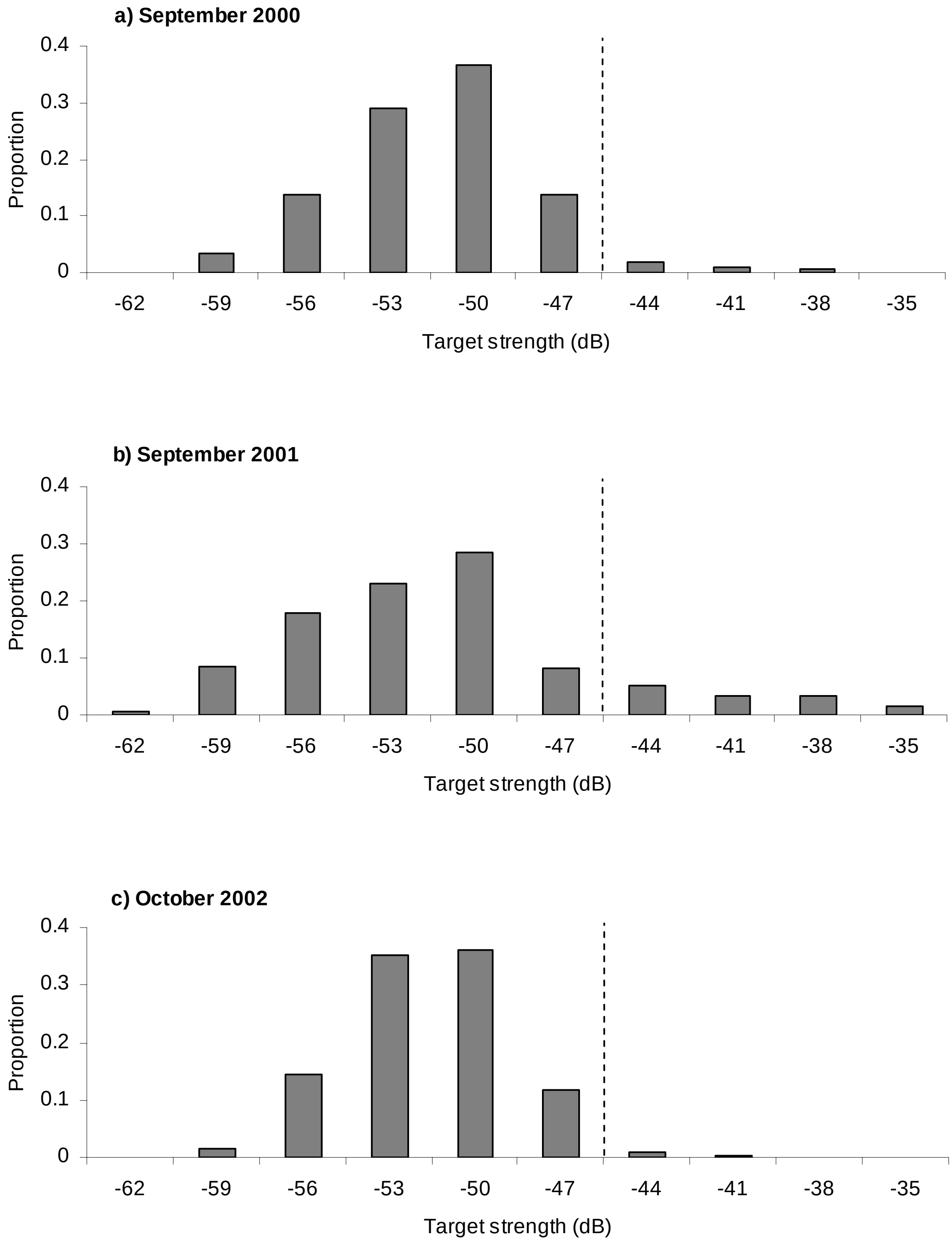


Figure 16. Acoustic size (target strength) distributions for 70kHz data showing cut-off points applied to distinguish age 0+ from older fish in Quesnel Lake, 2000-2002.

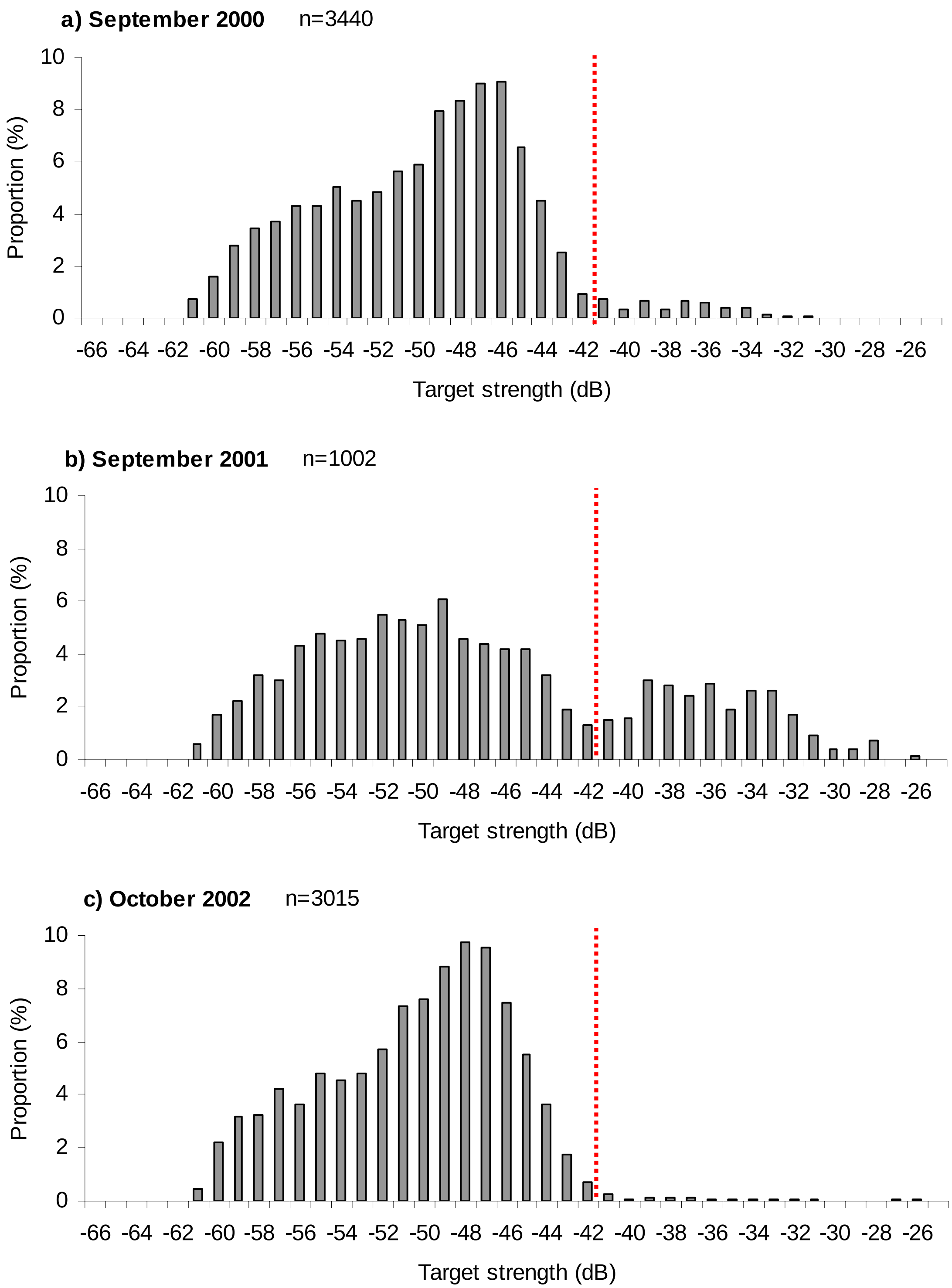


Figure 17. Target strength distributions for tracked targets based on 120kHz split beam data for 2000-2002 surveys in Quesnel Lake, showing cut-off between age 0+ and older fish.

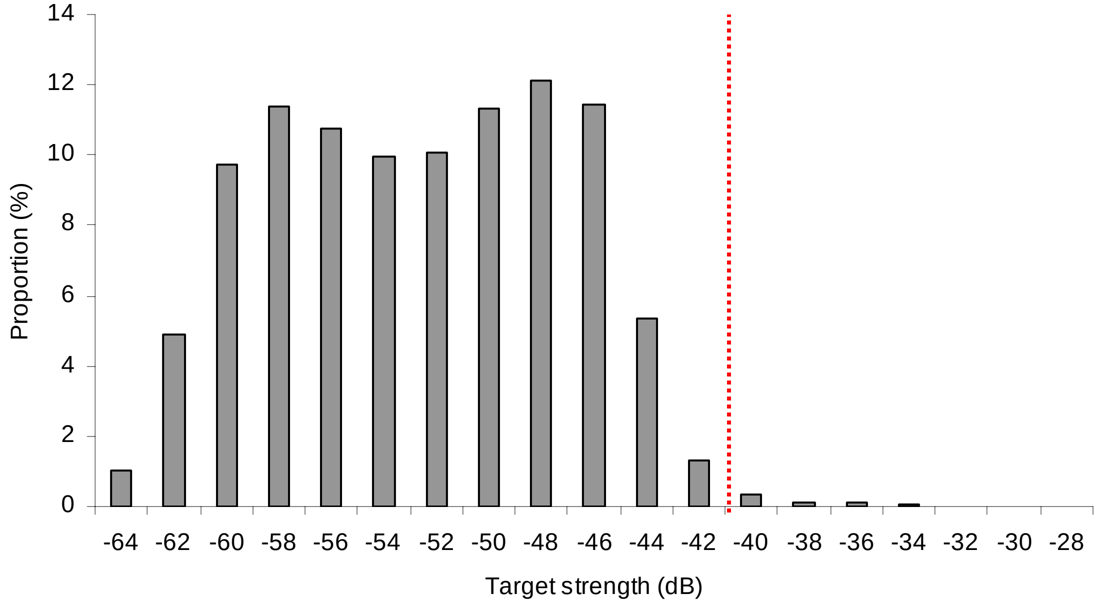


Figure 18. Target strength distributions for tracked targets based on 200kHz DFO split beam data for the October 2002 survey in Quesnel Lake showing cut-off between age 0+ and older fish.

