EVALUATION OF THE SALISH CREEK MITIGATION PROJECT

by

TYESE MARIA. PATTON

B.Sc., The University of Guelph, 1995

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

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

RESOURCE MANAGEMENT AND ENVIRONMENTAL STUDIES

(Institute for Resources, Environment and Sustainability)

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

April 2003

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the head of my department or by his or her representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Resource Management and Environmental Studies

The University of British Columbia
Vancouver, Canada

Date April 22nd, 2003

DE-6 (2/88)

Abstract

I investigated colonization patterns of coho salmon (*Oncorhynchus kisutch*), cutthroat trout (*Oncorhynchus clarki*), largemouth bass (*Micropterus salmoides*), and the endangered Salish sucker (*Catostomus Sp*) and Nooksack dace *(Rhinichthys Sp.)* into a newly constructed channel in a headwater stream in British Columbia's Fraser Valley over a one-and-a-half year period. Fish fence and mark-recapture data indicated that the study area was colonized by all species beyond the level found in the original channel in terms of numerical abundance indicating no net loss. The densities found in high quality natural habitat were not reached by the end of the study period. A total of 4897 fish entered and 710 exited the study area during the first year. Coho achieved highest numbers and densities in the shortest period followed by cutthroat trout and Salish sucker with few Nooksack dace entering or remaining. Colonization was greatest during the spring months for all species and from upstream and downstream sources. Coho salmon and cutthroat trout were mainly juveniles dispersing shortly after hatching in spring. Salish sucker colonizers were primarily spawning adults. The relatively small number of Salish sucker and Nooksack dace colonizers reflects their rareness, more restricted movements and, in the case of the dace, selectivity of the fences. Other than smolt migration, little coho movement occurred at temperatures below 9°C and most movement took place at temperatures from 10 to 15°C, roughly corresponding to preferred temperatures. Movement of cutthroat trout occurred at temperatures from 2°C to over 20°C. The majority of adult Salish suckers entered from Pepin Brook between temperatures of 4 to 10°C. Males outnumbered females by almost 3:1. The condition factor and growth rates of Salish sucker in the study area were significantly greater than those in mainstem habitat. Largemouth bass moved most often at temperatures above 17°C, consistent with life history characteristics. ANOVA did not reveal consistent statistical results of fish movement in relation to season, temperature and discharge. However, season, discharge and temperature were inter-correlated. The relatively short time frame of movement for the vast number of fishes reflects the need for appropriate physiological, developmental and/or reproductive states of the fish to coincide with appropriate stream conditions for movement to occur together with an attempt to colonize new, unexploited habitat.

Table of Contents

List of Tables

List of Figures

Acknowledgements

I would like to extend my deepest thanks to my supervisor Dr. Michael Healey for his advice and sense of humour throughout the life of my thesis. I would also like to thank Brent Stapleton (my most dedicated weekend volunteer), Mike Pearson and members of the Pepin Brook Streamkeepers for their very capable and much appreciated field assistance as well as Columbia Bitulithic staff including Paul Simpson and Leon Sparrow among others, for their dedication and enthusiasm toward this project. This thesis was funded by the Habitat Stewardship Program for Species at Risk, Habitat Conservation Trust Fund, Urban Salmon Habitat Program and Fisheries Renewal BC.

Chapter 1

An Introduction

Introduction

Human population growth and development are transforming the ecosystem of the lower Fraser Basin. Once a valley bottom of forests, wetlands and flood plains, it is now home to over 1.8 million people and has one of the fastest rates of population growth in the country (Healey 1998). Intensive agricultural practices and the expansion of the land base required to satisfy industry and housing demands are the primary causes associated with many negative environmental impacts (Fraser Basin Council 1997).

