THE WINTER ECOLOGY OF JUVENILE COHO SALMON

(*Oncorhynchus kisutch*) IN INTERIOR BRITISH COLUMBIA

STREAMS

by

JESSICA MARGARET BRATTY

B.Sc., The University of British Columbia, 1994

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

(Department of Resource Management and Environmental Studies)

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

**1999

Department of _Resource Management and Environmental Studies_

The University of British Columbia
Vancouver, Canada

Date _Dec. 20, 1999._

ABSTRACT

I investigated seasonal patterns in habitat related movement, distribution and abundance of juvenile coho salmon in two interior British Columbia streams, and in particular, used individual and categorical marks to examine how size-dependent overwinter growth and survival relate to freshwater production. Counter to results from coastal streams, I found no evidence of autumnal movement into off-channel areas or other sites considered favourable winter habitat. Abundance in these habitat types remained relatively constant throughout both years indicating juveniles utilized refuge areas year-round, not just during winter. During a year when overall juvenile abundance was relatively high, the proportion of both fall and post-winter standing stock found in off-channels was comparable to the availability of this habitat in the streams (~ 20 %). However, during a year when juvenile production was likely limited by spawner abundance, off-channels accounted for much higher proportions (~ 55 %) of estimated standing stock. These habitat types may therefore be particularly important to coho production when spawning stocks are low. Results suggested relatively short, low gradient streams on the North Thompson River floodplain may contribute much more to regional coho production than previously recognized, and counter to some suggestions, adequately seeded interior systems may exhibit production levels comparable to those of coastal streams (~ 0.2 to 0.4 smolts$\cdot$m^{-2}).

Investigations of size-dependent growth and survival differed from some previous studies. Smaller juveniles grew more during the winter than their larger conspecifics, and differences in specific growth rate were greater than predicted from an allometric model. Greater overwinter growth by smaller fish may have been driven by selective pressure for individuals to attain a certain threshold smolt size. However, in a cold stream with relatively unfavourable winter growth conditions, the smallest juveniles grew the least overwinter, indicating that in some situations it may be favourable for fish to delay smolting and spend an additional year in freshwater. Counter to some previous studies, there was no consistent evidence of size-related overwinter survival, and higher winter growth rates by small juveniles were not associated with decreased overwinter survival.

Fall location appeared to explain more of the variation in overwinter survival than initial fish size, and in one year, juveniles in off-channels exhibited both higher recapture probabilities and growth rates than fish in mainstem areas. Results from this study indicate an existing production model based on a positive size-dependent survival function may not be applicable in interior streams.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

ACKNOWLEDGEMENTS

GENERAL INTRODUCTION

The status of many wild coho salmon (*Oncorhynchus kisutch*) populations on the west coast of North America is currently of great concern. Spawning stocks in many regions are markedly depressed (Brown et al. 1994, CRT 1998, Nehlsen et al. 1991, Slaney et al. 1996), and over the past few decades, marine survival rates of both wild and hatchery produced coho have decreased dramatically (Cross et al. 1991, Emlen et al. 1990, Nickelson et al. 1986). Furthermore, reversal of these trends does not appear imminent. Some populations may continue to decline even in the absence of fishing mortality (CRT 1998).

In British Columbia, conservation concerns appear to be particularly serious for coho that spawn in interior river systems (Figure 1.1, inset; CRT 1998). Some Thompson River stocks have experienced reductions in escapement of 50 – 70 % per generation (Bradford 1998) and in 1997, adult returns to upper Skeena watersheds were at unprecedented lows (Holtby 1998). The potential consequences of these declines are severe. Coho from Thompson and upper Fraser tributaries are genetically distinct from stocks in the lower Fraser and the rest of B.C. (Small et al. 1998a). In addition, variation in microsatellite DNA among Thompson and upper Fraser populations has revealed significant spatial substructuring within the drainage area (Small et al. 1998b). Therefore, population declines appear likely to result in continued erosion of overall stock structure and genetic diversity of the species (Walters and Cahoon 1985).

In 1997, the Department of Fisheries and Oceans (DFO) began to restrict fishing pressure in an effort to reduce and or eliminate exploitation of threatened coho populations (Anon. 1998). Conservation measures have been maintained in recent years, and the government appears committed to a long-term stock rebuilding process (e.g., Anon. 1999). Many agree future management of the species is on the cusp of change, and the debate over shaping this future garners much attention (e.g., Anon. 1999, CPMPNAS 1996, Glavin 1998, Walters 1995). However, this debate has also highlighted significant deficiencies in our knowledge of coho ecology that may hamper

efforts to restore and protect the species. In this thesis, I address two of these gaps in our current understanding.

Firstly, I investigate aspects of the winter ecology of juvenile coho in interior streams. Information regarding the ecology of salmonids in interior regions is sparse (Bustard 1986, Harding et al. 1994, Swales et al. 1986), and most of our understanding of coho freshwater ecology and behaviour comes from research conducted in coastal streams (e.g., Bustard and Narver 1975; Fausch 1993; Hartman et al. 1996; Holtby 1988; Nickleson et al. 1992; Peterson 1982b; Thedinga et al. 1989). How applicable this knowledge is to interior regions is largely unknown. For example, it has been shown in coastal systems that off-channel areas, riverine ponds and areas formed by instream structures such as large organic debris (LOD) are utilized extensively by juvenile coho during winter (Bisson et al. 1992, Bustard and Narver 1975, Cederholm and Scarlett 1981, Peterson 1982a, Quinn and Peterson 1996). The hydrology of coastal streams is believed to explain at least part of the seasonal association of fish with these areas. Peak flows in coastal systems are generally associated with high winter rainfall events, and certain habitat features may provide important velocity refuges for stream-dwelling organisms (e.g., Bilby and Bisson 1987, Bjornn and Reiser 1991, Cunjak 1996, McMahon and Hartman 1989, Murphy et al. 1984, Tschaplinski and Hartman 1983). However, the opposite discharge pattern is observed in interior streams; freshets occur in late spring and early summer during snowmelt, and autumn and winter are usually periods of low flow. It is not known whether differences between regional hydrologies are associated with distinct seasonal patterns in fish distribution and abundance. In the first chapter of this thesis, I address this question and describe habitat related movement, distribution and abundance of juvenile coho in two interior streams during the winters of 1996 and 1997. Better understanding of the importance of different habitat types would be an important management asset as it would allow the proper design of land-use guidelines and enhancement and restoration prescriptions relevant to interior systems.

Secondly, I investigate juvenile coho overwinter growth and survival and assess how these factors relate to freshwater production. When spawner abundance is low, variation

in freshwater production may be an important component of overall population dynamics, and stock - recruit relationships may be most influenced by juvenile survival (Bradford et al. 1997, Hilborn and Walters 1992). Therefore, thorough understanding of freshwater production dynamics is integral to effective management and conservation of threatened populations (Wood 1998). However, while winter is well recognized as a critical period governing production of juvenile salmonids in streams (Bustard and Narver 1975, Holtby 1988, Holtby and Hartman 1982, Quinn and Peterson 1996, Tschaplinski and Hartman 1982), the factors affecting juvenile overwinter survival are still not well understood. Research has generally been limited to pre and post-winter population-level comparisons (Cunjak 1996) and information on individual fish is sparse. This limits detailed investigation of some important winter dynamics, and studies to date have largely been unable to resolve the complex interactions among habitat, fish size, overwinter growth, and survival (Quinn and Peterson 1996). In the second chapter of this thesis, I investigate these interactions and present information on habitat related size-dependent growth and survival of individually and categorically marked juveniles. Size-dependent factors may be critical determinants of juvenile coho production, and their prevalence may have substantial implications for how we model freshwater production (Holtby and Hartman 1982). The thesis provides some novel insight into the winter ecology of juvenile coho because information on both individual fish and interior systems is lacking.

CHAPTER 1:

SEASONAL PATTERNS IN HABITAT RELATED MOVEMENT, DISTRIBUTION AND ABUNDANCE OF JUVENILE COHO SALMON IN INTERIOR STREAMS

Wild coho salmon (*Oncorhynchus kisutch*) salmon populations in the interior of British Columbia are in a critical state. In some areas, forecasts under present marine survival conditions do not predict a recovery of spawning stocks, even in the absence of fishing mortality (CRT 1998). Thus, the design and implementation of an effective regional conservation and restoration strategy is currently of great concern (Wood 1998, Wood and Holtby 1998). An integral component of this strategy may be the preservation of as large an extant population aggregate as possible in the region (Bradford 1998). While management of escapement levels is critical to such an approach, it is also important to protect the quality and quantity of habitat utilized by juveniles (CRT 1998, Wood 1998). Yet information regarding the freshwater ecology of salmonids in interior streams is sparse, especially for coho (Bustard 1986, Harding et al. 1994, Swales et al. 1986). Most of our understanding of seasonal patterns in juvenile coho abundance and habitat use comes from research conducted in coastal streams (e.g., Bustard and Narver 1975; Fausch 1993; Hartman et al. 1996; Holtby 1988; Nickleson et al. 1992; Peterson 1982b; Thedinga et al. 1989). How applicable this knowledge is to streams in the interior of the province is largely unknown.

There are marked distinctions between interior and coastal regions that suggest information from one region may not be directly relevant in the other. For example, the temperate climate characteristic of coastal areas generally produces relatively warm, dry summers and mild, very wet winters. High precipitation during winter months creates dynamic, high energy environments. In such conditions, instream structures such as large organic debris (LOD) that diffuse high flows are important for maintaining the physical integrity of stream channels (Meehan 1991). They also provide important refuges for stream dwelling organisms; fish affiliation with these structures has been shown to increase with the onset of winter spates (Tschaplinski and Hartman 1983). Other

apparent adaptations to winter conditions in coastal streams include fish movement into off-channel areas such as riverine ponds, ephemeral streams and swamps, and groundwater tributaries (Bustard and Narver 1975, Cederholm and Scarlett 1981, Peterson 1982a). These areas have been found to support a relatively high proportion of the overwintering juvenile population in some streams (e.g., Decker 1998, Everest et al. 1986). For example, in Carnation Creek on Vancouver Island, approximately 20 % of overwintering juvenile coho salmon were found in off-channel habitat (Brown and Hartman 1988). There is considerable evidence from coastal streams that coho freshwater production may be regulated in part by the availability and abundance of these types of suitable winter habitat (Brown and Hartman 1988, Nickleson et al. 1992, Quinn and Peterson 1996).

In contrast, hydrographs for most interior rivers generally peak with snowmelt in late spring and early summer, while annual low flows occur during winter (Bustard 1986). Although interior rivers fed by glaciers or significant alpine snow pack may exhibit relatively high flows into October (Bustard 1994), freshet conditions in lower elevation watersheds usually subside by mid-summer. In some interior streams, access to off-channel habitat such as beaver ponds may only be possible during high water, creating distinct patterns in seasonal habitat use by juvenile salmonids (Bustard 1986, Riley and Lemieux 1998). Overall, the climate in the interior is generally much drier and has far greater temperature extremes than the coast. During interior winters, low flows and cold temperatures result in substantial ice cover in many streams, and sometimes de-watering and freezing of off-channel areas (Bustard 1986). These conditions may create markedly different winter mortality agents for juvenile salmonids compared to coastal streams. For example, rather than having to contend with high winter flows, juveniles in interior systems may experience freezing, suffocation or increased predation due to stranding in dewatered areas (Bustard 1986, Power and Mitchell 1994). In addition, low winter temperatures may be associated with physiological stresses (Cunjak 1988b) that both increase starvation risk (Gardiner and Geddes 1980; Riddell and Leggett 1981) and decrease swimming ability (Cunjak 1996, Webb 1978), thereby making juveniles more vulnerable to predation (e.g., Dolloff 1993, Hunt 1969). Overwinter movement and

distribution patterns may also differ in interior rivers. In areas lacking substantial groundwater influence (Swales et al. 1986), accumulation of ice may require juveniles to move out of off-channel areas during winter (Bustard 1986); the opposite of the pattern observed in coastal streams. Groundwater discharge may therefore be especially critical in cold water systems by providing important thermal refugia for overwintering fish (Craig and Poulin 1975, Cunjak and Power 1986, Hunt 1969, Smith and Griffith 1994). However, the importance of these habitat features in the overwinter ecology of juvenile coho in interior streams is not well understood.

The primary objective of this chapter is to augment our understanding of juvenile coho winter ecology in interior streams and in so doing, investigate some potential differences between coastal and interior systems. Specifically, this chapter presents information on habitat related movement, distribution and abundance of juvenile coho during the winters of 1996 and 1997 in two interior streams. A secondary objective of this chapter is to contrast results from this study to data from previous surveys of juvenile coho distribution and abundance in interior streams, and to estimates of juvenile density obtained in coastal regions. Although reliable historical information on juvenile coho in interior streams is limited, results from this temporal analysis may be useful in the design of future assessment programs. Comparison of interior and coastal results may provide insight into potential differences in production dynamics between regions.

STUDY AREA

REGIONAL FEATURES

The study was conducted in the North Thompson River watershed that drains approximately 21,000 km^2 of south-central interior British Columbia into the Thompson and eventually the Fraser rivers (Figure 1.1, inset). The North Thompson River is an important hydrologic component of this overall system and accounts for about 55 % of the main Thompson's flow with a mean annual discharge (MAD) of 424 $m^3 \cdot s^{-1}$ (WSC

1999). The watershed is also notable with respect to salmon production and supports populations of coho, sockeye (*O. nerka*), chinook (*O. tschawytscha*) and pink (*O. gorbuscha*) salmon. Historically, interior populations formed an important component of overall coho production in the Fraser River basin; roughly one-third of wild coho escapement in the system was to the upper river (Anon. 1997). Approximately 35 % of adult returns to the Thompson spawned in the North Thompson watershed (Harding et al. 1994).

The North Thompson's largest tributary is the Clearwater River (MAD = 231 $m^3 \cdot s^{-1}$; WSC 1999) which roughly divides the watershed into two distinct physiographic units (Figure 1.1). To the north and east, the upper North Thompson drains the Cariboo and Monashee mountains, and finds its source only a few kilometers from the upper Fraser River in rugged, high relief and relatively wet terrain (~ 700 mm rain and 200 mm snow annually; Harding et al. 1994). South of the Clearwater, the lower North Thompson drains the Shuswap Highlands and Thompson Plateau and flows through much drier (~ 450 mm rain and 100 cm snow annually), lower relief terrain containing numerous small, relatively productive fish lakes and streams (Harding et al. 1994). Differences in physiography, hydrology and climate within the North Thompson watershed are associated with several distinct biogeoclimatic zones with aquatic habitats of varying productive capacities (Harding et al. 1994).

This study was conducted in the southern portion of the North Thompson watershed in two nearby (< 20 km) tributaries of comparable size. Lemieux and Mann creeks both flow in a south-easterly direction from the Thompson Plateau and join the North Thompson River approximately 100 river km north of Kamloops (Figure 1.1). The creeks are located in a region of the watershed with moderate precipitation, and exhibit typical timing (mid-May peak) and duration (April to July) of spring runoff (Figure 1.2). Although low flow and high water temperatures are thought to limit summer rearing in the creeks during some years (e.g., Anon. 1992), both streams were historically among the most productive coho streams in the North Thompson watershed (Harding et al. 1994). Until 1990, Lemieux and Mann creeks, respectively, were among the system's

major (> 1000 spawners) and significant (> 100 spawners) coho producers (Anon. 1992). However recently, adult returns to the creeks have declined markedly. In Lemieux Creek, the brood year (1996) for the second season of this study was the lowest escapement year on record at 159 (± 26) fish (Irvine et al. 1998).

Aquatic community assemblages in Lemieux and Mann creeks are quite similar. Both systems sustain relatively small stocks (< 100 adults) of chinook and sockeye salmon, as well as resident populations of rainbow trout (*O. mykiss*) and sculpins (*Cottus spp.*). Mountain whitefish (*Prosopium williamsonii*), and longnose and largescale suckers (*Catostomus catostomus* and *C. macrocheilus*) are also present in the streams. Of these, rainbow trout are the most abundant. Small numbers of brook trout (*Salvelinus fontinalis*) are present in Mann Creek, likely due to dispersal from stocked populations in headwater lakes. Adult bull trout (*S. confluentus*) have historically been observed in Lemieux Creek, but no juveniles were encountered during this study. Mink (*Mustela vison*), mergansers (*Mergus merganser*) and beaver (*Castor canadensis*) are the most abundant mammals and birds. The former two along with resident parr and other fish are likely the dominant predators of juvenile coho.

Lemieux and Mann creeks originate in the Sub-Boreal Spruce and Engelmann Spruce-Subalpine Fir biogeoclimatic zones, and terminate in the Interior Douglas Fir zone (Harding et al. 1994). Approximately 20% and 35% of the Lemieux and Mann Creek watersheds, respectively, have been logged (1990 data), more than half of which has occurred within the past 20 years (Harding et al. 1994). Portions of the upper watersheds of both creeks are situated within the five-year planning zones of the region's major forest licensees. However, no industrial logging presently occurs in the lower reaches of the creeks. Areas accessible to coho are located within the provincial Agricultural Land Reserve, and land tenure in riparian areas is almost exclusively private. Land-use impacts are dominated by agriculture (mostly cattle ranching) and transportation corridors (e.g. Yellowhead Highway, CN railway, pipelines, and transmission lines; Anon. 1995, Bradford and Irvine 1999).

STREAM FEATURES

Lemieux Creek is a fourth order stream (Johnston and Slaney 1996) with a total mainstem length of 39.8 km and a watershed area of 454 km^2. It joins the North Thompson River at the town of Little Fort, 88 river km north of Kamloops. Lemieux Creek has five tributaries and is fed by Taweel Lake, situated at mainstem km 26. The creek also contains an artificial groundwater channel (Ianson channel) at mainstem km 7.6 that was constructed in 1988. Lemieux Creek has a mean annual flow of 2.8 m$^3 \cdot$ s^{-1}, and a peak daily flow of 30.1 m$^3 \cdot$ s^{-1} (spring freshet; Sigma 1991; Figure 1.2). An impassable waterfall at mainstem km 13.4 constrains Lemieux Creek's anadromous reach to the lower portion of an agricultural valley. The gradient of this reach is generally < 1.5 %, but increases along with substrate size upstream of mainstem km 8 (Harding et al. 1994, Sigma 1991). There is virtually no spawning and rearing habitat between km 10 and the anadromous barrier (Stewart et al. 1983; this study). Previous adult and juvenile coho surveys found fish almost exclusively restricted to the lower 8 km of stream (J. Irvine, DFO, Pacific Biological Station, Nanaimo, B.C.; unpub. data; Anon. 1992; Stewart et al. 1983). For these reasons, the reach upstream of km 10 was excluded from study. Three tributaries (Eakin, Nehaliston and Demers creeks) are located downstream of km 10, but all have relatively high gradients (> 1.5 %) and have been found to contain limited spawning and rearing habitat (J. Irvine, DFO, Pacific Biological Station, Nanaimo, B.C.; unpub. data). Therefore, tributaries were also excluded from study.

Mann Creek is a slightly smaller fourth order stream that drains 291 km^2 and has a mainstem length of 56.7 km. It is fed by one tributary and two lakes and joins the North Thompson River near the community of Blackpool, 10 river km south of the town of Clearwater, and 107 river km north of Kamloops. Mean annual flow in Mann Creek is 3.0 m$^3 \cdot$ s^{-1}, and peak daily flow is 41.3 m$^3 \cdot$ s^{-1} (spring freshet; Sigma 1991; Figure 1.2). There is an anadromous barrier in Mann Creek at mainstem km 11.2 (Anon. 1992) however, a four metre high falls at km 4.7 also limits adult and juvenile access upstream. In addition, the highway culvert at mainstem km 1.6 is believed to deter adult and

juvenile movement (Anon. 1992, Hutton et al. 1983). Gradient above the highway is quite high, especially upstream of km 4.7 (~ 1.5 - 4 %; ARC 1997), and the stream contains limited coho spawning and rearing habitat between the culvert and km 4.7 (Hutton et al. 1983). For these reasons, I excluded the portion of Mann Creek upstream of mainstem km 4.7 from study. The reach downstream of km 1.6 contains the majority of spawning and rearing habitat in the system and is meandering, low gradient and constrained to the North Thompson River floodplain (Hutton et al. 1983). For comparison, fish population information is compiled for both the accessible portion of the creek (downstream of km 4.7), and the reach downstream of the highway culvert.

Both streams are the focus of limited long-term coho stock assessment programs in the Thompson drainage. The DFO has operated an adult counting fence on Lemieux Creek since 1993 (Atagi et al. 1999) and the North Thompson Indian Band began adult enumeration on Mann Creek in 1997. The study streams are also among about a dozen streams in the Thompson region where surveys of fall juvenile coho densities are conducted annually. Smolt production has not been assessed in either system.

METHODS

HABITAT SURVEY

Detailed habitat surveys of the anadromous portions of both creeks were conducted at the end of August 1997. Habitat surveys were not conducted in 1996; total stream area and gross habitat characteristics (i.e., cover designations and habitat type) were assumed constant between years. Photographs taken during each sampling period support this assertion. The amount of mainstem (including and excluding riffles) and off-channel habitat available during 1996 was summarized from 1997 information.

During the 1997 habitat assessment, the surveyor began at stream mouth and proceeded upstream, classifying all habitat units as riffles, runs, or pools based on criteria established by Johnston and Slaney (1996). Off-channel areas and braids were also

mapped and measured and included in estimates of total stream area and length. For the purpose of this thesis, mainstem or river length and area refer to measurements excluding braids and off-channel areas. Habitat units were mapped by recording cumulative distance (nearest metre) at the downstream and upstream end of each unit using a hip chain. Poorly defined habitat units less than 1.5 times as long as their wetted width were included as part of the length of the adjacent unit upstream. Depending on size and uniformity of the unit, two to eight wetted and bankfull channel widths (nearest 0.1 and 0.5 m, respectively) were obtained for each habitat unit using a spring-loaded logger's tape. The wetted area of each habitat unit was estimated as the product of average wetted width and the difference between cumulative upstream and downstream distances. Estimates of the total area of each habitat type within a reach were calculated as the sum of all individual unit areas. To facilitate relocation of habitat units selected for fish population sampling, small numbered discs and flagging tape were placed at 200 m intervals, and the cumulative upstream distance of these markers and the location of potential access points were noted.

The surveyor also subjectively assigned a cover rating to each habitat unit based on a visual assessment of percent cover. The purpose of this designation was to facilitate further stratification within habitat types, if necessary. Cover was categorized as large or small woody debris, overhanging branches within 0.5 m of water surface, large boulders, deep pools, and/or instream vegetation (after (Johnston and Slaney 1996). Units containing less than 25 % cover (all types combined) were designated without cover. Units containing more than 25 % cover, but with cover distribution only along stream margins, were designated as having lateral cover. Units containing more than 25 % cover with instream distribution were designated as having cover.

In both years, wetted area, percent cover, substrate composition, and mean depth and flow were estimated for each sample site during each sampling period. In 1997, data loggers were installed in each stream to record water temperatures in each reach. In 1996, surface water temperatures were measured daily throughout the sampling periods.

POPULATION SAMPLING

Sampling periods

Population sampling was conducted during the fall, early winter and early spring in both 1996 and 1997. I attempted to sample fish populations in both creeks i) at the end of the summer growth period and before fish redistribution prior to winter (the fall period), ii) immediately before ice formation (the pre-winter period), and iii) immediately after ice-off (the post-winter period). Therefore for the purposes of this thesis, 'winter' is defined as that period extending from the onset of ice formation and concomitant decline in water temperature until the loss of the majority of surface ice prior to significant increase in stream flow (Cunjak and Power 1986). This definition is considered to have more biological relevance than one dependent on calendar dates (Cunjak 1996), but it also means sampling dates were not consistent between years due to differences in stream conditions. In 1996, fall, pre and post-winter sampling occurred in early October, late November and early April, respectively. In 1997, sampling occurred in early September, mid November and mid March. Post-winter sampling occurred later in 1996 because an exceptionally cold winter delayed spring thaw. Fall and pre-winter sampling occurred earlier in 1997 to ensure both periods were conducted prior to the onset of winter.

Sample sites

Some biologists have argued that because stream habitats vary in a fairly regular pattern (e.g., pool-riffle), the amount of replication needed to obtain reliable abundance estimates can be reduced by sampling long sections of stream that encompass a series of habitat types. These sections may then be assumed to represent average fish densities in a typical, or representative, stretch of stream (e.g., Holtby and Hartman 1982; but see Hankin 1984). In 1996, this approach was adopted and a representative section sampling design was applied in both study streams. Six sites in Lemieux Creek and five sites in Mann Creek were selected for intensive population sampling. The 1996 sites were not

selected randomly; Ianson groundwater channel in Lemieux Creek, two off-channel areas in Mann Creek, and riverine ponds in both systems were selected *a priori*. Sites were not selected randomly because the total number of off-channel areas was limited in both streams. The remaining sites (four in Lemieux and two in Mann) were located in mainstem areas of the streams, and some were chosen for comparison to historical information. Limited juvenile coho sampling was conducted by DFO in Lemieux Creek during 1993 and 1994 (Atagi et al. 1999), and several of their sites were resampled in 1996. Overall, sample sites were chosen to ensure adequate replication of both mainstem and off-channel habitat types during 1996. For analysis, mainstem and off-channel areas were considered separate strata, but no reach or other habitat type stratification was applied.

In 1997, the sampling design was changed to address the high spatial variability in fish distribution and abundance encountered in 1996 (Armour et al. 1983, Bohlin et al. 1982, Hall and Knight 1981). Information from the habitat survey was used to apply a stratified random sampling design. Simple random sampling was not used because correlations between fish abundance and reach or habitat characteristics were expected (Hankin 1984, Hankin and Reeves 1988). Differences in gradient, cover, substrate composition, and previous information on fish densities (Atagi et al. 1999; 1996 sampling) was used to divide Lemieux and Mann creeks into three and two reaches, respectively. Sample sites were then selected randomly from tabulated habitat survey information within each reach. For analysis, each habitat type and reach combination was considered a unique stratum. Runs were chosen by randomly selecting a pool in each reach, and then including either the nearest upstream or downstream run with or without cover. Off-channel sites were chosen randomly with one exception: Ianson channel in Lemieux Creek (reach 2) was selected *a priori*. For logistical reasons, only one riffle per reach was sampled in each creek. Coho abundance in riffle portions of mainstem sites was consistently low in 1996, and higher effort was allocated to other habitat types during 1997 to improve the precision of abundance estimates (e.g., see Decker et al. In press, Riley and Korman 1995).

Fish capture

The majority of fish were captured using Gee minnow traps (1/4 inch mesh) baited with preserved salmon roe. Traps in riffles and runs were placed along stream margins. Traps in off-channel areas and pools were distributed evenly throughout the sites. The number of traps, time set, and time recovered were noted. Effort at each site was kept relatively constant both within and among sampling periods, and traps were always fished overnight and for a minimum of 18 h. This was done to avoid bias arising from fish diurnal activity patterns (Heggenes et al. 1993).

Pole seining and electrofishing were also conducted to test gear selectivity for fish size. Pole seining was generally ineffective because of low fish abundance, and sample sizes were too low for analysis. In addition, electrofishing was sometimes employed in riffles and runs where minnow traps were less effective due to swiftly flowing water. However, electrofishing was not used extensively for several reasons. Firstly, the method has been shown to inhibit fish growth (Dwyer and White 1997, Schill and Beland 1995, Thompson et al. 1997), and therefore may have biased study results. Secondly, electrofishing can be both harmful and less efficient at low water temperatures, and therefore could not be employed effectively during the pre and post-winter sampling periods. Finally, many sample sites were quite deep (> 1 m) and contained abundant instream cover; both factors that can limit electroshocker efficiency (Rodgers et al. 1992).

Throughout the study, all fish were sampled at their capture site and anesthetized with MS-222 (TMS, tricane methane sulphonate; stock solution: $10.0 \text{ g} \cdot \text{l}^{-1}$ H_2O; 45-55 ml stock solution per 7.5 l basin; final concentration $\cong 0.07 \text{ g} \cdot \text{l}^{-1}$). The amount of anesthetic used varied inversely with water temperature, and the anesthetic bath was changed regularly to ensure proper dosage. Once anesthetized, all fish were counted and identified to species. Chinook salmon, rainbow trout and other species were separated and placed in a recovery basin or basket. Coho were measured (forklength to nearest mm), marked, and a sub-set of at least 150 individuals per site were weighed (nearest 0.05 g). Scale smears were taken from approximately 50 coho greater than 60 mm each

fall and post-winter sampling period. The presence of all marks, physical anomalies and sampling mortalities was noted. Fish were released at their capture location once sampling was complete.

Mass of non-weighed individuals was later predicted using linear regression of $\log_{10}$-transformed length vs. mass relationships calculated by creek, year, period, and site (1996) or habitat type (1997). Regressions were significant in all cases ($p < 0.001$) and r^2 values were consistently greater than 0.90. Individual condition factors were the residuals from this regression (Keeley 1998), thus condition factor analyses are based on weighed individuals only.

All fish capture, abundance and movement analyses (below) are based on non age-selected data; corrections for age class were only applied in fish size, growth and survival comparisons (see Chapter 2).

Capture probability

The mark recapture method was used to estimate abundance during the study (see Abundance methods, below), and thus recapture probabilities were obtained at each site during both fall and post-winter sampling. This information was compiled to assess differences in capture probability between habitat types, sampling periods, creeks, and years. Use of within period recapture probabilities minimized the potential effect of fish mortality that may occur over longer time intervals. For each creek, year and sampling period, recapture proportions in off-channels and mainstem areas (1996), and off-channels and pools (1997) were contrasted using t-tests. Comparisons of other habitat types were not possible due to low sample sizes (see Abundance results, below). Data for all habitat types were then pooled, and comparisons were made between periods, creeks and years.

Fish marking

Sequential coded wire tags

In the 1996 fall sampling period, coho were individually marked using sequential coded wire tags (s-cwt; Northwest Marine Technology, NMT, P.O. Box 427, Ben Nevis Road, Shaw Island, Washington, U.S.A. 98286). S-cwt are 1 mm long by 0.25 mm diametre sections of stainless steel wire that are inserted into the nasal cartilage of juvenile fish. S-cwt are similar to conventional cwt used extensively by fisheries agencies to collect stock assessment information. However, unlike conventional cwt, s-cwt can be used to identify individuals or small batches of fish. S-cwt are binary coded in six rows of marks along their longitudinal axis: the Master, Data 1 (D1), D2, Agency, D3, and D4 rows. The Master is used during decoding, the D1, D2 and Agency rows relate general information about river system and tagging agency, and the D3 and D4 rows describe consecutive tag numbers.

S-cwt were implanted using an automated NMT MK-IV tagging machine. At the beginning of the study, two tags were retained between each one implanted in order to ensure tag codes were unique (one tag on either side of the one inserted so its number can be interpolated, if necessary). However, the process was extremely time-consuming and the tagging protocol was changed to retain tags every 15-25 individuals. This decision was based on logistical and financial tradeoffs with other research objectives. A correction factor was derived by dividing the tagging interval (difference between the codes of the tags retained) by the number of fish tagged, and was used to identify individual fish. Each tag group was comprised of comparably sized individuals to minimize identification errors arising from within group variation in the correction factor. The incidence of identification errors was likely small because the likelihood of overlapping tag codes within each group is minimal (P. Ekstrom, NMT, personal communication).

Before commencing s-cwt application, the appropriate sized head mold was selected and tagging machine needle length and bevel were aligned and sharpened. Two or three anesthetized individuals were then tagged, given a lethal dose of anaesthetic, and dissected to check proper tag placement in cartilage. Needle penetration and head mold size were adjusted as necessary and checked periodically throughout tagging. Fish were anesthetized and their adipose fins were removed using small clippers prior to tagging. Length and weight information was collected as each individual was tagged. Throughout tagging, incidence of naturally absent adipose fins was noted and a device was used to ensure each fish contained a tag. Juveniles were released at their capture location following tagging; a random sub-set of 200-400 individuals were retained overnight to assess 24 h tag retention and post-tagging mortality. This information was used to calculate the number of tags released.

Other marks

During the 1996 fall and pre-winter periods, fish were also batch marked according to capture location. Sub-dermal marks at a combination of anal and caudal fin locations were applied using a Pan-Jet needleless injector (Wright Health Group Ltd. Kingsway, West Dundee, DD2 3QD, Scotland; Tel. 01-382-833-866) filled with Alcian Blue dye (Sigma Chemical Co. P.O. Box 14508, St. Louis, MO, 63178; Tel. 314-771-5750). Dye was pre-mixed into a supersaturated solution of approximately $7 \text{ g} \cdot \text{l}^{-1}$ distilled H_2O. At some capture locations, caudal fins were clipped instead of marked sub-dermally. Consequently, two mark groups were encountered the following spring: the fall group identifiable externally by an adipose fin clip and a Pan-Jet or fin clip mark, and the pre-winter group identifiable by a Pan-Jet or fin clip mark only. During the post-winter period, the fall mark group was sampled and then sacrificed by applying a lethal dose of anaesthetic. Individuals were labeled and preserved for future tag extraction and decoding. Pre-winter and unmarked fish were sampled, checked for marks, and released at their capture location.

In the autumn of 1997, s-cwt were not applied. Instead, juveniles were categorically marked based on fall size class. Individuals were divided into six length categories: <60 mm, 60-64 mm, 65-69 mm, 70-74 mm, 75-79 mm, and >80 mm. Categories were chosen based on preliminary analysis of the 1996 fall population length-frequency information. Each category received a unique sub-dermal Pan-Jet mark. As in the fall of 1996, fish were also marked according to capture location. However in 1997, capture location was defined by habitat type, not sample site. Habitat type was identified by a cold-brand applied in specific locations on either side of the dorsal fin. Fish in pools received a different mark than fish in off-channel areas, and fish in runs were not branded (they only received a Pan-Jet mark). Fish in runs did not receive a brand because extremely low numbers made it logistically difficult. The 1997 marking scheme meant fish in pools in reach 2 received the same mark as fish in pools in reach 1. Although limiting assessment of juvenile movement patterns, the scheme was favoured over 1996 methods for several reasons. Firstly, preliminary analysis of 1996 data revealed no consistent movement patterns among reaches in either creek (see Movement results below). Secondly, the high number of sample sites in 1997 precluded unique sample location marks. Thirdly, study objectives centred on investigating potential differences among habitat types, not reaches.

During the pre-winter period in 1997, fish were also marked according to habitat type location. Fish in pools received a lower caudal clip, while fish in off-channel areas received an upper caudal clip. Almost no fish were captured in runs, and the few fish found were not marked. Consequently, several mark groups were encountered the following spring: fall captures identifiable externally by a Pan-Jet and cold-brand; fall and pre-winter captures with a combination of Pan-Jet, cold brand and caudal clip marks; and pre-winter captures identifiable by the presence of a caudal clip only. Throughout 1997, individuals were also checked for adipose clips representing 1996 juveniles that did not smolt the previous spring. All adipose clipped fish were sampled, checked for external marks, and sacrificed for subsequent s-cwt identification.

Mark retention

In 1997, a mark-retention experiment was conducted at Bell-Irving Hatchery on Kanaka Creek, in Maple Ridge, B.C. The objectives were to assess Pan-Jet mark longevity, and test whether the three Pan-Jet mark locations utilized during the study exhibited differential mark loss rates. The potential influence of fish size on mark longevity could not be assessed because hatchery fish were very similarly sized. Also, hatchery coho were much larger than juveniles in study streams; the hatchery size range only overlapped with the largest individuals in the wild population. At the beginning of the experiment, coho were divided into three groups of approximately 175 individuals; each batch received a unique Pan-Jet mark and a fin clip to identify experimental grouping. Marking took place during early December 1997, fish were reared together in one trough through the winter, and mark incidence was rechecked during early April 1998. Overwinter mortalities preserved by the hatchery manager were also examined at this time.

ABUNDANCE ESTIMATES

Abundance estimates were obtained at each sample site during the fall and post-winter sampling periods using the mark recapture method. Fall marks used to identify fish by size category and sample site were used to generate fall estimates. Small caudal fin clips applied during initial post-winter sampling were used to generate post-winter estimates. In both periods, recaptures were performed 3 - 5 days after marking, and if necessary, fish were remarked and sampling was repeated until higher numbers of recaptures were obtained. During instances where multiple censuses were required (less than 20 % of sessions; Appendices 1 and 2), recaptures were re-released to the marked population. These recaptures were not identified with a secondary mark due to the limited number of the total marks available, and concerns about potential sampling stress. Although contrary to the recommended protocol, multiple censuses were only conducted

at sites with small numbers of total captures. Therefore it is unlikely the modification substantially biased overall abundance estimates (Ricker 1975).

The mark recapture method of estimating abundance was used instead of the removal method for several reasons. As explained above, electrofishing was not appropriate for the study, and therefore electrofishing depletions could not be conducted. Depletions using traps were not used because they were considered too time consuming as traps would have had to remain in streams overnight. There was also no suitable means of retaining relatively large numbers of juveniles for 4 - 5 days at several different sample locations. In addition, compared to the depletion method, the mark recapture method has been shown to generate accurate estimates with less effort regardless of season, and possibly time of day (Peterson and Cedarholm 1984; Rodgers et al. 1992). This may be especially true when different gear types are used during marking and recapture (Ricker 1975). However as noted previously, it was not feasible to use alternate gear types in many of the sample sites. Thus, bias arising from 'trap-shy' or 'trap-happy' behaviour could only be addressed by waiting a minimum of three days between trapping events. It was also not possible to isolate sample sites between marking and recapture, and consequently populations could not be considered entirely closed. Potential bias arising from fish movement was assessed using mark recapture information (see Movement results, below), and comparisons of capture probability between habitat types (see Fish capture results, below).

Abundance estimates at single census sites were generated using the Chapman modified Petersen mark recapture equation (Ricker 1975):

$$N = (M+1)(C+1)/(R+1) \tag{1.1}$$

where,

N = *population estimate*
M = *number of fish marked*
C = *catch or sample taken for census*
R = *number of recaptured marks in the sample*

Standard error (SE) was approximated by the equation (Ricker 1975):

$$SE \quad = \quad \sqrt{N^2(C\text{-}R)\,/\,(C\text{+}1)(R\text{+}2)} \qquad (1.2)$$

SE at multiple census sites was also estimated using Equation 1.2, but $R = \sum R_t$ and $C = \sum C_t$ (definitions below). Abundance estimates at multiple census sites were generated using the Chapman modified Schnabel equation (Ricker 1975):

$$N \qquad = \quad \sum(C_t\,M_t)/(R\text{+}1) \qquad (1.3)$$

where,

C_t	=	catch or sample taken at time t
M_t	=	number marked at time t
R	=	$\sum R_t$, sum of recaptures at time t

Density and standing stock

The following equations were used to generate density and standing stock estimates for the study streams (Hankin 1984, Hankin and Reeves 1988):

$$d \qquad = \quad \sum c_j\,/\,\sum a_j \qquad (1.4)$$

$$var(d) \qquad = \quad (N-n)\sum(c_j - da_j)^2\,/\,nN(A/N)^2(n-1)$$

$$SS \qquad = \quad Ad \qquad (1.5)$$

$$var(SS) \qquad = \quad var(Ad)\ +\ second\ stage\ var\ = A^2 var(d)\ + N\sum\sigma_j^2/n$$

$$95\%\ CL \qquad = \quad 1.96\ \sqrt{var(SS)}$$

$$SS_{stream} \qquad = \quad \sum SS \qquad (1.6)$$

$$var(SS_{stream}) \qquad = \quad \sum var(SS) \qquad (1.7)$$

$$d_{stream} \qquad = \quad SS_{stream}\,/\,A_{stream} \qquad (1.8)$$

where,

d	=	density estimate for a particular stratum
c_j	=	mark recapture estimate for j units in the stratum
a_j	=	area estimate for j units in the stratum
σ_j^2	=	SE_j^2 from Eq.1.2
n	=	number of the units sampled in the stratum
N	=	total number of the units in the stratum
A	=	total area of the stratum

SS	=	*standing stock estimate for the stratum in fish numbers*
SS_{stream}	=	*standing stock estimate for the stream*
A_{stream}	=	*area estimate for the stream, including and excluding riffles*
d_{stream}	=	*density estimate for the stream*

Log_{10}-transformed fish numbers were positively correlated with log_{10}-transformed sample site areas (m^2) in both creeks during 1996 and Lemieux Creek in 1997 (ANOVA, Lemieux 1996: $r^2 = 0.57$, n = 16, p = 0.02; Mann 1996: $r^2 = 0.68$, n = 14, p = 0.008; Lemieux 1997: $r^2 = 0.53$, n = 37, p = 0.001; Mann 1997: $r^2 = 0.22$, n = 20, p = 0.34). Therefore, site densities instead of numbers were used estimate standing stock (Eq. 1.4; Hankin 1984). During both years, standing stock estimates were generated by scaling up fish densities by the area of each habitat type (1996) or habitat type/reach (1997) stratum (Eq. 1.5). However in 1996, standing stocks for the mainstem strata were calculated based on area excluding riffles. Riffles were not included in estimates of total mainstem area because sampling in both 1996 and 1997 revealed very low juvenile abundance in riffles. In addition, for Mann Creek during 1996, standing stock was generated from stream area downstream of Highway 5 only. Only seven individuals were captured upstream of the highway during 1997 (Appendix 2a), and previous assessments of habitat availability and spawner distribution in Mann Creek concluded the upper section supports a very small proportion of overall standing stock (Anon. 1992, Hutton et al. 1983). In both years, stratum estimates were summed to obtain standing stock for the whole stream (Eq. 1.6). Variance in overall standing stock was the sum of individual stratum variances (Eq. 1.7). Average stream density was calculated from estimates of overall standing stock and total area (Eq. 1.8). During 1996, overall stream densities (d_{stream}) are reported in three ways: for stream area excluding riffles, for stream area including riffles, and in Mann Creek, for stream area downstream of Highway 5 excluding riffles. During 1997, overall stream densities are reported for stream area excluding and including riffles. In each case SS_{stream} was kept constant, only A_{stream} was modified. The different estimates of d_{stream} were generated for ease of comparison to historical information on juvenile coho abundance in interior and coastal streams as juvenile abundance is often reported for total accessible stream length or area (e.g., Marshall and Britton 1990).