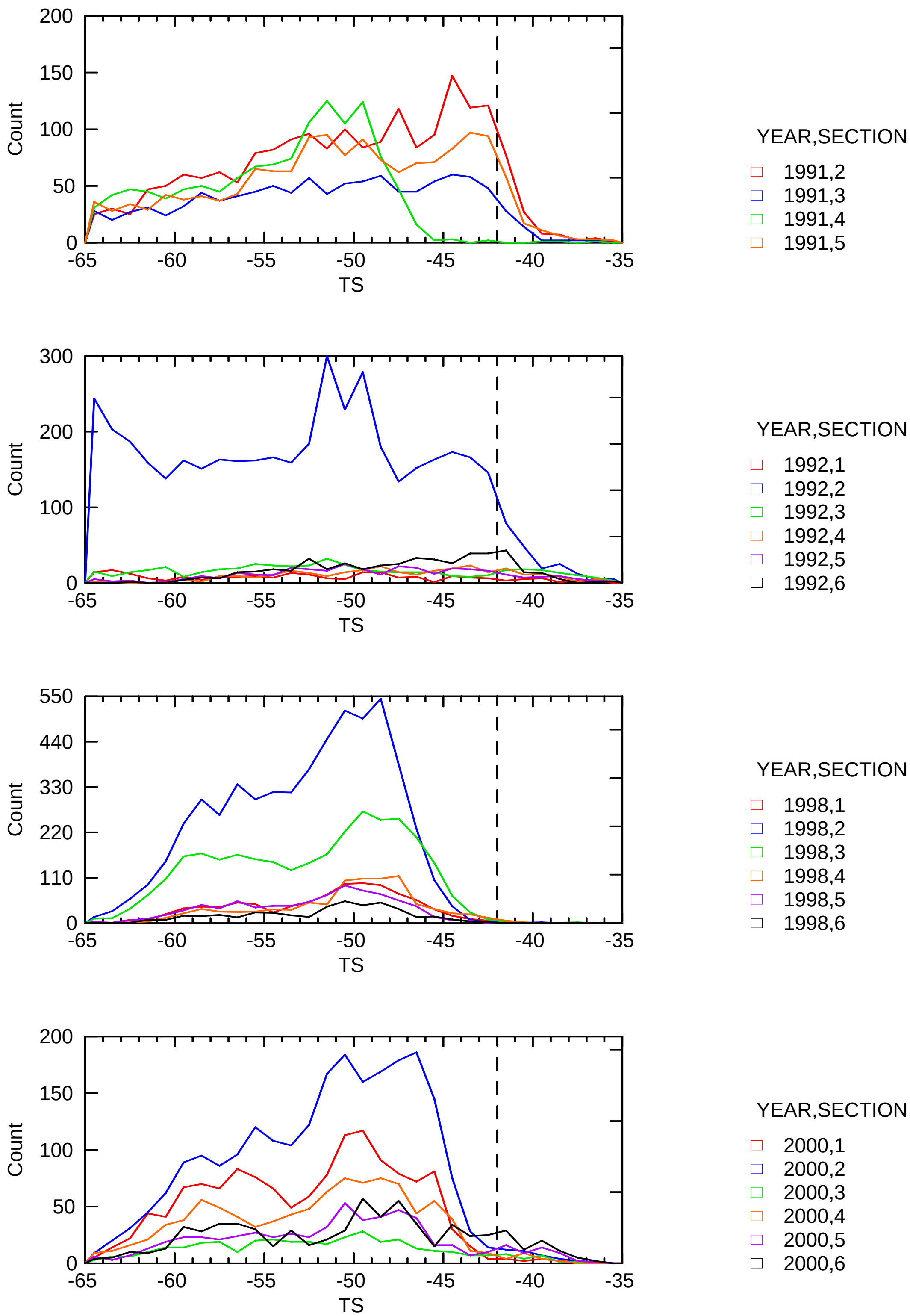


Figure 19. Target strength distributions for 420kHz DFO data on Quesnel Lake showing fixed Target Strength cut-off at -42dB from Stables (2001).

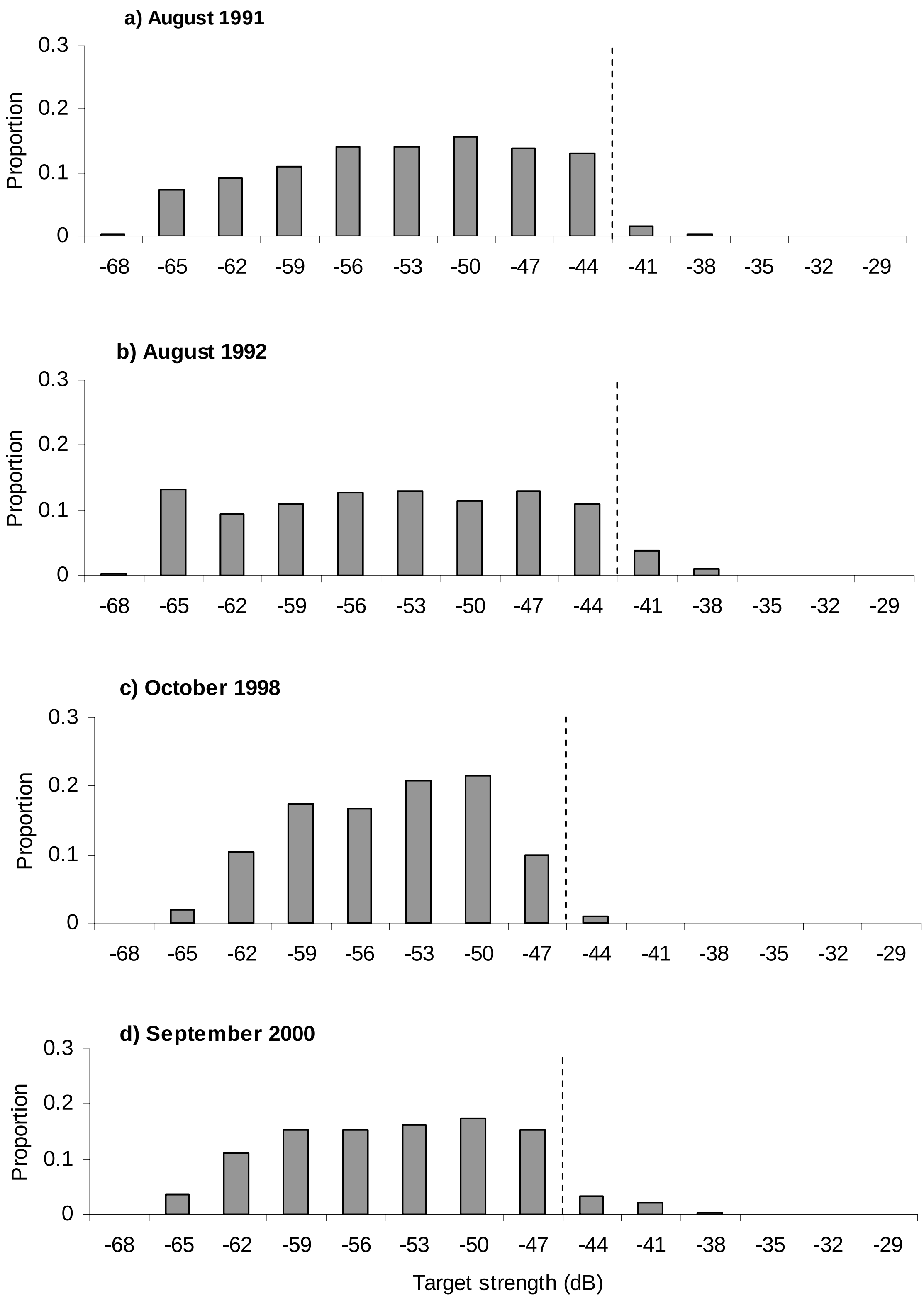


Figure 20. Revised TS distributions for 420kHz DFO data on Quesnel Lake grouped into 3dB bins and showing best fit cut-off by eye to separate age 0+ from older fish.

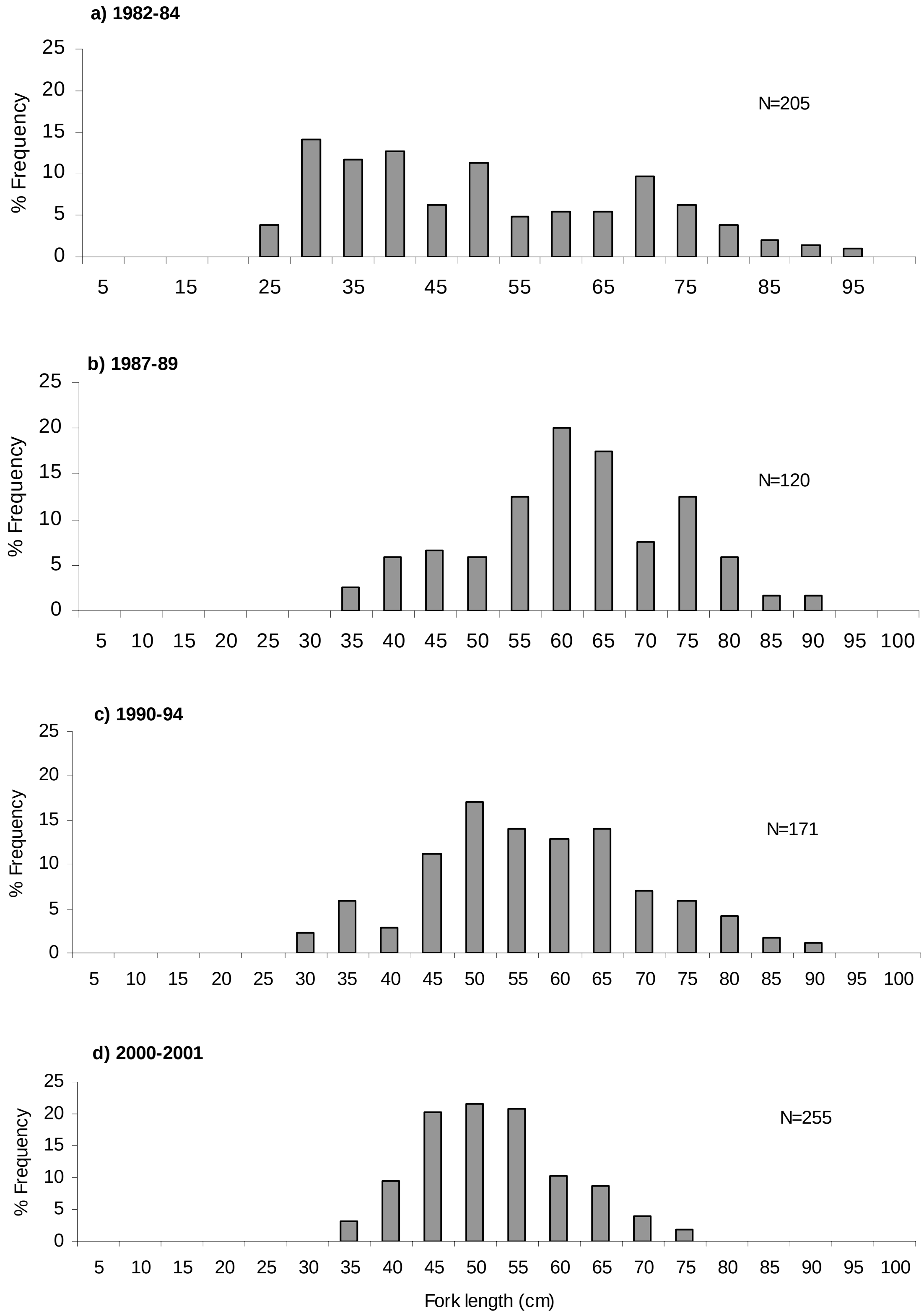


Figure 21. Percent frequency occurrence of Quesnel Lake rainbow trout captured in the sport fishery from May-September during the 1980s, early 1990s and early 2000s.