Increased demand for housing and industrial development assimilates large tracts of former forest and agricultural lands. Between 1974 and 1993, for example, seven percent of the lower Fraser Basin's Agricultural Land Reserve was lost, mostly to urbanization (Lavkulich et al. 1999). This loss of farmland and the desire to remain competitive in a local and global marketplace has led to the intensification of agricultural methods. Chemical, fertilizer and machinery use have all grown dramatically in recent years (Healey, 1998). The effects of these practices together with the expanding population are increasingly evident as the health of both rural and urban streams is threatened.

Of the 779 large, medium and small streams in the Fraser Basin, approximately 117 have disappeared since 1860. As many as 50 small streams in the greater Vancouver area that once supported runs of Pacific Salmon have been converted into storm sewers. Most of the remaining 662 streams are classified as endangered and are under considerable stress due to landscape alterations in watersheds, riparian zone degradation and pollution (Precision Identification Biological Consultants, 1998). The consequences are loss of species diversity and habitat, poor water quality and increased public health risks (Healey, 1998).

Streams are home for many species of plants and animals. They function as corridors for movement of energy and organisms (Vannote et al. 1980). They connect and integrate landscapes, acting as highways for birds and fish, and for the transport of water and nutrients. Stream habitats are also strongly influenced and dependent upon their surrounding terrestrial landscapes (Vannote et al. 1980; Ward 1989). This condition renders them particularly vulnerable to human disturbance and is partially responsible for the disproportionate declines in aquatic versus terrestrial fauna (Warren and Burr 1994). One out of three fish is rare or endangered in North America (Maurizi and Poillon, 1992) and in British Columbia 40 percent of the 85 recognized native fish taxa are believed to be at risk (Cannings and Ptolemy 1998). Their rate of extinction was recently estimated at 2.4% of species per decade - five times that of terrestrial fauna (Ricciardi and Rasmussen, 1999).

The widespread deterioration of native fish populations has prompted increased interest in the preservation of species and the restoration of degraded stream habitat (Ebersole et al. 1997). In the 1998 State of the Environment report, British Columbia's Ministry of Environment Lands and Parks (MoELP), lists the 'protection, conservation and restoration of a full range of biological and physical diversity native to B.C." as its first objective (MoELP 1998). Several other government agencies, at the municipal and federal levels, have made similar statements recognizing the preservation of biodiversity as a policy priority (Anonymous 1998). Such policy may necessitate protection of those remaining riparian ecosystems and watersheds that are relatively intact or less disturbed by the effects of intensive agriculture, urbanization and resource extraction (Ebersole et al. 1997). It will also require the recovery of habitat and systems that may be capable of at least partially re-expressing their previous capacity through restoration or some level of enhancement activities (Ebersole et al. 1997). As adequate quantities of usable resources are needed to support healthy populations, identifying and understanding the relationship between fish distribution and habitat is a major concern of conservationists, fisheries biologists and managers. Such information is especially critical in efforts to preserve endangered species and manage exploited populations (Frissel and Lonzarich, 1996).

This study was designed to evaluate the effectiveness of construction of nearly 1 kilometer of new stream habitat on Salish Creek. To my knowledge this study is the first of its kind and as such, embodies several practical and theoretical difficulties. For this project may not be defined as a work of rehabilitation, reclamation or restoration - all of which involve the return of an ecosystem to the close approximation of its condition prior to disturbance (Berger, 1990). These entail the reestablishment of pre-disturbance aquatic functions and related physical, chemical and biological characteristics - an obviously impossible task in this case as the pre-disturbance condition would be one of non-existence (Cairns, 1988). Instead, this project is defined as habitat creation, the purpose of which is mitigation in this case defined as the construction of an ecosystem in exchange for the destruction of an existing one (Jackson et al. 1995). This project becomes an exercise in approximation and in the construction of naturalistic rather than natural assemblages of plants and animals with their new physical environments (Berger, 1990). The level of numerical abundance required for populations of native fish species to become self-sustaining in this case is unknown. The nature of this project also precludes the use of a typical before-after-control-impact study design. However, this channel was constructed for the purpose of establishing healthy populations of native fish species including two of Canada's most endangered fish species, the Salish sucker (*Catostomus sp.*) and Nooksack dace (*Rhinichthys sp.*), and also coho salmon (*Oncorhynchus kisutch*), and cutthroat trout (*Oncorhynchus clarki*).