Sample site area, and fish abundance, density, and size information was assessed for normality using a combination of probability plots and one-sample Kolmogorov-Smirnov tests (Systat 1997). Log_{10}-transformations were applied where appropriate. Error bars for all non-transformed data are SEs. However, 95% confidence intervals are provided for back-transformed information.

MOVEMENT ANALYSES

Mark recapture information

The study was not designed to investigate seasonal coho movement patterns in detail. Rather, movement information was used qualitatively to assess broad scale movement patterns among habitat types, and to distinguish between the potential effects of size-dependent movement and mortality. Analyses were also conducted to determine whether coho emigrated from the study streams prior to post-winter sampling. These questions were primarily investigated using mark recapture information compiled by recapture site (1996), habitat type (1996 and 1997), and initial fall size class (1996 and 1997). Only individuals recaptured in a site or habitat type other than that in which they were originally marked were included in analyses. Movement indices for each site, habitat type and size class (MI $_i$) were calculated as the weighted proportion of recaptures given the following:

$$MI_{i,t} \quad = \quad \Sigma r_{i,t} / R_{i,t} \qquad\qquad (1.8)$$

$$R_{i,t} \quad = \quad N_{t-x} - M_{i,t-x} \qquad\qquad (1.9)$$

where,

$r_{i,t}$ = *number of class i recaptures during period t*
$R_{i,t}$ = *potential number of class i recaptures during period t*
N_{t-x} = *total marks applied during period t-x*
$M_{i,t-x}$ = *total marks applied in class i during period t-x*
i = *class of interest; either a site, habitat type or size class*
x = *period interval of interest; x=1 for fall to pre-winter and pre to post-winter movement, x=2 for fall to post-winter movement*

Since only those fish recaptured away from their original mark location were included in analyses, movement to a particular habitat type or site was weighted by (N_{t-1} - $M_{i, t-1}$) as the number of potential recaptures was determined by those marked in all other classes. This accounted for differences in initial mark proportions among classes. Size-dependent movement (where i = *size class*) was assessed in a similar fashion, but in this case, $R_{i, t}$ = $N_{i, t-x}$. To simplify presentation of results, only fall to post-winter movement ($\chi=2$) was investigated in size-dependent analyses. Normality of all movement indices was assessed using probability plots and data were $\log_{10}$-transformed when necessary. Information was then contrasted in three manners. Firstly, ANOVAs and t-tests were conducted on data pooled from all fall size categories to analyze the potential effect of recapture site (1996) and habitat type (1996 and 1997) on fish movement. Replicates for site analyses during 1996 were mark location, and data were complied for three sampling intervals: fall to pre-winter, pre to post-winter and fall to post-winter. Replicates for habitat type analyses in both years were sampling periods, and thus data are applicable to the winter period as a whole. Secondly, distances moved by individual fish were compiled for both creeks during 1996. Finally, ANOVAs were conducted for both years to determine the effect of initial fish size on overwinter movement. In these analyses, replicates were fall habitat type as defined by mark location.

Downstream fence trapping

In addition to mark recapture information, I used data from partial downstream fences to assess juvenile coho movement during 1996. Each fence was a downstream converging 'V' design (Conlin and Tutty 1979), and spanned approximately three-quarters of each stream's wetted width. Fences were installed during mid September to investigate potential seasonal emigration from the study streams. Some researchers have suggested juvenile coho may leave tributaries of the North Thompson prior to the onset of winter, presumably for the purpose of overwinter rearing in the mainstem (e.g., Scott et al. 1982, Stewart et al. 1983, Stewart and Matthew 1984). Trap boxes were checked at least once every two days until mid December, and about twice monthly thereafter.

Fences were operated until February 21, 1997 in Lemieux Creek and April 8, 1997 in Mann Creek. The fence in Lemieux Creek was removed earlier because several rapid freeze/thaw events had damaged the structure. The period of fence operation in both streams also allowed the potential early emigration of pre-smolts prior to post-winter sampling to be assessed. Fences were not re-installed in the fall of 1997 because fence captures were low in both systems during 1996.

RELATIVE SURVIVAL

In both years, overwinter survival was estimated for each stratum and stream by dividing post-winter standing stock (estimated number) by fall standing stock (estimated number). Normality of survival rate estimates was assessed using probability plots and data were arcsin-transformed when appropriate. Comparisons were made between habitat types, streams and years using t-tests.

RESULTS

HABITAT SURVEY

Lemieux Creek

The total length and area of Lemieux Creek considered in the study were 12.72 km and 106,900 m^2, respectively. This was classified into 288 distinct habitat units (Table 1.1a). Riffles comprised 53 % of the usable stream area and 42 % of habitat units. Runs encompassed 36 % of the stream area and 42 % of habitat units. Pools represented 3 % of stream area and 7 % of habitat units. Off-channels comprised 8 % of stream area and 5 % of habitat units. Estimated usable length and area excluding riffles were 7052 m and 50,679 m^2, respectively, comprised of 167 habitat units. This was further divided into 41,874 m^2 (4923 m) of mainstem habitat and 8805 m^2 (2129 m) of off-channel habitat.

Wetted widths ranged from 5 to 25 m, averaging approximately 8 m. Channel width ranged from 9 to 57 m, with an average of 18 m.

Lemieux Creek was stratified into three reaches approximately 5.4, 5.3 and 2.0 km long, from downstream (reach 1) to upstream (reach 3), respectively. Substrate consisted mainly of gravel and cobble in all reaches, with relatively high proportions of fines in reach 2 and boulders in reach 1 (Table 1.2). Cover and off-channel and pool habitat types were most abundant in reach 2, comprising 7.1 % of that reach's area vs. 3.0 and 1.5 % of reaches 1 and 3, respectively (Table 1.1a). Reach 2 was also the deepest overall (average depth excluding riffles ~124 cm in November; Table 1.2).

Mann Creek

The total usable length and area of Mann Creek at the time of the survey were 6.01 km and 45,970 m^2, respectively (Table 1.1a). This was comprised of 69 distinct habitat units, including a 1.3 km section immediately below the falls designated as a single riffle where morphology was riffle-cascade (Johnston and Slaney 1996). Riffles comprised 49 % of the stream area and 36% of habitat units. Runs encompassed 17 % of usable area and 32 % of habitat units. Pools represented 24 % of stream area and 19 % of habitat units. Off-channels comprised 9 % of usable area and 13 % of habitat units. Estimated length and area excluding riffles was 3054 m and 23,291 m^2, comprised of 44 separate habitat units. The majority of stream area excluding riffles was located downstream of Highway 5 (83 %; 19,396 m^2). This reach consisted of 16,288 m^2 (1339 m) of mainstem habitat and 3109 m^2 (719 m) of off-channel habitat. These were the area estimates used in 1996 standing stock calculations.

During 1997, the section downstream of Highway 5 was referred to as reach 1 (2.55 km). Reach 2 (3.46 km) encompassed the usable portion upstream. Substrate consisted mainly of gravel and fines in reach 1, and gravel and boulder in reach 2 (Table 1.2). Average percent cover was greater than three times greater in reach 1, and reach 1 contained over 90 % of all available pool and off-channel habitat (Tables 1.1 and 1.2).

Average depths excluding riffles were also greater in reach 1 (40 vs 118 cm; Table 1.2). Wetted widths in Mann Creek ranged from 2 to 24 m, and averaged approximately 8 m. Channel width ranged from 8 to 35 m, with a mean of approximately 18 m.

For Mann Creek as a whole, there were no apparent differences in fish abundance among habitat types (see Abundance results, below). For this reason, habitat survey information was stratified by cover designation to improve precision of standing stock estimates. The stream was stratified into cover, lateral cover and no cover representing 4, 26, and 71 % of wetted area, respectively (Table 1.1b). The lateral and no cover strata comprised the majority (90 %) of habitat units. In reach 1, the cover, lateral cover and no cover strata comprised 7, 45, and 48 % of wetted area, respectively. For both reach 1 and the stream as a whole, off-channels and pools accounted for over 90 % of the cover stratum; runs and riffles generally had only lateral or no cover.

POPULATION SAMPLING

Sample sites

1996

During the fall of 1996, fish populations in Lemieux Creek were sampled in 4 % of mainstem areas (9 % excluding riffles) and 60 % of off-channel areas (Table 1.3a). Roughly 8 % of total stream area, and 18 % of stream area excluding riffles was sampled. Average mainstem and off-channel sample site areas were 907 m^2 (7.2 by 142.3 m) and 2660 m^2 (10.4 by 297.5 m), respectively (Appendix 1a).

During the fall of 1996, fish populations in Mann Creek were sampled in 7% of mainstem areas (16 % excluding riffles) and 66 % of off-channel areas (Table 1.3a). These proportions increased to 15, 19 and 92 %, respectively, when only reach 1 was considered. Roughly 13 % of the total area and 25 % of the area excluding riffles was

sampled; proportions were 25 % and 30 %, respectively in reach 1. The average wetted areas of mainstem and off-channel sample site areas were 1509 m² (10.0 by 153.8 m) and 957 m² (8.2 by 109.6 m), respectively (Appendix 1a).

In both Lemieux and Mann creeks, sites sampled during the pre and post-winter periods during 1996 were identical to those sampled the previous fall (Table 1.3b). For analysis, it was assumed the proportion of area sampled also remained similar. However, during the post-winter period, small sections ($\cong$ 60 m) both upstream and downstream of the original site were also sampled. This was done in an attempt to recover as many fall and pre-winter marks as possible. These sections were not included in calculations of area sampled, and population estimates were not conducted in them; recovered marks were only used in analyses of movement (see below) and individual growth (Chapter 2).

1997

During the fall of 1997, fish populations in Lemieux Creek were sampled in 10 % of the usable wetted area (20 % excluding riffles; Table 1.4a). A total of 32 of 288 habitat units were sampled. Areas sampled ranged from 33 to 79 % among pools and off-channels only. Runs and riffles were sampled less intensively (< 1 to 19 % of wetted area). Sample site areas in Lemieux Creek averaged 335.6 m² (49.1 by 8.9 m; Appendix 2a).

During the fall of 1997, fish populations in Mann Creek were sampled in 19 % of the total stream area (33 % excluding riffles; 28 % excluding reach 2; Table 1.4a). Proportions sampled within Mann Creek strata ranged from < 1 % (reach 2 pools without cover) to 100 % (reach 1 pools with cover). A total of 20 out of 69 habitat units were sampled, 15 of which were located in reach 1. Sample site areas in Mann Creek averaged 433.6 m² (38.1 by 10.3 m; Appendix 2a).

In both Lemieux and Mann creeks, sites sampled during the pre and post-winter periods during 1997 were identical to those sampled the previous fall (Table 1.4b).

However, several additional off-channel and pools sites were sampled during the post-winter period.

Fish capture

Table 1.6 summarizes fish capture results for both streams and years, and appendices 1 through 5 provide site-specific information. The salient findings from these summaries are the following. During the fall of 1996, a total of approximately 3000 juveniles were found and marked in both streams, more than half of which were in off-channel sites (53 and 56 % in Lemieux and Mann, respectively). During pre-winter sampling, about 1500 juveniles were captured in both streams, 23 and 14 % of which were marked (Lemieux and Mann, respectively). During post-winter sampling, roughly 2100 coho were captured in Lemieux Creek, a total of 25 % of which were marked. In Mann Creek, about 1100 fish were captured during post-winter sampling, 22 % of these captures were marked. During the fall of 1997, approximately 2100 and 1100 coho were found and marked in Lemieux and Mann creeks, respectively. Recapture proportions during pre and post-winter sampling in Lemieux Creek were 29 and 60 %, respectively, and 23 to 34 %, respectively, in Mann Creek. In both streams and years, captures of coho fry were higher than for rainbow trout, chinook salmon, and sculpins (Appendix 3).

Capture probability

No habitat related differences in capture probability were found during any sampling period, for either creek or year (Bonferoni adjusted pooled variance t-tests, all $p > 0.05$). Therefore, recapture proportions were pooled for each sampling period. For post-winter sampling during 1997, capture probability was significantly greater in Lemieux than in Mann (Bonferoni adjusted pooled variance t-test, $t = 3.07$, $df = 24$, $p = 0.005$). In addition, for Lemieux Creek during post-winter sampling, capture probability was significantly greater in 1997 than in 1996 (Bonferoni adjusted separate variance t-test, $t = -2.92$, $df = 14.8$, $p = 0.01$). However in general, consistent differences in capture probability between periods, creeks and years were not apparent.

Gear selectivity

Tests of gear selectivity for fish size were conducted in both creeks during the fall of 1996. In both streams, minnow trapped juveniles were on average both longer, and weighed more than electroshocked fish (Table 1.5). However, these differences were generally not significant in either creek (Bonferoni adjusted pooled variance t-tests, Lemieux logFL: $t = -3.03$, df = 6, p =0.05; Lemieux logWT: $t = -0.44$, df = 6, p = 0.68; Mann logFL: $t = 0.38$, df = 5, p = 0.72). Similar analyses could not be conducted in 1997 due to sampling constraints and very low juvenile abundance in areas suitable for electrofishing.

Mark retention

Results from the experiment conducted at Kanaka Creek Hatchery during 1997 indicated Pan-Jet mark retention rates were very high (> 97 %) for all three fin locations analyzed. Previous studies have also found Pan-Jet marks with Alcian Blue dye to be reliable for over six months (Herbinger et al. 1990, Laufle et al. 1990, Pitcher and Kennedy 1977, Thedinga and Johnson 1995). For these reasons, fish capture results are not corrected for mark loss over the winter period.

ABUNDANCE ESTIMATES

Density and standing stock

1996 - Fall

During fall sampling in Lemieux Creek, overall juvenile coho density was 1.25 fish $\cdot$ m^{-2} (SE = 0.39) for the stream excluding riffles, and 0.59 fish $\cdot$ m^{-2} for the stream including riffles (Table 1.3a). Average juvenile coho density in Lemieux Creek

mainstem runs and pools was 1.19 fish$\cdot$m^{-2} (SE = 0.16), while average density in off-channel areas was 1.56 fish$\cdot$m^{-2} (SE = 0.17). Log$_{10}$-transformed densities were not significantly different between strata (separate variance t-test, t = -0.21, df = 5.5, p = 0.84). Standing stock was estimated at 63,450 ($\pm$ 29,030) coho, with 78 % (49,690 $\pm$ 28,780) fish in mainstem areas, and 22 % (13,770 $\pm$ 3780) fish in off-channel areas.

Juvenile densities in Mann Creek during the fall of 1996 were higher than in Lemieux Creek (separate variance t-test, t = -2.31, df = 12.5, p = 0.04).). During fall sampling in Mann Creek, overall juvenile densities were 2.82 fish$\cdot$m^{-2} (SE = 0.38) for reach 1 excluding riffles, 2.08 fish$\cdot$m^{-2} for reach 1 including riffles, and 1.05 fish$\cdot$m^{-2} for the entire stream (Table 1.3a). Average coho density in Mann Creek mainstem runs and pools was 2.34 fish$\cdot$m^{-2} (SE = 0.30), and average density in off-channel areas was 3.30 fish$\cdot$m^{-2} (SE = 0.33). Log$_{10}$-transformed density estimates were not significantly different between strata (separate variance t-test, t = 0.4, df = 4.6, p = 0.97). Fall standing stock in Mann Creek was 48,325 ($\pm$ 17,460), with 79 % (38,065 $\pm$ 17,260) coho in mainstem runs and pools, and 21% (10,260 $\pm$ 2617) coho in off-channel areas.

1996 – Post-winter

During post-winter sampling in Lemieux Creek, overall juvenile coho density was 0.43 fish$\cdot$m^{-2} (SE = 0.13) for the stream excluding riffles, and 0.20 fish$\cdot$m^{-2} for the stream including riffles (Table 1.3b). Pre-smolt density in Lemieux Creek mainstem runs and pools was 0.43 fish$\cdot$m^{-2} (SE = 0.56), while in off-channel areas it was 0.42 fish$\cdot$m^{-2} (SE = 0.38). As during the previous fall, log$_{10}$-transformed fish densities were not significantly different between strata (separate variance t-test, t = 0.39, df = 5.7, p = 0.71). Post-winter standing stock in Lemieux Creek was 21,630 ($\pm$ 8400), with 83% (17,900 $\pm$ 8260) coho in mainstem areas, and 17% (3730 $\pm$ 1525).

In contrast to the fall, post-winter juvenile density during 1996 was not significantly different between creeks (separate variance t-test, t = -1.81, df = 12, p = 0.10). During

post-winter sampling in Mann Creek, pre-smolt densities were 1.03 fish·m^{-2} (SE = 0.19) for reach 1 excluding riffles, 0.83 fish·m^{-2} for reach 1 including riffles, and 0.42 fish·m^{-2} for the entire stream (Table 1.3b). As during the fall, densities were not significantly different between mainstem runs/pools and off-channel strata (separate variance t-test, t = -0.13, df = 4.7, p = 0.91). Juvenile density in mainstem areas was 0.96 fish·m^{-2} (SE = 0.59), and in off-channels it was 1.09 fish·m^{-2} (SE = 0.89). Post-winter standing stock in Mann creek was 19,325 (± 9900) coho, with roughly 83 % (15,940 ± 9835) of fish in mainstem areas and 17 % (385 ± 1105) in off-channel areas.

In both Lemieux and Mann creeks throughout 1996, relative fish abundance in off-channels and mainstem runs and pools was comparable to overall availability of these habitat types in each stream. Approximately 20 % of juvenile coho standing stock estimates were attributed to off-channel areas (Table 1.3) and in both streams, off-channels accounted for about 20 % of total stream area excluding riffles (Table 1.1a).

1997 - Fall

Fall standing stock in Lemieux Creek during 1997 was estimated to be 11,250 (± 4760) fry. All juveniles were present in either mainstem pools or off-channel areas (Table 1.4a). However, these habitat types accounted for only 12 % of the usable stream area and 11 % of habitat units (Table 1.1a). Captures in runs and riffles were consistently too low to generate population estimates (Appendix 2a). Although no significant differences in log$_{10}$-transformed fish densities were found among habitat type/reach strata where estimates were obtained (GLM, F = 0.82, n = 14, p = 0.57), reach 2 off-channels contained the highest proportion of overall fall standing stock in Lemieux Creek (55 %; 6230 of 11250 fish). However, the stratum accounted for only 11 % of stream area excluding riffles (5548 of 50678 m^2; Table 1.4a). Within the reach 2 off-channel stratum, 44 % of estimated numbers were from one site, Ianson groundwater channel (2737 of 6230 fish; Appendix 2a). Ianson channel also accounted for 24 % of total coho standing stock in Lemieux Creek (2737 of 11250 fish), but only 4 % of stream area excluding riffles (2166 of 50680 m^2). However, coho density in Ianson channel (1.26 fish·m^{-2}) was

not the highest observed in Lemieux Creek during fall sampling (4.92 fish $\cdot$ m^{-2}; Appendix 2a). Fall fry densities within strata ranged from 0 fish $\cdot$ m^{-2} in reach 3 off-channels and all runs and riffles to 1.49 fish $\cdot$ m^{-2} (SE = 2.23) in reach 1 pools. Fall juvenile coho density in Lemieux Creek was 0.22 (SE = 0.65) fish $\cdot$ m^{-2} for the portion excluding riffles, and 0.11 fish $\cdot$ m^{-2} for the entire creek (Table 1.4a).

Fall standing stock in Mann Creek during 1997 was estimated to be 7,885 ($\pm$ 1715) fry. All juveniles were present in either pools or off-channel areas in reach 1, but these habitat types accounted for only 30 % of usable stream area and 25 % of habitat units (Table 1.1a). Only seven coho were found in reach 2, and captures in runs and riffles were consistently too low to generate population estimates (Appendix 2a). Reach 1 pools with cover (stratum 1) accounted for the highest proportion (50 %; 3905 of 7885 fish) of overall standing stock, despite the fact this stratum represented only 4 % of total stream area excluding riffles (825 of 23291 m^2; Table 1.4a). Furthermore, just one site accounted for 69 % of estimated total abundance within stratum 1 (2692 of 3905 fish; Appendix 2a). This site also represented 34 % of estimated standing stock in the entire stream (2692 of 7885 fish), but only 1 % of stream area excluding riffles (256 of 23,291 m^2). Fall fry density in this site during 1997 was 10.51 fish $\cdot$ m^{-2}, three times higher than the next highest density site (Appendix 2a). The site was located at the outlet of 1996's beaver pond off-channel site that also exhibited the highest juvenile fall abundance (4.53 fish $\cdot$ m^{-2}; Appendix 1a). However, high water during the spring of 1996 caused substantial changes in stream structure between years and altered hydrology resulted in the site being reclassified as a mainstem pool in 1997 rather than an off-channel area. Overall, fry density in stratum 1 was 4.75 fish $\cdot$ m^{-2}, while densities in other strata ranged from 0 fish $\cdot$ m^{-2} (all of reach 2 and pools without cover, runs and riffles in reach 1) to 0.95 fish $\cdot$ m^{-2} (reach 1 pools with lateral cover; Table 1.4a). Log$_{10}$-transformed fish densities differed among strata were estimates were obtained (GLM, F = 8.30, n = 8, p = 0.03). Fall coho density in Mann Creek was 0.34 (SE = 0.17) fish $\cdot$ m^{-2} in reach 1 only, 0.17 fish $\cdot$ m^{-2} for the entire creek, and 0.33 fish $\cdot$ m^{-2} for the portion excluding riffles (Table 1.4a). In contrast to 1996, no significant differences in log$_{10}$-transformed fall

densities were found between streams (separate variance t-test, t = -1.61, df = 18.5, p = 0.12).

1997 – Post-winter

Post-winter standing stock in Lemieux Creek during 1997 was estimated to be 5170 (± 1475), and again, the highest proportion of coho were present in reach 2 off-channels (56 %; 2904 of 5170 fish; Table 1.4b). As in the fall, captures in reach 3 off-channels and in runs and riffles were too low to generate abundance estimates. Ianson channel still accounted for the majority of estimated numbers in the reach 2 off-channels stratum (50 %; 1464 of 2904 fish; Appendix 2b), and 28 % of estimated numbers in the entire stream (1464 of 5170 fish). However, pre-smolt density in Ianson channel (0.68 fish $\cdot$ m^{-2}) was not the highest observed in the stream (2.29 fish $\cdot$ m^{-2}; Appendix 2b). Pre-smolt densities in Lemieux Creek ranged from 0 fish $\cdot$ m^{-2} (reach 3 off-channels and all runs and riffles) to 0.47 fish $\cdot$ m^{-2} (reach 1 pools). These strata corresponded to strata with the extremes in fall densities. However in contrast to the fall, $\log_{10}$-transformed post-winter densities were significantly different among strata where estimates were obtained (GLM, F = 7.47, n = 19, p = 0.002). Overall post-winter density in Lemieux Creek was 0.10 (SE = 0.20) fish $\cdot$ m^{-2} for the portion excluding riffles 0.05 fish $\cdot$ m^{-2} for the entire system, and (Table 1.4b).

Post-winter standing stock in Mann Creek during 1998 was approximately 3,690 (± 735) coho and again, all standing stock was attributed to pools and off-channel areas in reach 1 (Table 1.4b). Although the pools with cover stratum (stratum 1) exhibited the highest pre-smolt densities (1.55 fish $\cdot$ m^{-2}; SE = 1.82), the majority of standing stock (65 %) was found in reach 1 pools with lateral cover (stratum 2; 2394 of 3690 fish). In comparison to stratum 1, stratum 2 had a larger area (2409 vs. 825 m^2) but only slightly lower density (1.06 vs. 1.55 fish $\cdot$ m^{-2}; Table 1.4b). Indeed, differences in $\log_{10}$-transformed densities among strata were not significant (GLM, F = 2.02, n = 8, p = 0.23). As during the previous fall, the old beaver pond site accounted for the majority of estimated stratum 1 standing stock (71 %; 900 of 1259 fish), and 24 % of standing stock

for the entire stream (900 of 3690 fish; Appendix 2b). Density in that site remained very high at 5.63 fish $\cdot$ m^{-2}, more than three times higher than the next highest density site in the stream (Appendix 1b). Post-winter coho density in Mann Creek was 0.16 (SE = 0.10) fish $\cdot$ m^{-2} in reach 1 only, 0.08 fish $\cdot$ m^{-2} for the entire creek, and 0.16 fish $\cdot$ m^{-2} for the portion excluding riffles (Table 1.4b).

In contrast to 1996, standing stock estimates for the different habitat type/reach strata were not comparable to the overall availability of these strata in the streams. In each creek, one stratum accounted for 50 to 65 % of estimated standing stock, but only 4 to 11 % of stream area excluding riffles. Two sites in particular, Ianson channel in Lemieux Creek and the old beaver pond site in Mann Creek, accounted for approximately 24 – 34 % of total standing stock during both fall and post-winter sampling periods, but less than 5 % of each stream's area excluding riffles (Table 1.4; Appendix 2).

Differences between years

Marked between year differences in juvenile coho densities and standing stocks were found during both sampling periods. Although differences were not significant in Mann Creek, $\log_{10}$-transformed coho densities were higher in 1996 compared to 1997 (Bonferoni adjusted separate variance t-tests, Lemieux, fall: $t = 3.24$, df = 14.9, $p < 0.01$; post-winter: $t = 2.12$, df = 22.6, $p = 0.05$; Mann, fall: $t = 1.90$, df = 7.6, $p = 0.10$; post-winter: $t = 1.59$, df = 8.3, $p = 0.15$). $\log_{10}$-transformed standing stock estimates were also generally higher in 1996 compared to 1997 (Bonferoni adjusted separate variance t-tests, Lemieux, fall: $t = 2.94$, df = 5.9, $p = 0.03$; post-winter: $t = 2.55$, df = 5.7, $p = 0.05$; Mann, fall: $t = 3.10$, df = 2.5, $p = 0.07$; post-winter: $t = 1.79$, df = 2.9, $p = 0.17$). Results were minimally different when standing stock estimates based on biomass were used instead of numbers.

MOVEMENT ANALYSES

Mark recapture information

Overall, relatively few juvenile coho were recaptured in locations other than where they were initially marked. Thus, sample sizes for all analyses are relatively small and are noted in Figures 1.3 – 1.5 and Appendices 4 and 5.

Effect of site and habitat type

Movement indices were log-normally distributed in all cases. Thus, analyses focussed on differences among sites and habitat types where fish were recaptured; locations with no recoveries were excluded. Overall, no significant movement trends among sites were found in either creek during 1996 (GLM, $p > 0.05$ for all intervals in both creeks). Visual comparison of data pooled from all mark locations in both streams revealed an apparent trend towards higher numbers of recaptures at sites located further upstream (e.g. Figure 1.3: b, c, e). The only exception to this pattern was in Mann Creek during the fall to post-winter interval (Figure 1.3, f). In 1996, movement indices also did not appear to be consistently affected by habitat type in either creek. There were no significant differences between movement into off-channels from mainstem areas and movement into mainstem areas from off-channels (pooled variance t-tests, Lemieux: $t = 0.50$, $df = 4$, $p = 0.64$; Mann: $t = 0.05$, $df = 4$, $p = 0.96$; Figure 1.4). However in 1997, juvenile movement did appear to differ between habitat types. In Lemieux Creek, movement into off-channels from pools was greater than into pools from off-channels (pooled variance $t = -3.79$, $df = 4$, $p = 0.02$), whereas in Mann Creek, movement into pools from off-channels was greater than into off-channels from pools (pooled variance $t = 4.98$, $df = 4$, $p = 0.01$; Figure 1.4).

Individual movement

Overall, the furthest distance moved by an individual fish in a downstream direction was about 6550 m; in an upstream direction it was approximately 4600 m (both in Lemieux Creek; 1996 only). Movement of this magnitude occurred between pre and post-winter sampling and between fall and post-winter sampling. Less individual movement was observed between fall and pre-winter sampling. Changes in the 1997 sampling design precluded similar assessment of directional movement. However, most 1997 pre and post-winter recaptures were found in either Ianson channel in Lemieux Creek or in the old beaver pond site in Mann Creek, both of which are located relatively far upstream. This likely contributed to the previous observation that coho moving in Lemieux Creek during 1997 were more likely recaptured in off-channels over pools, and fish moving in Mann Creek during 1997 were more likely recaptured in pools over off-channels.

Size-dependent movement

Results of size-dependent overwinter movement were not significant for either stream or year (Figure 1.5). Fall size class did not appear to affect juvenile movement from mainstem or off-channel areas in 1996 (GLM, Lemieux: $F = 0.71$, $n = 15$, $p = 0.63$; Mann: $F = 0.75$, $n = 10$, $p = 0.60$), or movement from pools or off-channels in 1997 (GLM, Lemieux: $F = 0.12$, $n = 10$, $p = 0.98$; Mann: $F = 0.56$, $n = 3$, $p = 0.60$).

Downstream fence trapping

Downstream fence captures did not suggest concerted emigration to the North Thompson mainstem during autumn or prior to post-winter sampling (Figure 1.6). Fence captures were quite consistently low throughout the winter, and did not appear to be associated with stream temperature in either stream. No coho were captured at the Lemieux Creek fence during late winter, and although some juveniles were captured in Mann Creek during late February, it seems unlikely this represented concerted emigration

as captures were low the next time the fence was checked in mid March. The size of the fish captured in Mann Creek during late February was comparable to average juvenile size in the stream during the post-winter period (FL range 56 - 92 mm vs. average 63.1 mm; see Chapter 2, Table 2.2).

RELATIVE SURVIVAL

Overwinter survival rates were generally quite consistent among habitat types, creeks and years (Table 1.7). No significant differences in log_{10}-transformed survival rates were found between creeks in either 1996 or 1997 (pooled variance t-tests, 1996: t = -0.93, df = 2, p = 0.45; 1997: t = 0.06, df = 7, p = 0.97). Consequently, data from both streams were pooled. During 1996, differences in log_{10}-transformed survival between off-channel areas and mainstem pools and runs were also not significant (Bonferoni adjusted pooled variance t-tests, t = 2.12, df = 2, p = 0.17), and differences between pools and off-channels were not observed in 1997 (Bonferoni adjusted pooled variance t-tests, t = 2.25, df = 7, p = 0.06). However in Mann Creek during 1997, the pools with lateral cover stratum exhibited survival rates greater than 100 %, which indicates fish movement into this stratum may have occurred overwinter. This is corroborated by fish movement results for 1997 (above). Overall, survival rates were also not significantly different between years (separate variance t-test, t = -0.03, df = 10.1, p = 0.98). Overwinter survival rates averaged 34.1 ± 1.4 % in 1996 and 34.3 ± 1.7 % in 1997.

DISCUSSION

The proportion of area sampled during juvenile coho population surveys was relatively high throughout the study in both creeks and years (ranged from 18 to 30 % during 1996, and from 20 to 33 % during 1997 for stream areas excluding riffles). Consequently, results on fish abundance and distribution are likely good representations of actual numbers and habitat use patterns in the study streams. Results from stream-

wide mark recaptures conducted by DFO during the fall of 1997 support this assertion. The DFO mark recapture estimate of standing stock in Lemieux Creek was 10,430 ($\pm$ 1048 fish), and in Mann Creek it was 6730 ($\pm$ 517 fish; J. Irvine, DFO, Pacific Biological Station, Nanaimo, B.C.; unpub. data). Both values are within the confidence intervals of estimates obtained during this study using stratified random sampling.

Results from this study indicate juvenile abundance in both streams was low throughout 1997. Overall fall densities were about 0.15 fish·m^{-2} in both streams, lower than densities observed in 1996 (0.59 and 1.05 fish·m^{-2} in Lemieux and Mann respectively) and 1993 ($\sim$ 0.3 fish·m^{-2} in Lemieux assuming similar stream area as 1997; J. Irvine, DFO, Pacific Biological Station, Nanaimo, B.C.; unpub. data). It is not known which, if any fall abundance level is 'typical' for these systems. However, low fry abundance during 1997 did appear to affect pre-smolt standing stock and density measured during post-winter sampling. Pre-smolt abundance in 1996 was roughly four times greater than 1997 in Lemieux Creek, and five times greater than 1997 in Mann Creek.

Considerable changes in stream morphology may have accounted for some of this difference in abundance between years. Notably, riverine ponds in both streams were obliterated by spring freshet conditions in early 1997. These areas have been shown to be important to overwintering juvenile coho (Brown and Hartman 1988, Cederholm and Scarlett 1981, Decker 1998, Everest et al. 1986, Peterson 1982a, Peterson 1982b), and the availability of suitable winter habitat may be one factor regulating juvenile production from streams (Hartman et al. 1996; Nickelson et al. 1992; Swales and Levings 1989). However, habitat changes were likely insufficient to explain the observed differences in both fry and pre-smolt abundance. Low 1997 abundance may also have resulted from underseeding of the streams. In Lemieux Creek, escapements during 1996 (the brood year for 1997) were the lowest on record for that stream (159 $\pm$ 26 fish, $\sim$ 5 females·km^{-1}), almost six times lower than escapement in 1995 (921 $\pm$ 179 fish, $\sim$ 33 females·km^{-1}; Irvine et al. 1998). These results suggest smolt production in the study streams may have been escapement limited during 1997, and may provide some insight to the production

dynamics of interior streams when adult abundance is low. Other studies have also suggested productive output may be limited at spawner levels less than 19 females·km^{-1} (Bradford et al. In Press, Wood 1998).

Observed abundance during 1997 was also much lower than predicted productive capacity based on an empirical regression model developed using smolt data from coastal streams and estimates of accessible stream length and area (Marshall and Britton 1990). Assuming negligible mortality after post-winter sampling, and a 10 % incidence of two year old smolts (Hutton et al. 1983), smolt output during 1997 approximated 4600 fish ($\sim$ 0.04 smolts·m^{-2}; 0.36 smolts·m^{-1}) in Lemieux Creek, and 3300 fish ($\sim$ 0.07 smolts·m^{-2}; 0.55 smolts·m^{-1}) in Mann Creek. These numbers are likely overestimates as pre-smolt mortality has been shown to be quite high (e.g., Irvine and Ward 1989, McMahon and Holtby 1992). Nonetheless, predicted productive capacity from the Marshall and Britton regression model was much higher at roughly 16,000 smolts ($\sim$ 0.15 smolts·m^{-2}; 1.26 smolts·m^{-1}) in Lemieux, and 7500 smolts ($\sim$ 0.16 smolts·m^{-2}; 1.25 smolts·m^{-1}) in Mann. However, smolt production during 1996 was both greater than in 1997, and greater than predicted capacity from the Marshall-Britton model. Given similar assumptions as above, smolt output during 1996 approximated 19,500 fish (0.18 smolts·m^{-2}; 1.53 smolts·m^{-1}) in Lemieux, and 17,500 fish (0.38 smolts·m^{-2}; 2.91 smolts·m^{-1}) in Mann. 1996 estimates were on the high end of productivity measures from coastal streams where densities typically range from 0.1 to 0.8 smolts·m^{-2}, or 0.60 to 3.0 smolts·m^{-1} (Bradford et al. 1997, Marshall and Britton 1990). 1997 estimates were on the low end of this range. Overall, these results do not suggest interior streams have inherently lower productive capacity than coastal streams (e.g., see CRT 1998). Data from 1996 indicate that if adequately seeded, interior systems may exhibit production levels comparable to those of coastal streams. However, this study's production estimates are approximate and streams may not be representative of other interior systems. Further research and more rigorous estimation of smolt output from interior streams are required to effectively address the issue of differential productive capacities between regions.

Results from this study suggest relatively short, low gradient streams on the North Thompson River floodplain such as Mann Creek may contribute much more to overall coho production in the region than previously recognized. Historically, much more attention has been directed to systems with quite long anadromous rearing reaches, such as Lemieux Creek (e.g., Harding et al. 1994, Hutton et al. 1983, Whelen and Lister 1985). However in this study, both fall and post-winter population estimates were similar between study streams, despite the fact that rearing in Mann was limited to the lower 2.5 km (23,200 m^2) of stream compared to an approximately 10 km (92,400 m^2) reach in Lemieux. In addition, although Whelen and Lister (1985) observed limited movement of coho juveniles into some North Thompson tributaries during late summer, it seems unlikely the majority of the overwintering population in Mann Creek was spawned in the North Thompson. Previous studies have shown the lower reach in Mann contains both good quality rearing and spawning habitat (Anon. 1992, ARC 1997, Hutton et al. 1983). The regional importance of relatively small systems such as Mann Creek may be similar to the significance of small low land tributaries in coastal areas (Anon. 1997). Streams of this type in both regions are particularly vulnerable to anthropogenic impacts from development and agriculture (Bradford and Irvine 1999, Dorcey and Griggs 1991).

This research did not reveal substantial emigration from either study stream to the North Thompson mainstem during late fall. Relatively high numbers of captures in Mann Creek immediately following fence installation may have arisen from non-directed in-stream movement as captures did not remain high for more than a few days. This is counter to some studies that observed limited fall movement out of tributary steams (Scott et al. 1982, Stewart et al. 1983, Stewart and Matthew 1984). Therefore, it is possible there may be at least two rearing strategies for coho in the region (Harding et al. 1994). In some streams, fry may move into the North Thompson mainstem to rear overwinter. However, results from this study suggest that in most systems, a larger proportion of juveniles may rear and overwinter in their natal streams. Significant late winter movement out of tributary streams was also not found during the study, and there was no evidence to suggest emigration of juveniles was size-dependent. A study of juvenile coho winter movement patterns in coastal B.C. streams also did not show

significant size-dependent early emigration from artificial groundwater channels (G. Giannico, Institute for Resources and Environment, University of British Columbia, Vancouver, B.C.; unpub. data).

Consistent seasonal movement patterns were also not evident within creeks during the study. In contrast to findings from coastal streams (e.g., Cederholm and Scarlett 1981, Peterson 1982a), there did not appear to be any significant movement of juvenile coho into off-channel areas prior to the onset of winter. Fish abundance in off-channel sites remained relatively high throughout both years, suggesting juvenile use of these areas began prior to fall sampling. This is supported by previous studies in interior streams that indicated salmonid movement into off-channel habitat may be associated with freshet conditions during spring and early summer (Bustard 1986, Swales and Levings 1989). In streams with low autumn and winter discharge, fish access to these areas may be limited to periods of relatively high water (Bustard 1986, Bustard 1994, Riley and Lemieux 1998). Furthermore, off-channel areas with groundwater influence may provide important thermal refuge from high summer water temperatures (Cunjak 1996, Riley and Lemieux 1998, Swales and Levings 1989).

Although autumnal movement into off-channel habitat was not evident during the study, off-channel areas did support relatively high proportions of the overwintering population in both streams. In 1996, the proportion of juveniles found in off-channel areas (~ 20 %) was close to that reported for some coastal streams (Brown and Hartman 1988, Decker 1998, Everest et al. 1986). Relative fish abundance in off-channels during 1996 was also comparable to overall availability of this habitat type in both streams. However, fish use of off-channels in Lemieux Creek and mainstem pools in Mann Creek was much greater than the proportions available during 1997. For example only two sites, Ianson groundwater channel in Lemieux and the old beaver pond site in Mann, accounted for about 30 % of juvenile standing stock during both fall and post-winter sampling, but less than 5 % of stream wetted area. Although groundwater channels have been shown to be used extensively by overwintering juveniles in coastal streams (Decker 1999, Everest et al. 1986), the importance of beaver ponds, especially in low gradient

flood plain systems, has not been as thoroughly demonstrated (Riley and Lemieux 1998, Schlosser 1995). In some circumstances, beaver activity is believed to impede fish movement (Anon. 1992, Ptolemy 1983). However, results from this study emphasize the importance of both of these habitat types in interior streams.

The distribution of fish (Fraser and Sise 1980, Gillis and Kramer 1987) and other organisms (Taylor et al. 1978) may vary among habitat types depending on density. At high levels of abundance, juveniles may be distributed relatively evenly throughout suitable rearing areas. However at low levels of abundance, only preferred habitat may be utilized. The contrast in overall abundance observed between years during this study provides some insight to these patterns for juvenile salmonids. During the relatively low abundance year in 1997, coho were distributed in a highly clumped spatial pattern and were predominantly found in two off-channel and mainstem pool sites. Fish use of these sites was sometimes three orders of magnitude greater than observed at those same locations during 1996, when overall abundance was much higher. Results from this study confirm some habitats may support relatively high densities of juveniles, even when total numbers in the stream are low.

It has been shown that at escapement levels sufficiently low to limit freshwater production, spawner distribution and fry dispersal patterns may influence fish habitat use in streams (Lestelle et al. 1993). Some of the spatial variability in juvenile distribution patterns observed throughout 1997 may be attributed to these factors. However, there is also a large body of empirical and theoretical evidence that indicates fish distribution is partly the result of complex interactions among individual perception of resource availability, density of competitors, and the risks of moving and predation (e.g., Dill 1983; Elliott 1993; Fausch 1984; Gibson et al. 1993; Gillis and Kramer 1987; Grand 1997; Keeley and McPhail 1998; Power 1993; Reinhardt and Healey 1997). Although this study was not designed to assess these factors, they may explain why the locally high densities displayed during 1997 at some sites did not appear to be associated with decreased relative overwinter survival. For example, it is possible that despite high numbers of competitors, conditions may have remained favourable at certain locations for

other reasons, such as predator avoidance. Results from this study support the need for more detailed research on the winter behaviour of juvenile fish, both at different levels of overall abundance, and at scales relevant to the ecological factors individuals face at this time of year.