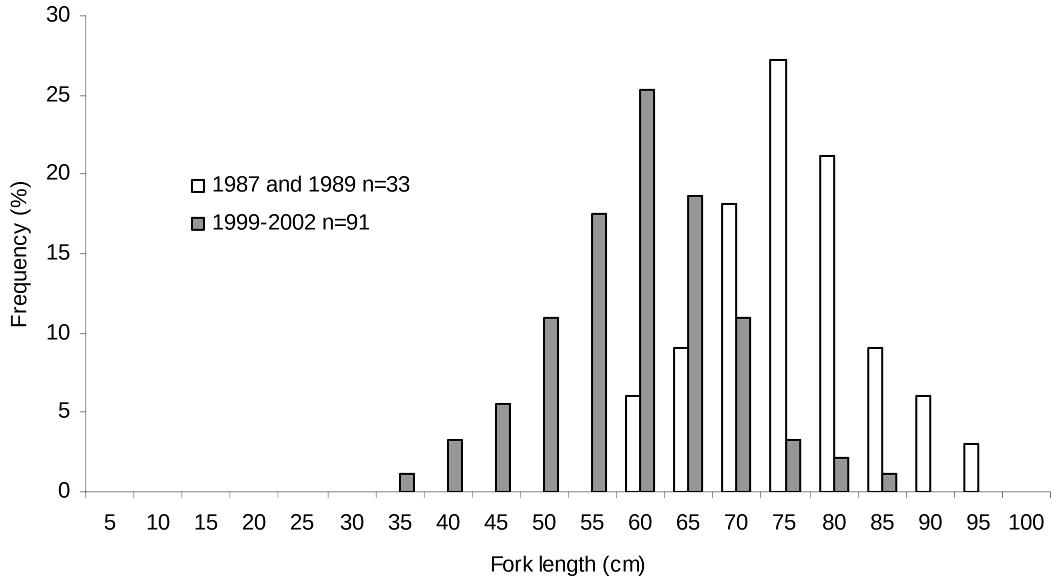


Figure 22. Comparison of spawner length frequency for Horsefly River rainbow trout during two time periods: 1987 & 1989 and 1999-2002.

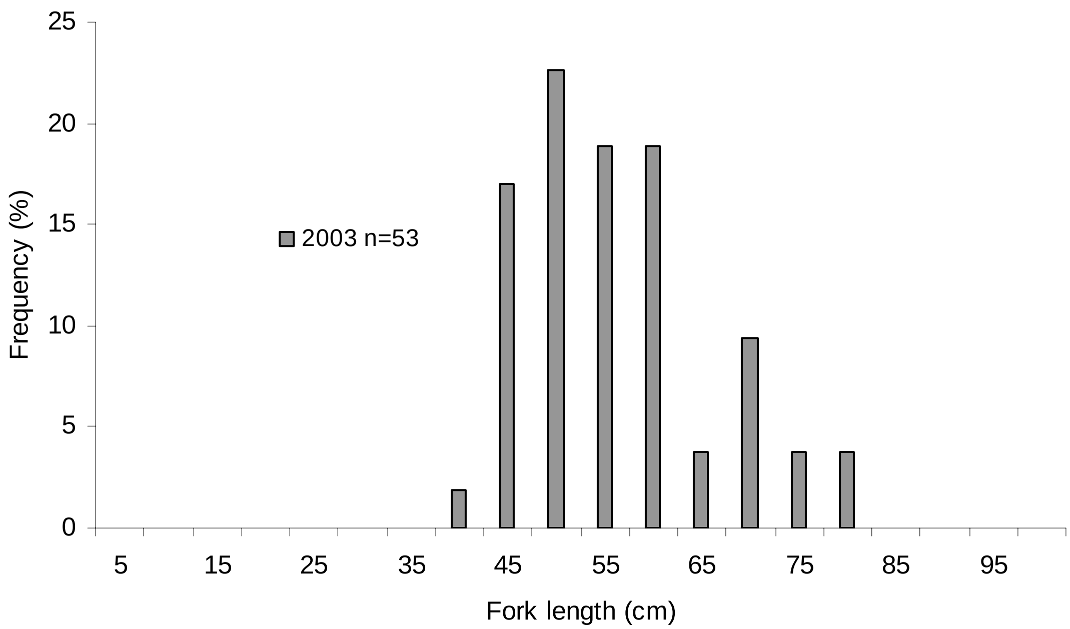


Figure 23. Spawner length frequency for Horsefly River rainbow trout captured in 2003.

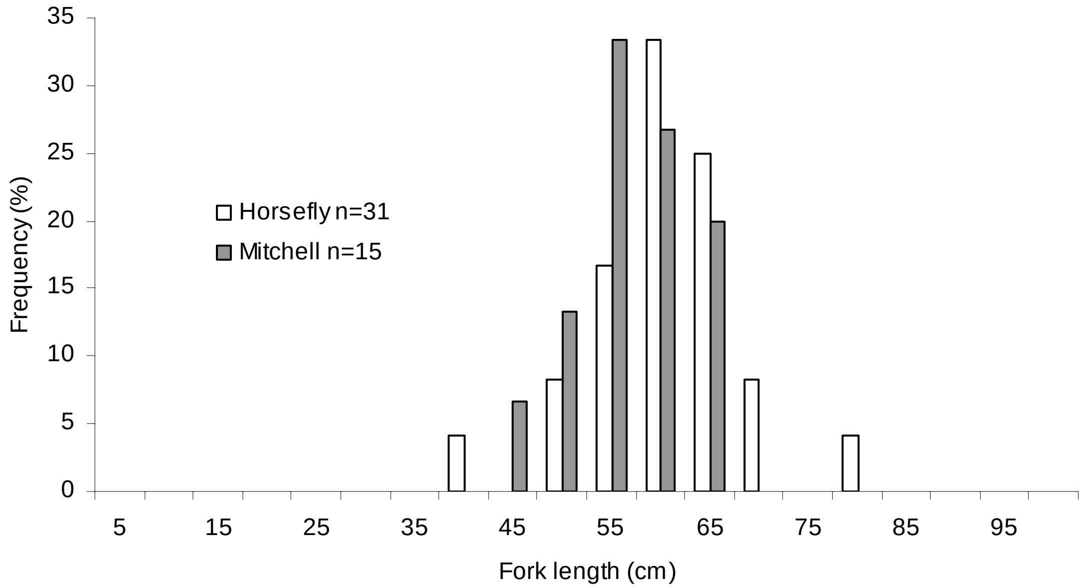


Figure 24. Comparison of length frequency distribution between Horsefly and Mitchell River spawning rainbow trout captured in 2000.

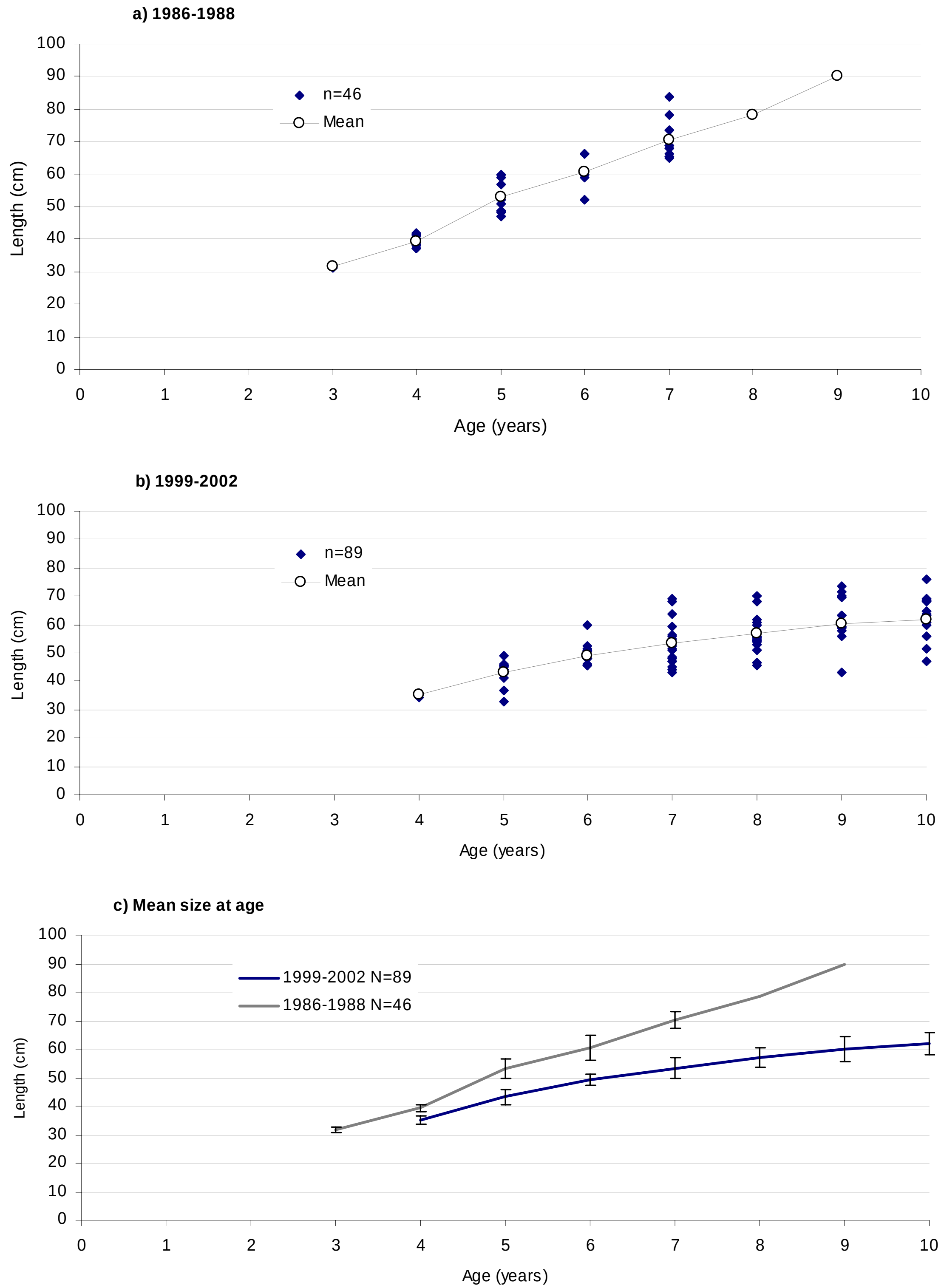


Figure 25. Length-at-age of spawning rainbow trout captured in the Horsefly River in a) 1986-1988, b) 1999-2002 and c) comparison of means with 95% confidence limits for the two time periods.

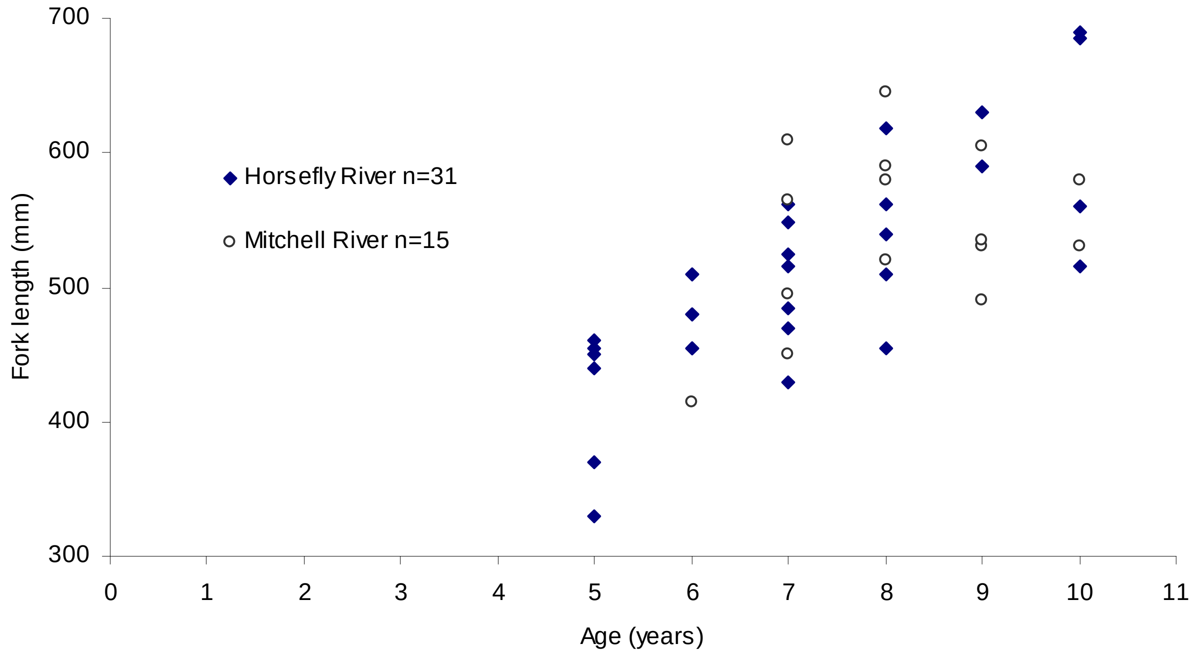


Figure 26. Comparison of length-at-age between Horsefly River and Mitchell River spawning rainbow captured by angling in 2000.