The primary objectives of this thesis are to:

- Summarize the land management history of the study site, life history characteristics and habitat use of the target fish species, and rationale for the habitat features incorporated into the design of the new channel (Chapter 1);
- Define fish colonization patterns over time, identify habitat use by the Salish sucker within this new channel, and assess the effectiveness of channel construction in creating suitable habitat for native fish species (Chapter 2); and
- Define the relationship between colonization season, discharge and temperature (Chapter 3).

Land Management History

This study focused on a newly diverted channel of Salish Creek, located in the Municipality of Abbotsford, British Columbia (Figure 1.0). Salish Creek is a first order tributary to Pepin Brook, a 16 km^2 Canadian watershed flowing south across the United States border into the Nooksack River. Salish Creek is located on land owned and operated by Columbia Bitulithic Limited, a national gravel extraction and paving company, which funded the creation of this new fish habitat as part of the company's site reclamation obligations.

More than 100 vertical feet of aggregate have been removed from the Abbotsford pit since its inception in 1973 (Paul Simpson, district manager, personal communication). Much of the surrounding property has also been mined within the last two decades including those immediately to the west and north. These properties are represented by a variety of stakeholders comprising private landowners, the City of Abbotsford, Ministry of Transportation and Highways as well as various gravel extraction companies.

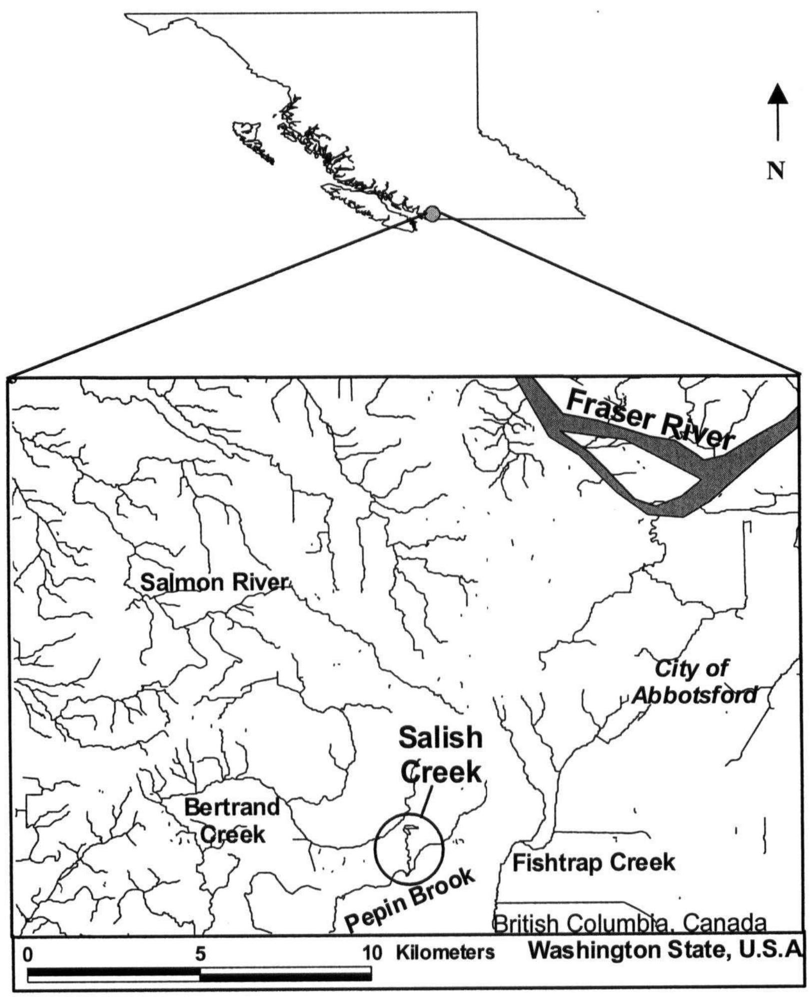
The origin of Salish Creek is complex. Approximately a decade ago, mining on the adjacent property intercepted the water table and resulted in excess surface water. The water was drained from the site through a ditch, that ran southwest across the midsection of the property and south through land owned by the City of Abbotsford (Jim Caine, landowner, personal communication). In 1992, the City was undertaking reclamation efforts, following completion of their gravel extraction operations. As the ditch complicated this work, they built a large earth berm at the northern-most corner of their land, in an attempt to prevent this water from entering City property (Willie Reimer, City of Abbotsford, personal communication).