These findings may have important consequences for the design of long term juvenile coho assessment programs. Salmonids are likely to be distributed unevenly within streams (Amiro 1990, Roper et al. 1997), and on both a watershed and tributary scale, spatial factors have been shown to account for as much as 65 % of variation in juvenile abundance (Milner et al. 1993). Therefore, an effective juvenile assessment strategy should explicitly account for spatial variation both within and among streams. Sampling designs that select only high quality coho habitat such as mainstem pools may produce relatively insensitive measures of annual trends in abundance for conservation purposes. For example, comparison of juvenile densities obtained during this study with those of previous assessments do not reflect the observed decline in adult escapement that has occurred in the region (Irvine et al. 1998). Juvenile survey data collected by the DFO for stock assessment also support this observation. Much higher juvenile densities were observed at some North Thompson index sites during 1997 (5.30 fry·m^{-2}; Vermelin Creek) and 1998 ($\sim$ 7 fry·m^{-2}; Raft River; J. Irvine, Pacific Biological Station, Nanaimo, B.C.; unpub. data) than at index sites sampled during 1981 (e.g., Ptolemy 1983). Sampling in only the best sites would produce positively biased estimates of total juvenile abundance, and may therefore obscure substantial spatial and temporal declines in overall abundance within streams. Stratified estimates of standing stock are more sensitive to changes in spatial distribution that may be associated with reductions in overall abundance at both the stream and watershed scale, and therefore may be more informative for monitoring populations, particularly when abundance is low.

Table 1.1a: Summary of habitat survey results for Lemieux and Mann creeks (RI = riffle; RU = run; P = pool; OC = off-channel).

Reach	Total Number of Habitat Units Present					Total Areas (m²) and Proportions Represented											Total Length (m)				
	RI	RU	P	OC	All	RI	%	RU	%	P	%	OC	%	All	%	RI	RU	P	OC	All
LEMIEUX																				
1	37	40	2	5	84	33814	62	17735	32	258	0	2972	5	54779	51	2909	1659	44	822	5434
2	52	62	12	8	134	14584	39	15458	41	1992	5	5548	15	37581	35	1740	1971	289	1247	5247
3	32	32	5	1	70	7828	54	5130	35	1302	9	285	2	14545	14	1021	746	214	60	2041
Stream	121	134	19	14	288	56226	53	38323	36	3551	3	8804.54	8	106905	100	5670	4376	547	2129	12722
MANN																				
1	15	15	10	7	47	3795	16	5575	24	10713	46	3109	13	23191	22	491	708	631	719	2549
2	10	7	3	2	22	18884	83	2414	11	228	1	1253	6	22779	21	2463	412	30	554	3459
Stream	25	22	13	9	69	22679	49	7989	17	10941	24	4362	9	45970	43	2954	1120	661	1273	6008

Table 1.1b: Summary of habitat survey results for Mann Creek stratified by cover rating (RI = riffle; RU = run; P = pool; OC = off-channel).

Cover Type[1]	Total Number of Habitat Units Present					Total Areas (m²) and Proportions Represented										Total Length (m)				
	RI	RU	P	OC	All	RI	%	RU	%	P	%	OC	%	All	%	RI	RU	P	OC	All
MANN: Both reaches																				
C	0	1	3	3	7	0	0	150	9	589	36	885	54	1624	4	0	100	60	313	473
LC	13	9	5	4	31	3174	27	3758	32	2410	20	2455	21	11796	26	424	580	197	428	1629
NC	12	12	5	2	31	19505	60	4081	13	7942	24	1023	3	32551	71	2530	440	404	532	3906
Stream	25	22	13	9	69	22679	49	7989	17	10941	24	4362	9	45970	100	2954	1120	661	1273	6008
MANN: Reach 1																				
C	0	1	3	3	7	0	0	150	8	825	44	885	48	1860	4	0	100	60	313	473
LC	13	8	5	3	29	3174	31	2558	25	2410	24	2098	20	10239	22	424	339	197	360	1320
NC	2	6	2	1	11	621	6	2631	24	7714	70	127	1	11093	24	67	269	374	46	756
Stream	15	15	10	7	47	3795	16	5339	23	10949	47	3109	13	23192	50	491	708	631	719	2549
MANN: Reach 2																				
C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LC	0	1	0	1	2	0	0	964	73	0	0	357	27	1321	3	0	241	0	68	309
NC	10	6	3	1	20	18884	88	1450	7	228	1	896	4	21458	47	2463	171	30	486	3150
Stream	10	7	3	2	22	18884	83	2414	11	228	1	1253	6	22779	50	2463	412	30	554	3459

[1] NC = no cover; LC = lateral cover; C = cover; see Chapter 1 methods for definitions.

Table 1.2: Summary of physical habitat characteristics in Lemieux and Mann creeks[1].

Reach	Depth[2] (cm)	Velocity $(m^3 s^{-1})$	Canopy %	Fine %	Gravel %	Cobble %	Boulder %	Total Cover[3] %
LEMIEUX								
1	78.4	0.44	13	24	16	44	16	31
2	123.9	0.52	22	44	49	24	4	49
3	98.5	0.48	17	21	59	30	2	44
MANN								
1	118.4	0.34	2	45	35	15	4	37
2	40.3	0.24	8	3	19	11	16	10

[1] Values are means of pre-winter sample site measurements.

[2] Values are means of pre-winter and spring measurements; excluding riffles.

[3] See methods for definitions.

Table 1.3a: Sample sizes, areas sampled, and stratified abundance estimates (stratified by habitat type) for juvenile coho during the fall in Lemieux and Mann creeks, 1996.

Strata	Reach	Habitat Type[1]	Cover Rating	Total Area (m²)[2]	Area sampled m²	Area sampled %	Total N	Sampled n	Fall Density (fish m⁻²) Mean[3]	Fall Density (fish m⁻²) SE[4]	Fall Standing Stock Estimate	Fall Standing Stock CL[5]
LEMIEUX 1996												
1	n/a	MS	n/a	41874	3628	9	46	4	1.19	0.16	49685	28782
2	n/a	OC	n/a	8805	5320	60	3	2	1.56	0.17	13768	3775
Stream	All	excl. RI	-	50679	8948	18	49	6	1.25	0.39	63453	29029
Stream	All	All	-	106905 [6]	8948	8	111	6	0.59	-	63453	29029
MANN 1996												
1	1	MS	n/a	16287	3018	19	11	2	2.34	0.30	38065	12385
2	1	OC	n/a	3109	2870	92	3	3	3.30	0.33	10260	2617
Stream	1	excl. RI	-	19396	5888	30	14	5	2.82	0.38	48325	12659
Stream	1	All	-	23191 [6]	5888	25	16	5	2.08	-	48325	12659
Stream	All	All	-	45970 [7]	5888	13	33	5	1.05	-	48325	12659

[1] MS = Mainstem representative sites, OC = Off-channel sites.

[2] Excluding riffles.

[3] sumc/suma; overall density = SS/A; see Chapter 1 methods for details.

[4] Italics are SE based on sum of individual strata var(d); see Chapter 1 methods.

[5] 95% CL; based on first and second stage error.

[6] Area including riffles.

[7] Area including riffles and usable area upstream of Highway 5.

Table 1.3b: Sample sizes, areas sampled, and stratified abundance estimates (stratified by habitat type) for juvenile coho during post-winter sampling in Lemieux and Mann creeks, 1996.

Strata	Reach	Habitat Type[1]	Cover Rating	Total Area (m²)[2]	Area sampled m²	Area sampled %	Total N	Sampled n	Spring Density (fish m⁻²) Mean[3]	Spring Density (fish m⁻²) SE[4]	Spring Standing Stock Estimate	Spring Standing Stock CL[5]
LEMIEUX 1996												
1	n/a	MS	n/a	41874	3628	9	46	4	0.43	0.56	17903	8260
2	n/a	OC	n/a	8805	5320	60	3	2	0.42	0.38	3729	1526
Stream	All	excl. RI	-	50679	8948	18	49	6	0.43	*0.13*	21632	8400
Stream	All	All	-	106905[6]	8948	8	111	6	0.20	-	21632	8400
MANN 1996												
1	1	MS	n/a	16287	3018	19	11	2	0.96	0.59	15939	7388
2	1	OC	n/a	3109	3109	100	3	3	1.09	0.89	3384	1104
Stream	1	excl. RI	-	19396	6127	32	14	5	1.03	*0.19*	19323	7470
Stream	1	All	-	23191[6]	6127	26	16	5	0.83	-	19323	7470
Stream	All	All	-	45970[7]	6127	13	33	5	0.42	-	19323	7470

[1] MS = Mainstem representative sites, OC = Off-channel sites.

[2] Excluding riffles, see text for other.

[3] sumc/suma; overall density = SS/A; see Chapter 1 methods for details.

[4] Italics are SE based on sum of individual strata var(d); see Chapter 1 methods.

[5] 95% CL; based on first and second stage error.

[6] Area including riffles.

[7] Area including riffles and usable area upstream of Highway 5.

Table 1.4a: Sample sizes, areas sampled, and stratified abundance estimates (stratified by habitat type, reach and cover rating) for juvenile coho during the fall in Lemieux and Mann creeks, 1997.

Strata	Reach	Habitat Type	Cover Rating	Total Area (m²)	Area sampled m² [1]	Area sampled %	Total N	Sampled n	Fall Density (fish m⁻²) Mean[2]	Fall Density (fish m⁻²) SE[3]	Fall Standing Stock Estimate	Fall Standing Stock CL[4]
LEMIEUX 1997												
1	1	P	n/a	257	204	79	2	2	1.49	2.23	384	111
2	2	P	n/a	1992	667	33	12	3	1.20	0.41	2384	2125
3	3	P	n/a	1301	704	54	5	4	0.47	0.24	614	286
4	1	OC	n/a	2972	1602	54	5	2	0.55	0.12	1633	720
5	2	OC	n/a	5548	2441	44	8	2	1.12	0.62	6230	4188
6	3	OC	n/a	285	211	74	1	1	0.00	0.00	1	0
7	1	RU	n/a	17735	2038	11	40	6	0.00	0.00	0	0
8	2	RU	n/a	15458	1201	8	62	4	0.00	0.00	0	0
9	3	RU	n/a	5130	973	19	32	5	0.00	0.00	0	0
10	1	RI	n/a	33814	91	0	37	1	0.00	0.00	0	0
11	2	RI	n/a	14584	108	1	52	1	0.00	0.00	0	0
12	3	RI	n/a	7828	150	2	32	1	0.00	0.00	0	0
Stream	All	excl. RI	-	50678	10041	20	167	29	0.22	*0.65*	11248	4761
Stream	All	All	-	106905	10390	10	288	32	0.11	-	11248	4761
MANN 1997												
1	1	P	C	825	825	100	3	3	4.75	2.63	3905	81
2	1	P	LC	2409	347	14	5	2	0.95	0.64	2255	782
3	1	P	NC	7714	1047	14	2	1	0.18	0.00	1418	1347
4	1	OC	n/a	3109	2292	74	7	2	0.10	0.07	307	714
5	1	RU	n/a	5339	1895	35	15	6	0.00	0.00	0	0
6	1	RI	n/a	3795	108	3	15	1	0.00	0.00	0	0
7	2	P	C	0	0	n/a	0	0	0.00	0.00	0	0
8	2	P	LC	0	0	n/a	0	0	0.00	0.00	0	0
9	2	P	NC	228	0	0	3	0	0.00	0.00	0	0
10	2	OC	n/a	1253	152	12	2	1	0.00	0.00	0	0
11	2	RU	n/a	2414	1142	47	7	3	0.00	0.00	0	0
12	2	RI	n/a	18884	909	5	10	1	0.00	0.00	0	0
Stream	1	All	-	23191	6513	28	47	15	0.34	*0.17*	7785	1715
Stream	All	excl. RI	-	23291	7698	33	44	18	0.33	-	7785	1715
Stream	All	All	-	45970	8715	19	69	20	0.17	-	7885	1715

[1] Values are from sampled areas, not surveyed areas of sample sites.

[2] sumc/suma; SS/A for whole stream; see Chapter 1 methods for details.

[3] Italics are SE based on sum of individual strata var(d); see Chapter 1 methods.

[4] 95% CL; based on first and second stage error.

Table 1.4b: Sample sizes, areas sampled, and stratified abundance estimates (stratified by habitat type, reach and cover rating) for juvenile coho during post-winter sampling in Lemieux and Mann creeks, 1997.

Strata	Reach	Habitat Type	Cover Rating	Total Area (m²)	Area sampled m² [1]	%	Total N	Sampled n	Spring Density (fish m⁻²) Mean[2]	SE[3]	Spring Standing Stock Estimate	CL[4]
LEMIEUX 1997												
1	1	P	n/a	257	199	78	2	2	0.53	0.47	136	42
2	2	P	n/a	1992	498	25	12	5	0.79	0.36	1574	615
3	3	P	n/a	1301	511	39	5	4	0.18	0.10	228	73
4	1	OC	n/a	2972	1942	65	5	3	0.11	0.05	328	195
5	2	OC	n/a	5548	3156	57	8	4	0.52	0.13	2904	1351
6	3	OC	n/a	285	985	346	1	1	0.00	0.00	0	0
7	1	RU	n/a	17735	1852	10	40	5	0.00	0.00	0	0
8	2	RU	n/a	15458	1307	8	62	4	0.00	0.00	0	0
9	3	RU	n/a	5130	903	18	32	5	0.00	0.00	0	0
10	1	RI	n/a	33814	91	0	37	1	0.00	0.00	0	0
11	2	RI	n/a	14584	108	1	52	1	0.00	0.00	0	0
12	3	RI	n/a	7828	150	2	32	1	0.00	0.00	0	0
Stream	All	excl. RI		50678	11353	22	167	33	0.10	*0.20*	5171	1500
Stream	All	All	-	106905	11702	11	288	36	0.05	-	5171	1500
MANN 1997												
1	1	P	C	825	619	75	3	3	1.55	1.82	1259	261
2	1	P	LC	2409	446	19	5	3	1.06	0.48	2394	678
3	1	P	NC	7714	637	8	2	1	0.00	0.00	0	0
4	1	OC	n/a	3109	2692	87	7	3	0.01	0.05	34	106
5	1	RU	n/a	5339	1335	25	15	6	0.00	0.00	0	0
6	1	RI	n/a	3795	108	3	15	1	0.00	0.00	0	0
7	2	P	C	0	0	n/a	0	0	0.00	0.00	0	0
8	2	P	LC	0	0	n/a	0	0	0.00	0.00	0	0
9	2	P	NC	228	0	0	3	0	0.00	0.00	0	0
10	2	OC	n/a	1253	152	12	2	1	0.00	0.00	0	0
11	2	RU	n/a	2414	1095	45	7	3	0.00	0.00	0	0
12	2	RI	n/a	18884	909	5	10	1	0.00	0.00	0	0
Stream	1	All	-	23191	5837	25	47	17	0.16	*0.10*	3687	734
Stream	All	excl. RI	-	23291	6975	30	44	20	0.16	-	3687	734
Stream	All	All	-	45970	7991	17	69	22	0.08	-	3687	734

[1] Values are from sampled areas, not surveyed areas of sample sites.

[2] sumc/suma; SS/A for whole stream; see Chapter 1 methods for details.

[3] Italics are SE based on sum of individual strata var(d); see Chapter 1 methods.

[4] 95% CL; based on first and second stage error.

Table 1.5: Comparison of minnow trapped (MT) and electroshocked (ES) juvenile coho sizes, fall 1996 (CL = 95% confidence limits).
Significant differences are underlined (Bonferoni adjusted t-test; p = 0.05).

	Forklength				Weight			
	MT		ES		MT		ES	
Creek	mm	CL	mm	CL	g	CL	g	CL
Lemieux	66.93	1.01	63.19	1.03	3.09	1.01	2.97	1.11
Mann	61.80	1.01	61.28	1.02	2.38	1.03	2.05	1.06

Table 1.6: Fall, pre and post-winter capture summaries for Lemieux and Mann creeks, 1996 and 1997.

			Fall			Pre-winter					Un-	Total		Post-winter					
														Fall		Pre-winter		Fall + Pre-winter	
Year	Creek	Strata	C	%	M	C	R	$\%^1$	M	C	marked	R	$\%^1$	R	$\%^2$	R	$\%^2$	R	$\%^2$
1996	Lemieux	MS	1402	47	1402	650	176	27	474	801	625	176	22	120	68	57	32	n/a	n/a
		OC	1580	53	1580	1300	277	21	1023	1325	970	355	27	246	69	108	30	n/a	n/a
		Total	2982	100	2982	1950	453	23	1497	2126	1595	531	25	366	69	165	31	n/a	n/a
1996	Mann	MS	1385	44	1385	383	68	18	315	378	312	66	17	34	52	32	48	n/a	n/a
		OC	1773	56	1773	978	124	13	854	773	584	189	24	95	50	94	50	n/a	n/a
		Total	3158	100	3158	1361	192	14	1169	1151	896	255	22	129	51	126	49	n/a	n/a
1997	Lemieux	P	463	22	463	276	83	30	193	291	142	149	51	38	26	76	51	35	23
		OC	1628	77	1628	1511	437	29	1074	1238	464	774	63	188	24	387	50	199	26
		RU	18	1	18	45	8	18	37	10	8	2	20	0	0	2	100	0	0
		Total	2109	100	2109	1832	528	29	1304	1539	614	925	60	226	24	465	50	234	25
1997	Mann	P	1055	91	1055	504	119	24	385	490	324	166	34	58	35	74	45	34	20
		OC	72	6	72	104	22	21	82	31	16	15	48	7	47	7	47	1	7
		RU	33	3	33	19	2	11	17	12	12	0	0	0	0	0	0	0	0
		Total	1160	100	1160	627	143	23	484	533	352	181	34	65	36	81	45	35	19

M = New marks applied
C = Total captures
R = Recaptured marks
[1] Proportions are R/C
[2] Proportions are R/total R

Table 1.7: Estimated fall and post-winter standing stock in fish numbers and biomass, and relative overwinter survival of juvenile coho in Lemieux and Mann creeks, 1996 and 1997.

1996 estimates are based on areas excluding riffles and Mann 1996 is for reach 1 only.

| | | Hab. | | Standing Stock - Numbers (No.) | | | | | | Standing Stock - Biomass (g) | | | | Rel. Surv.[3] |
| | | | | Fall | | | Post-winter | | | Fall | | Post-winter | | |
Strata	Reach	Type	Cov.	No.	CL[1]	CL %	No.	CL[1]	CL %	g	CL[2]	g	CL[2]	%
LEMIEUX 1996														
1	n/a	MS	n/a	49685	28782	58	17903	8260	46	160783	87636	61340	26431	36
2	n/a	OC	n/a	13768	3775	27	3729	1526	41	46818	11609	14048	4878	27
Stream	-	All	-	63453	29029	46	21632	8400	39	207601	88402	75388	26878	34
MANN 1996														
1	n/a	MS	n/a	38065	12385	33	15939	7388	46	81934	45383	44678	23864	42
2	n/a	OC	n/a	10260	2617	26	3384	1104	33	24976	0	8884	0	33
Stream	-	All	-	48325	12659	26	19323	7470	39	106910	45383	53562	23864	40
LEMIEUX 1997														
1	1	P	n/a	384	111	29	136	42	31	1214	0	655	0	35
2	2	P	n/a	2384	2125	89	1574	615	39	7764	6710	7411	2884	66
3	3	P	n/a	614	286	47	228	73	32	2033	615	1143	288	37
4	1	OC	n/a	1633	720	44	328	195	59	5543	1341	1745	906	20
5	2	OC	n/a	6230	4188	67	2904	1351	47	16156	10638	11284	4738	47
6	3	OC	n/a	1	0	0	0	0	0	5	0	1	0	21
7	1	RU	n/a	0	0	0	0	0	0	0	0	0	0	0
8	2	RU	n/a	0	0	0	0	0	0	0	0	0	0	0
9	3	RU	n/a	0	0	0	0	0	0	0	0	0	0	0
10	1	RI	n/a	0	0	0	0	0	0	0	0	0	0	0
11	2	RI	n/a	0	0	0	0	0	0	0	0	0	0	0
12	3	RI	n/a	0	0	0	0	0	0	0	0	0	0	0
Stream	All	All	-	11248	4761	42	5171	1500	29	32716	12663	22240	5628	46
MANN 1997														
1	1	P	C	3905	81	2	1259	261	21	13393	0	5693	0	32
2	1	P	LC	2255	782	35	2394	678	28	7329	2703	9758	1721	106
3	1	P	NC	1418	1347	95	0	0	0	3889	0	0	0	0
4	1	OC	n/a	307	714	233	34	106	312	922	2548	164	484	11
5	1	RU	n/a	0	0	0	0	0	0	0	0	0	0	0
6	1	RI	n/a	0	0	0	0	0	0	0	0	0	0	0
7	2	P	C	0	0	0	0	0	0	0	0	0	0	0
8	2	P	LC	0	0	0	0	0	0	0	0	0	0	0
9	2	P	NC	0	0	0	0	0	0	0	0	0	0	0
10	2	OC	n/a	0	0	0	0	0	0	0	0	0	0	0
11	2	RU	n/a	0	0	0	0	0	0	0	0	0	0	0
12	2	RI	n/a	0	0	0	0	0	0	0	0	0	0	0
Stream	All	All	-	7885	1715	22	3687	734	20	21402	2804	13933	1721	47

[1] 95% CL; based on first and second stage error.

[2] 95% CL; Sampling error only.

[3] Spring Standing stock/Fall Standing stock (in numbers)
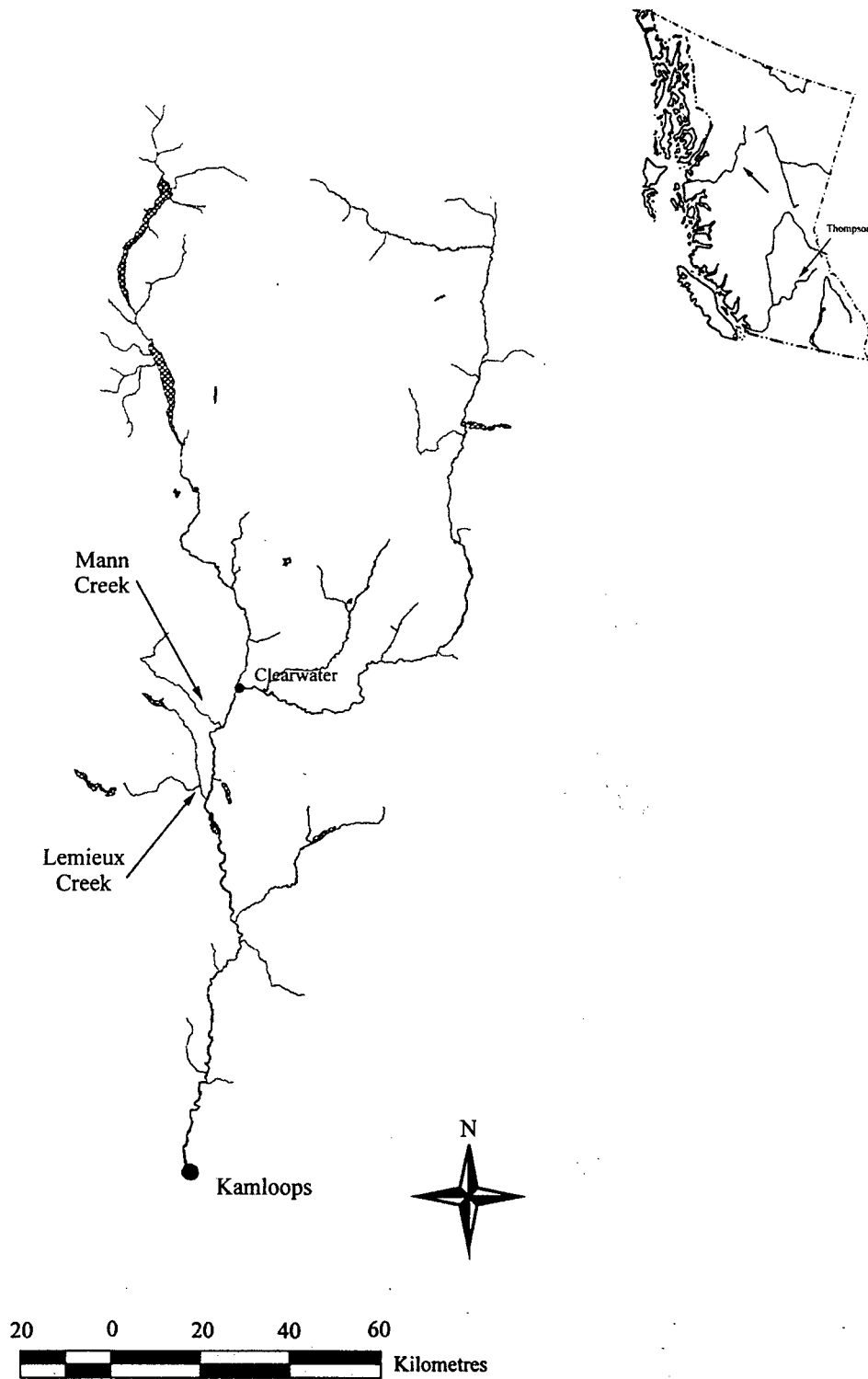
Figure 1.1: Map of the North Thompson River drainage showing location of the study streams.
Arrows on inset indicate major spawning regions for interior coho populations in British Columbia.
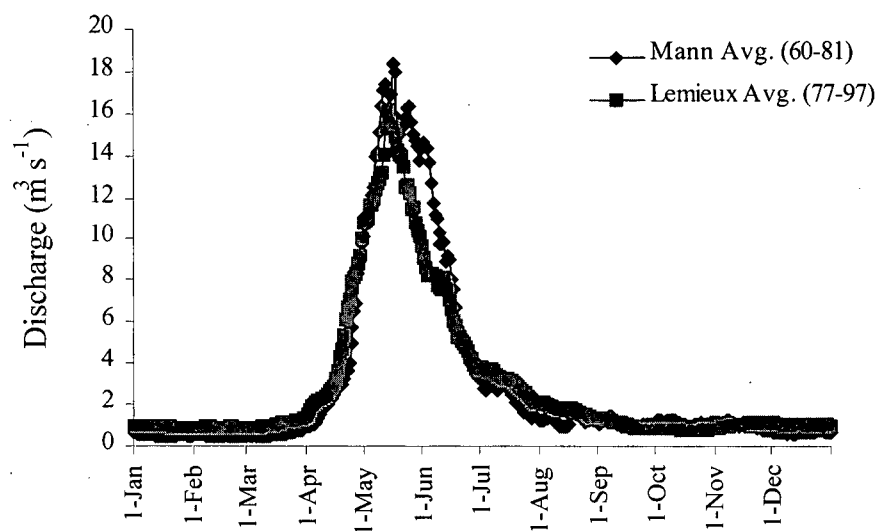
Figure 1.2: Annual hydrograph for Lemieux and Mann creeks.

Source: Water Survey of Canada. Daily discharge rates are the average for the periods indicated in the legend.

Winter movement 1996

Lemieux,Fall_Pre Lemieux,Pre_Post Lemieux,Fall_Post

Mann,Fall_Pre Mann,Pre_Post Mann,Fall_Post
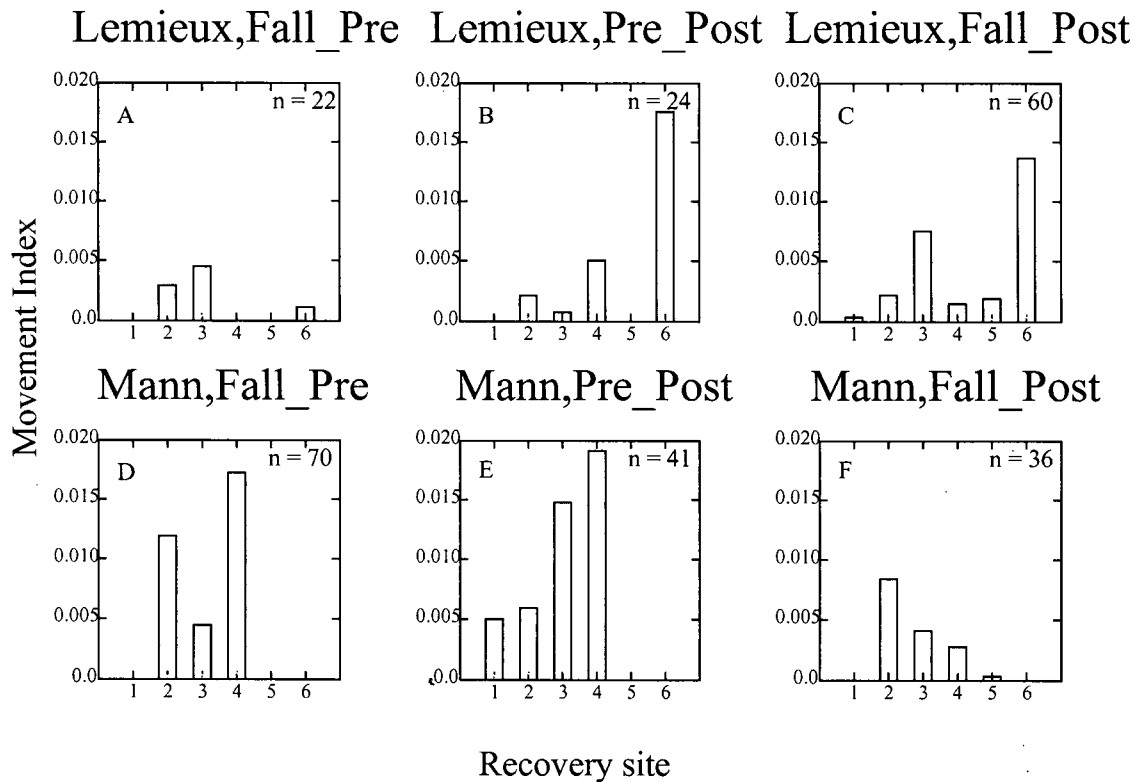
Recovery site

Figure 1.3: Site related movement of marked juveniles in Lemieux and Mann creeks for each sampling interval (i.e. fall to pre-winter; pre to post-winter; fall to post-winter) during 1996.

Recovery locations are ordered in a downstream (site 1) to upstream (site 6) fashion. The number of fish that moved during each interval is noted. No significant differences in $\log_{10}$-transformed movement indices were found among recapture locations (GLM; p > 0.05 for all intervals in both streams and years).

96,Lemieux

96,Mann

97,Lemieux

97,Mann

Recovery habitat type
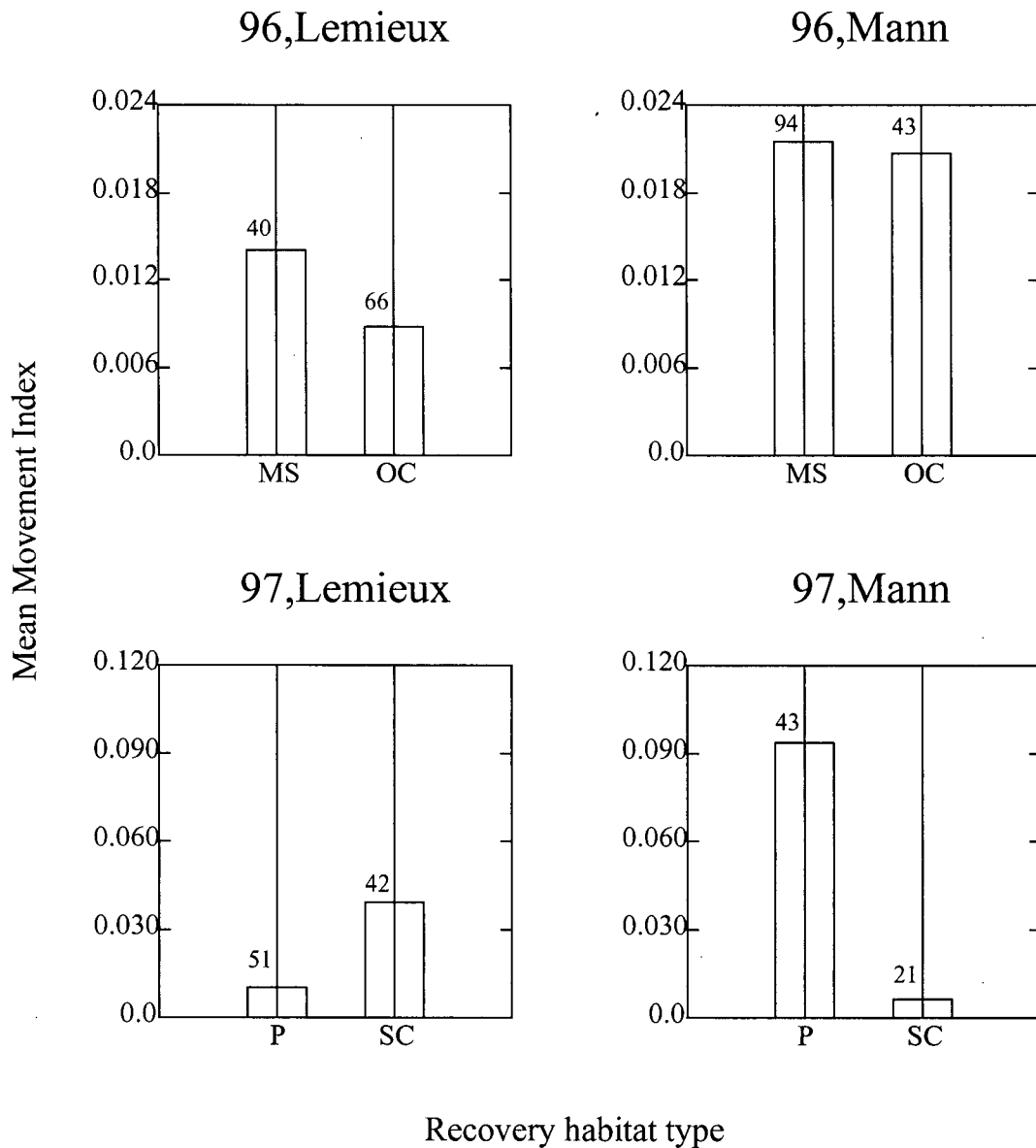
Figure 1.4: Habitat related overwinter movement of marked juveniles in Lemieux and Mann creeks during 1996 and 1997.

Errors are ± 95% confidence intervals of movement indices pooled across sampling intervals. The number of fish that moved into each habitat type is noted at the top of each bar. While no significant differences were found in fish movement between habitat types in 1996, distinct habitat related patterns were noted during 1997 (t-test; $p < 0.05$).

Figure 1.5: Size-related movement of marked juveniles in Lemieux and Mann creeks between fall and post winter sampling during 1996 and 1997.

Figure headings refer to the habitat type fish were moving from; i.e., size-dependent movement out of mainstem (MS) or off-channel (OC) sites in 1996, or out or pools (P) or side-channel (SC) sites in 1997. Overall size-dependent movement is also summarized (ALL). The number of fish that moved overall and that moved out of each habitat type is noted. No significant differences were found in fish movement among size classes in either creek or year (GLM; p > 0.05). In these analyses, data from each habitat type were pooled due to sample size constraints.

Lemieux Creek 1996
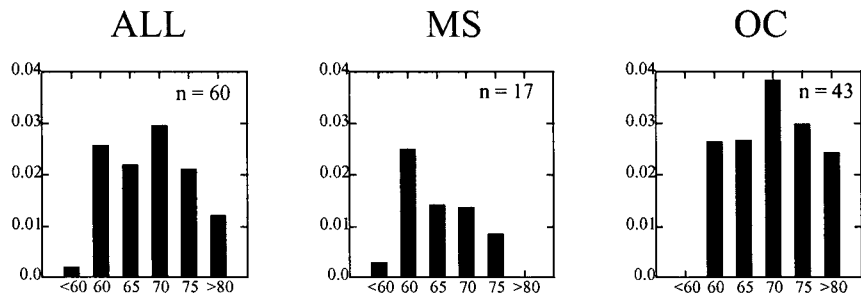
ALL

n = 60

MS

n = 17

OC

n = 43

Mann Creek 1996

ALL

n = 34

MS

n = 29

OC

n = 6

Lemieux Creek 1997

ALL

n = 22

P

n = 16

SC

n = 6

Mann Creek 1997

ALL

n = 7

P

n = 1

SC

n = 6
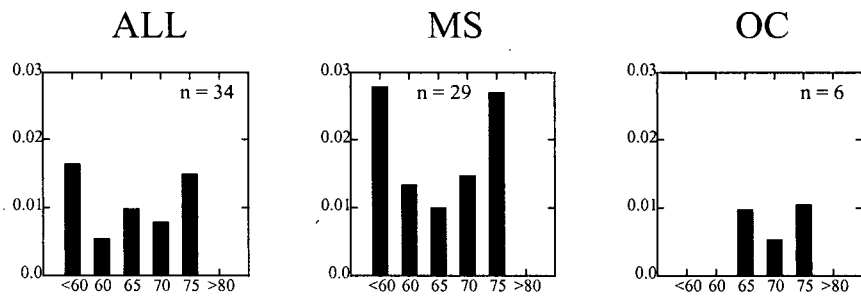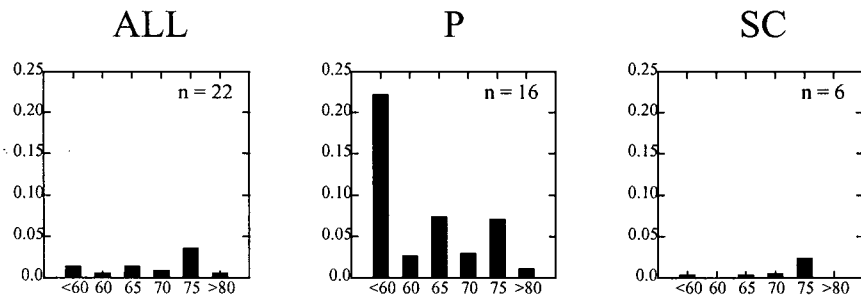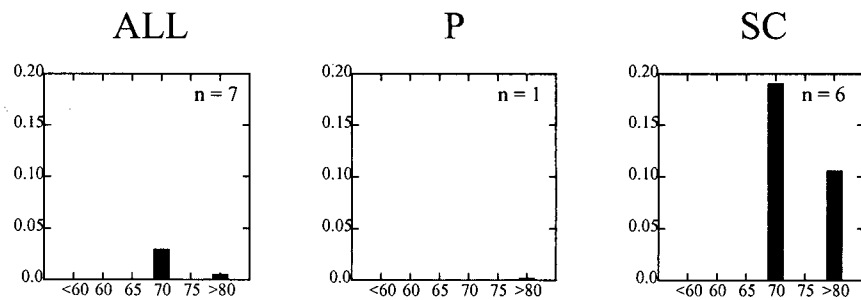
Movement Index

Fall size class
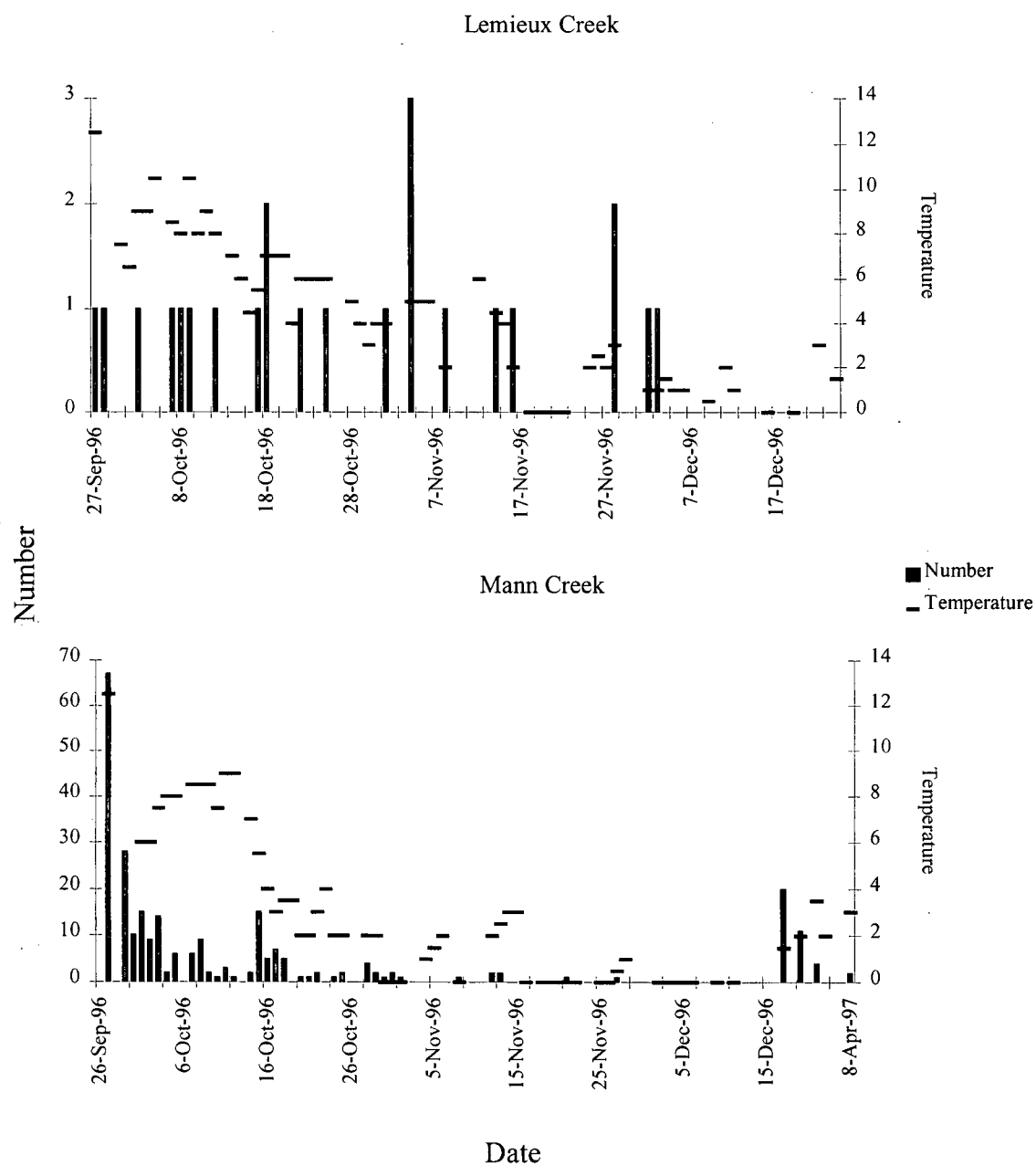
Figure 1.6: Number of coho captured at downstream fences during the winter of 1996 in Lemieux and Mann creeks.