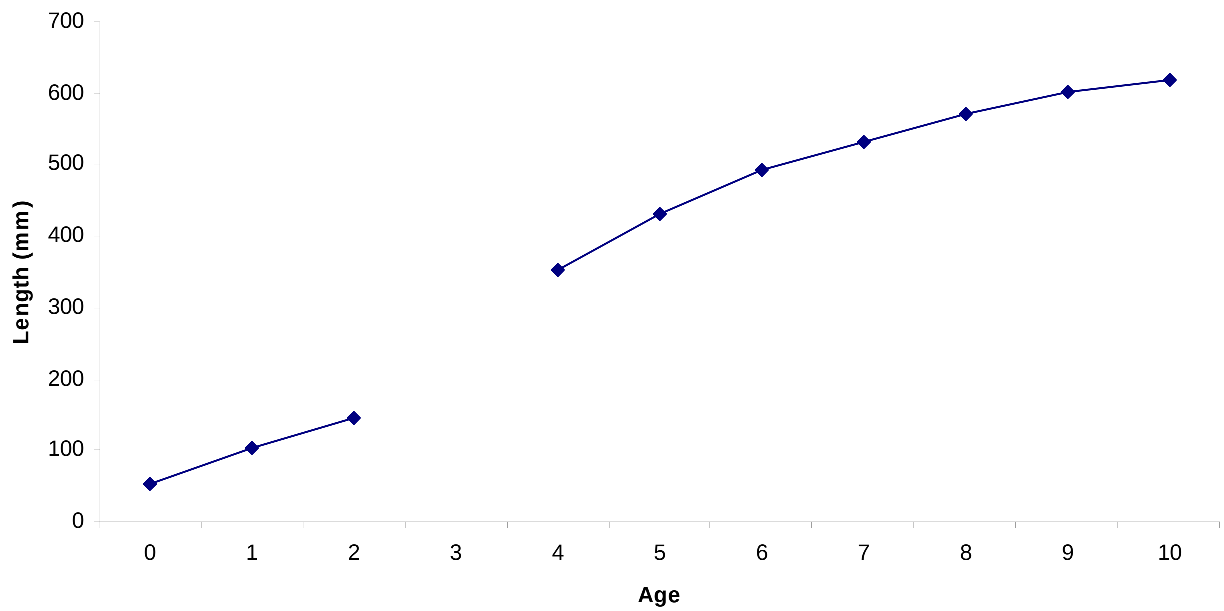


Figure 27. Mean size-at -age of Horsefly River juvenile (1987-89) and adult rainbow trout (1999-2002).

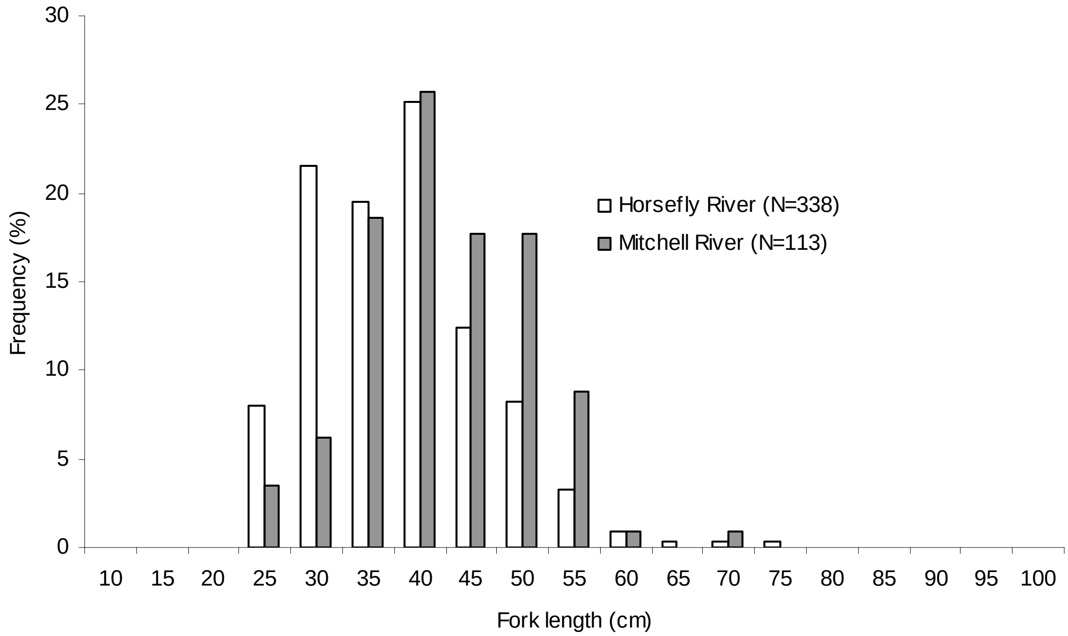


Figure 28. Percent frequency distribution of non-spawning rainbow trout captured in the Horsefly and Mitchell rivers from 1986-1988.

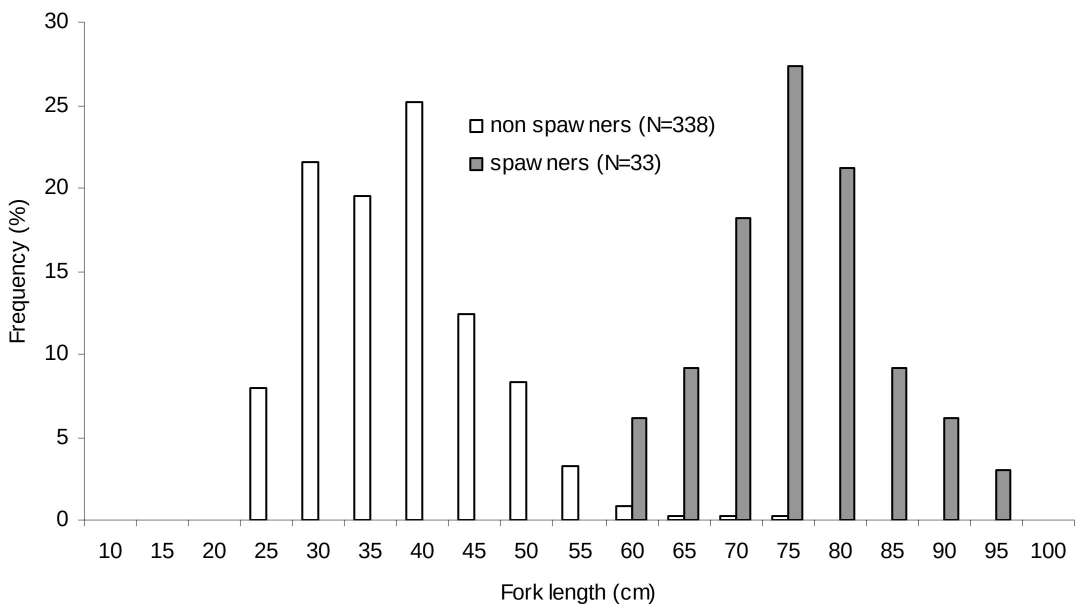


Figure 29. Comparison of length frequency distributions for non-spawning and spawning rainbow trout captured in the Horsefly River in 1986-1988 and 1987, 1989 respectively.

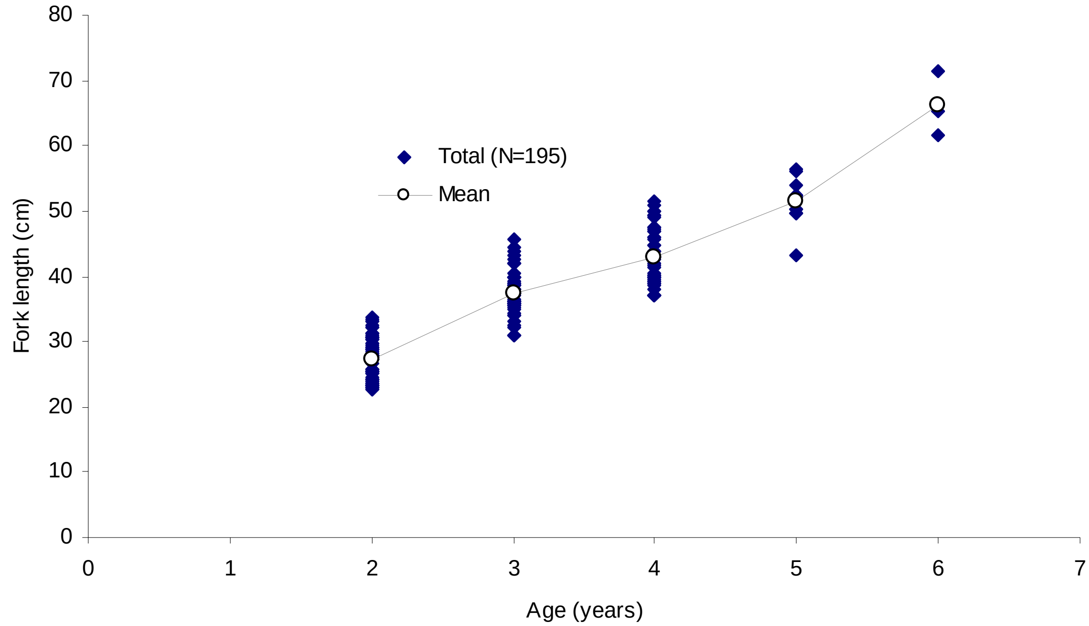


Figure 30. Mean length-at-age of non spawning rainbow trout captured in the Horsefly River from 1986-1988.

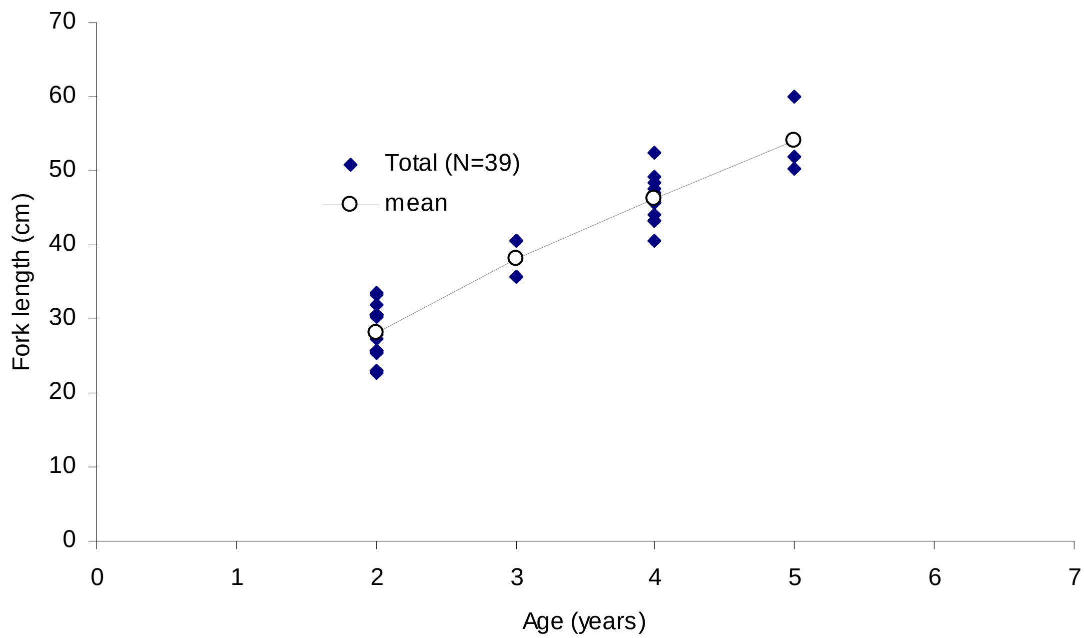


Figure 31. Mean length-at-age of non spawning rainbow trout captured in the Mitchell River from 1986-1988.