The berm served its purpose initially, but flooded the fields and produced three large, deep ponds covering an area of over 27,000 square meters (Photo 1, Appendix 1). In late 1992, after a severe storm, the berm collapsed and the attempt to contain this water ultimately failed. This caused massive flooding and erosion of both City of Abbotsford and Columbia Bitulithic property. At the request of the City, Columbia Bitulithic agreed to channel this water through an area of their quarry which was not currently being mined This was intended as a temporary solution to the immediate problem of flood control as Columbia Bitulithic hoped eventually to mine this area (Paul Simpson, district manager, personal communication) (Photo 2, Appendix 1). The new channel ran south and east through the northern end of the gravel quarry and connected to nearby Pepin Brook (Photo 3, Appendix 1).

In 1997, researchers discovered that Salish Creek had been colonized by cutthroat trout, three-spined stickleback (*Gasterosteus aculeatus*) and Salish sucker, and was also inhabited by largemouth bass (*Micropterus salmoides*), an invasive, non-native fish species (Pearson, 1998). Subsequent surveys also found coho salmon and Pacific lamprey (*Lampeta sp*) (Patton, unpublished data).

The lower and middle reaches of Salish Creek suffered from instability due to heavy sediment inputs from large piles of 'throwaway' (unusable, extracted fines) located along its south side and a gravel bluff bordering the north. Extensive substrate movement and channel braiding were common due to high levels of sediment input, coupled with the lack of stabilizing riparian vegetation and in-stream structure. This rendered the area generally unsuitable as fish spawning or rearing habitat. The channel also lacked habitat complexity. There were very few refuges (deep pools, side channels or protected areas behind logs and

Figure 1.0. Location of the Salish Creek Study Area.



boulders) in which fish could survive during winter high-flow and summer low-flow periods. Reed canary grass (*Phalaris arundinacea*) completely overgrew the midsection of the tributary during the spring and summer months also decreasing the creek's value as quality fish habitat.

The ponds created at the tributary's headwaters posed additional problems. Large areas of shallow water with little shade resulted in temperatures often exceeding 25°C in mid-summer. These temperatures are lethal to salmonids (Becker and Genoway 1979) and may have such sub-lethal effects on the Salish sucker and Nooksack dace as reduced health and fecundity (McPhail 1997). The ponds had also been illegally stocked with largemouth bass - an introduction that occurred some time after their origin in 1992. A 1999 survey of the pond area indicated that these bass populations were successfully breeding as thousands of juveniles and an unknown number of adults were present. The warm, deep pond waters were likely conducive to bass survival and proliferation (Terrell, 1995). This situation presented an ideal opportunity for their invasion of lower Salish Creek and Pepin Brook.