Stream temperatures measured at each fence are also indicated. Note difference in scales between creeks.

CHAPTER 2:
SIZE-DEPENDENT OVERWINTER GROWTH AND SURVIVAL
OF JUVENILE COHO IN INTERIOR STREAMS

Conservation concerns for coho populations throughout the Pacific northwest have highlighted the importance of effective assessment and restoration strategies. In British Columbia, much of the stock assessment is based on adult abundance time series (CRT 1998, Slaney et al. 1996). However when spawner abundance is low, variation in juvenile production may be an important component of overall population dynamics (Bradford 1999). Stock - recruit relationships at depressed population levels may be most influenced by freshwater production (Bradford et al. 1997, Hilborn and Walters 1992). Therefore, understanding the factors affecting juvenile survival is integral to effective management and conservation of threatened populations (Wood 1998).

In addition, information on coho escapements is often both unreliable and difficult to obtain (English et al. 1992, Slaney et al. 1996). Accurate counts can be made using fences, but obtaining these estimates is both logistically intensive and costly. Consequently in B.C., reliable escapement estimates are available for only a few wild coho populations (Slaney et al. 1996). In contrast, although the design of effective juvenile assessment programs is still a matter of some contention, obtaining reliable juvenile standing stock information can be relatively easy and inexpensive (e.g., Decker et al. In press, Riley and Korman 1995). For this reason, juvenile surveys may be an important component of coho stock assessment procedures (e.g., Holtby 1998, Simpson et al. 1997). In fact, the Department of Fisheries and Oceans (DFO) currently conducts limited juvenile sampling in 150 to 200 B.C. streams to provide indices of coho abundance and estimates of freshwater production. Sampling takes place in mid-fall and juvenile size and density information is incorporated into a model predicting subsequent smolt production (Holtby et al. 1992, Holtby 1998). Among other things, the model is based on a positive correlation between average fall size and overwinter survival observed in Carnation Creek, on the west coast of Vancouver Island (Holtby 1988,

Holtby and Hartman 1982). There is no other practical predictor of freshwater production, and existing models of productive capacity are based only on estimates of stream length and area (Bradford et al. 1997, Marshall and Britton 1990).

Juvenile abundance data could therefore be a valuable management tool, but its reliability depends at least in part on our understanding of coho freshwater ecology. For example, survival through the first winter of freshwater residence has long been recognized as a critical determinant of salmonid production in streams (Bustard and Narver 1975, Holtby and Hartman 1982, Quinn and Peterson 1996). Yet the factors influencing juvenile overwinter survival are not well understood. There is some suggestion that survival may be size-dependent, with large fall size associated with improved overwinter survival. Evidence to support this comes from both among year correlations between average fall size and subsequent overwinter survival (Holtby 1988, Hunt 1969) and within year comparisons of fall and spring size-frequency distributions (Irvine and Johnston 1992, Lindroth 1965, Oliver and Holeton 1979, Peterson 1982b, Thedinga et al. 1989, Toneys and Coble 1979, West and Larkin 1987). Authors cite a number of potential mechanisms for the relationship. Smaller members of a cohort have higher weight-specific maintenance requirements and lower energy storage capacity than larger juveniles (reviewed in Ricker 1979, Weatherly and Gill 1987). Thus, they may exhaust energy stores faster in cold winter temperatures and experience higher overwinter starvation rates (Cunjak 1988a, Gardiner and Geddes 1980, Riddell and Leggett 1981). Alternately, predation rates on smaller fish may be higher than on larger conspecifics (e.g., Hargreaves and LeBrasseur 1986, Healey 1982, Post and Evans 1989a). However specific examples of size-dependent survival are limited, and data collected from individually marked fish is sparse and not always consistent with the predicted association between large size and survival (Brown 1985, Quinn and Peterson 1996).

Many studies of juvenile salmonids record a shift in size-frequency distributions from negatively skewed to normal over the winter (e.g., Brown 1985, Decker 1999). However, comparison of fall and spring size-frequency distributions within years does not provide conclusive evidence for size-related survival if size-dependent growth or movement

occurs between sampling periods (Post and Evans 1989b). In addition, if variation in instantaneous mortality rate is linear with respect to length, even the presence of size-selective mortality does not necessarily change the shape of length frequency distributions (Jones 1958, Ricker 1975, Ricker 1979). For these reasons, thorough assessment of the role of size-dependent factors may be best achieved using individually marked fish. Ultimately, resolving the relative contributions of these factors may have important ramifications for how we understand and eventually model coho freshwater production.

Juvenile coho emigrate from freshwater rearing streams to marine environments as smolts during the spring. As for many other stream-dwelling salmonids, the age at which smolting occurs varies somewhat both within and among populations (e.g., Hartman et al. 1982a, Holtby et al. 1989, Jonsson et al. 1990, Nicieza and Brana 1993, Washington 1981). Freshwater growing conditions are believed to be important in determining this variation (Metcalfe and Thorpe 1990, Thorpe 1987). There is also considerable evidence the duration of the freshwater phase is related to both physiological and ecological advantages of attaining a threshold size to enter the marine environment (Henderson and Cass 1991; Holtby et al. 1990; Nicieza and Brana 1993; Ward and Slaney 1988). Therefore, juvenile coho may experience strong selective pressure to adopt behavioural tactics that allow them to attain a size consistent with smolting, while minimizing the risks associated with continued foraging (Dill 1983, Martel 1996, Metcalfe et al. 1986, Walters and Juanes 1993). For example, studies have shown juveniles often switch from active feeding, and aggressive and territorial behaviour during the summer (Chapman 1962; Mason and Chapman 1965; Nielsen 1992), to increased hiding and gregarious behaviour during winter (Cunjak 1988a, Murphy et al. 1989, Nickleson et al. 1992, Rimmer et al. 1983, Rimmer et al. 1984). This suggests selection may favour individuals that adopt risk-prone behaviour when growing conditions are good, but if conditions change, or a certain size is attained, risk-averse strategies may be more successful (Reinhardt and Healey 1999). This behavioural shift may also be one reason why winter is often considered a period of negligible growth (Conover 1992, Metcalfe and Thorpe 1992, Smith and Griffith 1994), when feeding is limited to that required to sustain a

minimal level of metabolic activity (Cunjak 1988b). However, lack of winter growth may have important consequences for individuals that are still relatively small at the end of summer. Research on Atlantic salmon (*Salmo salar*) has indicated the segregation of a population into fish that will smolt in a given spring and those that spend an additional year in freshwater is apparent by autumn (Metcalfe and Thorpe 1992). Fish that defer smolting tend to be relatively small individuals that exhibit virtual cessation of growth during winter, even under environmental conditions that would otherwise allow growth to occur. Larger individuals tend to smolt the following spring and continue to grow to a limited extent throughout their first winter of freshwater residence. However, similar research has not been conducted on juvenile coho, which may limit our understanding of life-history variation for this species. In addition, the prevalence of size-dependent overwinter growth, and the conditions that affect it, may influence the way we model coho freshwater production.

The purpose of this chapter is to investigate size-dependent survival and growth by juvenile coho during their first winter of freshwater residence. This is achieved by assessing individually and categorically marked juveniles in two interior B.C. streams during the winters of 1996 and 1997. The influence of habitat type and relative fish abundance on size-dependent patterns is also investigated. This information may help efforts to improve coho management by expanding our knowledge of freshwater production dynamics. Results may also be useful in testing the assumptions of an existing juvenile production model that is based on a positive size-survival function.

The specific objectives of this chapter are fourfold. The first objective is to examine overall and habitat related patterns in size-dependent overwinter survival. This is done to test the hypothesis that larger size is associated with improved winter survival. The second objective is to quantify the extent of overall and habitat related overwinter growth observed during the study. This is done to test the assertion that growth during winter is generally negligible, especially in streams experiencing near freezing winter water temperatures. The third objective is to compare individual and categorical winter growth rates across a range of initial fall sizes. Overall and habitat related growth rates are also

contrasted with those predicted from an allometric growth model. This is done both to determine the extent of size-selective growth in both creeks and years, and to assess whether observed patterns are distinct from those predicted from differences in body size alone. The fourth objective is to combine size-dependent overwinter growth and survival results and assess whether patterns in survival may be explained by differences in growth across size classes.

Size-dependent movement was not investigated in detail by this study, however qualitative trends were assessed in Chapter 1 to determine its potential role in the ecology of overwintering juveniles. Negligible overwinter movement was observed during the study, and marked size-dependent movement was also not evident. Size-dependent early emigration from study streams was likewise not observed. Therefore, for the purposes of this chapter, I assumed that size-dependent movement did not bias study results. The application and recapture of marks used to obtain survival and growth data is described in Chapter 1.

METHODS

AGE ANALYSES

Generally, juvenile coho in the Thompson region smolt after one year in freshwater and return to spawn in their natal streams as three years olds (Harding et al. 1994). Previous juvenile studies in have found very low proportions (<5 %) of age 1+ parr (Atagi et al. 1999), but other studies have revealed proportions of two-year old smolts may be as high as 15 % (Atagi et al. 1999, Hutton et al. 1983). In this study, I assessed population age structure in two ways. Firstly, scale samples were obtained and results indicated that a fall forklength of 80 mm was the approximate mid-point of overlap between 0+ and 1+ juveniles in both streams and years (Figure 2.1). Similar forklength cutoffs have been found for 15 other streams in the North Thompson watershed (J. Tadey, DFO, New Westminster, B.C.; unpub. data). Secondly, visual evaluation of this

study's fall length-frequency distributions confirmed 80 mm was a good approximation of the mid-point between frequency modes (Figure 2.2). Since fish were marked according to size category in 1997, the $\geq$ 80 mm class was also a feasible division point given the data. Therefore in both years, age 1+ juveniles were identified in the following manner. In the fall sample, all fish $\geq$ 80 mm were categorized as 1+ juveniles. In the pre-winter sample, all fish $\geq$ 80 mm during 1996, fish from the $\geq$ 80 mm fall size class, and unmarked fish $\geq$ 86 mm during 1997, were categorized as 1+ juveniles. In the post-winter sample, all $\geq$ 80 mm fall marks and all unmarked fish $\geq$ 88 mm were categorized as 1+ juveniles. These rules identified approximately 95 % of 1996 captures as young-of-the-year coho in both streams, and 65 (Mann) to 90 % (Lemieux) of captures as young-of-the-year coho during 1997. Analyses of coho size, growth and survival are based on information for 0 + juveniles. Except where noted, sample sizes for 1 + juveniles were too low for analysis.

SIZE-DEPENDENT SURVIVAL

A relative index of size-dependent survival was obtained in a manner similar to the population level analyses described in Chapter 1. For each creek, year and fall size class, the number of recaptures in a particular size class was divided by the number of fish initially marked in that same size class. Size-dependent survival was also summarized in both years by habitat type (off-channels and mainstem runs and pools in 1996; off-channels and pools in 1997) and relative abundance class. Abundance class was defined in the following manner. In both years, data from Ianson groundwater channel in Lemieux Creek and the beaver pond site in Mann Creek were compared to information from all other sites. These sites were selected for more intensive analysis because they sustained among the highest densities of juveniles in both years, and contributed substantially to juvenile coho production in both study streams (see Chapter 1). Therefore within each creek, data from these sites ('high' abundance class) were compared to data from all other sites ('low' abundance class), and to data from all sites combined ('all' class). Normality of all relative survival data was assessed using

probability plots and data were arcsine transformed as appropriate (Systat 1997). Sample sizes for all survival rate calculations are noted in Appendix 6.

Size-dependent relative survival rates were analyzed in five ways. Firstly, Chi-squared contingency tests were used to assess differences between observed and expected recapture frequencies in each size class, where expected numbers were weighted by the initial number marked in each size class. These analyses were conducted for each creek, year, habitat type, and abundance level, and were done to test the uniformity of survival rates across size classes. Secondly, t -tests were used to compare survival rates of relatively 'small' (<60 mm and 60 mm classes) and 'large' (65, 70, 75 mm classes) coho in each creek and year. Thirdly, individual mark data from the 1996 fall sampling period were divided into recaptured and non-recaptured juveniles, and t-tests were used to compare the fall sizes of each group. Similar comparisons were also made in both years and creeks using the post-winter capture information. This was done to check whether marked fish were representative of overall sizes in the population. Fourthly, frequencies of recaptured and non-recaptured juveniles were contrasted across ordered fall size categories using Cochran's test of linear trend (Systat 1997). This test is sometimes applicable to dichotomous response data (here, recapture or non-recapture) where there are three or more ordered categories (here, < 60, 60, 65, 70, 75 mm size classes). It tests the null hypothesis that the slope of the regression line across category proportions is 0. However, some authors have suggested the test may only be applicable when the number of data are large and there are at least four response categories (Zar 1984). In this study, only two response categories were tested, and thus borderline significance levels should be interpreted with caution. Tests were conducted for each creek, year, habitat type and abundance level to investigate potential patterns in relative survival across the range of observed size categories. Finally, 1996 fall sampling data were analyzed using logistic regressions to determine the effects of individual fall size, fall location (habitat type or site) and fall size*location interaction on recapture probability in each creek. Each individual encountered during fall sampling was assigned a recapture response of either 1 (recaptured during post-winter sampling) or 0 (not recaptured). Logistic regression is well suited to dichotomous response data of this sort because it utilizes a binomial

distribution to investigate the relationship between response probability (p; e.g., recapture) and explanatory variables (Systat 1997, Trexler and Travis 1993). The model employed had the form:

$$logit(p) \quad = \quad log\,(p/(1\text{-}p)) \quad = \quad \alpha + \Sigma \beta_i\, x_i + \varepsilon$$

implying,

$$p \quad = \quad e^{-logit(p)}\,/\,(1 + e^{-logit(p)}) \qquad\qquad (2.1)$$

and where,

α = *intercept parameter*
β_i = *various slope parameters*
x_i = *independent variables to be analyzed*
p = *proportion of successes where success defined as recapture*

The most parsimonious model within a hierarchy of models (i.e. model with the highest predictive power) was determined using the log likelihood ratio test (Hilborn and Mangel 1997, Systat 1997). In this analysis, the potential contributions of initial fish size, fall location and fall size*location interaction were compared by taking the difference of log likelihood estimates from the relevant models and multiplying by two (Trexler and Travis 1993). Location was defined by fall habitat type. When declines in log likelihoods were significant, parameters were seen to contribute to model predictive power and explain a significant amount of the variability in recapture probability. Log_{10}-transformed fish weights were used to represent fish size, but results were minimally different with log_{10}-transformed forklengths.

GROWTH MEASURES

The overwinter growth of juvenile coho was described in terms of length (forklength, l, in mm) and weight (w, in g) in the following three manners (Ricker 1975):

1. *Absolute growth:* $l_2 - l_1$ or $w_2 - w_1$
2. *Relative growth:* $(l_2 - l_1)/l_1$ or $(w_2 - w_1)/w_1$

3. *Percent instantaneous growth rate:* $(log_e l_2 - log_e l_1)/(t_2 - t_1) * 100$ or,

$$(log_e w_2 - log_e w_1) / (t_2 - t_1) * 100$$

Time intervals ($t_2 - t_1$; in days) were calculated from the mid-points of sampling periods. This corrected for differences in sampling dates between years and creeks. To simplify presentation of results, only instantaneous growth rates calculated for weight were discussed (G_w; g, % · day^{-1}, also referred to as specific or intrinsic growth rate). This is also a measure cited frequently in the literature (Ricker 1979). Findings based on other measures were presented only when they differ from those based on specific growth rates. Growth measures were calculated for both age 0+ and 1+ juveniles, but due to sample size constraints, most analyses focus on young-of-the-year. During 1996, outliers (8 out of 418 observations) from a linear regression of specific growth rate vs. log_{10}-transformed fall weight conducted by creek were excluded from the data set.

SIZE-DEPENDENT GROWTH

Individual marks

Individual growth measures were obtained only in 1996. They were calculated from individual fish sizes measured during the fall and post-winter sampling periods. Normality of growth increments was analyzed using probability plots and Kolmogorov-Smirnov one sample tests (Systat 1997). Outliers were inspected and omitted from subsequent analyses if errors in tag identification were suspected (see Chapter 1 methods). Growth measures pooled by creek and habitat type within creeks were compared to the initial fall size using ANOVAs. Quadratic and linear relationships were fit to the data and compared to assess potential growth patterns across the observed range of fall sizes.

<u>Categorical marks</u>

Overwinter growth was also represented in both years as average increments within five fall size categories: < 60 mm, 60-64 mm, 65-69 mm, 70-74 mm, and 75-79 mm. Categories were identified during the post-winter period from decoded s-cwt information in 1996 and external Pan-Jet marks in 1997. In 1996, overwinter growth was calculated as the difference between the average size of fish in a given size category during the fall (w_1), and the average size of fish from that same fall size category during post-winter sampling (w_2). Similar calculations were made in 1997, but growth was also described using pre and post-winter sampling data; the use of external marks during 1997 allowed data to be summarized in both manners. 1997 findings are mostly based on the pre to post-winter comparison because that interval more accurately reflects overwinter growth. Results from the fall to post-winter interval are presented only when they differ. Although the pre to post-winter interval could not be specified in 1996, fall sampling occurred later than in 1997 and thus results are also likely good approximations of overwinter growth. Growth was contrasted between years to assess potential bias arising from earlier sampling in 1996; analyses are described below. In 1996, growth increments for each category were also calculated from the average of individual measures, but results were minimally different and analyses were generally based on the former method to ensure consistency between years.

Differences in growth increments among fall size categories were assessed in several manners. Firstly, the extent of overwinter growth in the study streams was assessed using paired t-tests conducted by creek and year. Secondly, ANOVAs were conducted on 1996 individual mark data, and contrast statements (Systat 1997) were used to assess the pattern of growth across size classes. Thirdly, ANOVAs were conducted using information from both 1996 and 1997 to distinguish the relative effects of fall size class, sampling period, and size class*period interaction on overwinter growth. In 1997, this was conducted for both the fall to post-winter, and the pre to post-winter intervals.

Effect of abundance class, habitat type, creek and year

In both streams and years, the effect of abundance class on overwinter growth was considered using ANCOVAs, with initial fall size as the covariate. Abundance class was defined in a similar manner to that described previously for overwinter survival; information from Ianson channel in Lemieux Creek and the beaver pond site in Mann Creek comprised the 'high' abundance class, and information from all other sites comprised the 'low' abundance class. The effect of fall habitat type on overwinter growth was also assessed using ANCOVAs. Habitat type was defined by fall marking location: mainstem or off-channel in 1996, and pool or off-channel in 1997. In 1997, data were too sparse for other habitat types to be compared. Differences in overwinter growth between creeks and years were compared using t-tests on data grouped by fall size category. Differences between creeks were also examined by comparing the pattern of growth across fall size classes. In addition, data for all size classes were pooled to assess potential differences among sites. In these analyses, growth was averaged across size classes within sites, and site densities were used instead of numbers.

Allometric growth

Patterns in overwinter growth across fall size classes were also analyzed for potential allometric effects. Observed increments were compared to those predicted from a simple model of growth based only on body size and temperature (Elliott 1975a, Elliott 1975b, Elliott 1976):

$$G_i \quad = \quad 100(a + b_2 T)w_i^{-b_1} \qquad\qquad (2.2)$$

where,

$$
\begin{aligned}
G_i \quad &= \quad \textit{percent instantaneous rate of growth within fall size class i} \\
a, b_1 \textit{ and } b_2 \quad &= \quad \textit{growth parameters} \\
T \quad &= \quad \textit{average temperature in } ^\circ C \\
w_i \quad &= \quad \textit{average weight in grams of fish in fall size class i; } (w_1 + w_2)/2
\end{aligned}
$$

Elliott used arithmetic means to represent weight (w_i) in his analyses, but Ricker (1979) recommends $w_i = w_o(e^{Gn} - 1)/G_n$ for longer periods of exponential growth (n = time units) which may be more applicable to this study. However, no significant differences were found between weights predicted using the two methods (pooled variance t-test, t = 1.11, df = 38, p = 0.27) so arithmetic means were used to simplify presentation of results.

Allometric growth was predicted by creek, year and fall size class. A non-linear optimization routine within Microsoft Excel solver was used to compute the best parameter fit by minimizing the sum of squared deviations between observed and predicted values. Slopes of observed and predicted (allometric) growth rates across initial fall sizes were contrasted using ANOVAs, and a log likelihood ratio test was used to test whether observed and allometric growth were significantly different. In this analysis, the model of allometric growth was assumed to be nested within the model for observed growth (Hilborn and Mangel 1997). Descriptive statistics used in likelihood calculations ('true' population mean and standard deviation in growth) were calculated for each size class from values observed in each creek and year.

SIZE-DEPENDENT GROWTH AND SURVIVAL

Potential creek and year related differences in $\log_{10}$-transformed size-dependent survival rates were assessed using t-tests. Comparisons were made using all data, as well as information grouped by abundance class and habitat type. Between year analyses were also conducted on pooled data from off-channel areas in 1996 and 1997, and on pooled data from mainstem areas (1996) and pools (1997). In 1997, Mann Creek off-channels were not assessed due to low sample sizes. ANOVAs were used to investigate the relationship between size-dependent relative survival and growth information within each data grouping.

RESULTS

SIZE-DEPENDENT SURVIVAL

Overall, chi-square contingency tests of observed and expected recapture frequencies did not reveal consistent differences among fall size categories in either stream or year. During 1996, only the low abundance class in Mann Creek yielded significant differences in relative survival (χ^2 = 12.63, df = 4, p = 0.01; Figure 2.3 e). No other habitat related or abundance level comparisons were significant during 1996 (chi-square tests, all p > 0.05; Figures 2.3 and 2.4). For Mann Creek during 1997, size-related differences in recapture frequencies were evident only in off-channels (χ^2 = 11.68, df = 4, p = 0.02; Figures 2.6 c); no other habitat and abundance level related analyses were significant (Figures 2.5 and 2.6). However for Lemieux Creek during 1997, size-related differences in relative survival were evident using all data (χ^2 = 22.68, df = 4, p < 0.001; Figure 2.5 c), data from the high abundance class (χ^2 = 14.75, df = 4, p = 0.005; Figure 2.5 a), pools (χ^2 = 11.70, df = 4, p = 0.02; Figure 2.6 b), and off-channels (χ^2 = 23.86, df = 4, p < 0.001; Figures 2.6 a).

Differences in relative survival rates were also not consistent between relatively small (< 60 – 64 mm) and large (65 - 79 mm) fall size categories in either stream or year. During 1996, differences were significant only for the high abundance class in Lemieux Creek (Bonferoni adjusted pooled variance t-test, t = -6.05, df = 3, p = 0.01), where larger classes exhibited higher survival rates (mean = 18.06 %; SE = 0.29) than smaller classes (mean = 14.89 %; SE = 0.49). No other comparisons in 1996 or 1997 were significant (Bonferoni adjusted t-tests, all p > 0.05).

However, comparisons of fall sizes of recaptured and non-recaptured individuals during 1996 were significant for both creeks (Table 2.1). In Lemieux Creek, $\log_{10}$-transformed forklengths and weights were significantly larger for recaptured (66.64 ± 1.01 mm; 3.02 ± 1.03 g) than non-recaptured (65.15 ± 1.01 mm; 2.86 ± 1.01g) juveniles (Bonferoni adjusted pooled variance t-tests, logFL t = -3.37, df = 2765, p < 0.001; logWT

t = -2.71, df = 2765, p = 0.007). The opposite pattern was observed in Mann Creek during 1996; recaptured fish (58.53 ± 1.02 mm; 2.04 ± 1.07 g) were significantly smaller than non-recaptured individuals (60.75 ± 1.00 mm; 2.29 ± 1.01 g; Bonferoni adjusted pooled variance t-tests, logFL t = 3.28, df = 3021, p = 0.001; logWT t = 3.21, df = 3021, p = 0.001). This contrast in Mann Creek appeared largely driven by the very smallest individuals, because differences were not significant when < 60 mm size class coho were excluded from analyses (Bonferoni adujsted pooled variance t-tests, logFL: t = 1.09, df = 1742, p = 0.28; logWT: t = 0.96, df = 1742, p = 0.34). Differences were also not significant in either creek when averages of recaptured and non-recaptured fish within fall size classes were compared (Bonferoni adjusted pooled variance t-tests of logWT; Lemieux t = -0.03, df = 8, p = 1.00; Mann t = 0.07, df = 8, p = 1.00). Individual condition factors (see Chapter 1 methods) were not significantly different between groups in either creek (Bonferoni adjusted pooled variance t-tests, Lemieux: t = 0.89, df = 2759, p =0.37; Mann: t = 0.46, df = 1119, p =0.65). Log_{10}-transformed post-winter weights of marked and unmarked juveniles were also not significantly different in either stream or year (Bonferoni adjusted pooled variance t-tests, all p > 0.05). This indicated sizes of marked fish in both streams were likely representative of overall population sizes.

Linear trends in relative survival across size classes were also not consistent among creeks, years, abundance classes or habitat types. In Lemieux Creek, there was a significant increase in relative survival from small to large size classes during 1996 when data from all sites were combined (Cochran's test of linear trend; χ^2 = 6.01, df = 1, p = 0.01; Figure 2.3, c). However, an increase in relative survival across size classes was not apparent for the high or low abundance classes, or for mainstem and off-channel areas (Figures 2.3 and 2.4). The opposite trend in survival was observed in Mann Creek during 1996. Relative survival was greater for the largest size classes using data from all sites, from the low abundance class, and from off-channel areas (Cochran's test of linear trend; p-values = 0.01, 0.01, 0.02; Figure 2.3 f and e, Figure 2.4 d, respectively). However, other tests of linear trends for the remaining data groupings in Mann Creek during 1996 were not significant. In addition, none of the trends for Mann Creek were significant when the smallest size class (< 60 mm) was omitted from analyses (Cochran's test of

linear trend; all data: $\chi^2 = 1.35$, df = 1, p = 0.25; low abundance class: $\chi^2 = 0.03$, df = 1, p = 0.86; off-channel sites: $\chi^2 = 3.18$, df = 1, p = 0.07). This corroborates previous results that indicated the smallest individuals may have been driving the trends observed in Mann Creek during 1996. In 1997, a significant decline in survival across size categories was found for pools in Lemieux Creek (Cochran's test of linear trend; $\chi^2 = 3.86$, df = 1, p = 0.05; Figure 2.6, a) but again, the trend was not significant when the < 60 class was omitted ($\chi^2 = 0.15$, df = 1 , p = 0.70). No other significant linear trends were found for 1997 data in either stream (p > 0.05; Figures 2.5 and 2.6).

Logistic regression results corroborated linear trend findings in both study streams during 1996. In Lemieux Creek, a significant positive relationship existed between individual fall size and recapture probability when data from all sites were pooled and when only off-channel areas were analyzed (p = 0.007 and < 0.001, respectively; Figure 2.7 a). Regressions were not significant within either high or low abundance classes or within mainstem areas (p = 0.08, 0.56 and 0.28, respectively). As above, the opposite pattern was observed in Mann Creek where a significant negative relationship was found between fall size and recapture probability for all data, the low abundance class and for off-channel areas only (p = 0.001, < 0.001 and 0.006, respectively; Figure 2.7 b). However, results in Mann Creek were not significant when < 60 mm individuals were excluded from analyses (p = 0.34). In both streams, individual condition factors generally did not explain a significant portion of the variability in recapture probability (p = 0.37 and 0.81 for all data in Lemieux and Mann, respectively). The exception was in the low abundance class in Lemieux Creek where fish in better condition had a significantly lower recapture probability (p < 0.001).

Comparison of logistic regression log likelihoods from 1996 indicated fall location explained more of the variation in post-winter recapture probability than initial size. In Lemieux Creek, while both size and location explained differences in recapture probability, location was better at predicting recapture outcome than initial size (Figure 2.8 a). When location was removed from a model including both size and location, the decrease in log likelihood was significant ($\chi^2 = 28.8$, p < 0.001), yet when fall size was

removed from the same model, the decrease was not significant (χ^2 = 3.3, p = 0.07). However in Mann Creek, while both size and location explained differences in post-winter recapture probability, size appeared better at predicting recapture outcome than location. (Figure 2.8 b). Removal of location from a model including both size and location produced a significant decline in log likelihood (χ^2 = 4.6, p = 0.03), but the decline was greater when size was removed (χ^2 = 13.4, p < 0.001). However as was indicated from previous analyses, the significant negative size-survival relationship in Mann Creek was apparently due to the relatively high recapture probability exhibited by < 60 mm fall size class individuals. When these fish were excluded from analyses, the only significant logistic regression model was one containing the location and size*location variables (compared to constants only model; χ^2 = 5.9, p = 0.05). When location was removed from this model, the decline in log likelihoods was significant (χ^2 = 5.0, p = 0.03), thereby corroborating results from Lemieux Creek.

FISH SIZE

Throughout 1996 and 1997, no significant differences in $\log_{10}$-transformed coho weights or forklengths were found between habitat types in either creek (Bonferoni adjusted pooled variance t-tests, all p > 0.05; Table 2.2, Appendices 1 and 2). Consequently, data from all sites were pooled, and differences between creeks and years were assessed. During 1996, coho in Lemieux Creek were significantly heavier than those in Mann Creek (Bonferoni adjusted pooled variance t-tests of average $\log_{10}$WT, Fall: t = 2.65, df = 9, p = 0.05; Post-winter: t = 2.80, df = 9, p = 0.04). However in 1997, no significant differences in $\log_{10}$-transformed sizes were present between creeks (Bonferoni adjusted pooled variance t-tests of average $\log_{10}$WT, Fall: t = 1.52, df = 18, p = 0.29; Post-winter: t = 0.27, df = 23, p = 1.00). When data from both creeks were pooled, differences between years were not significant during the fall period (Bonferoni adjusted pooled variance t-test of $\log_{10}$WT, t = -2.00, df = 29, p = 0.11). However in the post-winter period, juveniles during 1997 were significantly larger than during 1996 (Bonferoni adjusted pooled variance t-test of $\log_{10}$WT, t = -5.91, df = 34, p < 0.001).

Comparisons of fish condition (see Chapter 1 methods) between habitat types, creeks and years were not significant (Bonferoni adjusted t-tests, all p > 0.05).

OVERALL GROWTH

The extent of overwinter growth observed in the study streams for each year is summarized in Table 2.3. Results indicate growth occurred in both streams during the winter period, despite relatively cold mean water temperatures. Absolute growth averaged approximately 3.0 mm and 0.4 g over both years and creeks. Relative growth rates ranged between 0.08 to 0.21 $g \cdot g^{-1}$, and 0.03 to 0.06 $mm \cdot mm^{-1}$. Overwinter increases in body weight averaged 0.08 %·day^{-1}, and were quite consistent between streams and years. Size-dependent differences in growth between streams and years are presented below. Sample sizes for all growth calculations are provided in Appendix 6.

SIZE-DEPENDENT GROWTH

Individual marks

During the fall of 1996, 2982 fry were sequential coded wire tagged (s-cwt) in Lemieux Creek, and 3158 fry were s-cwt in Mann Creek (see Chapter 1 methods). Post-tagging mortality in the fall of 1996 averaged 1.1 and 0.4 % in Lemieux and Mann creeks, respectively (Appendix 3a). 24-hour tag rejection rates ranged from 0 to 8 % in both creeks, but averaged less than 2.5 % overall. Given this, an adjusted total of 2939 s-cwt in Lemieux Creek and 3081 s-cwt in Mann Creek were released in 1996.

A total of 501 adipose fin clipped coho were recovered during post-winter sampling in 1996, 370 and 131 in Lemieux and Mann creeks, respectively. Of these, 325 and 120 s-cwts were decoded successfully; the remainder of fish either did not contain a s-cwt or the tag code was unreadable. The decoded s-cwts formed the basis of the individual and

categorical growth calculations obtained in 1996. After deletion of outliers (n = 8; see Methods) and of zero growth individuals (n = 10), final sample sizes for age 0+ growth analyses were 286 and 114 individuals in Lemieux and Mann creeks, respectively.

Plots of overwinter growth patterns revealed significant negative relationships between individual specific growth rates and initial fall size in both study streams (Figure 2.9; GLM, Lemieux: F = 25.37, n = 286, p < 0.001; Mann: F = 10.12, n = 114, p = 0.002). Although growth rates were quite variable (CV = 1.10 in Lemieux and 0.77 in Mann), smaller fish appeared to grow more during the winter than their larger conspecifics (Figure 2.9). Quadratic smoothing of the data (Systat 1997) suggested a significant linear decrease in growth across fall sizes in Lemieux Creek, but a curvilinear decrease in Mann Creek (Figure 2.9).

Categorical marks

Analysis of overwinter growth information compiled by fall size class revealed two important patterns. First, results confirmed the overall finding that juvenile coho in the study streams grew substantially during the winter in both 1996 and 1997 (paried t-tests, p < 0.05 for most cases; Table 2.4). Although the pre to post-winter difference was not significant in Mann Creek during 1997, results were significant for the fall to post-winter comparison. Significance of the former comparison was likely reduced by the relatively high degree of variation in growth measures among size classes (SD difference 0.53; Table 2.4). This variability is examined further below.

Second, analysis of categorical increments corroborated the individual-based result that size-dependent overwinter growth occurred in the study streams (Figure 2.10). In 1996, specific overwinter growth rates declined significantly across fall size classes in both Lemieux and Mann creeks (GLM contrast statements; Lemieux: F = 4.74, n = 286, p_{model} = 0.001 and $p_{contrast}$ < 0.001; Mann: F = 2.62, n = 114, p_{model} = 0.04 and $p_{contrast}$ = 0.01). Similar patterns were also found for other growth measures. In both years, tests of sampling period*fall size class interaction effects were also mostly significant (Table

2.5), implying the slopes of $\log_{10}$-transformed fall weight vs. size class regressions differed between periods. This provides further evidence of size-dependent growth in the study streams. For Mann Creek in 1997, interaction effects were significant only for the fall to post-winter comparison (Table 2.5). This may again be explained by higher variability in growth measures within size classes for the pre to post-winter interval (Figure 2.11).

Effect of abundance class, habitat type, creek and year

During 1996, the number of s-cwt fish captured at individual sites and in different habitat types differed significantly during both fall and post-winter sampling in both streams (Chi-square tests; all $p < 0.001$). However, capture probability did not differ between habitat types in either sampling period or stream (see Chapter 1 results). During post-winter sampling, the majority of marked individuals (53 and 52 %, respectively) were recovered in either Ianson groundwater channel in Lemieux Creek (site #6), or the beaver pond site in Mann Creek (site #4; Figure 2.12). These were the 'high abundance' class sites.

Post-winter recaptures of categorical size marks also varied spatially in both creeks during 1997. In Lemieux Creek, recapture frequencies were significantly higher in off-channels than in pools ($\chi^2 = 423.2$, df = 1, $p < 0.001$), and in Mann Creek frequencies were higher in pools than in off-channels ($\chi^2 = 125.9$, df = 1, $p < 0.001$). As in 1996, the majority (92 %; 716 of 774) of marked recaptures in Lemieux Creek were found in Ianson groundwater channel. Similarly, the majority (69 %; 114 of 166) of marks in Mann Creek during 1997 were recovered in the old beaver pond site. Due to the preponderance of recoveries in only two sites, and the variability in overall juvenile spatial distribution between habitat types (see Chapter 1), growth information was summarized by habitat type and abundance class for both years.

Despite the concentration of recaptures in only two sites, differences in overwinter growth between high and low abundance classes were not present for either creek in 1996 or 1997 (Table 2.6; Figure 2.13). During both years, differences between the slopes of individual growth vs. fall weight regressions for both abundance classes were not significant in either stream (abund_level*sizeclass interaction; Table 2.6), and when variation in growth due to fall size was taken into account, no significant differences in overwinter growth were found between abundance classes (ANCOVA, covariate = fall size, $p > 0.05$).

Consistent differences in overwinter growth measures were also not found between habitat types for either stream or year. During 1996, differences between the slopes of individual growth vs. fall weight regressions for both habitat types were not significant in either stream (sep_hab*sep_wt interaction; Table 2.7). When variation in growth due to fall size was taken into account, no significant differences in overwinter growth were found between habitat types (ANCOVA, covariate = fall size, $p > 0.05$). However, differences between habitat types were observed when growth rates calculated for fall size categories were analyzed. In Lemieux Creek during 1996, slopes of overwinter growth rate vs. fall size class were similar between habitat types (sep_hab*sizeclass interaction; Table 2.7), but intercepts were significantly different; fish in off-channels grew more than those in mainstem sites. The opposite pattern was found in Lemieux Creek during 1997; ANCOVA results indicated a significant effect of habitat type, but juveniles in mainstem pools grew more than those in off-channels. This pattern was present despite the fact the majority of marks were recovered in the same off-channel site (Ianson channel) during both years. No significant habitat related differences in categorical growth information were found in Mann Creek during 1996 (Table 2.7). Similar comparisons could not be conducted in this system during 1997 because of low numbers of recaptures in off-channels.

However, site related differences in growth were found when data from all size classes were pooled (Figure 2.14). Growth was calculated as the mean across size classes for each site, and site densities were used instead of numbers to standardize comparisons

among sites. No significant differences in log_{10}-transformed fall density were found between creeks in either year (separate variance t-tests, 1996: t = -1.70, df = 8.9, p = 0.12; 1997: t = 0.29, df = 9.5, p = 0.78), and thus data from both creeks were pooled. Overwinter growth and log_{10}-transformed fall density did not appear to be associated in 1996 (GLM, F = 1.69, n = 10, p = 0.23), but a significant negative relationship between the two variables existed in 1997 (GLM, F = 7.36, n = 14, p = 0.02).

Growth rates calculated by fall size class were not significantly different between creeks in either year (Bonferoni adujusted separate variance t-tests, all p > 0.05; Table 2.3), and thus data from both streams were pooled. Comparisons between years were also not significant (separate variance t-test, t = 0.45, df = 11.9, p = 0.66), which suggests earlier fall sampling did not elevate estimates of overwinter growth in 1996. However, absolute and relative changes in forklength were significantly different between creeks during 1996 (separate variance t-tests, absolute: t = 3.28, df = 5.8, p = 0.02; relative: t = 2.87, df = 7.9, p = 0.02; Figure 2.15). Similar differences were not present in 1997 (p > 0.05 for both cases).

Although direct comparisons of growth rate did not yield significant differences between creeks, the pattern of growth across size classes did appear to differ. Growth exhibited by the smallest fall size class (< 60 mm) was higher in Lemieux Creek than in Mann, although the difference was not significant during 1997 (Bonferoni adjusted pooled variance t-tests, replicates are abundance class; 1996: t = 5.80, df = 2, p = 0.03; 1997: t = 2.59, df = 2, p = 0.12). In Mann Creek, the declining trend in growth across size classes began at the second smallest class. This pattern in overwinter growth among fall size categories corroborated the curvilinear relationship found between individual growth and initial fish size in Mann Creek during 1996 (Figure 2.9).

Allometric growth

Parameter estimates for an allometric growth model (Eq. 2.2) fit to observed data were: a = -0.0100; b_1 = 0.325; b_2 = 0.003; and T = 3.746. These are comparable to values

found empirically for brown trout at temperatures between 3.8 and 12.8 °C (Elliott 1975a), and are within the range reported for several other species of fish ($b_1 = 0.17$ to 0.50; cf Elliott 1975). However, stream temperatures measured during 1997 averaged 2.81 and 0.80 °C from Nov. 15 to Mar. 1 in Lemieux and Mann creeks, respectively (Figure 2.16). Water temperatures in 1996 were similarly low throughout the winter (Lemieux: 2.03 °C; Mann: 0.67 °C; Figure 1.6). This difference between observed temperature and the temperature that produced the best fit to observed growth rates indicates either the allometric growth model was not applicable at low stream temperatures, or that temperatures measured during this study did not adequately reflect conditions fish experienced during winter. The latter was assumed for the purpose of this analysis.

Output from the allometric growth model reflected size-related differences in growth rate; smaller individuals exhibited higher growth rates than larger ones (Figure 2.17). However, differences in size among fall categories were not sufficient to explain the pattern in size-dependent growth observed throughout the study. In both creeks and years, observed slopes were significantly different from those predicted based on differences in body size alone (model*size interaction; Table 2.8). In addition, the log likelihood ratio test of observed and allometric growth was significant ($\chi^2 = 4.08$, df $= 1$, $p = 0.04$), indicating that additional factor(s) other than body size contributed to the observed pattern in growth among initial sizes. Sample sizes for Mann Creek were smaller because the < 60 mm size class was omitted due to non-linearity in observed specific growth rates among size classes (Figures 2.9 and 2.10), but results were minimally different when < 60 mm size class fish were included.

SIZE DEPENDENT GROWTH AND SURVIVAL

Size-dependent relative survival rates were significantly different between creeks within years, and between years for pooled creeks when all data were used, and when information was grouped by abundance class or habitat type (arcsin transformed data;

Bonferoni adjusted pooled variance t-tests, all p < 0.05). In each case, size-dependent survival rates were higher in Lemieux Creek than in Mann, and higher during 1997 than 1996. The only exception was for the high abundance class during 1997 where differences between creeks were not significant (t = 1.79, df = 8, p = 0.11).