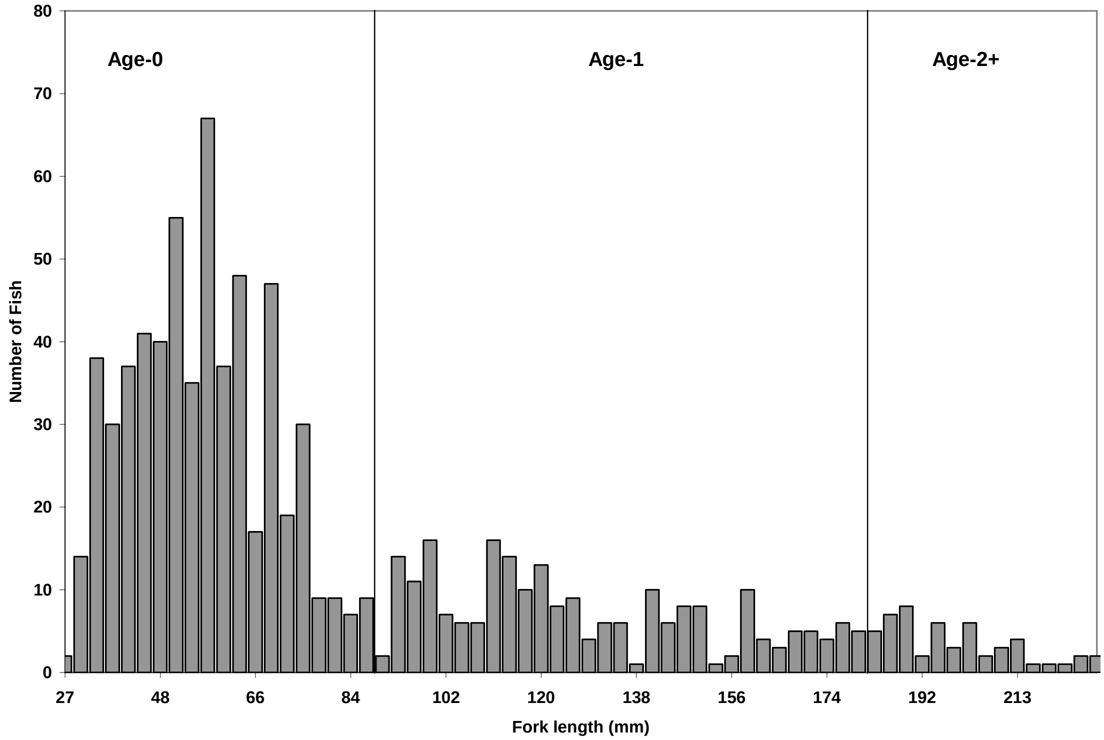


Figure 32. Length frequency distribution of kokanee found in the stomachs of all rainbow trout.

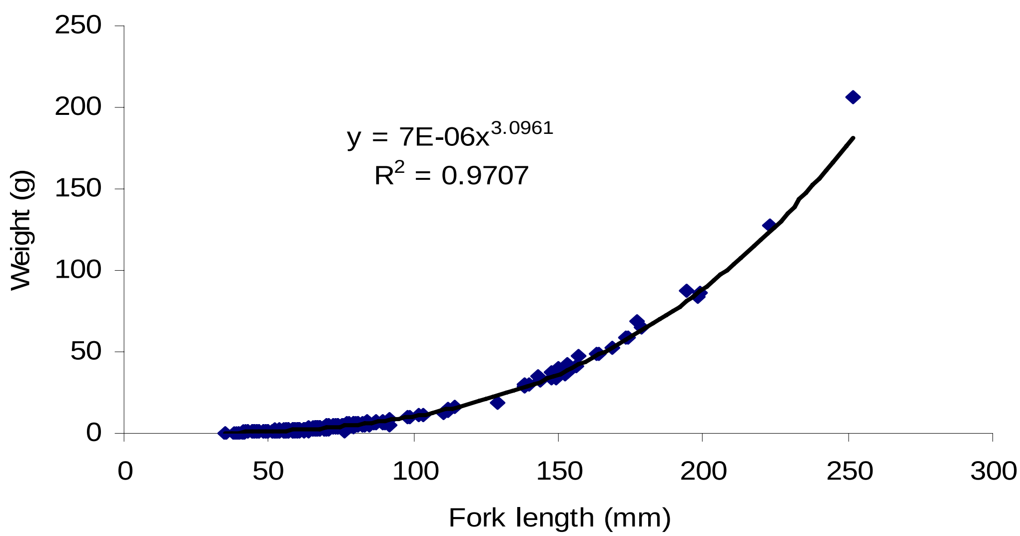
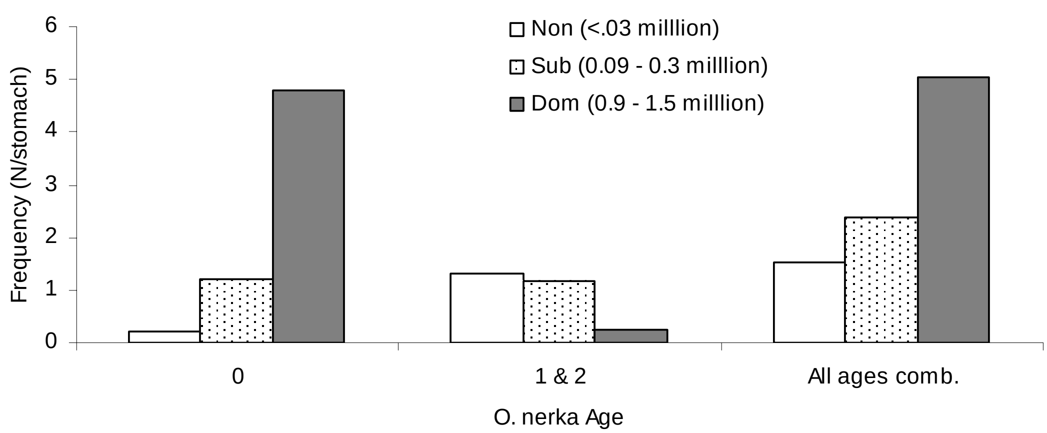


Figure 33. Length-weight regression from 1405 nerkid fry and older kokanee from the 2000-2002 trawls.

a) O. nerka per rainbow stomach



b) O. nerka biomass per rainbow stomach

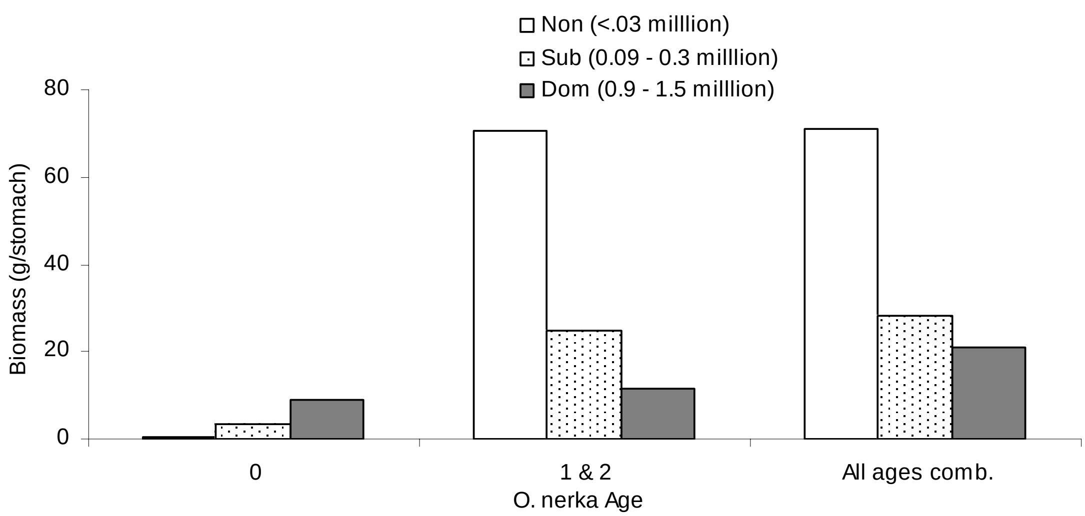
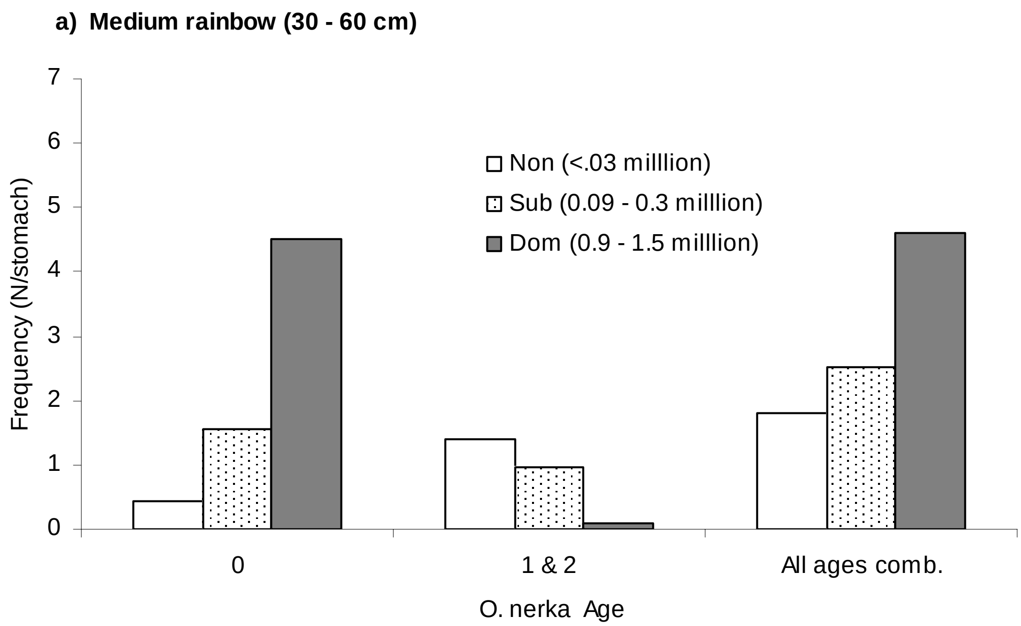


Figure 34. Proportion of nerkid fry and older kokanee by a) mean N/stomach and b) biomass (g/stomach) as found in rainbow trout stomachs following nondominant, subdominant, and dominant sockeye return years.