In 1998, following negotiations with MoELP (now Ministry of Water, Land and Air Protection), Columbia Bitulithic installed a number of sediment control structures and fenced off much of the upper segment of the tributary. Despite these efforts, the lower reaches remained problematic. The proximity of the channel to the large piles of fines, the steep gravel bluff on its lower north side and adjacent mining operations beyond the designated 30-meter set-back, exposed it to the risk of continuing degradation. There was also a possibility that the channel would become perched and run dry after the adjacent land had been mined as the pit's approved final elevation was several meters below the level of the existing streambed.

Under these circumstances, MoELP and Columbia Bitulithic agreed that the lower reaches of the tributary would be realigned through a site already at its final post-mining elevation. The existing tributary represented negligible fish habitat, while the new site would allow more scope to increase habitat quantity and improve habitat quality by incorporating more suitable habitat conditions within the new design structure. From a research standpoint, it presented an ideal situation for examination. From the standpoint of the quarry, materials that were previously inaccessible due to their proximity to the tributary would again become available for extraction.

In cooperation with Alex Sartori of Scott Environmental Consultants, I was given the opportunity to design structures and habitat features for inclusion in the project. In this design I attempted to provide habitat for all life stages of Salish sucker, Nooksack dace, coho salmon and cutthroat trout. The design included habitat such as deep pools and undercut banks that was lacking within local systems and the original tributary. The diversion was completed by August of 1999, and for the next 18 months, I collected data on fish colonization and distribution to assess the effectiveness of the constructed habitats.

Description of Native Fish Species

Understanding the requirements of each species and the factors that may limit its survival is essential to developing and implementing effective enhancement strategies. Such analysis must include habitat requirements at all life stages and encompass all seasons.

Salish sucker and Nooksack dace

The Salish sucker and the Nooksack dace are members of the Chehalis fauna, a unique assemblage of fish that survived the major glaciations of the Pleistocene Epoch, in an ice-free refuge within the Chehalis River Valley, Washington (McPhail, 1967; McPhail and Lindsey, 1986). Isolated from their parental species the Longnose sucker (*Catostomus catostomus*) and Longnose dace (*Rhinichthys cataractae*), they diverged to become genetically and morphologically distinct (McPhail, 1967; McPhail and Taylor, 1999). Recent genetic work indicates that both species may have been reproductively isolated prior to the most recent glaciations and possibly earlier than the Pleistocene (McPhail, 1997). As the glaciers retreated, the Salish sucker and Nooksack dace dispersed north through Puget Sound which was temporarily occupied by freshwater lakes (McPhail and Carveth, 1993). Eventually they reached the lower Fraser Valley where they are still found today.

Nooksack dace: Life History and Habitat Use

Adult Nooksack dace are benthic riffle specialists. Inglis and others (1994) found that adults prefer water depths of 10 to 19 cm at velocities of 25 to 30 cm/s over substrate of gravel, cobble or small boulders. Little is known of winter habitat use. McPhail (1997) suggests that they probably inhabit riffles year round in the Fraser Valley, but may shift to pools in more severe environments.

Both sexes reach maturity at the end of their second summer and spawn for the first time in their third spring. Four year-classes are generally present (Inglis et al. 1994) with the largest individuals usually not reaching more than 100 mm in fork length (McPhail 1997)

Dace spawn at night during April and May, near the upstream end of riffles. Females deposit 200 to 2000 eggs depending on body size (McPhail 1997); and there is no information on parental courtship behaviour or incubation periods. Young-of-the-year dace gather in shallow marginal pools over mud or sand substrates near the downstream ends of riffles. They feed on chironomid larvae and ostracods (McPhail 1997). The limited gut content analyses indicate that adult dace feed primarily on riffle dwelling insects, including caddisfly and mayfly nymphs, dytiscid beetle larvae, and adult riffle beetles (McPhail 1997). They have been observed foraging both during the day and at night (Pearson 1998). However, individuals collected at mid-morning have empty stomachs, but full intestines, suggesting that feeding is nocturnal (McPhail 1997).