To investigate the potential relationship between size-dependent survival and growth, data from both streams and years were pooled. However for the majority of data groupings, variation in survival was not explained by differences in overwinter growth (GLM, p > 0.05; Figure 2.18). The exception was for the mainstem and pool habitat type class where a significant positive relationship between overwinter growth and survival was noted (F = 6.25, n = 20, p = 0.02; Figure 2.18, e). Nonetheless, the proportion of variation in survival explained by growth in this comparison was small (r^2 = 0.26) and the trend was largely driven by relatively high survival rates in Lemieux Creek during 1997, especially survival rate of the <60 mm size class. As noted previously, omitting this category from size-dependent survival analyses produced non-significant results.

DISCUSSION

This research did not suggest survival of juvenile fish through the first winter of freshwater residence was positively related to fish size at the end of the summer growing season. This is counter to the findings of some previous studies (e.g., Hartman et al. 1982b, Holtby 1988, Hunt 1969, Oliver and Holeton 1979, Post and Evans 1989b, Quinn and Peterson 1996, Thompson et al. 1991, Toneys and Coble 1979). Although the predicted association between large size and survival was evident in pooled data from Lemieux Creek during 1996, the majority of comparisons by habitat type and abundance level within both steams and years were either not significant or did not reveal consistent size-dependent relationships. Results from Mann Creek in 1996 and Lemieux Creek in 1997, for example, indicated the opposite pattern of survival across fall sizes; smaller individuals appeared to survive better through the winter than their larger conspecifics.

The suggestion that relatively small young-of-the-year fish sometimes experience a survival advantage may reflect a decision by these individuals to adopt distinct, possibly risk averse, overwinter behaviour. The potential factors affecting this decision are discussed below, but variation in the behavioural strategies adopted by juveniles may result in nonlinear size-dependent survival patterns. In this study, evidence of nonlinearity was found in Mann Creek during 1996 and Lemieux Creek during 1997, where size-dependent survival functions were no longer significant when the smallest size class individuals were removed from analyses. Nonlinearity has also been observed in laboratory studies of juvenile yellow perch survival (Post and Evans 1989b) and in studies of size-dependent predation (Hargreaves and LeBrasseur 1986, Healey 1982, Parker 1971, Post and Evans 1989a, Taylor and McPhail 1985). Although assessing whether fish behaviour contributed to nonlinear survival functions was beyond the scope of this research, results may have important implications for how we model freshwater production. Specifically, results from this study indicate an existing production model based on juvenile size-frequency characteristics and a positive size-dependent survival function (Holtby 1998) may not be sufficient or applicable in some streams. Incorporation of additional factors to this model may be possible, but further information is required before this type of approach may be practical for stock assessment purposes.

This study supports the need for further research on size-selective survival within cohorts of young-of-the-year fish. While much of the empirical evidence of size-dependent mortality relies on comparisons between fall and spring size-frequency distributions (e.g., bluegill, *Lepomis macrohirus* and largemouth bass, *Micropterus salmoides*: Toneys and Coble 1979; smallmouth bass, *Micropterus dolomieui*: Shuter et al. 1980, Shuter and Post 1990; coho Irvine and Johnston 1992, Peterson 1982b), data of this sort are inconclusive if size-dependent growth or movement occurs between sampling periods (Post and Evans 1989b). In this study, the differential effects of size-related survival, growth and movement were resolved using individual marks, but results were still inconsistent. Similarly, other studies using individually or categorically marked fish either showed only slight differences in survival between large and small members of a cohort (Hunt 1969), failed to support the predicted association between

large size and survival (Brown 1985), or produced inconsistent results (Quinn and Peterson 1996). In addition, while positive correlations between mean fall size and overwinter survival have been found among years at the population level for some species (e.g., brook trout, *Salvelinus fontinalis*: Hunt 1969; coho, Holtby 1988), the opposite pattern has been observed in others. Some studies have found the benefits of large size may be more evident within cohorts of freshwater fishes than among years (e.g., juvenile Atlantic salmon, *Salmo salar*; Lindroth 1965 cf Oliver and Holeton 1979).

More consistent size-dependent survival results have been reported for juvenile salmonids during early ocean life when mortality of smaller members of a cohort is believed to be relatively high (e.g., Henderson and Cass 1991, Holtby et al. 1990, Ward and Slaney 1988, Ward et al. 1989), perhaps due to size-selective predation (Hargreaves and LeBrasseur 1986, Healey 1982, Parker 1971). Size-selective predation is also important in freshwater systems (Bugert and Bjornn 1991, Dolloff 1993, Post and Prankevicius 1987, Ruggerone and Rogers 1992, Taylor and McPhail 1985), and Quinn and Peterson (1996) speculated size-related predation may have been responsible for higher overwinter survival of larger juvenile coho in a coastal Washington stream. Fish swimming ability and critical holding ability are markedly reduced at low temperatures (Griffiths and Alderdice 1972, Rimmer et al. 1985, Webb 1978), and thus overwintering juveniles may be quite vulnerable, especially to endothermic predators (Cunjak 1996).

Differential selection of small fish did not appear to explain size-related mortality in either brook trout (Hunt 1969) or largemouth bass (Toneys 1977 cf Post and Prankevicius 1987) in Wisconsin streams. Instead, authors suggested size-dependent overwinter survival likely resulted from starvation of the smallest juveniles. Differential starvation is also believed to have lead to size-dependent mortality in other cold water systems (Conover 1992, Oliver and Holeton 1979, Smith and Griffith 1994, Thompson et al. 1991, Toneys and Coble 1979). While weight-specific basal metabolism increases as size decreases (Weatherly and Gill 1987), relative energy storage capacity decreases with fish size (Post and Evans 1989b, Shuter et al. 1980, Shuter and Post 1990). Consequently, smaller individuals exhaust energy stores earlier than larger juveniles, and

may therefore be more subject to overwinter mortality due to starvation (Post and Evans 1989b, Riddell and Leggett 1981). The importance of stored energy reserves is supported by field and experimental evidence of reductions in fat content per unit body weight over the winter (Cunjak 1988b, Gardiner and Geddes 1980, Reimers 1963, Toneys and Coble 1980). In addition, simulations of size-specific loss of energy stores has revealed mortality rates increase with winter duration (Post and Evans 1989b, Shuter et al. 1980). Starvation may therefore be an important mechanism behind the observed patterns in size-related overwinter survival in cold water systems. This is supported by the suggestion that winter feeding by juvenile fish (e.g., Cunjak 1988a, Riddell and Leggett 1981, Smith and Griffith 1994) is primarily a means of sustaining minimal metabolic activity (Cunjak 1988b) rather than growth (Conover 1992, Metcalfe and Thorpe 1992). However, results from this study show that even at very low mean temperatures, juveniles may continue to grow during winter. Growth was likely much less than during summer months (e.g., $0.0008 \text{ g·day}^{-1}$ in this study during winter vs. $0.0077 \text{ g·day}^{-1}$ in Carnation Creek during summer; Holtby and Hartman 1982), but was higher than observed for juvenile brown trout on purely maintenance ration ($< 0 \text{ g·day}^{-1}$; Elliott 1975a).

Results from this study indicated overwinter growth by juvenile coho was size-dependent. In both streams, smaller individuals grew more than larger members of the same cohort, and differences were greater than those predicted based on allometry alone. This contrasts markedly with studies of fish growth during summer that have found larger individuals tend to grow more than smaller ones, likely due to differences in foraging strategy arising from distinct dominance hierarchies within the stream (e.g., Chapman 1962; Chapman 1966; Mason and Chapman 1965; Nielsen 1992). This study also showed that when size-related variation in growth was accounted for, there were no consistent differences in overwinter growth between off-channel and mainstem habitat types. This was supported by the observation that fish sizes throughout both years were similar between habitat types in both streams. Some habitat-related differences in growth were apparent in Lemieux Creek, but similar findings were not observed in Mann.

Overall however, the pattern of size-dependent overwinter growth in both streams and years was consistent between habitat types.

The pattern of greater growth by smaller individuals was also consistent between years, despite significant differences in juvenile abundance during the study. While standing stock and overall stream densities were roughly four times higher in 1996 than in 1997, the highest sample site densities were actually observed during 1997 ($\sim$ 10 fish$\cdot$m^{-2}), not 1996 ($\sim$ 4 fish$\cdot$m^{-2}; see Chapter 1). The range in site densities observed during 1997 may explain why a significant relationship between density during the fall and overall (i.e. pooled among size classes) growth at each sample site was evident during 1997, but not in 1996. Nonetheless, when size-related differences in growth were accounted for, no significant differences in overwinter growth were found between relatively high and low abundance classes in either stream or year. Consistency in the pattern of growth across size classes for both abundance levels and habitat types suggests the prevalence of size-dependent overwinter growth was independent of juvenile spatial distribution within the streams.

Although habitat related differences in size-dependent growth were not apparent during the study, the importance of habitat type was evident in assessments of size-dependent overwinter survival. Results suggested within year variation in overwinter survival was better explained by the habitat type fish were located in at the onset of winter, rather than their initial size. In cases where individual fall size was found to be associated with overwinter survival (e.g., Lemieux and Mann during 1996), fish presence in off-channel areas during the fall was a better predictor of post-winter recapture probability than fall size. This contrasts with the population level comparisons of relative survival between habitat types based on standing stock that did not reveal distinct habitat related differences in overwinter survival (see Chapter 1). However, results based on individual marks are likely more reliable because they account for fish movement. Other studies have also speculated that habitat may affect the intensity of size-dependent overwinter survival (Brown 1985, Quinn and Peterson 1996), but the complex interactions among habitat, fish size, overwinter survival and growth are still not well

understood. For example, laboratory trials of juvenile salmonids have shown positive growth is unlikely below temperatures of approximately 3.5 ° C (Elliott 1975a, Elliott 1975b, Elliott 1976), but average temperatures measured during this study were much lower. This suggests that in order to maintain growth through the winter, juveniles must have exhibited small-scale selection for warmer conditions such as point sources of groundwater discharge (e.g., Cunjak 1988a, Cunjak and Power 1986). Therefore, the importance of these areas appeared to be related to both improved recapture probability and growth opportunity, which may have then reduced the prevalence of size-dependent overwinter survival arising from starvation. This provides further evidence for the importance of groundwater fed areas for overwintering juveniles in interior streams (Bustard 1986, Cunjak 1996, Swales et al. 1986).

Consistent and significantly greater growth by relatively small juveniles throughout the study may be indicative of strong selective pressure for individuals to attain a certain threshold smolt size (e.g., Metcalfe and Thorpe 1990, Nicieza and Brana 1993). The trade-off between foraging and predation risk has been well demonstrated for juvenile fish (Dill 1983, Grant and Noakes 1987, Martel 1996, Schlosser 1995, Walters and Juanes 1993). Combined with reduced swimming performance at low water temperatures (Griffiths and Alderdice 1972, Rimmer et al. 1985, Webb 1978), this trade-off may cause individuals to adopt distinct winter behavioural strategies that depend on their pre-winter size (e.g., Metcalfe and Thorpe 1990, Metcalfe and Thorpe 1992, Thorpe 1987). For large individuals that were successful at attaining a size consistent with smolting, the best overwinter strategy may be to adopt risk averse behaviour such as increased hiding, gregariousness and association with cover (Cunjak 1988a, Murphy et al. 1989, Nickleson et al. 1992, Rimmer et al. 1983, Rimmer et al. 1984). However, given the additional mortality risks associated with spending another year in freshwater, there may be strong selection for relatively small individuals to continue feeding through the winter. In addition, opportunity for compensatory growth during early spring (Holtby et al. 1989, Irvine and Ward 1989, McMahon and Holtby 1992, Nicieza and Brana 1993, Ward et al. 1989) may be limited, as marine survival is also positively related to the time of seawater entry (Bilton et al. 1982, Thedinga and Koski 1984). Although overall prey biomass may

be higher during the summer (Bridcut and Giller 1993, Irons et al. 1993, but see Cunjak 1996, Hynes 1972), the proportion of resources available to smaller individuals is likely greater during winter due to reduced competition from large juveniles. Winter may therefore be a period of growth opportunity for relatively small fish.

For many anadromous salmonids, the age at which smolting occurs varies both within and among populations, largely due to differences in environmental opportunities for growth (Metcalfe and Thorpe 1990, Thorpe 1987). In this study, marked differences in winter water temperatures likely explained the distinct patterns in size-dependent growth observed both within and between streams. Below an optimum of 11 to 15 ° C, growth opportunity for juvenile salmonids declines with water temperature (Elliott 1975a, Elliott 1976, Ricker 1979). Therefore, the size at which individuals may choose to adopt risk prone winter foraging behaviour should vary inversely with stream temperature. This variation should also be evident among streams with differing temperatures. Results from this study support this assertion. Water temperatures were colder in Mann Creek than in Lemieux Creek, and differences in absolute overwinter growth between streams suggest growth opportunity was likely higher in Lemieux than in Mann. In addition during both years, the smallest fish in Mann Creek grew both less than slightly larger individuals in that stream, and less than comparably sized individuals in Lemieux Creek. This may indicate a threshold size below which juveniles in Mann Creek were unlikely to attain a size consistent with smolting even if they grew more overwinter. A threshold size was not evident in Lemieux Creek possibly because of better growth conditions in that stream. Research on Atlantic salmon supports the presence of a threshold size for achieving overwinter growth (Metcalfe and Thorpe 1992, Thorpe 1987). In these studies, larger juveniles continued to grow, but the smallest individuals adopted risk averse behaviour and ceased growing, even under conditions that would otherwise allow growth to occur. Smaller individuals appeared to compensate for forfeited first winter growth by spending another year in freshwater (Metcalfe et al. 1986, Metcalfe and Thorpe 1992). Although overwinter behaviour was not investigated during this study, all of the marked two year old fish recovered during 1997 were less than 60 mm when they were tagged in the fall of 1996 (55.3 ± 1.04 mm; n = 27). Reduced growth by the smallest juveniles in

Mann Creek may also explain their significantly higher relative overwinter survival rates during 1996.

For the study as a whole, there was no indication that higher overwinter growth rates by small juveniles were associated with decreased survival. This is surprising given the expected trade-off between foraging and predation risk, but my results may be particular to cold water systems where ice may provide cover from birds and mammals, and low temperatures may reduce effectiveness of ectothermic predators. In addition, as long as stream conditions are suitable for overwinter growth, size-related mortality arising from differential starvation of smaller individuals may also be less likely.

In summary, there may be strong selection for distinct overwinter behavioural strategies that depend on fish size in the fall. It may be favourable for relatively large juveniles to adopt risk averse behaviour during winter, which may result in the winter being a period of growth opportunity for smaller members of the population. Smaller juveniles may gain access to a higher proportion of resources, be able to grow more, and consequently increase their likelihood of smolting the following spring. Under these conditions, selection of sites or habitat types with improved opportunities for growth may explain more of the variability in overwinter survival than fish size. Furthermore, spatial and temporal variation in environmental conditions for growth may reinforce size thresholds for the selection of different overwinter behavioural strategies. In some situations it may be favourable for fish to delay smolting and spend an additional year in freshwater.

Table 2.1: Fall sizes of juvenile coho that were recaptured (1) and not-recaptured (0) during post-winter sampling in Lemieux and Mann creeks, 1996.

Differences are significant overall using individual data, but not when average sizes for each class are compared.

Creek	Fall size class	Recovery category	N	Forklength (mm) Mean	95% CL	Weight (g) Mean	95% CL
Lemieux	<60	1	37	55.74	1.02	1.79	1.06
		0	478	54.95	1.01	1.75	1.02
	60	1	67	62.46	1.01	2.50	1.02
		0	558	62.04	1.00	2.46	1.01
	65	1	89	67.21	1.00	3.07	1.02
		0	643	66.89	1.00	3.04	1.01
	70	1	70	71.77	1.00	3.75	1.02
		0	540	71.61	1.00	3.79	1.01
	75	1	35	76.87	1.01	4.66	1.03
		0	250	76.70	1.00	4.67	1.01
	ALL	1	298	66.64	1.01	3.02	1.03
		0	2469	65.15	1.01	2.86	1.01
Mann	<60	1	63	52.95	1.02	1.50	1.07
		0	1216	54.09	1.00	1.60	1.01
	60	1	29	62.08	1.01	2.45	1.03
		0	710	61.91	1.00	2.42	1.01
	65	1	18	66.93	1.01	3.07	1.03
		0	596	66.80	1.00	3.04	1.01
	70	1	6	70.66	1.01	3.56	1.05
		0	251	71.67	1.00	3.74	1.01
	75	1	4	76.23	1.04	4.51	1.11
		0	130	76.38	1.00	4.53	1.01
	ALL	1	120	58.53	1.03	2.04	1.01
		0	2903	60.74	1.00	2.28	0.01

Table 2.2: Summary of fall, pre and post-winter juvenile coho sizes and condition factors for Lemieux and Mann creeks, 1996 and 1997.

No significant differences among habitat types were found in either stream or year (Bonferoni adjusted t-tests, p > 0.05).

Year	Creek	Strata	Fall						Pre-winter						Post-winter					
			FL	CL	WT	CL	CF	CL	FL	CL	WT	CL	CF	CL	FL	CL	WT	CL	CF	CL
1996	Lemieux	OC	66.7	1.0	2.7	1.0	0.000	0.002	67.4	1.0	3.2	1.0	0.000	0.006	72.1	1.0	3.6	1.0	0.000	0.004
		MC	63.7	1.0	3.0	1.0	0.005	0.003	65.1	1.0	2.9	1.0	0.000	0.008	68.8	1.0	3.2	1.0	0.005	0.010
		ALL	65.3	1.0	2.9	1.0	0.000	0.002	65.8	1.0	2.9	1.0	0.000	0.003	70.4	1.0	3.4	1.0	0.000	0.002
1996	Mann	OC	62.5	1.0	2.5	1.0	0.000	0.001	63.7	1.0	2.6	1.0	-0.001	0.004	64.1	1.0	2.6	1.0	0.002	0.005
		MC	58.4	1.0	2.0	1.0	0.000	0.001	57.3	1.0	2.0	1.0	0.002	0.004	60.8	1.0	2.2	1.1	-0.004	0.006
		ALL	60.7	1.0	2.3	1.0	0.000	0.001	61.0	1.0	2.4	1.0	0.000	0.003	63.1	1.0	2.4	1.0	0.000	0.004
1997	Lemieux	P	65.8	1.0	3.0	1.0	0.000	0.007	72.2	1.0	4.0	1.0	0.000	0.005	76.5	1.0	4.6	1.0	-0.003	0.005
		OC	62.6	1.0	2.8	1.0	-0.001	0.005	69.3	1.0	3.5	1.0	0.001	0.002	73.3	1.0	3.8	1.0	0.001	0.003
		RU	61.7	1.3	2.7	2.4	-	-	68.5	1.0	3.4	1.1	-	-	77.8	1.1	4.6	1.2	-	-
		ALL	63.6	1.0	2.9	1.0	0.000	0.000	69.7	1.0	3.6	1.0	0.000	0.002	73.9	1.0	3.9	1.0	0.000	0.003
1997	Mann	P	63.7	1.0	2.8	1.0	-0.003	0.006	73.5	1.0	4.0	1.0	0.000	0.000	76.3	1.0	4.2	1.0	0.001	0.005
		OC	64.1	1.0	2.9	1.1	0.014	0.010	72.8	1.0	3.9	1.1	0.001	0.006	77.5	1.0	4.7	1.1	-0.012	0.017
		RU	62.1	1.1	2.6	1.2	-0.007	0.007	68.3	1.1	3.2	1.2	-	-	75.4	1.1	4.2	1.4	-0.005	0.001
		ALL	63.7	1.0	2.8	1.0	-0.002	0.005	73.2	1.0	4.0	1.0	0.000	0.002	76.3	1.0	4.2	1.0	0.000	0.005

FL = forklength in mm; WT = weight in g; CF = Condition Factor; see Chapter 1 methods.
CL = 95% confidence limits

Table 2.3: Overwinter growth measures for 0+ juvenile coho in Lemieux and Mann creeks, 1996 and 1997.

Significant differences are underlined (Bonferoni adjusted t-tests; $p < 0.05$).

Year	Creek	Data source	Interval (days)	N	Absolute				Relative				Specific growth rate	
					FL mm	SE	WT g	SE	FL mm/mm	SE	WT g/g	SE	(% g/day)	SE
1996	Lemieux	Individual marks	174	294	3.54	0.17	0.47	0.03	0.05	0.00	0.16	0.01	0.08	0.01
	Mann		174	116	2.25	0.25	0.42	0.04	0.04	0.00	0.21	0.02	0.10	0.01
1996	Lemieux	Fall categories	174	5	4.03	0.30	0.48	0.04	0.06	0.01	0.17	0.03	0.09	0.02
	Mann		174	5	1.82	0.61	0.36	0.08	0.03	0.01	0.13	0.04	0.07	0.02
1997	Lemieux		124	5	4.00	0.56	0.34	0.08	0.06	0.01	0.13	0.05	0.07	0.02
	Mann		110	5	2.30	1.41	0.26	0.24	0.03	0.02	0.08	0.09	0.06	0.06
both	Lemieux	Fall categories	n/a	10	4.02	0.30	0.41	0.05	0.06	0.01	0.15	0.03	0.08	0.01
both	Mann			10	2.06	0.73	0.31	0.12	0.03	0.01	0.11	0.05	0.06	0.03
1996	both	Fall categories	n/a	10	2.93	0.49	0.42	0.05	0.05	0.01	0.15	0.03	0.08	0.01
1997	both			10	3.15	0.77	0.30	0.20	0.05	0.01	0.11	0.05	0.07	0.03

Table 2.4: Results from paired t-tests of overwinter changes in fish weight in Lemieux and Mann creeks, 1996 and 1997.

Year	Creek	Interval	Mean Difference (g)	SD Difference	t	df	p
1996	Lemieux	Fall to post-winter	0.48	0.08	13.69	4	< 0.001
	Mann	Fall to post-winter	0.36	0.18	4.51	4	0.010
1997	Lemieux	Pre to post-winter	0.34	0.18	4.17	4	0.014
	Mann	Pre to post-winter	0.26	0.53	1.1	4	0.333
1997	Lemieux	Fall to post-winter	0.95	0.36	5.86	4	0.004
	Mann	Fall to post-winter	0.92	0.60	3.43	4	0.027

Table 2.5: Results from ANOVA of size-dependent overwinter changes in fish weight for Lemieux and Mann creeks, 1996 and 1997.

In all cases, the dependent variable was $\log_{10}$ (weight), df = 4, sizeclass = fall size class, and period = sampling period. Slopes of overwinter growth rates across size classes were significantly different between sampling periods.

Year	Creek	Interval	N	Factor	F	p
1996	Lemieux	Fall to post-winter	3065	sizeclass*period	9.74	< 0.001
				period	344.14	<0.001
	Mann	Fall to post-winter	3143	sizeclass*period	2.48	0.042
				period	83.74	<0.001
1997	Lemieux	Pre to post-winter	978	sizeclass*period	4.92	0.001
				period	75.93	<0.001
	Mann	Pre to post-winter	118	sizeclass*period	1.59	0.183
				period	0.76	0.385
1997	Lemieux	Fall to post-winter	1171	sizeclass*period	55.95	<0.001
				period	820.53	<0.001
	Mann	Fall to post-winter	657	sizeclass*period	12.91	<0.001
				period	85.60	<0.001

Table 2.6: Results from ANCOVA of abundance related size-dependent changes in fish weight in Lemieux and Mann creeks, 1996 and 1997.

In all cases, the covariate was fall size, the dependent variable was specific growth rate and df = 2. Abund_level = high, low or all; see Chapter 2 methods for details. The pattern of size-dependent growth across size classes was not significantly different among abundance levels.

Year	Creek	Data source	N	Factor	F	p
1996	Lemieux	Categorical marks	15	abund_level*sizeclass	1.088	0.377
				abund_level	1.876	0.199
1996	Mann	Categorical marks	15	abund_level*sizeclass	0.052	0.949
				abund_level	0.156	0.858
1997	Lemieux	Categorical marks	15	abund_level*sizeclass	0.178	0.840
				abund_level	1.287	0.315
1997	Mann	Categorical marks	15	abund_level*sizeclass	0.193	0.828
				abund_level	2.644	0.115

Table 2.7: Results from ANCOVA of habitat related size-dependent changes in fish weight in Lemieux and Mann creeks, 1996 and 1997.

In all cases the covariate was fall size, the dependent variable was specific growth rate and df = 1. Sep_hab = fall location, either mainstem or off-channel in 1996, or pools or off-channels in 1997; see Chapter 2 methods for details. No analyses were conducted for Mann Creek 1997 due to limited data from off-channels. The pattern of size-dependent growth across size classes was generally not significantly different between habitat types.

Year	Creek	Data source	N	Factor	F	p
1996	Lemieux	Individual marks	286	sep_hab*sep_wt	0.624	0.204
				sep_hab	0.651	0.936
1996	Mann	Individual marks	114	sep_hab*sep_wt	0.031	0.861
				sep_hab	1.775	0.186
1996	Lemieux	Categorical marks	10	sep_hab*sizeclass	2.667	0.154
				sep_hab	10.181	0.015
1996	Mann	Categorical marks	10	sep_hab*sizeclass	0.409	0.546
				sep_hab	0.007	0.937
1997	Lemieux	Categorical marks	10	sep_hab*sizeclass	0.300	0.537
				sep_hab	34.763	0.001

Table 2.8: Results from ANOVA of allometric and observed size-dependent changes in fish weight in Lemieux and Mann creeks, 1996 and 1997.

In all cases the dependent variable was specific growth rate and df = 1. Model = data source, either predicted from allometric model or observed growth during study; size = initial fall size class; see Chapter 2 methods for details. Lower sample sizes in Mann Creek are due to the omission of the < 60 mm size class. Slopes of allometric and observed size-dependent growth rates were significantly different.

Year	Creek	Data source	N	Factor	F	p
1996	Lemieux	Categorical marks	10	model*size	141.62	< 0.001
				model	1.80	0.220
1996	Mann	Categorical marks	8	model*size	7.65	0.051
				model	0.12	0.740
1997	Lemieux	Categorical marks	10	model*size	34.09	0.001
				model	0.04	0.850
1997	Mann	Categorical marks	8	model*size	13.20	0.022
				model	0.17	0.690
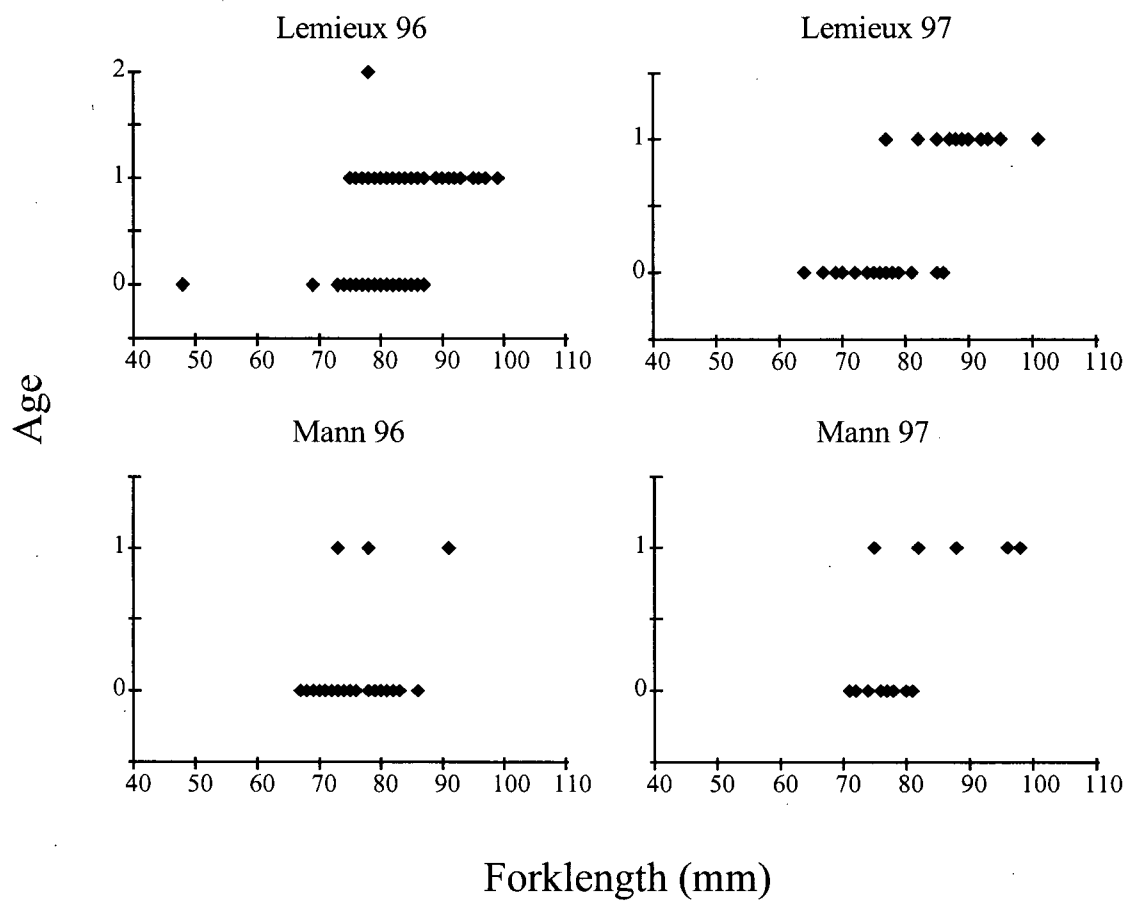
Figure 2.1: Plot of age data based on analysis of scale samples obtained during fall sampling in both creeks and years.

Figure 2.2: Length-frequency histograms of coho captured during each sampling period in both creeks and years.

Lemieux 1996

Fall
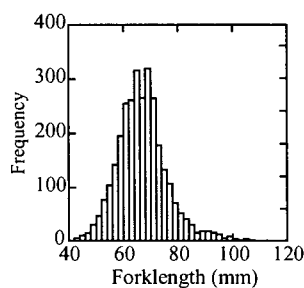
Pre-winter
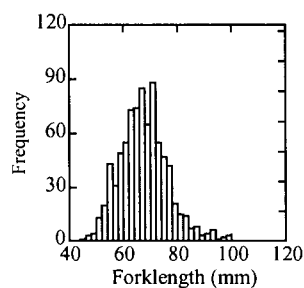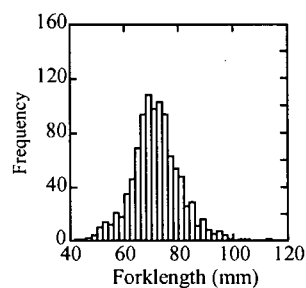
Post-winter

Mann 1996

Fall
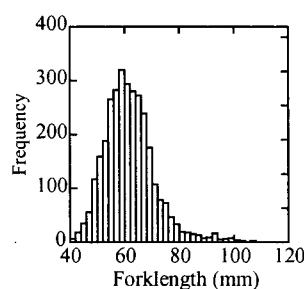
Pre-winter
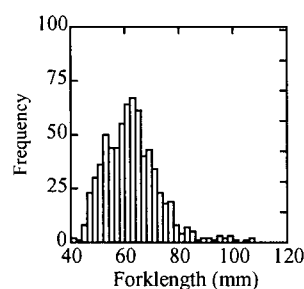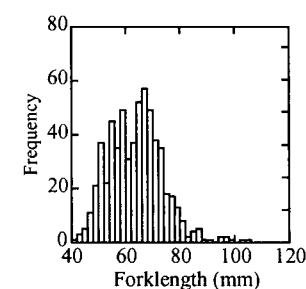
Post-winter

Lemieux 1997

Fall
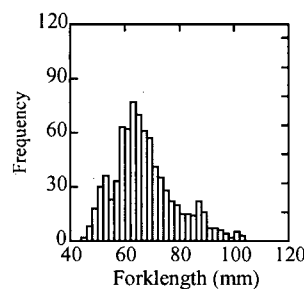
Pre-winter
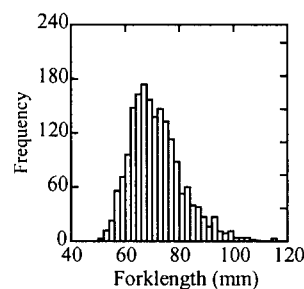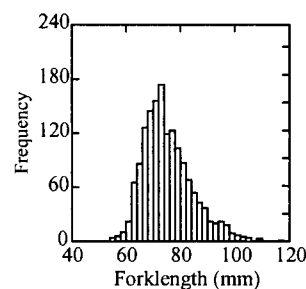
Post-winter

Mann 1997

Fall
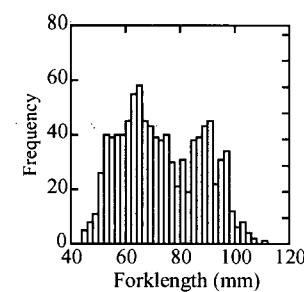
Pre-winter
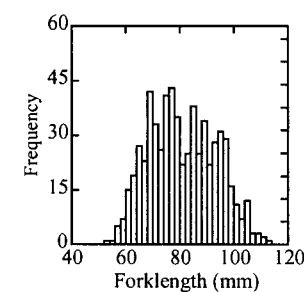
Post-winter

Lemieux Creek 1996

High

$X^2 = 1.85$, p = 0.76
Cochran $X^2 = 0.93$, p = 0.34

Low

$X^2 = 4.39$, p = 0.36
Cochran $X^2 = 0.001$, p = 0.98

All

$X^2 = 8.35$, p = 0.08
Cochran $X^2 = 6.01$, p = 0.01

Mann Creek 1996

High

$X^2 = 3.63$, p = 0.46
Cochran $X^2 = 2.76$, p = 0.10

Low

$X^2 = 12.63$, p = 0.01
Cochran $X^2 = 7.08$, p = 0.01

All

$X^2 = 6.67$, p = 0.15
Cochran $X^2 = 6.13$, p = 0.01
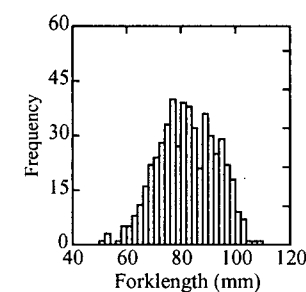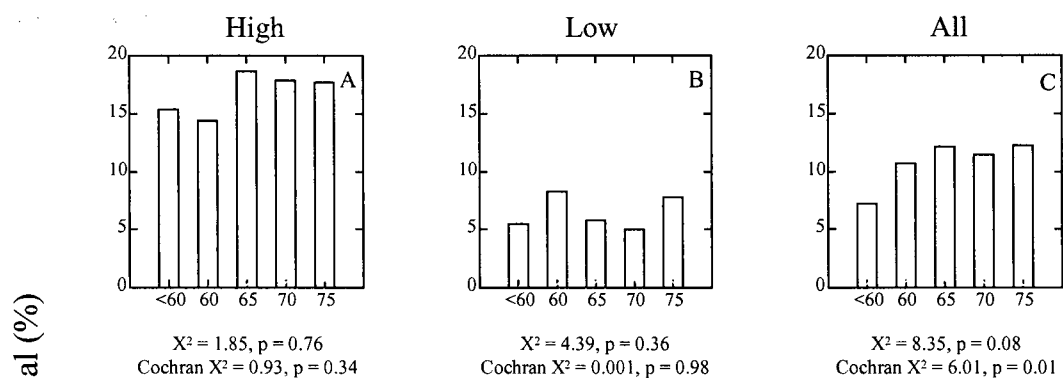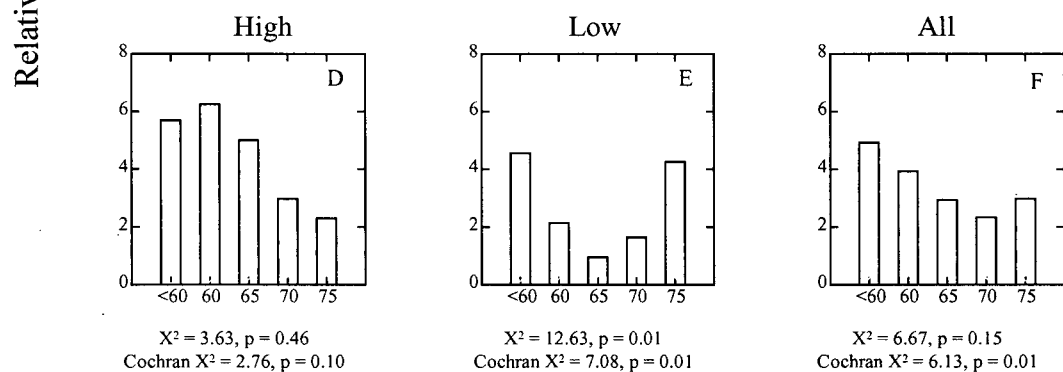
Relative survival (%)

Fall size class

Figure 2.3: Relative size-dependent overwinter survival rates of juvenile coho classified by site abundance level the previous fall, Lemieux and Mann creeks 1996.

Data are summarized for the creeks overall (All), for fish that were located in relatively high abundance sites the previous fall (High), and for fish that were located in all remaining, relatively low abundance sites, the previous fall (Low). Results from significance tests of differences in recapture frequencies among (χ^2) and linearly across (Cochran χ^2) initial size classes are indicated. Note differences in scales between streams. Sample sizes for all comparisons are found in Appendix 6.
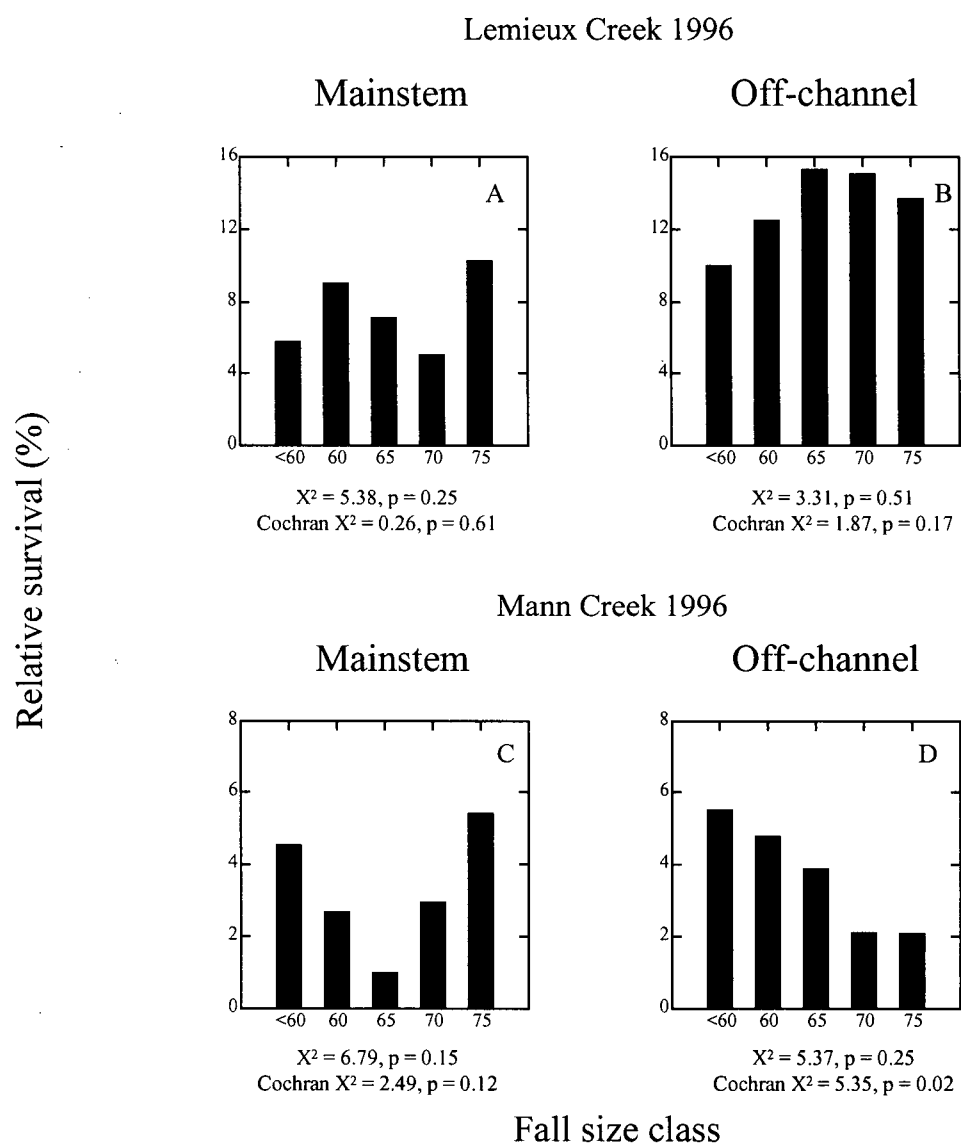
Figure 2.4: Relative size-dependent overwinter survival rates of juvenile coho classified by habitat type the previous fall, Lemieux and Mann creeks 1996.

Results from significance tests of differences in recapture frequencies among (χ^2) and linearly across (Cochran χ^2) initial size classes are indicated. Note differences in scales between creeks. Sample sizes for all comparisons are found in Appendix 6.