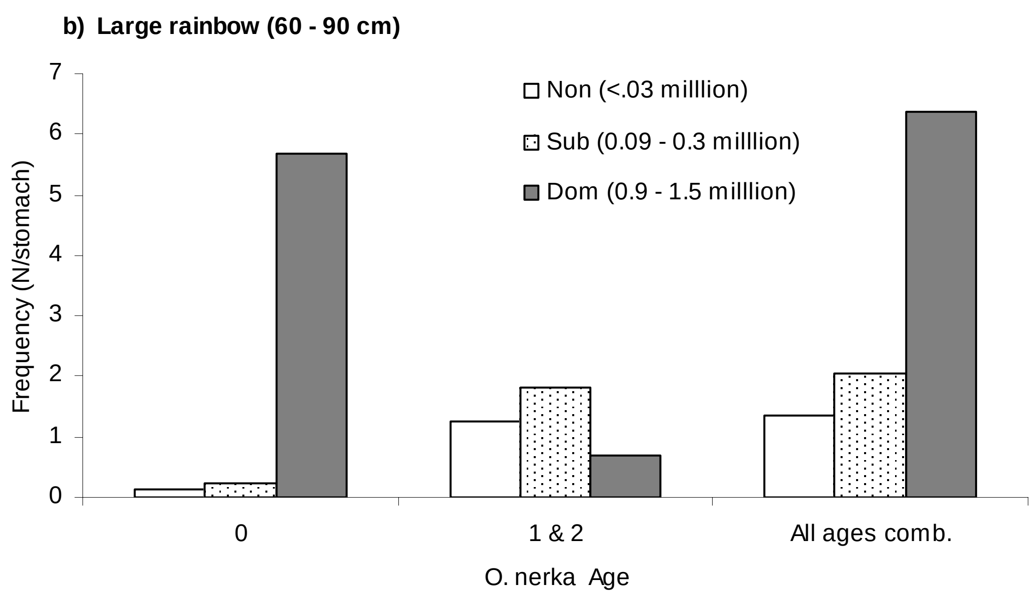


Figure 35. Frequency of nerkid fry and older kokanee (mean n/stomach) found in a) medium and b) large rainbow trout stomachs recovered from Quesnel Lake following nondominant, subdominant, and dominant sockeye return years.

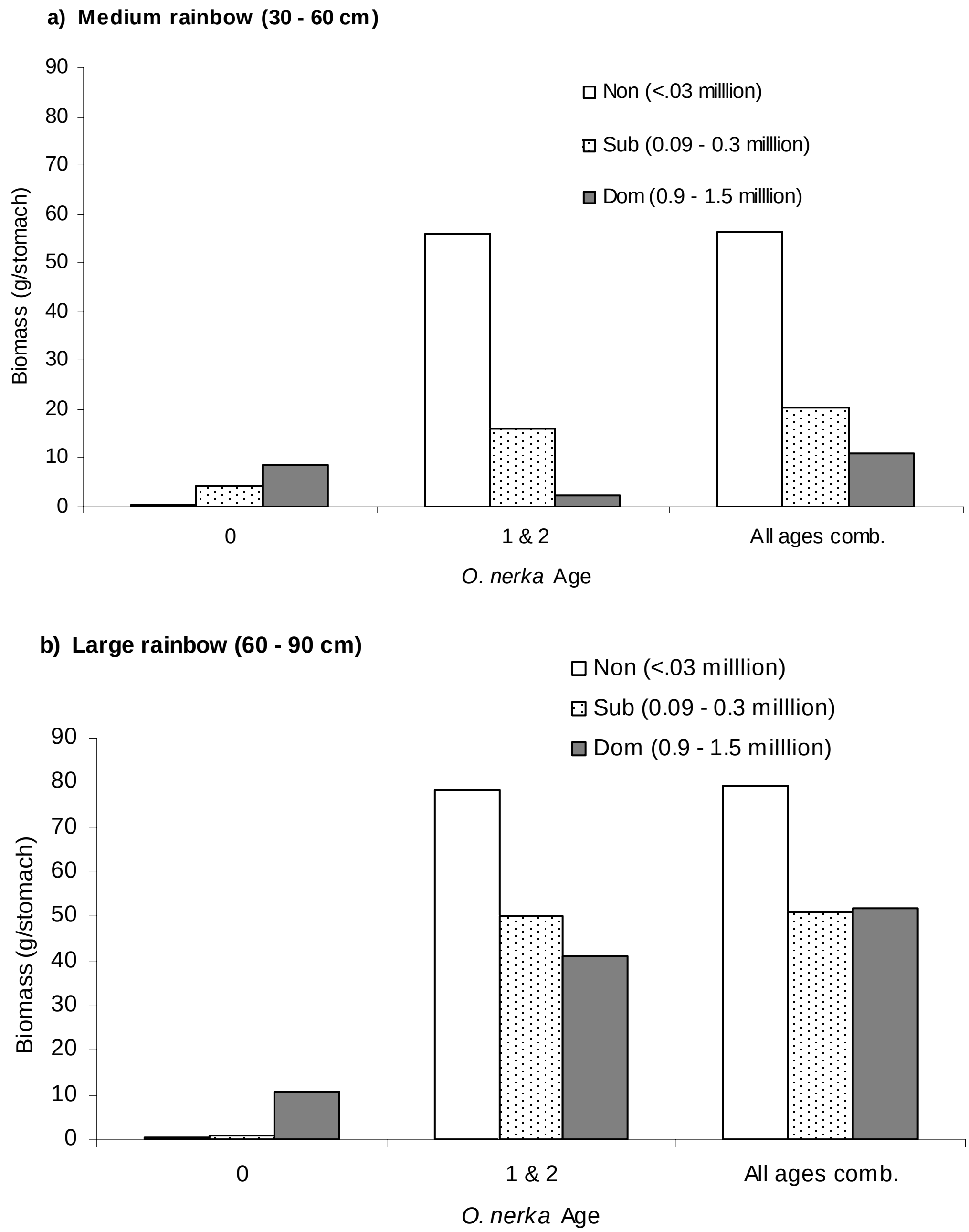


Figure 36. Biomass of nerkid fry and older kokanee (mean g/stomach) found in a) medium and b) large rainbow trout stomachs recovered from Quesnel Lake following nondominant, subdominant, and dominant sockeye return years.

APPENDICES

Appendix 1. Equipment and Data Processing Specifications

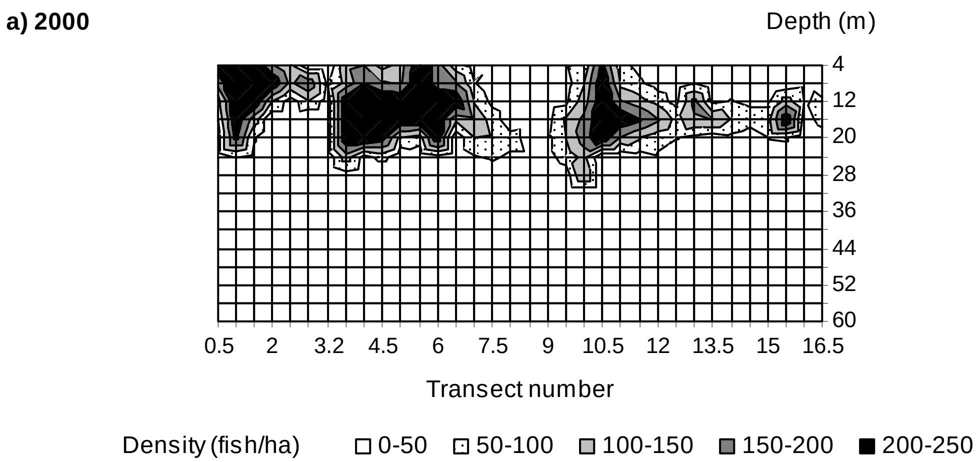
a) Echosounder Specifications and Field Settings

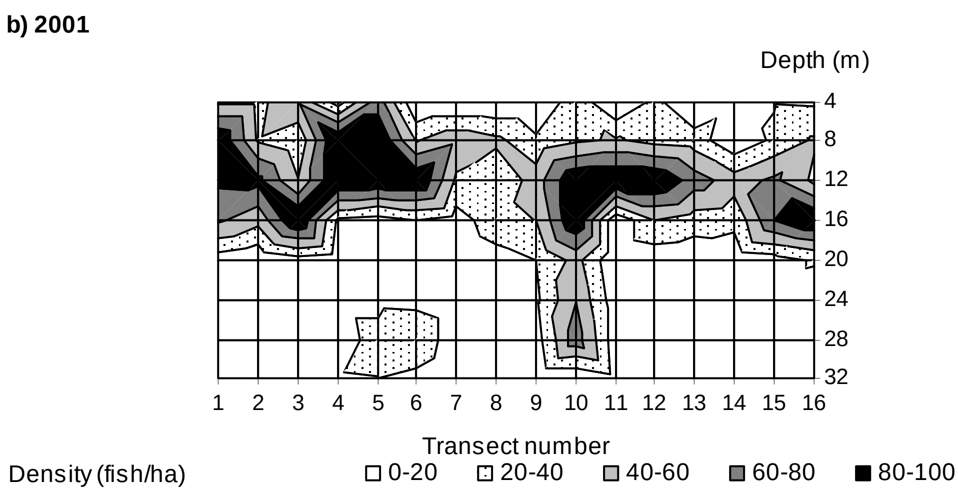
Description	SIMRAD EY200P-P
transducer type	Single beam 70 kHz
beam angle	11.6 degree5
receiver gain	3 (O dB)
pulse width (msec)	0.3
ping rate (p/sec)	medium (1.5)
time varied gain	40 log r
TVG range (m)	2 to 66
Attenuation	-15 dB
Power	1/1
Calibration	2 min. AC tone
Tape recorder	Sony TCD-D10
Record volume	3.5 fixed

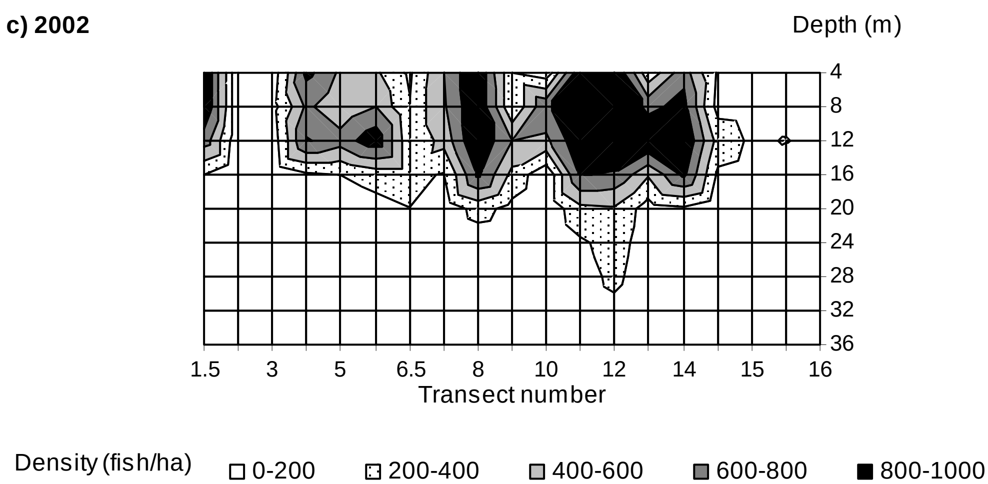
b) Data Processing Specifications

Description	**HADAS version 3.98**
Interface gain	Calibration tone to intersect 2 volts at 50 milliseconds
Threshold	Minimum detectable target approximately - 65 dB
Field calibrations	Date, peak sphere voltage, sphere depth and threshold used for survey
	Sept 23, 2000 Quesnel Lake 4100mV, sphere at 20m, threshold 240mV
	2001 and 2002 data were calibrated at 4100mV threshold 240mV after comparison with fish size captured in trawl
Lab calibration	July 8 1998, Applied Physics Laboratory UWA

Appendix 2. Fish density distribution by depth and transect for Quesnel Lake in September 2000 and 2001 and October 2002. Note density intervals between surveys were not standardized, but were adjusted to best show density “hot spots” during each survey.







Appendix 3a. Quesnel Lake habitat areas (ha) by depth stratum for 16 transect survey based on DFO file data

Depth	Transect number										
(m)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
surface	782	913	1249	1549	1905	3180	2616	1208	1228	1065	2840	1463
0-4	768	896	1218	1530	1891	3163	2602	1198	1220	1032	2823	1455
4-8	741	863	1157	1493	1862	3128	2574	1179	1203	966	2790	1439
8-12	715	830	1096	1456	1833	3093	2546	1160	1186	900	2757	1422
12-16	688	797	1035	1419	1804	3058	2519	1140	1169	834	2724	1406
16-20	661	764	974	1381	1775	3023	2491	1121	1152	767	2691	1390
20-24	634	731	914	1344	1746	2988	2463	1102	1135	701	2658	1373
24-28	607	698	853	1307	1717	2953	2436	1083	1118	635	2624	1357
28-32	580	665	793	1270	1689	2918	2408	1064	1101	572	2591	1341
32-36	542	628	741	1232	1661	2887	2383	1049	1085	538	2558	1324
36-40	502	590	692	1194	1634	2857	2359	1035	1068	512	2525	1308
40-44	462	552	642	1156	1607	2827	2335	1022	1052	487	2492	1292
44-48	422	514	593	1118	1580	2797	2311	1008	1036	461	2459	1276
48-52	382	476	543	1080	1553	2767	2287	994	1019	435	2425	1259
52-56	342	438	494	1042	1525	2737	2263	980	1003	409	2392	1243
56-60	302	400	445	1004	1498	2707	2239	966	987	383	2359	1227
60-64	273	372	408	976	1478	2685	2221	956	975	364	2328	1211
64-68	273	372	408	976	1478	2685	2221	956	975	364	2304	1198
68-72	273	372	408	976	1478	2685	2221	956	975	364	2279	1185
72-76	273	372	408	976	1478	2685	2221	956	975	364	2255	1173
76-80	273	372	408	976	1478	2685	2221	956	975	364	2230	1160
80-84	273	372	408	976	1478	2685	2221	956	975	364	2206	1147
84-88	273	372	408	976	1478	2685	2221	956	975	364	2181	1134
88-92	274	374	410	978	1480	2689	2225	958	980	366	2157	1121
92-96	253	347	385	953	1453	2645	2180	938	913	333	2132	1108
96-100	223	309	349	917	1413	2582	2116	910	815	286	2108	1095

Appendix 3a. cont.

Depth	Transect number				
	13	14	15	16	Total
surface	1424	1654	1603	1414	
0-4	1418	1647	1597	1403	
4-8	1406	1632	1587	1382	
8-12	1394	1617	1576	1362	
12-16	1382	1602	1566	1341	
16-20	1370	1587	1555	1320	
20-24	1358	1572	1545	1299	
24-28	1346	1557	1534	1279	
28-32	1334	1542	1524	1258	
32-36	1322	1527	1513	1237	
36-40	1311	1512	1503	1217	
40-44	1299	1497	1492	1196	
44-48	1287	1483	1482	1175	
48-52	1275	1468	1471	1154	
52-56	1263	1453	1461	1134	
56-60	1251	1438	1451	1113	
60-64	1240	1424	1440	1094	
64-68	1230	1412	1428	1082	
68-72	1221	1400	1417	1069	
72-76	1212	1388	1405	1057	
76-80	1203	1376	1394	1044	
80-84	1194	1364	1382	1032	
84-88	1185	1352	1371	1019	
88-92	1176	1340	1359	1007	
92-96	1167	1328	1348	994	
96-100	1158	1316	1336	982	

Appendix 3b. Quesnel Lake habitat areas (ha) by depth for 34 transect survey based on DFO survey data.

Depth	Transect number												
(m)	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.2**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
surface	261	326	399	426	442	433	543	1,131	779	761	969	1,247	1,301
0-4	251	322	393	419	431	422	525	1113	773	755	963	1234	1295
4-8	232	312	382	406	410	401	489	1076	762	744	951	1207	1284
8-12	214	302	370	392	389	380	453	1039	750	733	938	1181	1272
12-16	195	293	358	379	368	359	416	1002	739	721	925	1154	1260
16-20	176	283	347	365	346	337	380	965	727	710	913	1128	1248
20-24	157	274	335	352	325	316	344	928	716	699	900	1101	1236
24-28	138	264	324	338	304	295	307	891	704	687	888	1075	1224
28-32	119	254	312	325	282	274	271	856	692	676	875	1049	1212
32-36	103	235	302	310	255	252	236	832	681	666	862	1029	1200
36-40	88	214	293	295	226	230	201	810	669	656	849	1010	1187
40-44	73	193	284	280	197	208	166	789	657	645	837	992	1175
44-48	57	173	274	265	169	186	131	768	645	635	824	973	1162
48-52	42	152	265	250	140	164	96	747	633	625	811	954	1149
52-56	27	131	255	235	112	142	61	726	621	615	798	936	1137
56-60	11	111	246	220	83	120	26	705	609	604	785	917	1124
60-64	0	95	239	209	62	100	0	689	600	597	776	903	1115
64-68	0	95	239	209	62	86	0	689	600	597	776	903	1115
68-72	0	95	239	209	62	73	0	689	600	597	776	903	1115
72-76	0	95	239	209	62	59	0	689	600	597	776	903	1115
76-80	0	95	239	209	62	46	0	689	600	597	776	903	1115
80-84	0	95	239	209	62	32	0	689	600	597	776	903	1115
84-88	0	95	239	209	62	18	0	689	600	597	776	903	1115
88-92	0	96	240	210	62	4	0	691	601	598	777	905	1116
92-96	0	87	227	193	57	0	0	661	588	585	763	881	1098
96-100	0	75	209	168	49	0	0	618	568	566	743	845	1072

Appendix 3b. continued

Depth	Transect number												
(m)	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5
surface	2,572	1,469	877	586	526	604	618	505	610	1,402	1,139	627	705
0-4	2563	1461	871	581	522	600	613	491	570	1396	1129	624	702
4-8	2544	1445	861	572	515	591	602	464	490	1383	1110	618	697
8-12	2525	1428	850	563	508	583	590	437	410	1370	1091	613	691
12-16	2506	1412	839	553	501	574	579	410	330	1358	1072	607	686
16-20	2487	1396	829	544	494	566	568	384	250	1345	1053	601	680
20-24	2468	1379	818	535	487	557	557	357	170	1333	1034	596	675
24-28	2449	1363	807	526	480	549	545	330	90	1320	1015	590	669
28-32	2430	1347	797	517	473	541	534	303	15	1307	996	584	664
32-36	2414	1333	787	510	467	533	522	283	0	1295	977	579	658
36-40	2398	1319	777	504	461	526	510	263	0	1282	959	573	652
40-44	2382	1305	768	499	456	520	497	244	0	1270	940	567	647
44-48	2366	1291	758	493	450	513	485	225	0	1257	921	562	641
48-52	2351	1278	749	487	445	506	473	206	0	1244	902	556	636
52-56	2335	1264	739	481	439	499	460	187	0	1232	883	550	630
56-60	2319	1250	729	475	433	492	448	167	0	1219	864	545	625
60-64	2307	1240	722	471	429	487	439	153	0	1207	847	539	619
64-68	2307	1240	722	471	429	487	439	153	0	1195	836	534	613
68-72	2307	1240	722	471	429	487	439	153	0	1184	825	529	606
72-76	2307	1240	722	471	429	487	439	153	0	1172	814	524	600
76-80	2307	1240	722	471	429	487	439	153	0	1161	804	519	594
80-84	2307	1240	722	471	429	487	439	153	0	1150	793	515	588
84-88	2307	1240	722	471	429	487	439	153	0	1138	782	510	581
88-92	2309	1242	724	472	430	489	442	154	0	1127	771	505	575
92-96	2284	1215	709	462	417	453	402	140	0	1115	760	500	569
96-100	2248	1177	689	447	399	401	344	120	0	1104	750	495	562

Appendix 3b. cont.

Depth	Transect number								
(m)	13	13.5	14	14.5	15	15.5	16	16.5	
surface	685	705	939	844	779	715	605	436	
0-4	683	702	935	841	776	712	602	431	
4-8	677	697	926	836	771	706	595	422	
8-12	671	691	917	830	766	699	588	412	
12-16	666	685	908	825	761	693	581	403	
16-20	660	680	900	819	757	687	574	394	
20-24	654	674	891	814	752	681	567	384	
24-28	649	668	882	809	747	674	560	375	
28-32	643	663	874	803	742	668	553	365	
32-36	637	657	865	798	737	662	546	356	
36-40	632	651	856	792	732	656	539	346	
40-44	626	646	848	787	727	649	532	337	
44-48	620	640	839	781	722	643	525	327	
48-52	615	634	830	776	717	637	518	318	
52-56	609	629	821	771	712	631	511	308	
56-60	603	623	813	765	707	624	505	299	
60-64	598	617	804	760	702	618	498	291	
64-68	593	613	796	755	698	612	494	289	
68-72	588	609	789	750	693	605	489	286	
72-76	584	604	781	744	688	599	485	283	
76-80	579	600	773	739	683	592	480	280	
80-84	574	595	765	734	678	586	476	278	
84-88	570	591	757	729	673	579	471	275	
88-92	565	586	749	724	669	572	467	272	
92-96	561	582	742	719	664	566	463	270	
96-100	556	577	734	714	659	559	458	267	

Appendix 4a. Summary fish density (number·ha^{-1}) by transect for 2000-2002 from 70Khz single beam acoustic data.

Transect	2000	2001	2002
0.5	603		
1	2852	321	
1.5	3304		3636
2	599	236	139
2.5	272		
3	318	275	259
3.2	58		
3.5	3198		
4	2473	490	2592
4.5	1802		
5	1833	477	1987
5.5	2403		
6	1936	394	2511
6.5	790		1223
7	491	123	1916
7.5	385		
8	228	129	6579
8.5	149		
9	186	163	1593
9.5	419		
10	903	687	1470
10.5	4103		
11	726	199	5174
11.5	572		
12	422	258	6955
12.5	251		
13	444	175	3004
13.5	267		
14	225	127	4422
14.5	156		790
15	183	210	484
15.5	474		428
16	115	324	347
16.5	152		

Appendix 4b. Summary of fish density (number·ha^{-1}) by transect for 2000-2002 120KHz split beam acoustic data.

Transect	2000	2001	2002
1	1103	272	
1.5			1850
2	399	180	108
3	101	84	219
4	2193	433	1721
5	1942	463	1125
6	1962	246	1433
7	313	107	1280
8	222	95	3462
9	185	72	946
10	491	486	399
11	592	194	3032
12	424	119	3305
13	333	75	1638
14	414	32	2474
15	169		426
16	192	182	270

Appendix 5a. Maximum likelihood estimates and bounds for September 2000 Quesnel Lake surveys based on Monte Carlo simulations.