Lemieux Creek 1997

High	Low	All
A	B	C
$X^2 = 29.42$, $p < 0.001$	$X^2 = 4.02$, $p = 0.40$	$X^2 = 22.68$, $p < 0.001$
Cochran $X^2 = 2.85$, $p = 0.09$	Cochran $X^2 = 0.20$, $p = 0.66$	Cochran $X^2 = 3.60$, $p = 0.06$

Mann Creek 1997

High	Low	All
D	E	F
$X^2 = 2.64$, $p = 0.62$	$X^2 = 2.10$, $p = 0.72$	$X^2 = 1.84$, $p = 0.76$
Cochran $X^2 = 0.23$, $p = 0.63$	Cochran $X^2 = 0.03$, $p = 0.86$	Cochran $X^2 = 1.04$, $p = 0.31$
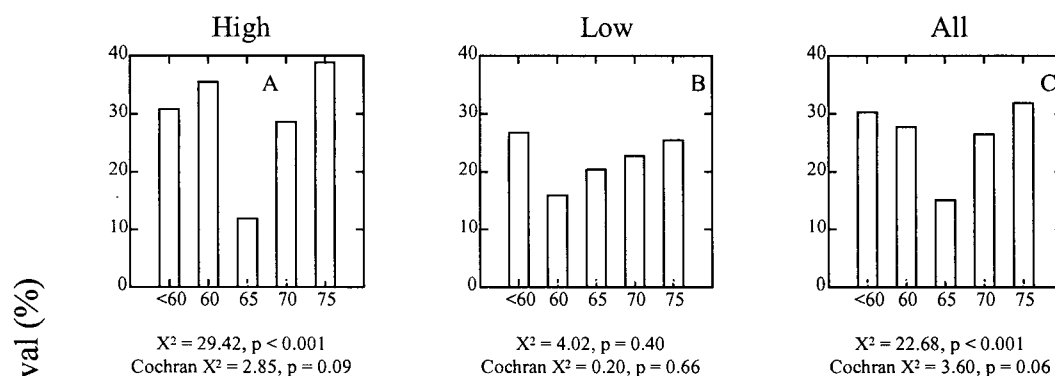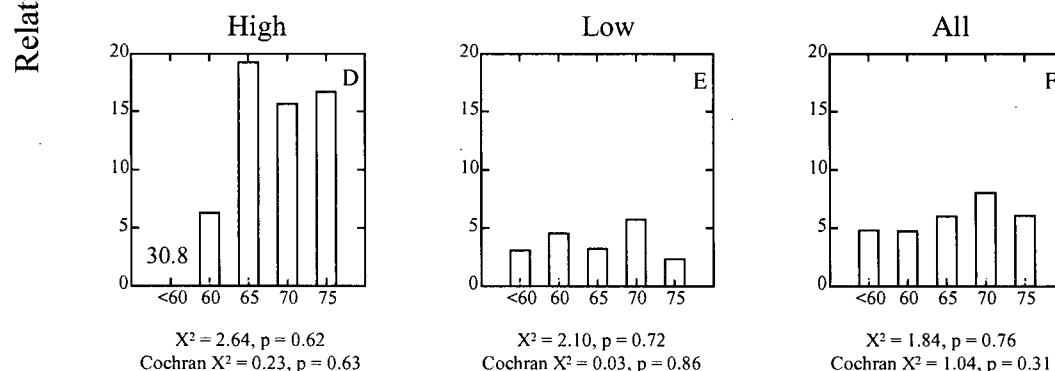
Relative survival (%)

Fall size class

Figure 2.5: Relative size-dependent overwinter survival rates of juvenile coho classified by site abundance level the previous fall, Lemieux and Mann creeks 1997.

Data are summarized for the creeks overall (All), for fish that were located in relatively high abundance sites the previous fall (High), and for fish that were located in all remaining, relatively low abundance sites, the previous fall (Low). Results from significance tests of differences in recapture frequencies among (χ^2) and linearly across (Cochran χ^2) initial size classes are indicated. Note differences in scales between creeks. Sample sizes for all comparisons are found in Appendix 6.

Lemieux Creek 1997

Off-channels

Pools

$X^2 = 23.86$, p < 0.001
Cochran $X^2 = 2.27$, p = 0.13

$X^2 = 11.70$, p = 0.02
Cochran $X^2 = 3.86$, p = 0.05

Mann Creek 1997

Off-channels

Pools

$X^2 = 11.68$, p = 0.02
Cochran $X^2 = $ n/a

$X^2 = 1.41$, p = 0.84
Cochran $X^2 = 0.01$, p = 0.91
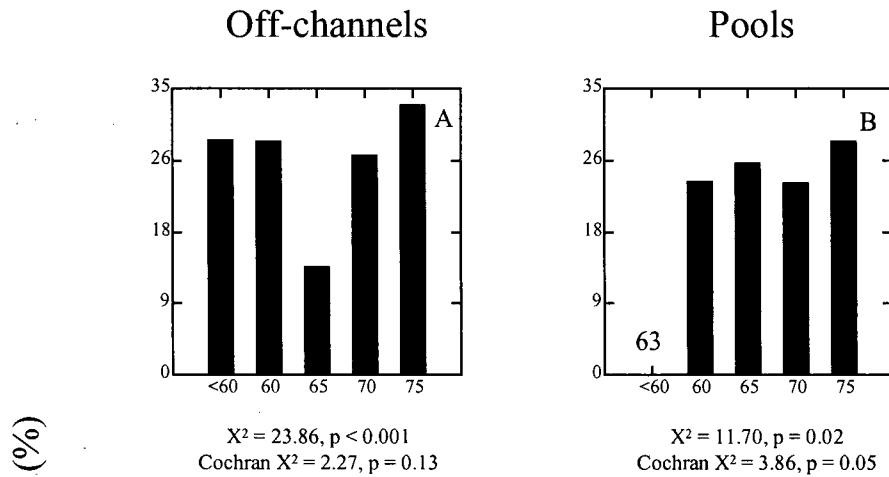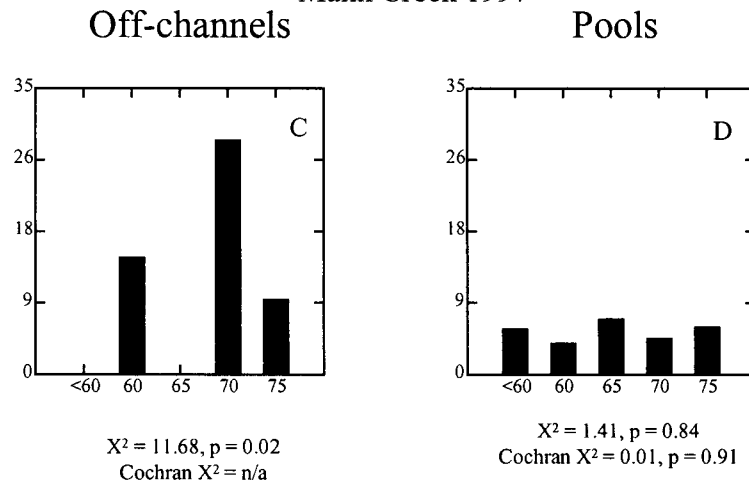
Relative survival (%)

Fall size class

Figure 2.6: Relative size-dependent overwinter survival rates of juvenile coho classified by habitat type the previous fall, Lemieux and Mann creeks 1997.

Results from significance tests of differences in recapture frequencies among (χ^2) and linearly across (Cochran χ^2) initial size classes are indicated. Note differences in scales between creeks. Sample sizes for all comparisons are found in Appendix 6.
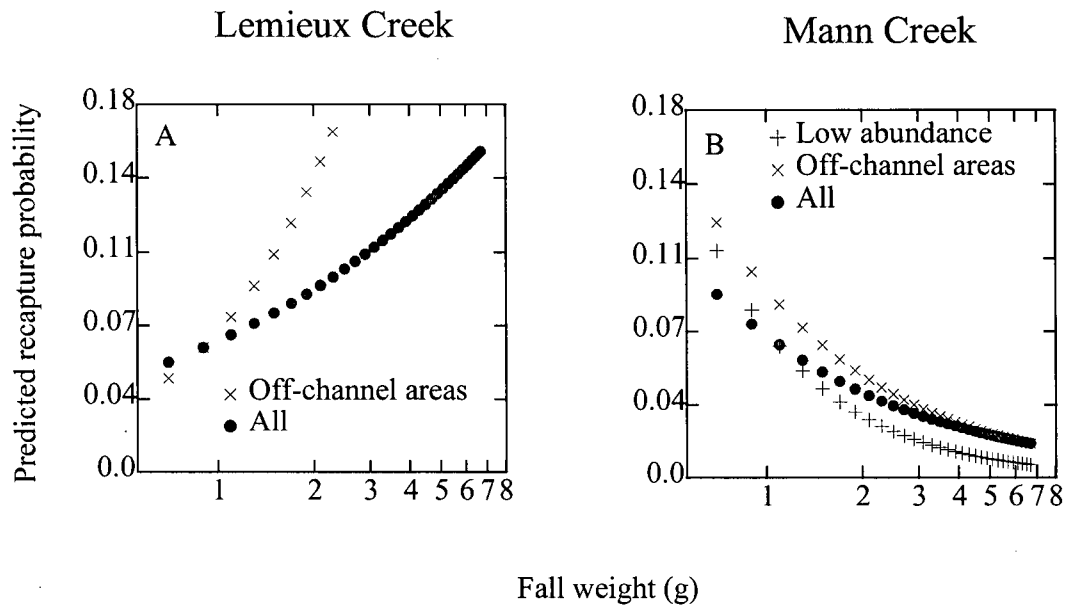
Figure 2.7: Modeled size-related recapture probability based on significant logistic regression results for Lemieux and Mann creeks, 1996.

Recapture probability is considered an index of relative overwinter survival and is represented by Equ. 2.1.

Figure 2.8: A flow chart of model hierarchy for post-winter recapture probability of juvenile coho in Lemieux (A) and Mann (B) creeks, 1996.

Log likelihood ratio tests were used to contrast the relative importance of fall size and location in explaining variability in overwinter survival at different levels of the hierarchy. The likelihood ratio chi-square (df = 1) for deletion of either fall size, location or size*location interaction is listed on the arrow connecting models. Size refers to initial fall weight in g, location refers to initial fall location expressed as habitat type (mainstem or off-channel), and S*L refers to the interaction of fall size and fall location. Significant differences are in bold type. The log-likelihood for each model is enclosed in a box with its name. It was found that fall location explained more of the variability in post-winter recapture probability than initial fish size.

Lemieux Creek 1996 - A

```
                    ┌─────────────────────────┐
                    │  Size + Location + S*L   │
                    │         -927.2           │
                    └─────────────────────────┘
            1.96          │ 0.02          1.20
       ┌────────────┐  ┌─────────────────┐  ┌─────────────────┐
       │ Size + S*L │  │ Size + Location │  │ Location + S*L  │
       │   -928.2   │  │     -927.3      │  │     -927.8      │
       └────────────┘  └─────────────────┘  └─────────────────┘
      26.9│  28.8    0.1        0.8    3.3      2.1
       ┌────────┐      ┌────────┐      ┌──────────┐
       │  Size  │      │  S*L   │      │ Location │
       │ -941.7 │      │ -928.3 │      │  -928.9  │
       └────────┘      └────────┘      └──────────┘
           7.5       34.2       33.1
                    ┌────────────┐
                    │  Constant  │
                    │   -945.4   │
                    └────────────┘
```

Mann Creek 1996 - B

```
                    ┌─────────────────────────┐
                    │  Size + Location + S*L   │
                    │         -497.5           │
                    └─────────────────────────┘
            1.1           │ 0            5.9
       ┌────────────┐  ┌─────────────────┐  ┌─────────────────┐
       │ Size + S*L │  │ Size + Location │  │ Location + S*L  │
       │   -498.0   │  │     -497.5      │  │     -500.4      │
       └────────────┘  └─────────────────┘  └─────────────────┘
      3.5│  4.6   13.4       8.5    13.4       7.5
       ┌────────┐      ┌────────┐      ┌──────────┐
       │  Size  │      │  S*L   │      │ Location │
       │ -499.7 │      │ -504.7 │      │  -504.2  │
       └────────┘      └────────┘      └──────────┘
          10.1       0.2        1.2
                    ┌────────────┐
                    │  Constant  │
                    │   -504.8   │
                    └────────────┘
```
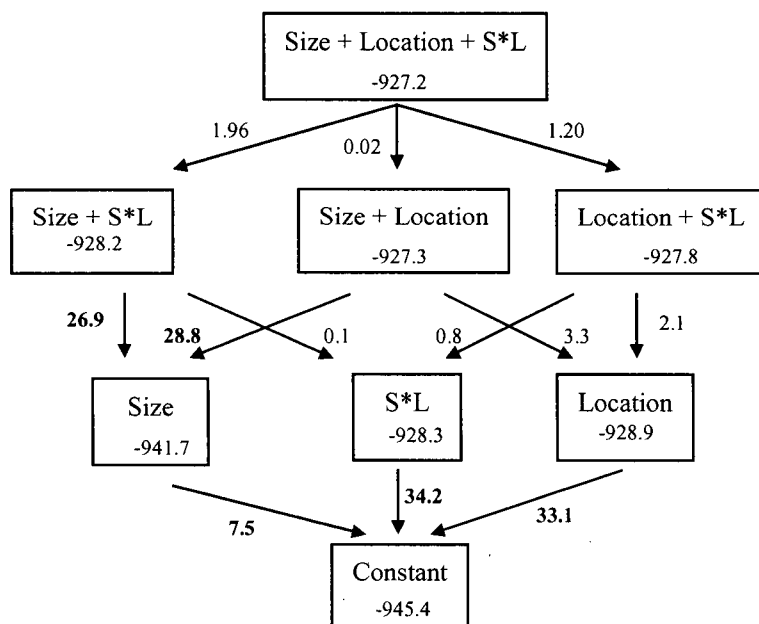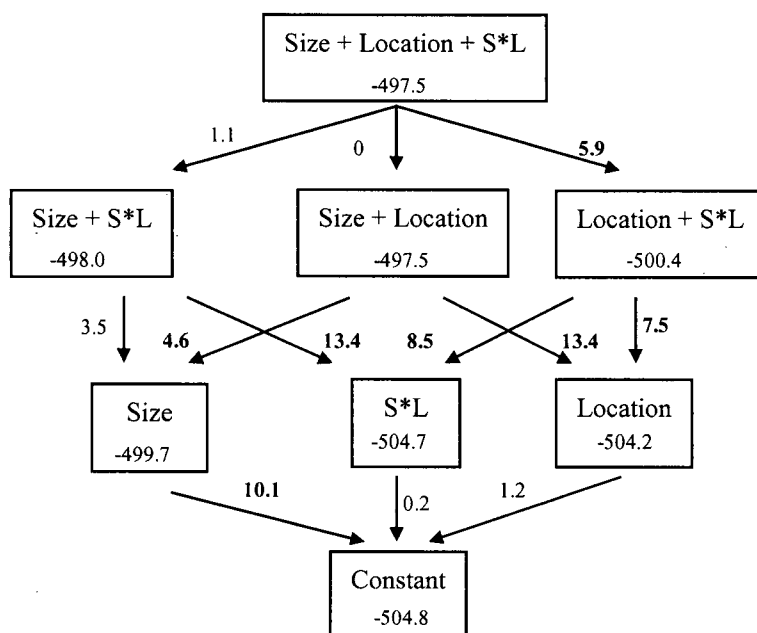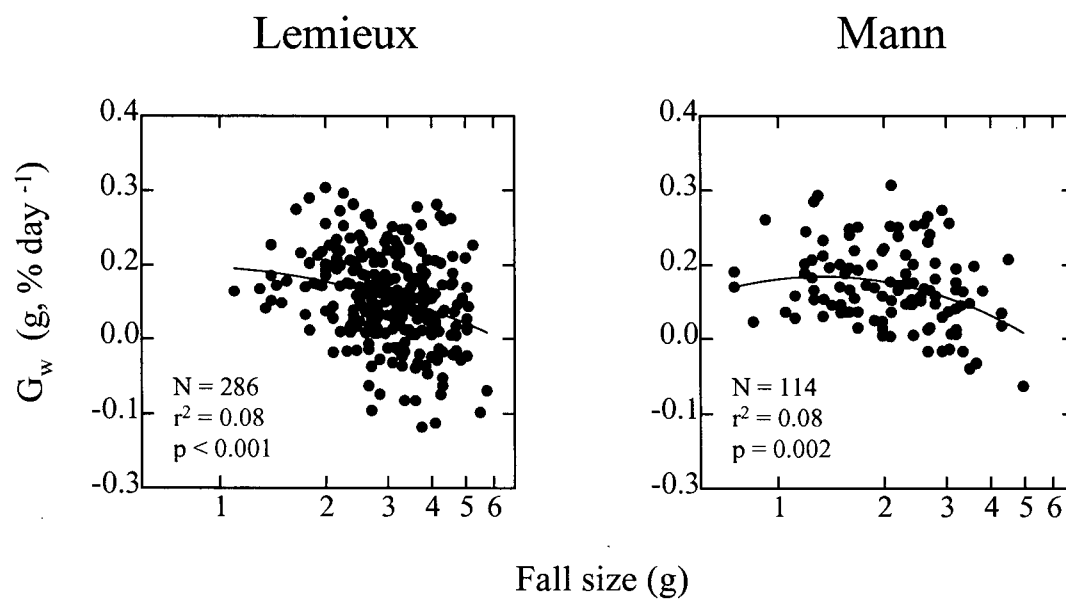
Figure 2.9: Plot of individual instantaneous growth rates in weight (G_w) against initial fall size of fish overwintering in Lemieux and Mann creeks during 1996.

Lines are the quadratic smooth of the data. Sample sizes, r^2 values and p values from GLM analyses are noted.
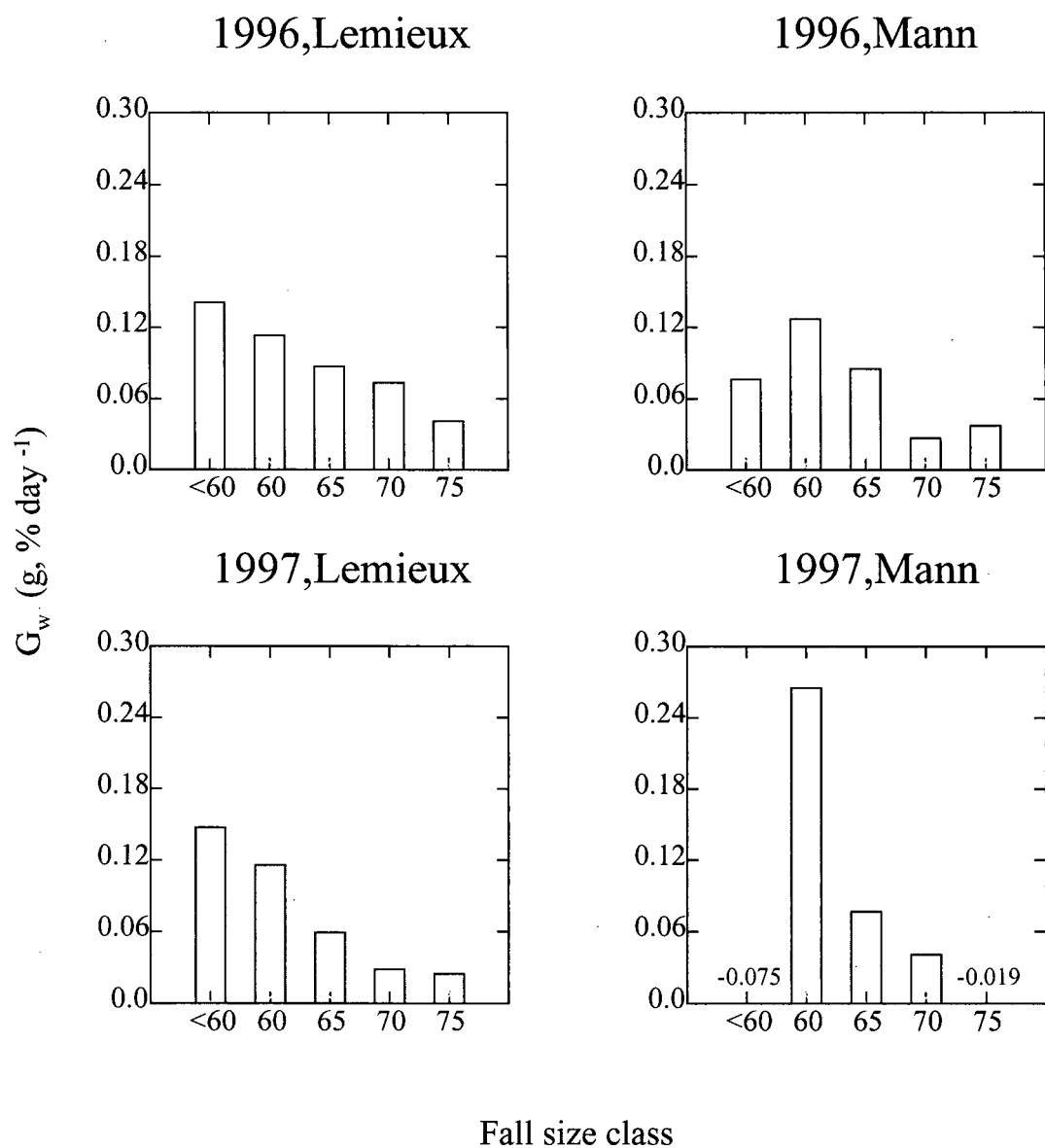
Figure 2.10: Graph of categorical instantaneous growth rates in weight (G_w) against initial fall size class of fish overwintering in Lemieux and Mann creeks during 1996 and 1997.

Bars are growth rates calculated from the difference between the average size of fish in a particular size class in autumn, and the average size of those same fish following winter. Sample sizes for all comparisons are noted in Appendix 6.

Fall to post-winter   **Pre to post-winter**

Fall size class
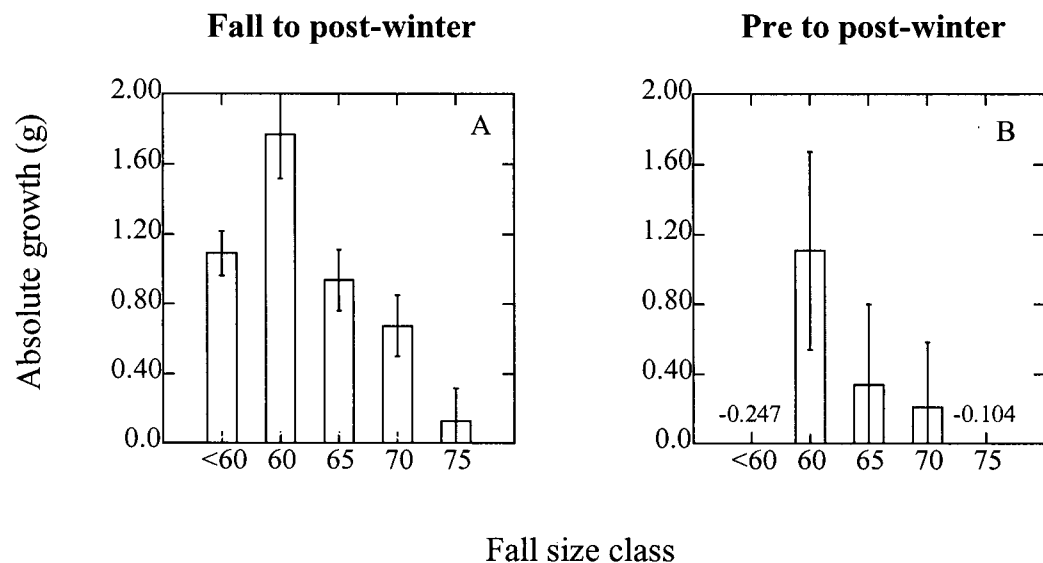
Figure 2.11: Comparison of size-dependent absolute overwinter growth in weight (G_w) using fall to post-winter sampling data and pre to post winter sampling data from Mann Creek during 1997.

Errors are ± one standard error bars for differences between two means (Zar 1984). Note higher variability in absolute growth within size classes in the pre to post winter data.

Lemieux
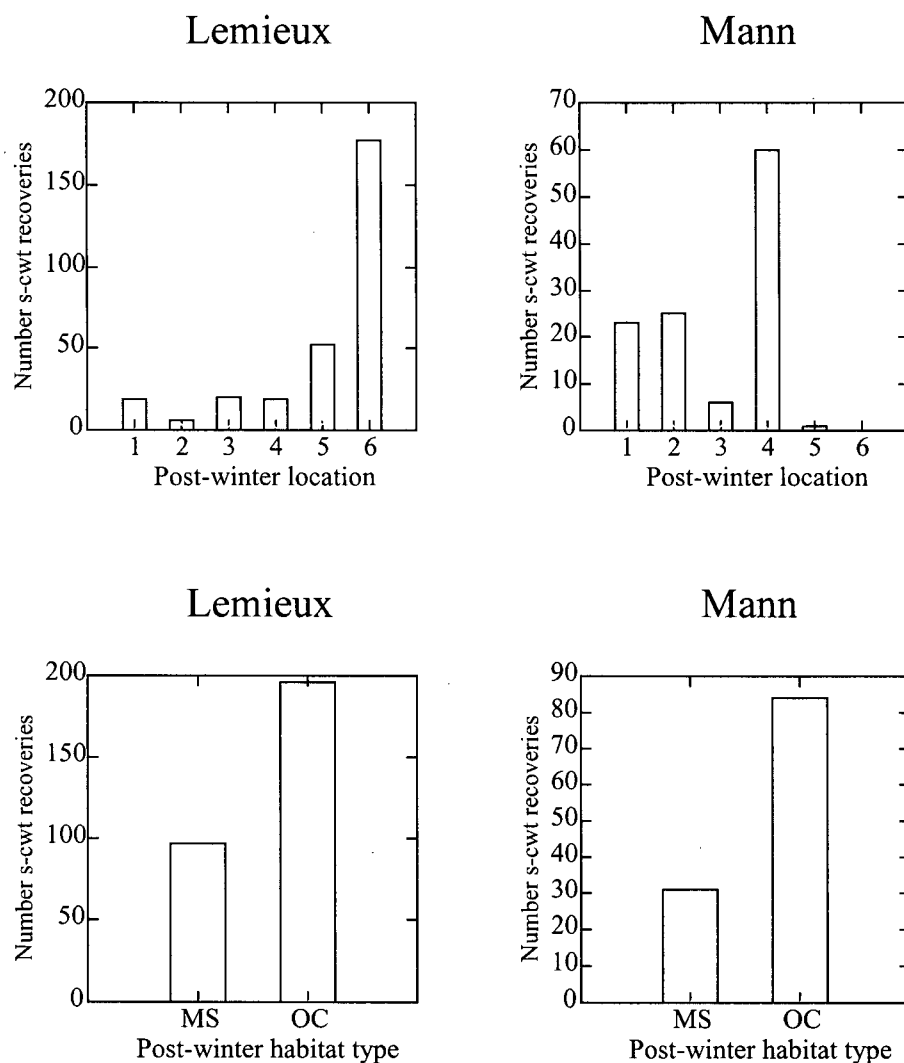
Mann

Lemieux

Mann

Figure 2.12: Spatial distribution of post-winter sequential coded wire tag recoveries by site and habitat type in Lemieux and Mann creeks, 1996.

Site numbers are ordered in a downstream (site 1) to upstream (site 6) fashion. OC = off-channel sites; MS = mainstem sites. Note differences in scale between creeks. Recapture frequencies were significantly different among sites and between habitat types in both creeks (Chi-square; $p < 0.05$).

Figure 2.13: Plot of instantaneous overwinter growth rates in weight (G_w) across initial fall size classes for different abundance levels.

All = data from all sites; High abundance = data from Ianson channel (Lemieux) or the beaver pond site (Mann) only; Low abundance = data from all other sites. The pattern of growth across size classes was consistent among abundance levels.

113
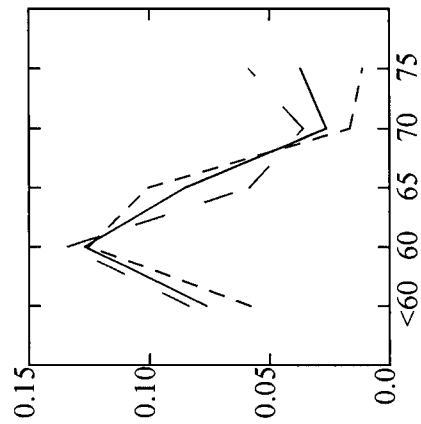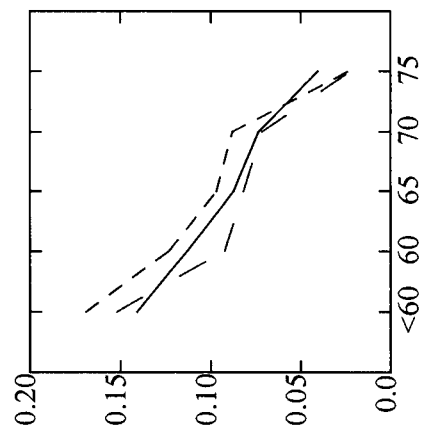
Lemieux
Mann
1996
1997
September size
Growth weight (g, % day^{-1})
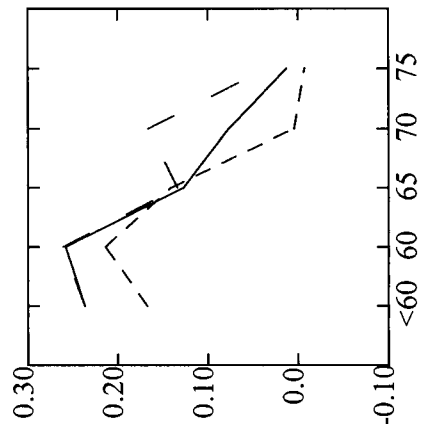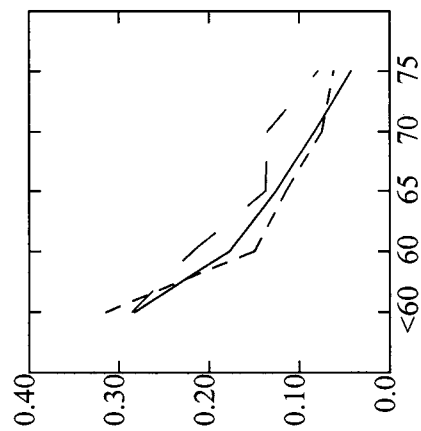
All
High abundance
Low abundance
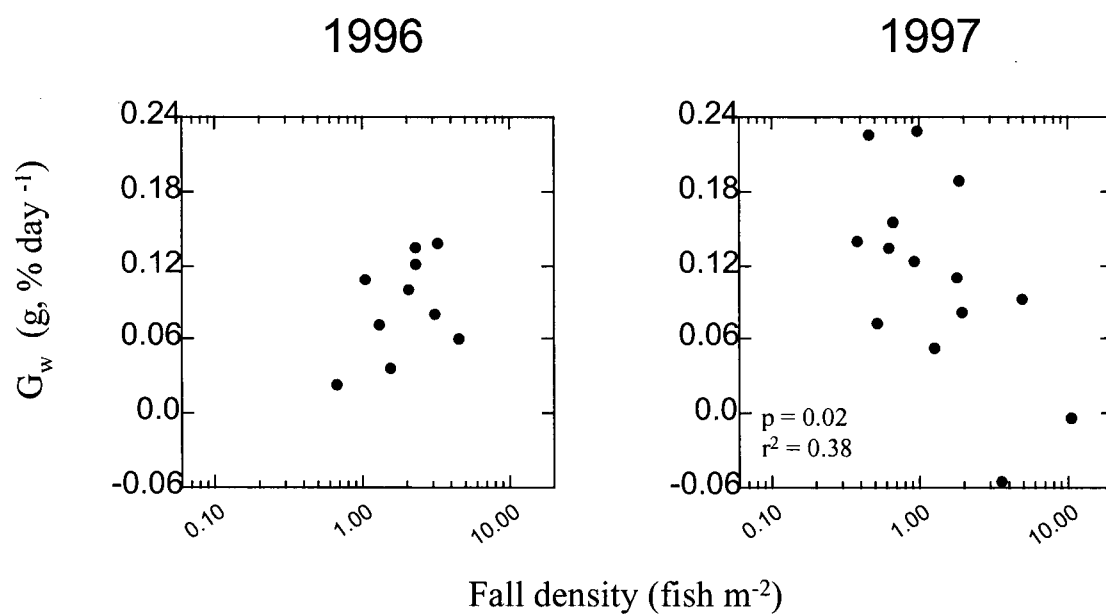
Figure 2.14: Relationship between fall site densities and instantaneous overwinter growth rates in weight (G_w) for data from both streams combined, 1996 and 1997.

Each dot represents data from one sample site. No relationship between variables was evident in 1996; a significant negative relationship was found in 1997.
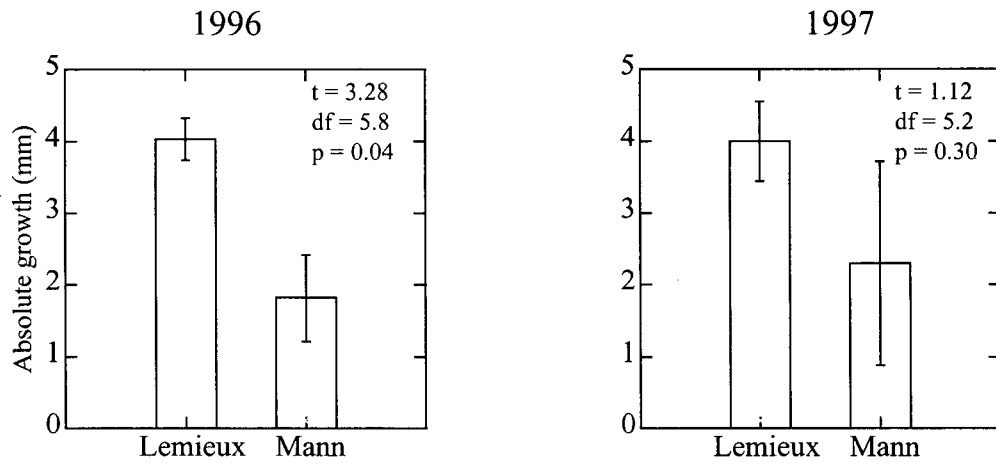
Figure 2.15: Comparison of absolute overwinter growth in weight between creeks during 1996 and 1997.

Differences in growth between creeks were noted in 1996, but not in 1997.

Lemieux Creek
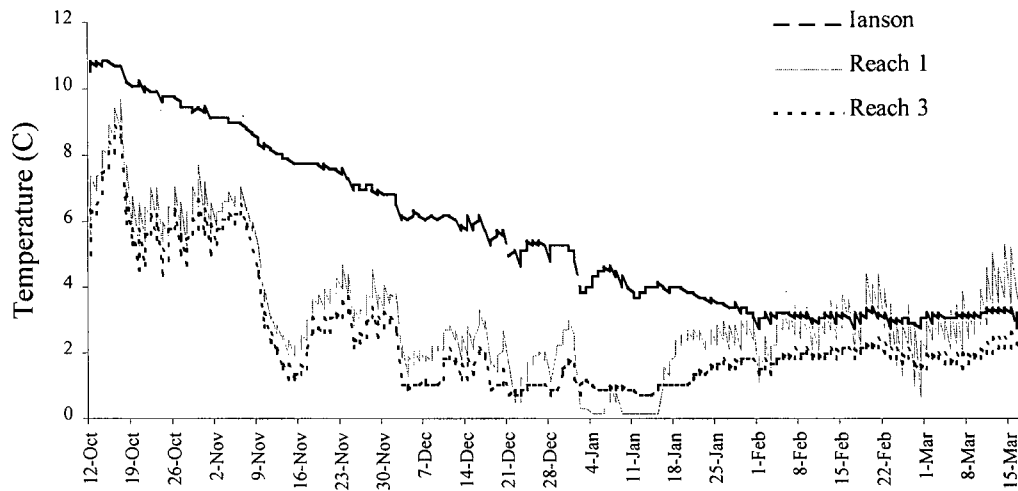
Mann Creek
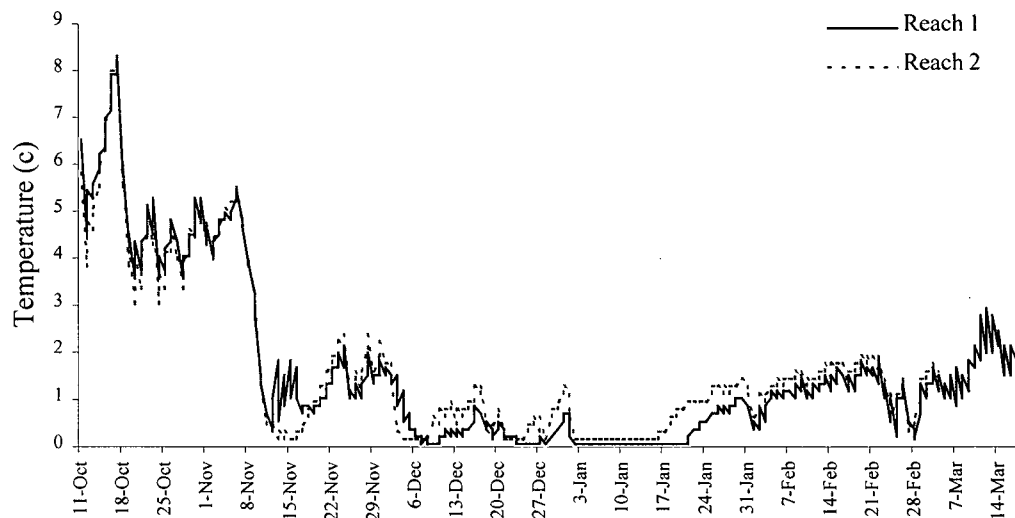
Figure 2.16: Annual thermographs measured during 1997 using data loggers placed in Ianson groundwater channel in Lemieux, and each reach in both creeks.

Figure 2.17: Comparison of observed size-dependent instantaneous overwinter growth rates in weight (G_w) and growth rates predicted from a model of allometric growth.

Allometric differences were not sufficient to explain observed differences in growth across initial fall size classes. Note different scale for Mann Creek, 1997.

118

Mann

Lemieux

G_w (g, % day^{-1})

September size

Predicted
Observed

1996

1997
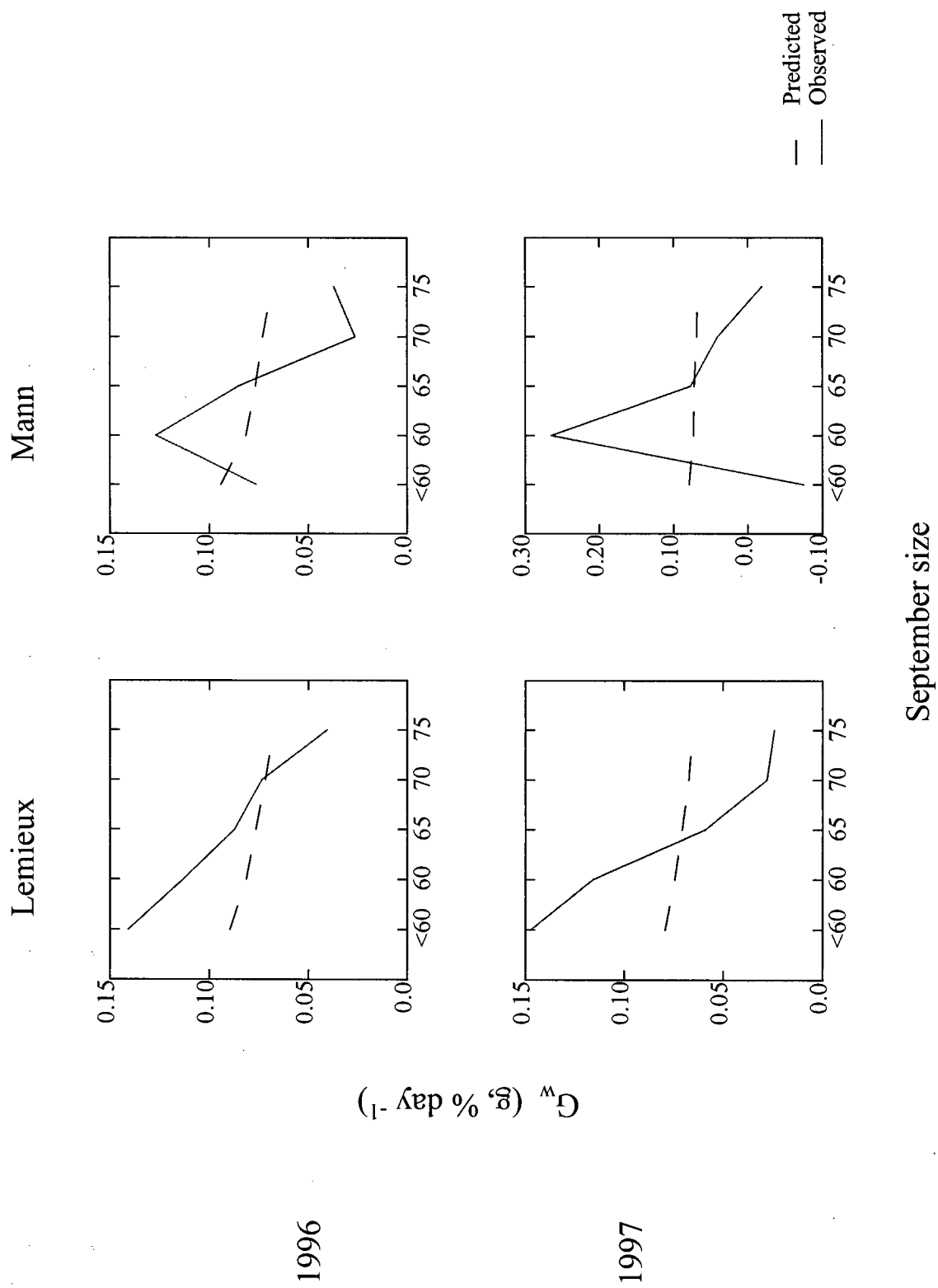
Figure 2.18: Relationship between instantaneous overwinter growth rates in weight (G_w) and relative overwinter survival in both creeks and years.

Data are summarized by abundance level and habitat type in both streams and years. In most comparisons, no relationship between variables was noted.

Low Abundance

High Abundance

All

Mainstem/Pools

Off-channel

▲ 1997,Mann
+ 1997,Lemieux
× 1996,Mann
● 1996,Lemieux

C

B

A

E

D

p = 0.02
r² = 0.26

Relative survival

Specific growth rate (g, % day^{-1})
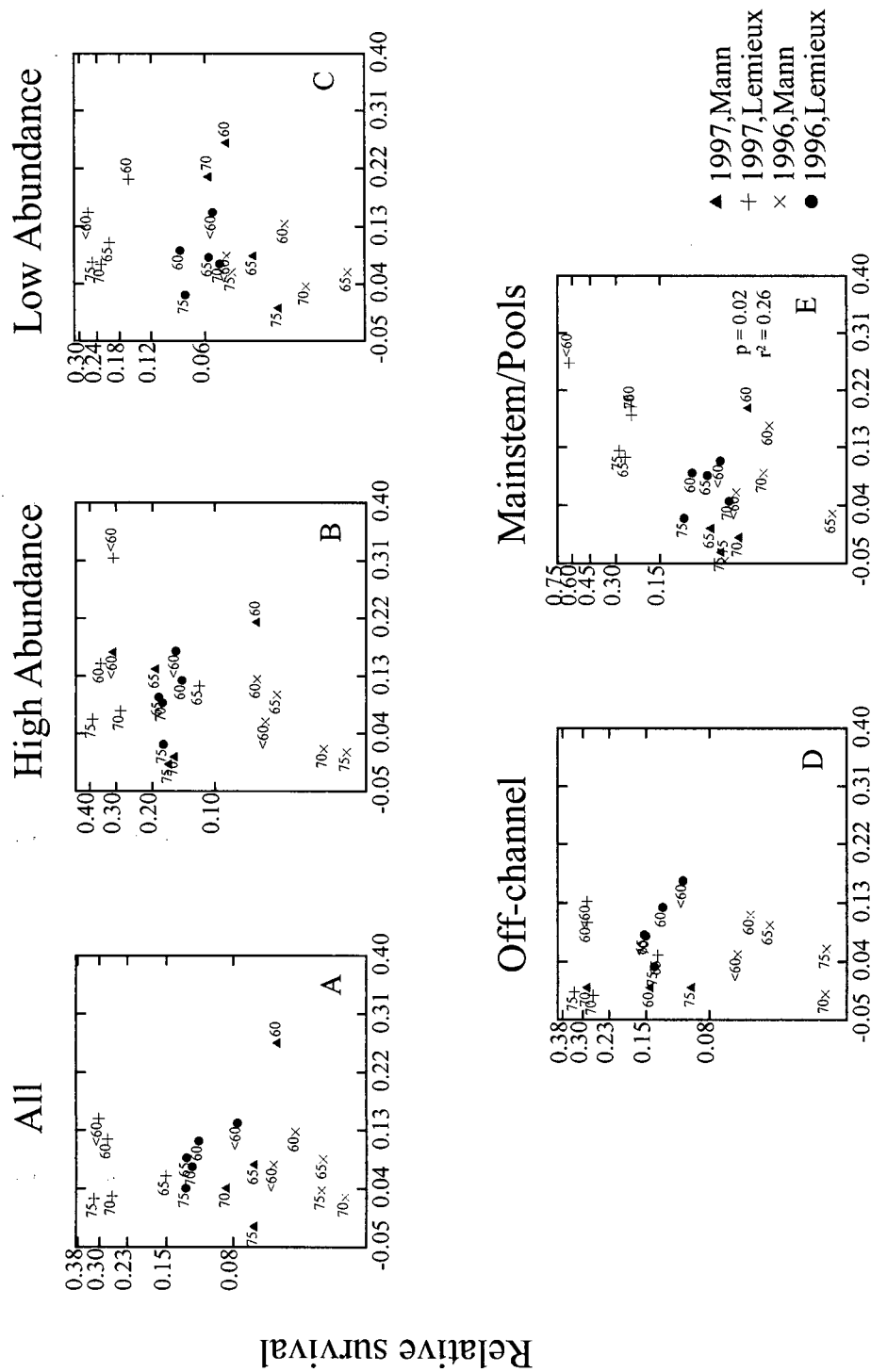
LITERATURE CITED

Amiro, P. G. 1990. Variation in juvenile Atlantic salmon population densities between consecutive enclosed sections of streams. *In* I. G. Cowx, Ed. Developments in Electric Fishing. Blackwell Scientific Publications Ltd., Cambridge, MA.

Anon. 1992. Fish Habitat Inventory and Information Program, Stream Summary Catalogue. Subdistrict #29J, Clearwater. Department of Fisheries and Oceans, Fraser River, Northern B. C. and Yukon Division, Fisheries Branch. January 1992.

Anon. 1995. Kamloops Land and Resource Management Plan. Province of B. C. Victoria, B. C. July 1995.

Anon. 1997. The Fraser Basin: Sustainability through Responsibility. Habitat and Enhancement Branch, Fisheries and Oceans Canada. Vancouver, B.C. FS 23-315/1997E.

Anon. 1998. Coho Backgrounder. Department of Fisheries and Oceans. Vancouver, B. C. March 27, 1998.

Anon. 1999. Staying the course: salmon management plans for 1999. Restructuring Canada's Pacific Fishery 2: 1-16.

ARC. 1997. Mann Creek Watershed: Fish and Fish Habitat Inventory Program. ARC Environmental Ltd. Report prepared for Slocan Forest Products Ltd. Kamloops, B. C. April 1997.

Armour, C. L., K. P. Burnham, and W. S. Platts. 1983. Field methods and statistical analyses for monitoring small salmonid streams. U. S. Fish Wildl. Serv. FWS/OBS-83/33. 200 p.

Atagi, D. Y., R. E. Diewert, J. M. Bratty, L. C. Walthers, and J. R. Irvine. 1999. 1993 and 1994 coho spawning escapement and juvenile studies in Louis and Lemieux Creeks (North Thompson River). Can. Manuscr. Rep. Fish. Aquat. Sci 2747: 80 p.

Bilby, R. E. and P. A. Bisson. 1987. Emigration and production of hatchery coho salmon stocked in streams draining an old-growth and a clear-cut watershed. Can. J. Fish. Aquat. Sci. 44: 1397-1407.

Bilton, H. T., D. F. Alderdice, and J. T. Schnute. 1982. Influence of time and size at release of juvenile coho salmon on returns at maturity. Can. J. Fish. Aquat. Sci. 39: 426-447.

Bisson, P. A., T. P. Quinn, G. H. Reeves, and S. V. Gregory. 1992. Best management practices, cumulative effects, and long-term trends in fish abundance in Pacific Northwest river systems. Pages 189-232. *In* R. J. Naiman, Ed. Watershed Management: Balancing Sustainability and Environmental Change. Spronger-Verlag, New York.

Bjornn, T. C. and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138. *In* W. R. Meehan and T. C. Bjornn, Eds. Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats. American Fisheries Society Special Publication 19.

Bohlin, T., C. Dellefors, and U. Faremo. 1982. Electro-fishing for salmonids in small streams: aspects of the sampling design. Rep. Inst. Freshwater Res. Drottningholm 60: 15-18.

Bradford, M. J. 1998. A risk assessment for Thompson River coho salmon. Department of Fisheries and Oceans. Vancouver, B. C. May 1998. PSARC Working Paper. S98-18.

Bradford, M. J. 1999. Temporal and spatial trends in the abundance of coho salmon smolts from western North America. Trans. Amer. Fish. Soc. 128.

Bradford, M. and J. Irvine. 1999. Land-use, fishing, climate change and the decline of Thompson River British Columbia coho salmon. Can. J. Fish. Aquat. Sci. In Press.

Bradford, M. J., R. A. Myers, and J. R. Irvine. In Press. Reference points for coho salmon harvest rates and escapement goals based on freshwater production. Can. J. Fish. Aquat. Sci. .

Bradford, M. J., G. C. Taylor, and J. A. Allan. 1997. Empirical review of coho salmon smolt abundance and the prediction of smolt production at the regional level. Trans. Amer. Fish. Soc. 126: 49 - 64.

Bridcut, E. E. and P. S. Giller. 1993. Diet variability in relation to season and habitat utilisation in brown trout in a southern Irish stream. In R. J. Gibson and R. E. Cutting, Eds. Production of juvenile Atlantic salmon in natural waters. Can. Spec. Publ. Fish. Aquat. Sci. 118.

Brown, L. R., P. B. Moyle, and R. M. Yoshiyama. 1994. Historical decline and current status of coho salmon in California. N. Amer. J. Fish. Manag. 14: 237-261.

Brown, T. G. 1985. The role of abandoned stream channels as over-wintering habitat for juvenile salmonids. Masters Thesis, Department of Forestry, University of British Columbia, Vancouver, B.C. 191 p.

Brown, T. G. and G. F. Hartman. 1988. Contributions of seasonally flooded lands and minor tributaries to the production of coho salmon in Carnation Creek, B.C. Trans. Amer. Fish. Soc. 177: 546-551.

Bugert, R. M. and T. C. Bjornn. 1991. Habitat use by steelhead and coho salmon and their responses to predators and cover in laboratory streams. Trans. Amer. Fish. Soc. 120: 486-493.

Bustard, D. 1986. Some differences between coastal and interior stream ecosystems and the implications to juvenile fish production. Pages 117-126, In J. H. Patterson, Ed. Workshop on Habitat Improvements, Whistler, B.C., May 8-10, 1984. 1483.

Bustard, D. 1994. Juvenile coho population estimates in the Telkwa River ponds, May 1994. Unpublished Report prepared for the Department of Fisheries and Oceans. Vancouver, B.C. May 1994.

Bustard, D. R. and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon and steelhead trout. J. Fish. Res. Bd. Can. 32: 667-680.

Cederholm, C. J. and W. J. Scarlett. 1981. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. Pages 98-110, In E. L. Brannon and E. O. Salo, Eds. Salmon and Trout Migratory Behaviour Symposium,

Chapman, D. W. 1962. Aggressive behaviour in juvenile coho salmon as a cause of emigration. J. Fish. Res. Board Can. 19: 1047-1080.

Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. Amer. Nat. 100: 345-357.

Conlin, K. and D. Tutty. 1979. Juvenile field trapping manual. Fish. and Mar. Serv. Manu. Rep. 1530.

Conover, D. O. 1992. Seasonality and the scheduling of life history at different latitudes. J. Fish. Biol. 41 (Supp. B): 161-178.

CPMPNAS. 1996. Upstream: Salmon and Society in the Pacific Northwest. National Academy Press, Washington, D. C. 410.

Craig, P. C. and V. A. Poulin. 1975. Movements and growth of arctic greyling and juvenile arctic char in a small arctic stream, Alaska. J. Fish. Res. Board Can. 32: 689-697.

Cross, C. L., L. Lapi, and E. A. Perry. 1991. Production of chinook and coho salmon from British Columbia hatcheries, 1971 through 1989. Can. Tech. Rep. Fish. Aquat. Sci. 1816.

CRT. 1998. Coho Response Team: Final Report. Report prepared for the Department of Fisheries and Oceans. Vancouver, B.C.

Cunjak, R. A. 1988a. Behaviour and microhabitat of young Atlantic salmon during winter. Can. J. Fish. Aquat. Sci. 45: 2156-2160.

Cunjak, R. A. 1988b. The physiological consequences of overwintering: the cost of acclimatization? Can. J. Fish. Aquat. Sci. 45: 443-452.

Cunjak, R. A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Can. J. Fish. Aquat. Sci. 53: 267-282.

Cunjak, R. A. and G. Power. 1986. Winter habitat utilization by stream resident brook trout and brown trout. Can. J. Fish. Aquat. Sci. 43: 1970-1981.

Decker, A. S. 1998. Influence of off-channel habitat restoration and other enhancement on the abundnace and distribution of salmonids in the Coquitlam River. Unpublished report prepared for B.C. Hydro Power Facilities. Burnaby, B.C. 35 p.

Decker, A. S. 1999. Effects of primary production and other factors on the size and abundance of juvenile coho salmon in artificial off-channel habitat. Masters Thesis, Department of Forest Sciences, University of British Columbia, Vancouver, B.C. 146 p.

Decker, A. S., J. M. Bratty, S. Riley, and J. Korman. In press. Estimating coho salmon and cutthroat trout standing stock in a small stream: a comparison of sampling designs. Can. Tech. Rep. Fish. Aquat. Sci.

Dill, L. M. 1983. Adaptive flexibility in the foraging behaviour of fishes. Can. J. Fish. Aquat. Sci. 40: 398-408.

Dolloff, C. A. 1993. Predation by river otters on juvenile coho salmon and Dolly Varden in southeast Alaska. Can. J. Fish. Aquat. Sci. 50.

Dorcey, A. H. and J. R. Griggs, Eds. 1991. Water in Sustainable Development: Exploring Our Common Future is the Fraser River Basin. Westwater Research Centre, University of B.C., Vancouver, B.C. 288 p.

Dwyer, W. P. and R. G. White. 1997. Effect of electroshock on juvenle arctic greyling and Yellowstone cutthroat trout growth, 100 days after treatment. N. Amer. J. Fish. Man. 17: 174-177.

Elliott, J. M. 1975a. The growth rate of brown trout fed on maximum rations. J. Anim. Ecol. 44: 805-821.

Elliott, J. M. 1975b. The growth rate of brown trout fed on reduced rations. J. Anim. Ecol. 44: 823-842.

Elliott, J. M. 1976. The energetics of feeding, metabolism and growth of browth trout in relation to body weight, water temperature and ration size. J. Anim. Ecol. 45: 923-948.

Elliott, J. M. 1993. The self-thinning rule applied to juvenile sea-trout. J. Anim. Ecol. 62: 371-379.

Emlen, J. M., R. R. Reisenbichler, A. M. McGie, and T. E. Nickelson. 1990. Density-dependence at sea for coho salmon. Can. J. Fish. Aquat. Sci. 47: 1765-1772.

English, K. K., R. C. Bocking, and J. R. Irvine. 1992. A robust procedure for estimating salmon escapement based on the area under the curve method. Can. J. Fish. Aquat. Sci. 49: 1982-1989.

Everest, F. H., G. H. Reeves, J. R. Sedell, J. Wolfe, D. Hohler, and D. A. Heller. 1986. Abundance, behaviour and habitat utilization by coho salmon and steelhead trout in Fish Creek, Oregon, as influenced by habitat enhancement. Annual Report, Bonnevile Power Administration, Division of Fish and Wildlife. Portland, OR. Project 84-11.

Fausch, K. D. 1984. Profitable stream positions for salmonids: relating specific growth rate to net energy gain. Can. J. Zool. 62: 441-451.

Fausch, K. D. 1993. Experimental analysis of microhabitat selection by juvenile steelhead and coho salmon in a British Columbia stream. Can. J. Fish. Aquat. Sci. 50: 1198-1207.

Fraser, D. F. and T. E. Sise. 1980. Observations of stream minnows in a patchy environment: a test of a theory of habitat distribution. Ecology 61: 790-797.

Gardiner, W. R. and P. Geddes. 1980. The influence of body composition on the survival of juvenile salmon. Hydrobiologia 69: 67-72.

Gibson, R. J., D. E. Stansbury, R. R. Whalen, and K. G. Hillier. 1993. Relative habitat use, and inter-specific and intra-specific competition of brook trout and juvenile Atlantic salmon in some Newfoundland waters. Pages 53-69. *In* R. J. G. a. R. E. Cutting, Ed. Production of juvenile Atlantic salmon in natural waters. Can. Spec. Publ. Fish. Aquat. Sci. 118.

Gillis, D. M. and D. L. Kramer. 1987. Ideal interference distributions: population density and patch use by zebrafish. Anim. Behav. 35: 1875-1882.

Glavin, T. 1998. Last Call: The will to save Pacific Salmon. Report prepared for the David Suzuki Foundation. Vancouver, B. C.

Grand, T. C. 1997. Foraging site selection by juvenile coho salmon: ideal free distribution of unequal competitors. Anim. Behav. 53: 185-196.

Grant, J. W. A. and D. L. G. Noakes. 1987. A simple model of optimal territory size for dift-feeding fish. Can. J. Zool. 65: 270-276.

Griffiths, J. S. and D. F. Alderdice. 1972. Effects of acclimation and acute temperature on the swimming speed on juvenile coho salmon. J. Fish. Res. Board Can. 29: 251-264.

Hall, J. D. and N. J. Knight. 1981. Natural variation in abundance of salmonid populations in streams and its implications for design of impact studies. EPA. Corvallis, OR. July 1981. Project summary. EPA-600 / S3-81-021.

Hankin, D. G. 1984. Multistage sampling designs in fisheries research: applications in small streams. Can. J. Fish. Aquat. Sci. 41: 1575-1591.

Hankin, D. G. and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Can. J. Fish. Aquat. Sci. 45: 834-844.

Harding, T., L. Jaremovic, and G. Kosakoski. 1994. Strategic Review of Fisheries Resources: North Thompson Habitat Management Area. Fraser River Action Plan. Department of Fisheries and Oceans. Vancouver, B. C. January 1994.

Hargreaves, B. and R. J. LeBrasseur. 1986. Size selectivity of coho preying on juvenile chum salmon. Can. J. Fish. Aquat. Sci. 43: 581-586.

Hartman, G. F., B. C. Andersen, and J. C. Scrivener. 1982a. Seaward movement of coho salmon fry in Carnation Creek, an unstable coastal stream in British Columbia. Can. J. Fish. Aquat. Sci. 39: 588-597.

Hartman, G. F., L. B. Holtby, and J. C. Scrivener. 1982b. Some effects of natural and logging-related winter stream temperature changes on the early life history of coho salmon in Carnation Creek, British Columbia. Pages 141-148, In W. R. Meehan, J. T. R. Merrell, and T. A. Hanley, Eds. Fish and Wildlife Relationships in Old Growth Forests, Juneau, Alaska,

Hartman, G. F., J. C. Scrivener, and M. J. Miles. 1996. Impacts of logging in Carnation Creek, a high energy coastal stream in British Columbia, and their implication for restoring fish habitat. Can. J. Fish. Aquat. Sci. 53 (Supp. 1): 237-251.

Healey, M. 1982. Timing and relative intensity of size-selective mortality of juvenile chum salmon during early sea life. Can. J. Fish. Aquat. Sci. 39: 952-957.

Heggenes, J., O. M. W. Krog, O. R. Lindas, J. G. Dokk, and T. Bremnas. 1993. Homeostatic behvioural responses in a changing environment: brown trout become noctural during winter. J. Anim. Ecol. 62: 295-308.

Henderson, M. A. and A. J. Cass. 1991. Effect of smolt size on smolt-to-adult survival for Chilko Lake sockeye salmon. Can. J. Fish. Aquat. Sci. 48: 988-994.

Herbinger, C. M., G. F. Newkirk, and S. T. Lanes. 1990. Individual marking of Atlantic salmon: evalutaion of cold branding and jet injection of Alcian blue in several fin locations. J. Fish Biol. 36: 99-101.

Hilborn, R. and M. Mangel. 1997. The Ecological Detective: Confronting models with data. Princeton University Press, Princeton, NJ. 315.

Hilborn, R. and C. J. Walters. 1992. Quantitative Fisheries Stock Assessment: Choice, dynamics and uncertainty. Chapman and Hall, New York. 570 p.

Holtby, B., T. Hammond, R. Kadowaki, K. Simpson, and B. Finnegan. 1992. Using distributional properties of juvenile forklength to assess stock status of Georgia Strait coho and the productive potential of streams. Pages 374-378, In L. Berg and P. W. Delaney, Eds. Proceedings of the Coho Workshop, Nanaimo, B.C., May 26-28, 1992.

Holtby, L. B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon. Can. J. Fish. Aquat. Sci. 45: 502-515.

Holtby, L. B. 1998. A risk assessment for north coast coho fisheries in 1998, with commentary on risk in southern inside and outside fisheries. Department of Fisheries and Oceans. Vancouver, B. C. May 1998. PSARC Working Paper. S98-12.

Holtby, L. B., B. C. Andersen, and R. K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon. Can. J. Fish. Aquat. Sci. 47: 2181-2194.

Holtby, L. B. and G. F. Hartman. 1982. The population dynamics of coho salmon in a west coast rain forest stream subjected to logging. Pages 308-347, *In* G. F. Hartman, Ed. Carnation Creek Workshop: a ten year review, Nanaimo, B. C., Department of Fisheries and Oceans,

Holtby, L. B., T. E. McMahon, and J. C. Scrivener. 1989. Stream temperatures and inter-annual variability in the emigration timing of coho salmon smolts and fry and chum salmon fry from Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 46: 1396-1405.

Hunt, R. L. 1969. Overwinter survival of wild fingerling brook trout in Lawrence Creek, Wisconsin. J. Fish. Res. Bd. Can. 26: 1473-1483.

Hutton, R., C. Manson, M. Lauder, and P. Fee. 1983. 1982 coho studies, North Thompson River system. Report prepared for the Department of Fisheries and Oceans, Fraser River, Northern B.C. and Yukon Divison. June 1983.

Hynes, H. B. N. 1972. The Ecology of Running Waters. University of Toronto Press, Toronto. 555 p.

Irons, J. G., L. K. Miller, and M. W. Oswood. 1993. Ecological adaptations of aquatic macroinvertebrates to overwintering in interior Alaska subarctic streams. Can. J. Zool. 71: 98-108.

Irvine, J. R. and N. T. Johnston. 1992. Coho salmon use of lakes and streams in the Keogh River drainage, British Columbia. Northwest Science 66: 15-25.

Irvine, J. R. and B. R. Ward. 1989. Patterns of timing and size of wild coho salmon smolts migrating from the Keogh River watershed on northern Vancouver Island. Can. J. Fish. Aquat. Sci. 46: 1086-1094.

Irvine, J. R., K. Wilson, B. Rosenberger, and R. Cook. 1998. Stock assessment of Thompson River/Upper Fraser River coho salmon. Department of Fisheries and Oceans. Vancouver, B. C. May 1998. PSARC Working Paper. S98-13.

Johnston, N. T. and P. A. Slaney. 1996. Fish Habitat Assessment Procedures. Ministry of Environment, Lands and Parks. Vancouver, B. C. April, 1996. Watershed Restoration Technical Circular. Report Number 8.

Jones, R. 1958. Lee's phenomenon of "apparent change is growth rate" with particular reference to cod and plaice. Int. Comm. Northwest Atl. Fish. Spec. Pub. 1: 229-242.

Jonsson, N., B. Jonsson, and L. P. Hansen. 1990. Partial segregation in the timing of migration of Atlantic salmon of different ages. Anim. Behav. 40: 313-321.

Keeley, E. R. 1998. Behavioural and demographic responses to food and space competition by juvenile steelhead trout. PhD, Department of Zoology, University of British Columbia, Vancouver, B.C.

Keeley, E. R. and J. D. McPhail. 1998. Food abundance, intruder pressure and body size as determinants of territory size in juvenile steelhead trout. Behaviour 135: 65-82.

Laufle, J. C., L. Johnson, and C. L. Monk. 1990. Tattoo-ink marking method for batch identification of fish. American Fisheries Society Symposium 7: 38-41.

Lestelle, L. C., G. R. Blair, and S. A. Chitwood. 1993. Approaches to supplementing coho salmon in the Queets River, Washington. Pages 104-119, *In* L. Berg and P. W. Delaney, Eds. Proceedings of the Coho Workshop, Nanaimo, B.C., May 26 -28, 1992.

Lindroth, A. 1965. First winter mortality of Atlantic salmon parr in the hatchery. Can. Fish Cult. 36: 23-26.

Marshall, D. E. and E. W. Britton. 1990. Carrying capacity of coho salmon in streams. Department of Fisheries and Oceans. Vancouver, B. C. March, 1990. Can. Man. Report Fish. Aquat. Sci. 2058.

Martel, G. 1996. Growth rate and influence of predation risk on territoriality in juvenile coho. Can. J. Fish. Aquat. Sci. 53: 660-669.

Mason, J. C. and D. W. Chapman. 1965. Significance of early emergence, environmental rearing capacity and behavioural ecology of juvenile coho salmon in stream channels. J. Fish. Res. Board Can. 22: 173-190.

McMahon, T. E. and G. F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon. Can. J. Fish. Aquat. Sci. 46: 1551-1557.

McMahon, T. E. and L. B. Holtby. 1992. Behaviour, habitat use and movements of coho salmon smolts during seaward migration. Can. J. Fish. Aquat. Sci. 49: 1478-1485.

Meehan, W. R. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Bethesda, MD

Metcalfe, N. B., F. A. Huntingford, and J. E. Thorpe. 1986. Seasonal changes in feeding motiviation of juvenile Atlantic salmon. Can. J. Zool. 64: 2439-2446.

Metcalfe, N. B. and J. E. Thorpe. 1990. Determinants of geographical variation in the age of seaward-migrating salmon, *Salmo salar*. J. Anim. Ecol. 59: 135-145.

Metcalfe, N. B. and J. E. Thorpe. 1992. Anorexia and defended energy levels in over-wintering juvenile salmon. J. Amin. Ecol. 61: 175-181.

Milner, N. J., R. J. Wyatt, and M. D. Scott. 1993. Variability in the distribution and abundance of stream salmonids, and the associated use of habitat models. J. Fish Biol. 43: 103-119.

Murphy, M. L., J. Heifetz, J. F. Thedinga, S. W. Johnson, and K. V. Koski. 1989. Habitat utlization by juvenile Pacific salmon in the glacial Taku River, southeast Alaska. Can. J. Fish. Aquat. Sci. 46: 1677-1685.

Murphy, M. L., J. F. Thedinga, K. V. Koski, and G. B. Grette. 1984. A stream ecosystem in an old-growth forest in southeast Alaska: Seasonal changes in habitat utilization by juvenile salmonids. Pages 89-98, *In* W. R. Meehan, J. T. R. Merrell, and T. A. Hanley, Eds. Fish and Wildlife Relationships in Old Growth Forests, Juneau, Alaska, 1984. Amer. Inst. Fish. Res. Biol.,

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16: 4-20.

Nicieza, A. G. and F. Brana. 1993. Compensatory growth and optimum size in one-year old smolts of Atlantic salmon. Pages 225-237. *In* R. J. Gibson and R. E. Cutting, Eds. Production of juvenile Atlantic salmon in natural waters. Can. Spec. Publ. Fish. Aquat. Sci. 118.

Nickelson, T. E., M. F. Solazzi, and S. L. Johnson. 1986. Use of hatchery coho salmon presmolts to rebuild wild populations in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 43: 2443-2449.

Nickelson, T. E., M. F. Solazzi, S. L. Johnson, and J. D. Rodgers. 1992. Effectiveness of selected stream improvement techniques to creating suitable summer and winter rearing habitat for juvenile coho salmon in oregon coastal streams. Can. J. Fish. Aquat. Sci. 49: 790-794.

Nickleson, T. E., J. D. Rodgers, S. L. Johnson, and M. F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 49: 783-789.

Nielsen, J. L. 1992. Microhabiat specific foraging behaviour, diet and growth of juvenile coho salmon. Trans. Amer. Fish. Soc. 121: 617-634.

Oliver, J. D. and G. F. Holeton. 1979. Overwinter mortality of fingerling smallmouth bass in relation to size, relative energy stores, and environmental temperature. Trans. Amer. Fish. Soc. 108: 130-136.

Parker, R. R. 1971. Size-selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28: 1503-1510.

Peterson, N. P. 1982a. Immigration of juvenile coho salmon into riverine ponds. Can. J. Fish. Aquat. Sci. 39: 1308-1310.

Peterson, N. P. 1982b. Population characteristics of juvenile coho salmon overwintering in riverine ponds. Can. J. Fish. Aquat. Sci. 39: 1303-1307.

Peterson, N. P. and C. J. Cedarholm. 1984. A comparison of the removal and mark-recapture methods of population estimation for juvenile coho salmon in a small stream. N. Amer. J. Fish. Man. 4: 99-102.

Pitcher, T. J. and G. J. A. Kennedy. 1977. The longevity and quality of fin marks made with a jet inoculator. Fish. Mgmt. 8: 16-18.

Post, J. R. and D. O. Evans. 1989a. Experimental evidence of size-dependent predation mortality in juvenile yellow perch. Can. J. Zool. 67: 521-523.

Post, J. R. and D. O. Evans. 1989b. Size-dependent overwinter mortality of young-of-the-year yellow perch: laboratory, in-situ enclosure, and field experiments. Can. J. Fish. Aquat. Sci. 46: 1958-1968.

Post, J. R. and A. B. Prankevicius. 1987. Size-selective mortality in young-of-the-year yellow perch: evidence from otolith microstructure. Can. J. Fish. Aquat. Sci. 44: 1840-1847.

Power, G. 1993. Estimating production, food supplies and comsumption by juvenile Atlantic salmon. Pages 163-174. *In* R. J. Gibson and R. E. Cutting, Eds. Production of juvenile Atlantic salmon in natural waters. Can. Spec. Pub. Fish. Aquat. Sci. 118.

Power, G. and J. Mitchell. 1994. The influence of river ice on birds and mammals. Pages 315-330, *In* T. D. Prowse, Ed. Proceedings of the Workshop on Environmental Aspects of River Ice, Saskatoon, Sask., August 18-20, 1993. National Hydrology Research Institute,

Ptolemy, R. A. 1983. Salmonid biomass assessment and potential carrying capacity of Louis Creek near Barriere, B. C. Fish and Wildlife Branch, Ministry of Environment. Victoria, B. C. OSB81-0065.

Quinn, T. P. and N. P. Peterson. 1996. The influence of habitat complexity and fish size on overwinter survival and growth of individually marked juvenile coho salmon in Big Beef Creek, Washington. Can. J. Fish. Aquat. Sci. 53: 1555-1564.

Reimers, N. 1963. Body condition, water temperature and overwinter survival of hatchery-reared trout in Convict Creek, California. Trans. Amer. Fish. Soc. 92: 39-46.

Reinhardt, U. G. and M. C. Healey. 1997. Size-dependent foraging behaviour and use of cover in juvenile coho salmon under predation risk. Can. J. Zool. 75: 1652-1651.

Reinhardt, U. G. and M. C. Healey. 1999. Season and size-dependent risk taking in juvenile coho salmon: experimental evaluatiion of asset protection. Animal Behaviour 57: 923-933.

Ricker, W. E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Department of the Environment, Fisheries and Marine Service, Ottawa, Canada. 382 p.

Ricker, W. E. 1979. Growth rates and models. Pages 677-743. *In* W. S. Hoar, D. J. Randall, and J. R. Brett, Eds. Fish Physiology. Academic Press Vol. 8, New York.

Riddell, B. E. and W. C. Leggett. 1981. Evidence of an adaptive basis for geographic variation in body morphology and time of downstream migration of juvenile Atlantic salmon. Can. J. Fish. Aquat. Sci. 38: 308-320.

Riley, S. C. and J. Korman. 1995. Juvenile salmonid monitoring in the Cheakamus River: results of a pilot study and recommendations for monitoring design. Unpublished report prepared for B. C. Hydro. Vancouver, B. C. December 1, 1995.

Riley, S. C. and P. J. Lemieux. 1998. The effects of beaver on juvenile coho salmon habitat in Kispiox River tributaries. Unpublished report prepared for the Department of Fisheries and Oceans. Prince Rupert, B. C. March 2, 1998.

Rimmer, D. M., U. Paim, and R. L. Saunders. 1983. Autumnal habitat shift of juvenile Atlantic salmon in a small river. Can. J. Fish. Aquat. Sci. 40: 671-680.

Rimmer, D. M., U. Paim, and R. L. Saunders. 1984. Changes in the selection of microhabitat by juvenile Atlantic salmon at the summer-autumn transition in a small river. Can. J. Fish. Aquat. Sci. 41: 469-475.

Rimmer, D. M., R. L. Saunders, and U. Paim. 1985. Effects of temperature and season on the position holding performance of juvenile Atlantic salmon. Can. J. Zool. 63: 92-96.

Rodgers, J. D., M. F. Solazzi, S. L. Johnson, and M. A. Buckman. 1992. Comparison of three techniques to estimate juvenile coho salmon populations in small streams. N. Amer. J. Fish. Man. 12: 79-86.

Roper, B. B., D. L. Scarnecchia, and T. J. LaMarr. 1997. Summer distribution of and habitat use by chinook salmon and steelhead within a major basin of the South Umpqua River, Oregon. Trans. Am. Fish. Soc. 123: 298-308.

Ruggerone, G. T. and D. E. Rogers. 1992. Predation on sockeye salmon fry by juvenile coho salmon in the Chignik Lakes, Alaska: implications for salmon management. N. Amer. J. Fish. Man. 12: 87-102.

Schill, D. J. and K. F. Beland. 1995. Electrofishing injury studies: a call for population perspective. Fisheries 20: 28-29.

Schlosser, I. J. 1995. Dispersal, boundary processes, and trophic-level interactions in streams adjacent to beaver ponds. Ecology 76: 908-925.

Scott, K. J., M. A. Wheln, L. B. MacDonald, J. D. Morgan, and W. R. Olmsted. 1982. 1981 Biophysical studies of selected chinook and coho salmon producing tributaries of the North Thompson drainage. Part 1: Juvenile salmon investigatons. Fisheries and Oceans, Fisheries Operations. North Vancouver, B.C. March 1982. DSS Contract No. 05SB.FP501-0-1810.

Shuter, B. J., J. A. MacLean, F. E. Fry, and H. A. Regier. 1980. Stochastic simulation of temperature effects on first year survival of smallmouth bass. Trans. Amer. Fish. Soc. 109: 1-34.

Shuter, B. J. and J. R. Post. 1990. Climate, population viability and the zoogeography of temperate fishes. Trans. Amer. Fish. Soc. 119: 314-336.

Sigma, E. L. 1991. Assessment of resource users in the North Thompson Habitat Management Area. Report prepared for the Department of Fisheries and Oceans.

Simpson, K., R. Diewert, R. Kadowaki, C. Cross, and S. Lehmann. 1997. A 1996 update of assessment information for Strait of Georgia coho salmon stocks. Department of Fisheries and Oceans. Nanaimo, B. C. April, 1997. PSARC Working Paper. S97-*.

Slaney, T. L., K. D. Hyatt, T. G. Northcote, and R. J. Fielden. 1996. Status of anadromous salmon and trout in British Columbia and Yukon. Fisheries 21: 20-35.

Small, M. P., T. D. Beacham, R. E. Withler, and R. J. Nelson. 1998a. Discriminating coho salmon populations within the Fraser River, British Columbia, using microsatellite DNA markers. Molecular Ecology 7: 141-155.

Small, M. P., R. E. Withler, and T. D. Beacham. 1998b. Population structure and stock identification of British Columbia coho salmon based on microsatellite DNA variation. Fish. Bull. 96: 843-858.

Smith, R. W. and J. S. Griffith. 1994. Survival of rainbow trout during their first winter in the Henry's Fork of the Snake River, Idaho. Trans. Amer. Fish. Soc. 123: 747-756.

Stewart, G. O., R. B. Lauzier, and P. R. Murray. 1983. Juvenile salmonid studies in the North Thompson region of B. C., 1982. Envirocon Limited. Vancouver, B.C. February, 1983. 045B FP 576-1-0487.

Stewart, R. W. J. and P. L. Matthew. 1984. Juvenile salmonid studies in selected streams of the North Thompson drainage and a preliminary review of the Bridge River near Lillooet. Report prepared for the CED Program, SEP Operations. Kamloops, B. C. June 1984. DSS Contract No. 085 B.F.P 576-3-0256.

Swales, S., R. B. Lauzier, and C. D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Can. J. Zool. 64: 1506-1514.

Swales, S. and C. D. Levings. 1989. Role of off-channel ponds in the life cycle of coho salmon and other juvenile salmonids in the Coldwater River, British Columbia. Can. J. Fish. Aquat. Sci. 46: 232-242.

Systat. 1997. Systat 7.0 Statistics. SPSS Inc., Chicago, IL, U.S.A.

Taylor, E. B. and J. D. McPhail. 1985. Burst swimming and size-related predation of newly emerged coho salmon. Trans. Amer. Fish. Soc. 114: 546-551.

Taylor, L. R., I. P. Woiwod, and J. N. Perry. 1978. The density-dependence of spatial behaviour and the rarity of randomness. J. Anim. Ecol. 47: 383-406.

Thedinga, J. F. and S. W. Johnson. 1995. Retention of jet-injected marks on juvenile coho and sockeye salmon. Trans. Amer. Fish. Soc. 124: 782-785.

Thedinga, J. F. and K. V. Koski. 1984. A stream ecosystem in an old-growth forest in southeast Alaska. Part VI. The production of coho salmon smolts and adults from Procupine Creek. Pages 99-108, In W. R. Meehan, T. R. Merrell, and T. A. Haney, Eds. Fish and Wildlife Relationships in Old Growth Forests: Proceedings of a Symposium, Juneau, Alaska, April 12-15, 1982. American Institute for Fishery Research Biologists,

Thedinga, J. F., M. L. Murphy, J. Heifetz, K. V. Koski, and S. W. Johnson. 1989. Effects of logging on size and age composition of juvenile coho salmon and density of presmolts in southeast Alaska streams. Can. J. Fish. Aquat. Sci. 46: 1383-1391.

Thompson, J. M., E. P. Bergersen, C. A. Carlson, and L. R. Kaeding. 1991. Role of size, condition and lipid content in the overwinter survival of age-0 Colorado squawfish. Trans. Amer. Fish. Soc. 120: 346-353.

Thompson, K. G., E. P. Bergersen, R. B. Nehring, and D. C. Bowden. 1997. Long-term effects of electrofishing on growth and body condition of brown and rainbow trout. N. Amer. J. Fish. Man. 17: 154-159.

Thorpe, J. E. 1987. Environmental regulation of growth patterns in juvenile Atlantic salmon. *In* R. E. Summerfelt and G. E. Hall, Eds. The Age and Growth of Fish. Iowa State University Press, Armes, Iowa.

Toneys, M. L. 1977. Mortality, osmoregulation, and fat depletion of young of the year of some species of freshwater fish in winter conditions. Masters Thesis, University of Wisconsin, Steven's Point, Wisconsin, USA.

Toneys, M. L. and D. W. Coble. 1979. Size-related, first winter mortality of freshwater fishes. Trans. Amer. Fish. Soc. 108: 415-419.

Toneys, M. L. and D. W. Coble. 1980. Mortality, hematocrit, osmolality, electrolyte regulation and fat depletion of young of the year freshwater fishes under simulated winter conditions. Can. J. Fish. Aquat. Sci. 37: 225-232.

Trexler, J. C. and J. Travis. 1993. Nontraditional regression analyses. Ecology 74: 1629-1637.

Tschaplinski, P. J. and G. F. Hartman. 1982. Winter distribution of juvenile coho salmon in Carnation Creek and some implications to overwinter survival. Pages 273-288, *In* G. F. Hartman, Ed. Carnation Creek Workshop: a ten year review, Nanaimo, B. C., Department of Fisheries and Oceans,

Tschaplinski, P. J. and G. F. Hartman. 1983. Winter distribution of juvenile coho salmon before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. Can. J. Fish. Aquat. Sci. 40: 452-461.

Walters, C. J. 1995. Fish on the line: the future of Pacific fisheries. Report prepared for the David Suzuki Foundation. Vancouver, B. C.

Walters, C. J. and P. Cahoon. 1985. Evidence of decreasing spatial diversity in British Columbia salmon stocks. Can. J. Fish. Aquat. Sci. 42: 1033-1037.

Walters, C. J. and F. Juanes. 1993. Recruitment limitation as a consequence of natural selection for use of restricted feeding habitats and predation risk taking by juvenile fishes. Can. J. Fish. Aquat. Sci. 50: 2058-2070.

Ward, B. R. and P. Slaney. 1988. Life history and smolt to adult surivival of Keogh River steelhead tout and the relationship to smolt size. Can. J. Fish. Aquat. Sci. 45: 1110-1122.

Ward, B. R., P. A. Slaney, A. R. Facchin, and R. W. Land. 1989. Size-biased survival in steelhead trout: back calculated lengths from adult's scales compared to migrating smolts at the Keogh River, British Columbia. Can. J. Fish. Aquat. Sci. 46: 1853-1858.

Washington, P. M. 1981. The influence of the size of juvenile coho salmon on seaward migration and survival. Pages 146-151, *In* E. L. Brannon and E. O. Salo, Eds. Salmon and trout migratory behaviour symposium.,

Weatherly, A. H. and H. S. Gill. 1987. The Biology of Fish Growth. Academic Press, London

Webb, P. W. 1978. Temperature effects on acceleration of rainbow trout. J. Fish. Res. Board Can. 35: 1417-1422.

West, C. J. and P. A. Larkin. 1987. Evidence of size-selective mortality of juvenile sockeye salmon in Babine Lake, British Columbia. Can. J. Fish. Aquat. Sci. 44: 712-721.

Whelen, M. A. and D. B. Lister. 1985. CN Twin track project environmental design program. Juvenile salmonid rearing studies, North Thompson River 1984. Report prepared for CN Rail. Clearbrook, B.C. April 1985.

Wood, C. C. 1998. Defining assessment units for the conservation of wild coho salmon in the Pacific region. Discussion paper prepared for the Department of Fisheries and Oceans. Nanaimo, B. C. June 19, 1998.

Wood, C. C. and L. B. Holtby. 1998. Defining conservation units for Pacific salmon using genetic survey data. Action before Extinction, Vancouver, B. C., 16-18 February, 1998. World Fisheries Trust International,

Zar, J. H. 1984. Biostatistical Analysis. Prentice Hall, New Jersey, USA. 718 p.