Zone	Depth	N	R^2	Density	Std Dev	Area	Stratum Pop.	Statistic	Abundance
1	4	7	0.59	300	102.4	2632	790,538	**West**	
1	8	7	5.63	500	179.7	2500	1,249,373	**LB=**	**1,548,333**
1	12	6	0.41	218	116.8	2367	515,498	**MLE=**	**2,639,167**
1	16	6	0.32	35	22.6	2235	77,264	**UB=**	**3,893,333**
1	20	6	0.30	15	10.5	2102	32,433		
1	24	7	0.45	20	8.9	1970	38,557		
1	28	7	0.39	4	1.9	1837	6,739		
1	32	6	0.43	1	0.5	1693	1,630		
1	36	7	0.01	0	0.3	1547	85		
1	40	7	0.30	0	0.3	1401	574		
1	44	6	0.14	0	0.3	1255	339		
1	48	6	0.15	0	0.5	1108	528		
2	4	6	0.90	129	19.6	8567	1,108,457	**Main**	
2	8	6	0.98	157	10.5	8437	1,324,291	**LB=**	**12,260,000**
2	12	6	0.96	491	47.0	8308	4,075,550	**MLE=**	**14,230,000**
2	16	6	0.89	739	116.5	8178	6,041,491	**UB=**	**16,640,000**
2	20	6	0.69	147	44.4	8049	1,185,212		
2	24	6	0.76	28	7.0	7919	217,788		
2	28	6	0.98	9	0.7	7791	73,353		
2	32	6	0.86	5	1.0	7683	41,296		
2	36	6	0.98	53	3.2	7580	400,537		
3	4	6	0.94	33	3.6	5050	166,741	**North**	
3	8	6	0.63	22	7.6	4960	110,773	**LB=**	**2,430,000**
3	12	7	0.59	53	17.9	4870	256,626	**MLE=**	**2,781,667**
3	16	7	0.64	71	21.9	4780	339,059	**UB=**	**3,110,000**
3	20	7	0.81	80	16.0	4690	374,534		
3	24	6	0.94	47	5.5	4600	214,329		
3	28	6	0.88	17	2.9	4511	77,241		
3	32	6	0.88	13	2.2	4435	58,724		
3	36	6	0.18	3	2.4	4361	12,304		
3	40	7	0.13	0	0.1	4288	223		
4	4	1	1.00	216	21.0	490	105,557		
4	8	1	1.00	962	96.0	410	394,087		
4	12	1	1.00	995	99.0	330	328,221		
4	16	1	1.00	888	88.0	250	221,785		
4	20	1	1.00	660	66.0	170	112,009	**East**	
5	4	12	0.46	21	6.9	9437	198,538	**LB=**	**2,600,000**
5	8	12	0.47	31	9.8	9341	289,309	**MLE=**	**3,273,750**
5	12	12	0.74	84	14.9	9245	778,404	**UB=**	**3,749,167**
5	16	12	0.77	146	24.1	9150	1,339,390		
5	20	11	0.65	39	9.2	9054	355,463	**Total**	
5	24	11	0.73	13	2.5	8958	114,063	**LB=**	**20,546,667**
5	28	11	0.80	8	1.2	8862	68,336	**MLE=**	**23,120,000**
5	32	11	0.72	4	0.7	8766	33,014	**UB=**	**25,693,333**

Appendix 5b. Maximum likelihood estimates and bounds for September 2001 Quesnel Lake surveys based on Monte Carlo simulations.

Zone	Depth	N	R^2	Density	Std Dev	Area	Stratum Pop.	Statistic	Abundance
1	4	3	0.95	40	6.6	2762	110,367	**West**	
1	8	2	0.97	33	6.1	2641	85,866	**LB=**	**511,000**
1	12	3	0.97	81	9.2	2520	203,560	**MLE=**	**612,000**
1	16	3	0.88	60	15.7	2400	142,830	**UB=**	**711,000**
1	20	3	0.73	7	2.8	2279	14,993		
1	24	3	0.93	11	2.0	2158	23,340		
1	28	3	0.98	12	1.2	2037	25,115		
1	32	3	0.69	3	1.2	1911	4,821		
2	4	3	0.41	28	23.6	6482	179,863	**Main**	
2	8	2	1.00	148	10.2	6381	945,162	**LB=**	**2,580,000**
2	12	3	0.97	223	23.4	6280	1,398,862	**MLE=**	**3,090,000**
2	16	3	0.94	14	2.6	6179	88,571	**UB=**	**3,460,000**
2	20	3	0.98	7	0.7	6078	39,660		
2	24	3	1.00	16	0.6	5977	95,557		
2	28	3	0.91	25	5.6	5877	145,063		
2	32	3	0.98	18	1.7	5780	103,238		
2	36	3	0.27	4	4.6	5685	22,474		
3	8	3	0.90	41	9.6	4892	199,334	**North**	
3	12	3	0.93	41	8.1	4828	196,705	**LB=**	**582,000**
3	16	3	0.90	33	7.5	4764	155,337	**MLE=**	**733,000**
3	20	3	0.89	16	3.9	4700	74,709	**UB=**	**876,000**
3	24	3	0.88	12	3.1	4636	54,815		
3	28	3	0.99	8	0.5	4573	38,140		
3	32	3	0.97	2	0.3	4517	10,706		
4	4	1		34	6.8	966	33,031	**T10**	
4	8	1		37	7.3	900	32,928	**LB=**	**420,000**
4	12	1		153	30.6	834	127,616	**MLE=**	**516,000**
4	16	1		285	56.9	767	218,406	**UB=**	**628,000**
4	20	1		47	9.4	701	33,031		
4	24	1		59	11.9	635	37,665		
4	28	1		72	14.3	572	40,930	**East**	
5	4	5	0.67	13	4.7	10236	136,953	**LB=**	**1,450,000**
5	8	5	0.94	32	4.2	10128	328,992	**MLE=**	**1,770,000**
5	12	5	0.92	59	8.5	10021	589,502	**UB=**	**2,160,000**
5	16	4	0.77	45	14.2	9913	448,298	**Total**	
5	20	5	0.70	5	1.8	9806	52,087	**LB=**	**6,080,000**
5	24	6	0.93	10	1.2	9698	95,554	**MLE=**	**6,620,000**
5	28	6	0.73	10	2.6	9590	91,752	**UB=**	**7,300,000**

Appendix 5c. Maximum likelihood estimates and bounds for October 2002 Quesnel Lake surveys based on Monte Carlo simulations.

Zone	Depth	N	R^2	Dens.	Std Dev	Area	Stratum Pop.	Statistic	Abundance
1	4	3	0.33	381	383.0	2762	1,053,318	**Zone 1**	
1	8	3	0.46	400	309.7	2641	1,057,683	**LB=**	410,000
1	12	3	0.37	238	217.9	2520	599,670	**MLE=**	2,860,000
1	16	3	0.60	111	64.0	2400	265,545	**UB=**	6,140,000
1	20	3	0.07	8	20.3	2279	17,550		
1	24	3	0.59	59	35.1	2158	127,715		
1	28	3	0.46	42	31.8	2037	84,545		
1	32	3	0.38	21	18.5	1911	39,508		
1	36	3	0.42	16	13.0	1783	27,946		
1	40	3	0.33	4	4.2	1656	6,818		
1	44	3	0.39	4	3.8	1529	6,601		
1	48	3	0.32	2	2.1	1402	2,862		
2	4	11	0.68	590	127.4	19664	11,597,907	**Zone 2**	
2	8	11	0.77	565	97.5	19367	10,940,742	**LB=**	46,000,000
2	12	11	0.84	1025	141.0	19070	19,540,196	**MLE=**	54,000,000
2	16	12	0.69	393	78.6	18773	7,377,235	**UB=**	63,400,000
2	20	12	0.75	164	28.9	18476	3,026,949		
2	24	11	0.69	62	13.0	18179	1,122,743		
2	28	11	0.54	27	8.0	17886	487,823		
2	32	11	0.50	18	5.8	17632	318,654		
2	36	11	0.40	6	2.1	17389	96,333		
2	40	11	0.55	2	0.5	17145	32,507		
2	44	11	0.54	2	0.7	16901	40,732		
2	48	11	0.51	1	0.3	16657	16,308		
3	4	3	1.00	58	2.4	3695	215,509	**Zone 3**	
3	8	3	0.99	114	7.2	3658	415,797	**LB=**	1,550,000
3	12	3	0.96	165	22.6	3620	598,432	**MLE=**	1,780,000
3	16	3	0.96	136	19.9	3583	487,814	**UB=**	2,000,000
3	20	3	0.98	8	0.7	3546	26,731		
3	24	3	0.69	3	1.2	3508	8,929	**Total**	
3	28	4	0.44	1	0.8	3471	4,068	**LB=**	50,500,000
3	32	3	0.94	3	0.6	3434	10,641	**MLE=**	59,400,000
3	36	3	0.87	2	0.5	3396	5,625	**UB=**	68,900,000

Appendix 6. Love's (1977) empirical relation of fish length to acoustic target strength.

$TS = 19.1 \log_{10} (L) - 0.9 \log_{10} (F) - 62$

where TS = target strength in decibels (dB)

L = length in cm and

F = frequency in kHz

HADAS size class (db)[1]	Acoustic size range (dB)		Fish length range[2] (mm)	
-35	-35	-33.1	317	500+
-38	-38	-35.1	221	317
-41	-41	-38.1	154	221
-44	-44	-41.1	107	154
-47	-47	-44.1	75	107
-50	-50	-47.1	52	75
-53	-53	-50.1	36	52
-56	-56	-53.1	25	36
-59	-59	-56.1	18	25
-62	-62	-59.1	12	18

1 HADAS was set up to view 30 dB range in 10 size classes of 3 dB.

2 From Love's (1977) empirical formula (Dorsal aspect).

Appendix 7. Comparison of total and potential kokanee abundance estimates from 4 echosounders.

Year	**Month**	**Data/analyses**	**No. of transects**	**Abundance (all ages)**	**TS cut-off[1] (in decibels)**	**Non-fry estimate**
1991	8	420(Stables)	32	65,108,000	-42	2,866,360
1991	8	420(Stables revised)	32	65,108,000	-41	1,327,731
1992	8	420(Stables)	32	28,899,000	-42	2,300,700
1992	8	420(Stables revised)	32	28,899,000	-41	1,439,294
1998	10	420(Stables)	32	56,255,200	-42	141,140
1998	10	420(Stables revised)	32	56,255,200	-44	644,164
2000	9	420 kHz(DFO)	33	17,759,000	?	1,313,671
2000	9	420(Stables)	32	16,465,300	-42	247,146
2000	9	420(Stables)	32	16,465,300	-44	955,896
2000	9	70KHz (WLAP)	33	23,120,000	-44	776,969
2000	9	70KHz (WLAP)	16	20,038,396	-44	601,519
2000	9	120 split (WLAP)	16	19,174,816	-41	847,259
2001	9	70KHz pop	16	6,620,000	-44	788,000
2001	9	120 split	15	4,115,224	-41	464,082
2002	10	70KHz pop	19	59,400,000	-44	588,111
2002	10	120Khz split	16	39,136,014	-41	402,393
2002	10	200KHz	34	71,142,345	-40	436,401

Note: revised based on visible inflection point

Appendix 8. Numbers of rainbow trout floy tagged in the Horsefly, Mitchell and Quesnel Rivers by year and season.

Location	Year	Total # of Fish Tagged	Spring	Summer	Fall	Winter
Horsefly River	1986	277	23	117	137	
	1987	154	48	62	18	26
	1988	9	9			
	TOTAL	440	80	179	155	26
Mitchell River	1986	49		49		
	1987	46		46		
	1988	31		31		
	TOTAL	126		126		
Quesnel River	1984	125		73	52	
	1988	49	14	23	12	
	TOTAL	174	14	96	64	
TOTAL		740	94	401	219	26