APPENDICES

Appendix 1a: Fall mark-recapture population estimates at each sample site for Lemieux and Mann and Mann creeks, 1996.

LEMIEUX CREEK 1996; Fall

Sept 28 - Oct 4; 18-20 October

SITE	Site No.	Habitat Type[1]	Dist.[2]	M	C	R	P	Estimate	SE	95% CL	%	Length m	Width m	Area m²	Density #/m	Density #/m²	Coho size FL (mm)	CL	Wt (g)	CL
Spencely	1	OC	1653	334	315	22	0.07	4603	904.67	1773.15	0.39	205.9	15.1	3521.1	22.35	1.31	65.2	1.0	3.0	1.0
Ianson	6	OC	8191	1246	1203	403	0.33	3716	150.53	295.03	0.08	389.0	5.6	1798.8	9.55	2.07	67.2	1.0	3.0	1.0
Burton	2	MS	3042	286	209	63	0.30	942	97.39	190.89	0.20	59.9	6.0	303.0	15.72	3.11	65.3	1.0	2.8	1.0
Cartwright	3	MS	4578	353	222	83	0.37	940	80.48	157.74	0.17	54.9	7.5	407.1	17.12	2.31	62.3	1.0	2.5	1.0
Cochrane	4	MS	6472	344	122	32	0.26	1286	188.64	369.74	0.29	133.4	9.5	1225.2	9.64	1.05	64.1	1.0	2.8	1.0
Fowler	5	MS	7642	419	202	74	0.37	1137	103.55	202.95	0.18	320.9	5.9	1692.4	3.54	0.67	63.3	1.0	2.8	1.0
TOTAL				2982	2273	677	0.30	12623			0.22	194.0	8.3	1491.3	12.99	1.75	65.3	1.0	2.9	1.0
Mainstem				1402	755	252	0.33	4304				142.3	7.2	906.9	11.51	1.78	63.7	1.0	2.7	1.0
Off-channel				1580	1518	425	0.20	8319				297.5	10.4	2660.0	15.95	1.69	66.7	1.0	3.0	1.0

MANN CREEK 1996; Fall

7-12; 15-17 October

SITE	Site No.	Habitat Type[1]	Dist.[2]	M	C	R	P	Estimate	SE	95% CL	%	Length m	Width m	Area m²	Density #/m	Density #/m²	Coho size FL (mm)	CL	Wt (g)	CL
Lower s/ch	1	OC	585	101	113	3	0.03	2907	1277.04	2503.00	0.86	120.0	10.5	1263.6	24.23	2.30	58.3	1.0	1.9	1.1
Beaver Pond	4	OC	957	1367	886	195	0.22	6191	389.31	763.05	0.12	140.1	10.5	1365.6	44.19	4.53	62.3	1.0	2.5	1.0
Upper s/ch	5	OC	1086	305	92	75	0.82	374	18.24	35.76	0.10	68.8	3.5	240.8	5.44	1.56	65.1	1.0	2.9	1.0
Mainstem	2	MS	585	907	389	72	0.19	4851	508.40	996.47	0.21	164.8	13.5	2341.1	29.44	2.07	57.6	1.0	1.9	1.0
Reach 3	3	MS	801	478	238	51	0.21	2202	267.49	524.29	0.24	142.7	6.5	676.5	15.43	3.25	59.9	1.0	2.2	1.0
TOTAL				3158	1718	396	0.23	13678			0.30	127.3	8.9	1177.5	23.74	2.74	60.7	1.0	2.3	1.0
Mainstem				1385	627	123	0.20	7053				153.8	10.0	1508.8	22.43	2.66	58.4	1.0	2.0	1.0
Off-channel				1773	1091	273	0.35	9472				109.6	8.2	956.7	24.62	2.80	62.5	1.0	2.5	1.0

[1] MS = Mainstem sites; OC = Off-channel sites.

[2] Dist. = Distance upstream from mouth

Coho sizes for young-of-the-year only

Appendix 1b: Post-winter mark-recapture population estimates at each sample site for Lemieux and Mann creeks, 1996.

LEMIEUX CREEK 1996, Spring
March 28 - April 9, 1997

| | Site | Hab. | | | | | | sum | | | | | Length | Width | Area | Density | | Coho size FL | | Wt. | |
SITE	No.	Type¹	Dist.²	M	C	R	P	CM³	Est.	SE	95% CL	%	m	m	m²	#/m	#/m²	(mm)	CL	(g)	CL
Spencely	1	OC	1653	277	61	15	0.25	16897	1077	225.05	441.09	0.41	205.9	15.1	3521.1	5.23	0.31	73.9	1.0	3.7	1.0
Ianson	6	OC	8191	457	207	80	0.39	94599	1176	101.49	198.91	0.17	389.0	5.6	1798.8	3.02	0.65	71.3	1.0	3.5	1.0
Burton	2	MS	3042	98	46	5	0.11	1486	248	87.43	171.36	0.69	59.9	6.0	303.0	4.13	0.82	71.4	1.0	3.6	1.1
Cartwright	3	MS	4578	143	134	17	0.13	6483	360	76.92	150.77	0.42	54.9	7.5	407.1	6.56	0.88	66.6	1.0	2.9	1.1
Cochrane	4	MS	6472	101	60	6	0.10	2037	291	96.80	189.73	0.65	133.4	9.5	1225.2	2.18	0.24	69.6	1.0	3.4	1.1
Fowler	5	MS	7642	165	109	27	0.25	17985	652	104.56	204.93	0.31	320.9	5.9	1692.4	2.03	0.39	68.7	1.0	3.1	1.1
TOTAL				1241	617	150	0.24		3804			0.44	194.0	8.3	1491.3	3.86	0.55	70.4	1.0	3.4	1.0
Mainstem				507	349	55	0.15		1551				142.3	7.2	906.9	3.73	0.58	68.8	1.0	3.2	1.0
Off-channel				734	268	95	0.32		2253				297.5	10.4	2660.0	4.13	0.48	72.1	1.0	3.6	1.0

MANN CREEK 1996; Spring
2-9 April, 1997

| | Site | Hab. | | | | | | sum | | | | | Length | Width | Area | Density | | Coho size FL | | Wt. | |
SITE	No.	Type¹	Dist.²	M	C	R	P	CM³	Est.	SE	95% CL	%	m	m	m²	#/m	#/m²	(mm)	CL	(g)	CL
Lower s/ch	1	OC	585	145	165	13	0.08	23925	1731	427.72	838.32	0.48	120.0	10.5	1263.6	14.43	1.37	61.4	1.0	2.2	1.1
Beaver Pond	4	OC	957	305	186	16	0.09	27456	1615	362.96	711.40	0.44	140.1	10.5	1365.6	11.53	1.18	64.0	1.0	2.6	1.1
Upper s/ch	5	OC	1086	36	35	7	0.20	1260	167	48.95	95.93	0.58	197.9	3.3	567.9	0.84	0.29	71.8	1.0	3.6	1.1
Mainstem	2	MS	585	131	137	6	0.04	17947	2602	896.41	1756.96	0.68	164.8	13.5	2341.1	15.79	1.11	60.1	1.0	2.1	1.1
R3	3	MS	801	25	26	1	0.04	650	351	195.00	382.20	1.09	142.7	6.5	676.5	2.46	0.52	64.7	1.1	2.6	1.2
TOTAL				642	549	43	0.08		6466			0.65	153.1	8.9	1242.9	9.01	0.90	63.1	1.0	2.4	1.0
Mainstem				156	163	7	0.04		2953				153.8	10.0	1508.8	9.13	0.82	60.8	1.0	2.2	1.1
Off-channel				486	386	36	0.12		3513				152.7	8.1	1065.7	8.93	0.95	64.1	1.0	2.6	1.0

¹ MS = Mainstem sites; OC = Off-channel sites.

² Dist. = Distance upstream from mouth

³ Number captured*number marked, see Ch. 1 Methods

Shaded areas indicate Schnabel estimate; other estimates are Petersen type.

Coho sizes for young-of-the-year only

Appendix 2a: Fall mark-recapture population estimates at each sample site for Lemieux and Mann creeks, 1997.

LEMIEUX CREEK 1997; Fall
Aug 30 - Sep 8

	Hab.					Final							95%		Length	Width	Area	Density		Coho size			
SITE	Type	Reach	Cov.¹	Dist.²	M	M	sum CM³	C	R	P	Est.	SE	CL	%	m	m	m²	#/m	#/m²	FL (mm)	CL	Wt (g)	CL
P25	P	1	LC	1239	0	0	n/a				1	0.00	0.00	0.00	17.3	14.2	136.0	0.06	0.01	72.0	-	4.0	-
P37	P	1	C	1408	92	135	n/a	61	18	0.30	303	56.51	110.76	0.36	12.0	5.7	61.6	25.29	4.92	66.3	1.0	3.0	1.1
P127	P	2	C	6530	27	29	n/a	2	0	0.00	84	48.50	95.05	1.13	14.1	13.2	183.4	5.96	0.46	66.4	1.1	3.1	1.2
P139	P	2	C	6764	102	127	n/a	30	5	0.17	532	180.63	354.03	0.67	21.3	13.3	286.8	24.98	1.86	66.5	1.0	3.1	1.1
P174	P	2	C	7708	43	68	n/a	32	7	0.22	182	52.66	103.21	0.57	16.8	11.6	196.4	10.84	0.92	64.9	1.0	3.0	1.1
P190	P	3	C	8547	36	82	n/a	54	8	0.15	226	65.39	128.17	0.57	19.5	9.0	233.1	11.60	0.97	63.0	1.0	2.8	1.1
P233	P	3	C	9596	9	18	n/a	9	0	0.00	100	67.08	131.48	1.31	14.6	10.8	150.4	6.85	0.66	73.2	1.2	4.2	1.7
P300	P	3	C	9923	3	3	n/a				4	0.00	0.00	0.00	15.8	8.9	148.1	0.25	0.03				
P296	P	3	C	10091	1	1	n/a				2	0.00	0.00	0.00	21.0	7.7	172.0	0.10	0.01				
SC3	OC	1	n/a	1274	143	243	n/a	125	25	0.20	698	119.64	234.50	0.34	340.7	5.9	1122.7	2.05	0.62	63.5	1.0	3.1	1.1
SC7	OC	1	n/a	1700	93	126	n/a	67	34	0.51	183	21.20	41.56	0.23	78.0	8.0	479.4	2.34	0.38	68.9	1.0	3.8	1.1
SC11	OC	2	n/a	4205	3	3	n/a				4	0.00	0.00	0.00	76.0	2.8	274.6	0.05	0.01	70.2	1.2	4.0	1.7
SC36	OC	3	n/a	9696	0	0	n/a				1	0.00	0.00	0.00	43.6	4.8	211.5	0.02	0.00	60.5	1.2	2.6	1.5
SC99	OC	2	n/a	8191	926	1256	n/a	498	168	0.34	2737	170.72	334.60	0.12	347.0	6.4	2166.1	7.89	1.26	59.5	1.0	2.4	1.1
RU27	RU	1	NC	1276	0	0									36.7	9.6	322.2	0.00	0.00				
RU33	RU	1	C	1540	2	2									12.0	8.8	100.1	0.00	0.00	68.0	-	3.5	-
RU35	RU	1	NC	1821	0	0									57.5	13.6	693.8	0.00	0.00				
RU49	RU	1	C	2548	0	0									60.0	12.5	771.8	0.00	0.00				
RU52	RU	1	NC	2749	0	0									15.4	9.1	150.4	0.00	0.00				
RU97	RU	2	NC	5465	2	2									46.9	12.0	582.9	0.00	0.00	58.8	2.9	2.3	22.5
RU105	RU	2	C	5837	7	7									31.0	7.7	226.0	0.00	0.00				
RU107	RU	2	C	5951	0	0									30.9	8.9	245.4	0.00	0.00				
RU181	RU	2	C	8191	4	4									22.0	6.9	146.8	0.00	0.00				
RU183	RU	3	NC	8231	0	0									22.8	6.2	135.3	0.00	0.00				
RU191	RU	3	NC	8579	2	2									32.7	6.8	176.2	0.00	0.00				
RU231	RU	3	NC	9564	0	0									19.5	6.9	140.5	0.00	0.00				
RU235	RU	3	C	9645	1	1									20.6	11.2	226.5	0.00	0.00				
RU241	RU	3	NC	9851	0	0									33.0	8.9	294.8	0.00	0.00				
RI32	RI	1	NC	1530	0										13.0	7.0	91.0	0.00	0.00				
RI98	RI	2	NC	5477	0	0									12.0	9.0	108.0	0.00	0.00				
RI242	RI	3	NC	9871	0										20.0	7.5	150.0	0.00	0.00				
TOTAL					1496	2109		878	265		5057				49.1	8.9	335.0	3.17	0.39	63.6	1.0	2.9	1.0

unmarked C1 fish from SC7,P37,P127,P139,P174,P190,P233 were not marked before release.

MANN CREEK 1997; Fall

Aug 30 - Sep 8

SITE	Hab. Type	Reach	Cov.[1]	Dist.[2]	M	Final M	sum CM[3]	C	R	P	Est.	SE	95% CL	%	Length m	Width m	Area m[2]	Density #/m	Density #/m^{2}	Coho size FL (mm)	CL	Wt. (g)	CL
P2	P	1	C	365	208	316	28496	137	29	0.21	961	152.76	299.40	0.31	26.0	19.0	496.0	37.05	1.94	65.5	1.0	3.1	1.1
P10	P	1	C	1004	386	386	80750	314	29	0.09	2692	459.84	901.29	0.33	21.0	11.1	256.0	128.17	10.51	67.8	1.0	3.4	1.1
P28	P	1	C	893	123	123	8415	85	31	0.36	263	36.27	71.10	0.27	17.0	4.6	73.6	15.47	3.57	61.6	1.0	2.4	1.1
P15	P	1	LC	1505	48	65	1344	28	11	0.39	118	25.15	49.29	0.42	54.0	4.6	228.0	2.19	0.52	63.9	1.0	2.9	1.1
P17	P	1	LC	1116	86	86	4464	62	20	0.32	213	37.00	72.53	0.34	17.0	6.8	118.8	12.50	1.79	66.2	1.0	3.2	1.1
P3	P	1	NC	435	78	78	3272	103	16	0.16	192	41.49	81.33	0.42	53.6	18.8	1046.8	3.59	0.18	60.4	1.0	2.4	1.1
SC1	OC	1	LC	553	30	30	339	26	2	0.08	113	53.27	104.41	0.92	129.4	12.7	1736.7	0.87	0.07	60.4	1.0	2.4	1.2
SC9	OC	1	LC	1331	41	41	1932	84	16	0.19	114	23.96	46.96	0.41	68.5	8.5	555.7	1.66	0.20	66.7	1.0	3.2	1.1
SC12	OC	2	LC	2182	1	1									28.0	5.3	151.5	0.00	0.00				
RU5	RU	1	NC	553	24	24									53.2	16.5	919.6	0.00	0.00	61.0	1.1	2.4	1.3
RU16	RU	1	LC	1101	1	1									13.5	5.0	67.5	0.00	0.00	68.0	1.0	3.6	1.0
RU20	RU	1	LC	1183	0	0									18.8	9.6	183.4	0.00	0.00				
RU24	RU	1	LC	1300	3	3									27.0	12.0	336.1	0.00	0.00	55.5	1.5	1.9	3.2
RU30	RU	1	NC	929	0	0									23.0	8.4	190.5	0.00	0.00				
RU37	RU	1	NC	2701	0	0									14.5	10.6	153.0	0.00	0.00				
RU45	RU	2	NC	1959	0	0									28.0	12.7	351.0	0.00	0.00				
RU47	RU	2	NC	1862	0	0									26.5	10.8	288.0	0.00	0.00				
RU53	RU	2	NC	1716	5	5									47.0	11.7	502.8	0.00	0.00	73.0	1.0	4.4	1.2
RI46	RI	2	NC	1941	1	1									79.0	11.5	908.5	0.00	0.00				
RI16	RI	1	NC	1101	0	0									18.0	6.0	108.0	0.00	0.00				
TOTAL					1035	1160		839	154		4666				38.1	10.3	433.6	10.08	0.94	63.7	1.0	2.8	1.0

Shaded areas indicate Schnabel estimate.
Other estimates are Petersen type.
C1 fish from P28, SC9, P17, P10, P3 were not released until after C2
Coho sizes for young-of-the-year only

[1] NC = no cover; LC = lateral cover; C = cover; see methods for definitions.
[2] Dist. = Distance upstream from mouth
[3] Number captured*number marked, see Ch. 1 Methods

Appendix 2b: Post-winter mark-recapture population estimates at each sample site for Lemieux and Mann creeks, 1997.

LEMIEUX CREEK 1997; Spring — March 14 - 25

SITE	Hab. Type	Reach	Cov.[1]	Dist.[2]	M	CM[3] sum	C	R	P	Est.	SE	95%CL	%	Length m	Width m	Area m[2]	Density #/m	Density #/m^{2}	Coho size FL (mm)	CL	Wt. (g)	CL
P25	P	1	C	1239	13	n/a	9	2	0.22	47	19.52	38.26	0.82	19.0	8.0	152.6	2.46	0.31	80.9	1.0	5.4	1.1
P37	P	1	C	1408	42	n/a	14	10	0.71	59	8.74	17.13	0.29	10.4	4.5	46.8	5.64	1.25	73.6	1.0	4.1	1.1
P127	P	2	C	6530	14	n/a	12	7	0.58	24	5.04	9.88	0.41	15.1	4.9	74.3	1.61	0.33	75.0	1.0	4.4	1.1
P139	P	2	C	6764	38	n/a	30	13	0.43	86	16.51	32.36	0.37	17.8	12.9	229.6	4.85	0.38	76.1	1.0	4.5	1.1
P165	P	2	C	7522	33	n/a	26	5	0.19	153	51.00	99.96	0.65	15.2	4.4	66.9	10.07	2.29	78.6	1.0	4.9	1.1
P174	P	2	C	7708	21	n/a	26	6	0.23	85	25.82	50.61	0.60	15.1	4.6	69.5	5.62	1.22	73.9	1.0	4.1	1.1
P179	P	2	C	8016	9	n/a	8	1	0.13	45	22.91	44.91	1.00	10.0	5.8	58.0	4.50	0.78	75.9	1.1	4.5	1.2
P190	P	3	C	8547	24	n/a	23	8	0.35	67	16.67	32.67	0.49	23.0	6.5	147.3	2.90	0.45	76.7	1.0	4.6	1.1
P233	P	3	C	9596	9	n/a	5	2	0.40	20	7.07	13.86	0.69	13.7	10.9	149.3	1.46	0.13	83.2	1.0	5.7	1.2
P300	P	3	C	9923	1	n/a	1			4		0.00	0.00	13.6	9.9	134.6	0.29	0.03				
P296	P	3	C	10091	0	n/a	0			1		0.00	0.00	13.5	5.9	79.7	0.07	0.01				
SC3	OC	1	n/a	1274	66	n/a	39	21	0.54	122	17.04	33.40	0.27	165.5	4.7	793.4	0.74	0.15	80.2	1.0	5.1	1.1
SC33	OC	1	n/a	1274	16	n/a	11	4	0.36	41	12.72	24.93	0.61	254.4	3.1	916.9	0.16	0.04	77.8	1.0	4.7	1.1
SC7	OC	1	n/a	1700	29	n/a	18	10	0.56	52	9.71	19.02	0.37	64.0	3.6	232.1	0.81	0.22	78.5	1.0	4.8	1.1
SC11	OC	2	n/a	4205	34	n/a	33	15	0.45	74	13.13	25.73	0.35	112.1	2.3	288.9	0.66	0.26	76.8	1.0	4.5	1.1
SC12	OC	2	n/a	4400	5	n/a	11	1	0.09	36	18.97	37.19	1.03	95.3	5.7	538.5	0.38	0.07	80.1	1.0	5.2	1.1
SC26	OC	2	n/a	6997	0	n/a	0					0.00	0.00	2.0	32.0	64.0	0.00	0.00				
SC30	OC	2	n/a	8007	33	n/a	24	10	0.42	77	16.69	32.72	0.42	44.7	3.6	162.0	1.73	0.48	74.0	1.0	4.0	1.1
SC36	OC	3	n/a	9696	0	n/a	0			1		0.00	0.00	44.0	11.2	984.7	0.02	0.00				
SC99	OC	2	n/a	8191	842	n/a	607	349	0.57	1464	50.92	99.80	0.07	347.0	6.4	2166.1	4.22	0.68	72.2	1.0	3.6	1.0
RU27	RU	1	NC	1276										38.2	10.2	388.4	0.00	0.00				
RU33	RU	1	C	1540										9.4	8.3	77.6	0.00	0.00	84.9	1.6	6.0	3.9
RU35	RU	1	NC	1821										37.6	12.3	463.7	0.00	0.00				
RU49	RU	1	C	2548										60.0	12.5	771.8	0.00	0.00				
RU52	RU	1	NC	2749										15.4	9.1	150.4	0.00	0.00				
RU97	RU	2	NC	5465										66.2	9.5	631.1	0.00	0.00				
RU105	RU	2	C	5837										31.0	7.7	226.0	0.00	0.00	84.0	-	5.8	-
RU107	RU	2	C	5951										30.9	8.9	245.4	0.00	0.00				
RU181	RU	2	C	8191										22.6	9.0	204.2	0.00	0.00	75.3	1.1	4.2	1.4
RU183	RU	3	NC	8231										14.5	4.4	63.3	0.00	0.00				
RU191	RU	3	NC	8579										33.2	5.4	178.2	0.00	0.00	74.0	-	4.0	-
RU231	RU	3	NC	9564										19.5	6.9	140.5	0.00	0.00				
RU235	RU	3	C	9645										20.6	11.2	226.5	0.00	0.00				
RU241	RU	3	NC	9851										33.0	8.9	294.8	0.00	0.00				
RI32	RI	1	NC	1530										13.0	7.0	91.0	0.00	0.00				
RI98	RI	2	NC	5477										12.0	9.0	108.0	0.00	0.00				
RI242	RI	3	NC	9871										20.0	7.5	150.0	0.00	0.00				
TOTAL					1229		897	464	0.39	2458				47.9	8.1	318.0	1.30	0.25	73.9	1.0	3.9	1.0

MANN CREEK 1997; Spring
March 14 - 25

SITE	Hab. Type	Reach	Cov.[1]	Dist.[2]	M	sum CM[3]	C	R	P	Est.	SE	95% CL	%	Length m	Width m	Area m[2]	Density #/m	Density #/m^{2}	Coho size FL (mm)	CL	Wt. (g)	CL
P2	P	1	C	365	21	81	6	1	0.17	41	19.76	38.73	0.96	24.9	18.1	394.9	1.63	0.10	69.9	1.1	3.5	1.2
P10	P	1	C	1004	170	32980	194	36	0.19	901	0.00	257.93	0.29	19.2	8.3	159.9	46.94	5.63	77.9	1.0	4.4	1.0
P28	P	.1	C	893	4	36	9	2	0.22	17	6.97	13.67	0.82	14.4	4.4	63.8	1.16	0.26	69.7	1.1	3.4	1.2
P3	P	1	NC	435	0	0	0	0	0.00	0	0.00	0.00	0.00	28.8	10.8	636.5	0.00	0.00				
P9	P	1	LC	966	21	672	32	1	0.03	363	0.00	398.13	1.10	28.4	7.4	209.3	12.78	1.73	74.6	1.0	3.8	1.1
P15	P	1	LC	1505	5	30	6	3	0.50	11	3.07	6.03	0.57	39.7	2.5	122.9	0.26	0.09	74.9	1.1	4.4	1.3
P17	P	1	LC	1116	52	899	35	8	0.23	100	27.36	53.62	0.54	21.8	5.2	114.1	4.58	0.88	75.5	1.0	4.2	1.1
SC1	OC		LC	553	0	0	0	0	0.00	0	0.00	0.00	0.00	129.4	12.7	1736.7	0.00	0.00				
SC77	OC	1	LC	1331	6	96	16	4	0.25	24	8.16	16.00	0.67	106.0	4.5	474.0	0.22	0.05	75.6	1.0	4.4	1.2
SC9	OC	1	LC	1331	7	31	9	2	0.22	10	4.32	8.47	0.82	80.0	6.0	481.6	0.13	0.02	79.8	1.1	5.1	1.3
SC12	OC	2	LC	2182		0	0	0						28.0	5.3	151.5	0.00	0.00	89.0	1.0	9.2	1.0
RU5	RU	1	NC	553		0	0	0						51.0	13.5	688.5	0.00	0.00	72.8	1.2	3.8	1.7
RU16	RU	1	LC	1101		0	0	0						24.0	5.1	123.2	0.00	0.00				
RU20	RU	1	LC	1183		0	0	0						18.8	3.9	79.6	0.00	0.00				
RU24	RU	1	LC	1300		0	0	0						15.0	8.0	120.0	0.00	0.00				
RU30	RU	1	NC	929		0	0	0						23.0	7.4	171.0	0.00	0.00				
RU37	RU	1	NC	2701		0	0	0						14.5	10.6	153.0	0.00	0.00				
RU45	RU	2	NC	1959		0	0	0						25.0	9.6	240.0	0.00	0.00				
RU47	RU	2	NC	1862		0	0	0						22.0	9.7	212.3	0.00	0.00				
RU53	RU	2	NC	1716		0	0	0						49.4	13.0	642.2	0.00	0.00				
RI46	RI	2	NC	1941		0	0	0						49.4	13.0	642.2	0.00	0.00				
RI16	RI	1	NC	1101		0	0	0						18.0	6.0	108.0	0.00	0.00				
TOTAL					286		307	57	0.18	1466				37.8	8.4	351.1	3.08	0.40	76.3	1.0	4.2	1.0

Shaded areas indicate Schnabel estimate.
Other estimates are Petersen type.
Coho sizes for young-of-the-year only

[1] NC = no cover; LC = lateral cover; C = cover; see methods for definitions.

[2] Dist. = Distance upstream from mouth

[3] Number captured*number marked, see Ch. 1 Methods

Appendix 3a: Fall effort, coded wire tag, and non-coho capture summary for Lemieux and Mann creeks, 1996.

SITE	Site No.	Hab. Type	Initial sampling Traps	Initial sampling Date	Pop. sampling #Traps	Pop. sampling Date	Coho Tagged	QCD[1] Loss	QCD[1] %	Post-Tag Morts	Post-Tag %	Released Coho	Released CWT	Coho from other sites 1	2	3	4	5	6	Other[2] CN	RB	SC
LEMIEUX CREEK 1996; Fall																						
Spencely	1	OC	184	28-Sep	160	18-Oct	353	3	0.8	19	5.4	334	331		1	1	1	1		0	0	0
Ianson	6	OC	166	7-Oct	155	20-Oct	1256	0	0.0	10	0.8	1246	1246					1		1	93	33
Burton	2	MS	62	1-Oct	62	18-Oct	286	9	3.1	0	0.0	286	277							1	1	0
Cartwright	3	MS	75	1-Oct	80	19-Oct	353	29	8.2	0	0.0	353	324						1	97	47	7
Cochrane	4	MS	85	3-Oct	85	20-Oct	345	1	0.3	1	0.3	344	343			1				22	56	9
Fowler	5	MS	90	3-Oct	86	19-Oct	422	1	0.2	3	0.7	419	418			4			1	48	68	2
TOTAL			662		628		3015	43	1.4	33	1.1	2982	2939	0	1	6	1	2	2	169	265	51
MANN CREEK 1996; Fall																						
Lower s/ch	1	OC	76	9-Oct	72	16-Oct	103	0	0.0	2	1.9	101	101		11	1				0	0	9
Beaver Pond	4	OC	157	11-Oct	134	16-Oct	1373	44	3.2	6	0.4	1367	1323		4					10	1	6
Upper s/ch	5	OC	49	12-Oct	50	15-Oct	305	0	0.0	0	0.0	305	305							0	0	4
Mainstem	2	MS	110	10-Oct	110	17-Oct	908	31	3.4	1	0.1	907	876	3	1					37	5	9
R3	3	MS	50	9-Oct	45	17-Oct	481	2	0.4	3	0.6	478	476							4	2	2
TOTAL			442		411		3170	77	2.4	12	0.4	3158	3081	3	16	1	0	0	0	51	8	30

[1] QCD = Quality Control Device to assess cwt loss rates.

[2] CN = Chinook; RB = Rainbow; SC = Sculpin

Appendix 3b: Fall effort, marking, and non-coho capture summary for Lemieux and Mann creeks, 1997.

Hab. Type	Reach	Initial sampling		Population sampling		Coho Marked	Other[1]	
		Traps	Date	Traps	Date		CN	RB
LEMIEUX CREEK 1997; Fall								
P	ALL	197	28-Aug to 2-Sep	205	2-Sep to 9-Sep	463	154	520
OC	ALL	322	28-Aug to 2-Sep	325	2-Sep to 9-Sep	1628	64	382
RU	ALL	94	28-Aug to 2-Sep	90	2-Sep to 9-Sep	18	37	172
TOTAL	n/a	613	-	620	-	2109	255	1074
MANN CREEK 1997; Fall								
P	ALL	143	28-Aug to 2-Sep	145	2-Sep to 9-Sep	1055	195	21
OC	ALL	136	28-Aug to 2-Sep	135	2-Sep to 9-Sep	72	29	4
RU	ALL	83	28-Aug to 2-Sep	80	2-Sep to 9-Sep	33	58	19
TOTAL	n/a	362	-	360	-	1160	282	44

[1] CN = Chinook; RB = Rainbow
Coho sizes for young-of-the-year only

Appendix 4a: Pre-winter catch summary and movement data for Lemieux and Mann creeks, 1996.

Lemieux Creek 1996; Pre-winter
Nov 14-18   UPSTREAM →

Site No.	Site	Habitat Type	Distance	Sampled	Tallied	C¹	Unmarked	R²	Fall marks³ 1	2	3	4	5	6	Total
1	Spencely	OC	1653	139	150	289	263	15	15	8	3				26
2	Burton	MS	3042	134	0	134	91	43		43					43
3	Cartwright	MS	4578	138	77	215	162	53			53				53
4	Cochrane	MS	6472	146	0	146	108	34			4	34			38
5	Fowler	MS	7642	137	18	155	113	39			1		39	2	42
6	Ianson	OC	8191	138	873	1011	760	247			4			247	251
TOTAL				832	1118	1950	1497	431	15	51	65	34	39	249	453
Representative				555	95	650	474	169	0	43	58	34	39	2	176
Off-channel				277	1023	1300	1023	262	15	8	7	0	0	247	277

Mann Creek 1996; Pre-winter
Nov 28- Dec 4   UPSTREAM →

Site No.	Site	Habitat Type	Distance	Sampled	Tallied	C¹	Unmarked	R²	Fall marks³ 1	2	3	4	5	Total
1	Lower s/ch	OC	585	138	271	409	371	4	4	24	7	3		38
2	Mainstem	MS	585	138	45	183	162	15		15	5	1		21
3	Reach 3	MS	801	138	62	200	153	19		3	19	25		47
4	Beaver Pond	OC	957	138	279	417	333	80		2	2	80	4	84
5	Upper s/ch	OC	1086	152	0	152	150	19				2	19	2
TOTAL				704	657	1361	1169	137	4	44	33	111	23	192
Representative				276	107	383	315	34	0	18	24	26	0	68
Off-channel				428	550	978	854	103	4	26	9	85	23	124

¹ Values include all CWT fish.   Coho sizes based on age corrected data

² Values only include that site's CWT.   ³ Column number refers to mark site number, ordered in upstream direction.

Appendix 4b: Post-winter catch summary and movement data for Lemieux and Mann creeks, 1996.

Lemieux Creek 1996; Post-winter March 12 - April 9 UPSTREAM →

The "Pre-winter marks²" and "Fall marks²" headings each span sub-columns 1, 2, 3, 4, 5, 6, Total.

Site	Site No.	Habitat Type	Distance	Location	Sampled	Tallied	C¹	Unmarked	PW 1	PW 2	PW 3	PW 4	PW 5	PW 6	PW Total	Fall 1	Fall 2	Fall 3	Fall 4	Fall 5	Fall 6	Fall Total
Spencely	1	OC	1673	u/s	0	4	5	4							0						1	1
Spencely	1	OC	1653	site	146	131	297	266	9	1				1	11	11	2	3	1		3	20
Spencely	1	OC	1653	site pop	0	61	67	48	11			2			13	2	2		1	1		6
Spencely	1	OC	1633	d/s	0	5	5	4	1						1							0
Burton	2	MS	3042	site	31	0	36	28		3					3		5					5
Burton	2	MS	3042	site pop	0	29	29	25		3	1				4							0
Burton	2	MS	3042	site repop	5	0	8	5							0		3					3
Burton	2	MS	3042	site repop	0	12	12	12							0							0
Burton	2	MS	2916	d/s	0	0	0	0							0							0
Cartwright	3	MS	4645	u/s	0	3	5	3							0						2	2
Cartwright	3	MS	4578	site	34	0	43	30			3	1			4			8			1	9
Cartwright	3	MS	4578	site pop	41	0	46	39				2			2	1	1	3				5
Cartwright	3	MS	4578	site repop	46	0	58	45				1			1			11			1	12
Cartwright	3	MS	4578	site repop 2	0	47	47	46				1			1							0
Cartwright	3	MS	4518	d/s	0	5	5	5							0							0
Cochrane	4	MS	6487	u/s	0	11	11	11							0							0
Cochrane	4	MS	6472	site	28	0	37	27		1					1				6		3	9
Cochrane	4	MS	6472	site pop	0	20	25	17				3			3				5			5
Cochrane	4	MS	6472	site repop	19	0	24	19							0			1	4			5
Cochrane	4	MS	6472	site repop 2	0	21	21	21							0							0
Cochrane	4	MS	6426	d/s (lost)	0	13	13	13							0							0
Fowler	5	MS	7657	u/s	0	8	8	6						2	2							0
Fowler	5	MS	7642	site	119	46	218	133					25	7	32			4		37	12	53
Fowler	5	MS	7642	site pop	0	109	117	106						3	3					7	1	8
Fowler	5	MS	7542	d/s	0	35	38	34		1					1				1	2		3
Ianson	6	OC	8191	site	142	315	629	379						78	78	1		10	1	1	159	172
Ianson	6	OC	8191	site pop	0	207	233	207							0			2		1	23	26
Ianson	6	OC	8191	d/s	0	67	89	62						5	5					2	20	22
TOTAL					611	1149	2126	1595	21	9	4	10	25	96	165	14	14	42	19	51	226	366
site only					611	998	1947	1453	20	8	4	10	25	89	156	14	14	42	18	47	203	338

¹ Values include all CWT fish.

² Column number refers to mark site number, ordered in upstream direction.

Mann Creek 1996; Post-winter
March 31 - April 9

UPSTREAM →

Site	Site No.	Habitat Type	Distance	Location	Sampled	Tallied	C[1]	Unmarked	Pre-winter marks							Fall marks[2]						
									1	2	3	4	5	-	Total	1	2	3	4	5	-	Total
Lower s/ch	1	OC	585	site	145	0	160	117	18	3	2	5			28	1	9	4	1			15
Lower s/ch	1	OC	585	site pop	0	165	178	143	17	2		3			22	4	7		2			13
Mainstem	2	MS	605	u/s	0	3	3	3							0							0
Mainstem	2	MS	585	site	131	0	142	120	3	5	3				11		7	4				11
Mainstem	2	MS	585	site pop	0	137	149	120	1	5	10	1			17		9	3	1			13
Reach 3	3	MS	821	u/s	0	22	23	22							0			1				1
Reach 3	3	MS	801	site	25	0	32	24			1				1		1	5		1		7
Reach 3	3	MS	801	site pop	0	26	29	23	1		2				3		2	1				2
Beaver Pond	4	OC	957	site	102	0	122	87				13	2		15				19		1	20
Beaver Pond	4	OC	957	site pop	0	102	128	93				9			9				23	1	2	26
Beaver Pond	4	OC	957	site repop	0	84	104	75				9			9				20			20
Beaver Pond	4	OC	942	d/s	0	9	9	9							0							0
Upper s/ch	5	OC	1086	site	36	0	37	30				2	4		6					1		1
Upper s/ch	5	OC	1086	site pop	35	0	35	30				5			5							0
TOTAL					474	548	1151	896	39	16	18	47	6	0	126	5	35	18	65	3	3	129
site only					474	514	1116	862	39	16	18	47	6	0	126	5	35	17	65	3	3	128

[1] Values include all CWT fish.

[2] Column number refers to mark site number, ordered in upstream direction.

Appendix 5a: Pre-winter catch summary and movement data for Lemieux and Mann creeks, 1997.

Lemieux Creek 1997; Pre-winter
Nov 14-18

Habitat Type	C¹	Un-marked	R²	Fall marks³			
				OC	P	RU	Total
P	276	193	67	14	67	2	83
OC	1511	1074	422	422	1	14	437
RU	45	37	1	7	0	1	8
TOTAL	1832	1304	490	443	68	17	528

Mann Creek 1997; Pre-winter
Nov 28- Dec 4

Habitat Type	C¹	Un-marked	R²	Fall marks³			
				OC	P	RU	Total
P	504	385	113	1	113	5	119
SC	104	82	9	9	12	1	22
RU	19	17	0	0	2	0	2
TOTAL	627	484	122	10	127	6	143

[1] Values include all marked fish.

[2] Values only include that habitat type's marks.

[3] Column designation refers to habitat type mark applied in.

Appendix 5b: Post-winter catch summary and movement data for Lemieux and Mann creeks, 1997.

Lemieux Creek 1997; Post-winter
Mar 14 - 25

Habitat Type	Total			R²	Fall marks [3]				Pre-winter marks [3]				Fall and Pre-winter marks [4]			
	C¹	Marks	Unmarked		OC	P	RU	Total	OC	P	RU	Total	OC	P	RU	Total
P	291	149	142	114	13	21	4	38	12	64	0	76	6	29	0	35
OC	1238	774	464	747	179	7	2	188	380	7	0	387	188	11	0	199
RU	10	2	8	0	0	0	0	0	1	1	0	2	0	0	0	0
TOTAL	1539	925	614	861	192	28	6	226	393	72	0	465	194	40	0	234

Mann Creek 1997; Post-winter
Mar 14 - 25

Habitat Type	Total			R²	Fall marks [3]				Pre-winter marks [3]				Fall and Pre-winter marks [4]			
	C¹	Marks	Unmarked		OC	P	RU	Total	OC	P	RU	Total	OC	P	RU	Total
P	490	166	324	129	4	53	1	58	21	53	0	74	11	23	0	34
OC	31	15	16	7	3	4	0	7	3	4	0	7	1	0	0	1
RU	12	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	533	181	352	136	7	57	1	65	24	57	0	81	12	23	0	35

[1] Values include all marked fish.
[2] Values only include that habitat type's marks.
[3] Column designation refers to habitat type mark applied in.
[4] Column designation refers to September habitat type.

Appendix 6: Sample sizes for growth and relative survival analyses by size class, habitat type and abundance level for Lemieux and Mann creeks, 1997.

Yr	Creek	Fall size class	All sites Fall	Pre	Post	High abundance class Fall	Pre	Post	Low abundance class Fall	Pre	Post	Mainstem sites - 1996 / Pools - 1997 Fall	Pre	Post	Off-channel sites - 1996 & 1997 Fall	Pre	Post
96	Lemieux	<60	515		37	91		14	424		23	345		20	170		17
		60	625		67	250		36	375		31	321		29	304		38
		65	732		89	365		68	367		21	281		20	451		69
		70	610		70	308		55	302		15	218		11	392		59
		75	285		35	130		23	155		12	117		12	168		23
		>80	248		27	112		24	136		3	124		3	124		24
		ALL 0	2767	n/a	298	1144	n/a	196	1623	n/a	102	1282	n/a	92	1485	n/a	206
		ALL	3015	n/a	325	1256	n/a	220	1759	n/a	105	1406	n/a	95	1609	n/a	230
96	Mann	<60	1279		63	422		24	857		39	752		34	527		29
		60	739		29	320		20	419		9	299		8	440		21
		65	614		18	300		15	314		3	201		2	413		16
		70	257		6	135		4	122		2	68		2	190		4
		75	134		4	87		2	47		2	37		2	96		2
		>80	148		0	110		0	38		0	32		0	116		0
		ALL 0	3023	n/a	120	1264	n/a	65	1759	n/a	55	1357	n/a	48	1666	n/a	72
		ALL	3171	n/a	120	1374	n/a	65	1797	n/a	55	1389	n/a	48	1782	n/a	72
97	Lemieux	<60	602	130	182	516	110	159	86	20	23	27	6	17	575	120	165
		60	405	127	112	242	78	86	163	49	26	76	17	18	329	106	94
		65	364	114	55	227	69	27	137	45	28	54	15	14	310	96	41
		70	235	71	62	147	37	42	88	34	20	34	8	8	201	59	54
		75	113	45	36	54	23	21	59	22	15	28	12	8	85	35	28
		>80	190	47	28	70	14	11	120	33	17	90	25	11	100	21	17
		ALL 0	1719	487	447	1186	317	335	533	170	112	219	58	65	1500	416	382
		ALL	1909	534	475	1256	331	346	653	203	129	309	83	76	1600	437	399
97	Mann	<60	208	12	10	13	3	4	195	12	6	181	11	10	27	4	0
		60	148	15	7	16	0	1	132	15	6	134	10	5	14	5	2
		65	150	14	9	26	1	5	124	12	4	134	10	9	16	2	0
		70	137	16	11	32	2	5	105	16	6	116	12	5	21	6	6
		75	116	15	7	30	7	5	86	9	2	105	11	6	11	2	1
		>80	588	70	54	349	47	42	239	23	12	569	65	49	19	3	4
		ALL 0	759	72	44	117	13	20	642	64	24	670	54	35	89	19	9
		ALL	1347	142	98	466	60	62	881	87	36	1239	119	84	108	22	13