Nooksack dace are commonly found with cutthroat trout, rainbow trout (*Oncorhynchus mykiss*), juvenile coho salmon, and prickly sculpin (*Cottus asper*), all potential predators (Inglis et al. 1994).

Salish Sucker: Life History and Habitat Use

In Canada, Salish suckers are limited to small headwater streams and associated ponds, however in Washington, several lake populations exist (McPhail 1987). Although adults are found in a variety of habitat types within headwater streams, by far the highest densities are found in marshy reaches with long stretches of pools over 70 cm in depth (M. Pearson, University of British Columbia, Institute for Resources and Environment, pers com. 2001). Less data is available on young-of-the-year suckers, but they seem to prefer shallower pools with overhanging vegetation (Inglis et al.1992; Pearson, unpublished data).

There appear to be 5 age classes in British Columbia populations (McPhail 1987; Inglis et al. 1992) although older individuals are known from Washington (McPhail 1987). Males are sexually mature in their second year and females in their third year with a minimum spawning size of 87 mm and 95 mm, respectively (McPhail and Taylor 1996 MS). The largest individual known from Canadian waters, 282 mm fork length, was captured during this study in Salish Creek.

Suckers spawn in riffles over fine gravel at current velocities of up to 50 cm/s (McPhail and Taylor, 1996 MS) beginning in March or April when water temperatures reach 7 or 8°C (McPhail 1987). The period is very protracted and may extend through to mid July at water temperatures greater than 20°C (Inglis et al. 1992; McPhail and Taylor 1996; M. Pearson, University of British Columbia, Institute for Resources and Environment, pers com. 2001). Salish suckers are broadcast spawners. No nest is built and the adhesive eggs stick to gravel and rocks (McPhail, 1987). No information is available on incubation period.

Adults appear to be generalized insectivores, but the diet of the young is unknown (McPhail 1987). Salish sucker fry and juveniles are likely preyed upon by all of the piscivorous fish with which they share their habitat (cutthroat and rainbow trout, coho salmon, prickly sculpin), in addition to introduced species (bullfrogs, brown bullhead, largemouth bass), and birds. Predation on adults is probably limited to mink and birds.

Present-day Status

Present day Canadian populations of both species are found within Bertrand, Cave, Pepin and Fishtrap Creeks of the Nooksack system. In addition, the Salish sucker is known to inhabit the Salmon River, Chilliwack Creek and Salwein Creek (Inglis et al. 1992; Pearson, 1998). Recent reconnaissance sampling has also identified populations north of the Fraser River in Agassiz Slough and Miami Creek (M. Pearson, University of British Columbia, Institute for Resources and Environment, pers com. 2001).

Despite these recent discoveries, these species are considered to be in steep decline within Canada (McPhail, 1987; Pearson, 1998). Both have recently disappeared from Howes Creek, a tributary of Bertrand, and the Salish sucker is believed to be extirpated from the Little Campbell

River (Inglis et al, 1992). Healthy populations of Nooksack dace are known to exist only within limited areas of Bertrand Creek, while Salish sucker populations are also found in Pepin and Cave Creeks (Pearson, 1998 and pers com.; McPhail, 1997).

The global distribution of both fish is also severely restricted. The nearest known Washington population of suckers is 100 km to the south. Consequently, if the sucker disappears from British Columbia, re-colonization would be unlikely (McPhail and Carveth, 1993). While distribution of the Nooksack dace is even more restricted within B.C., it is more widespread in the state of Washington, especially within the Nooksack River (McPhail and Carveth, 1993).

Population declines are likely due to the progressive decrease in the quality and quantity of existing habitat. Possible limiting factors include loss of riffle habitat, changes in flow regime, declining water quality and increased competition and predation by introduced species (Pearson, 1998).

In 1993, it was predicted that unless some active effort was made to preserve the Salish sucker, it would likely disappear from B.C. within the decade (McPhail and Carveth, 1993). A similar prognosis was made for both species in 1998 (Pearson 1998). However, additional studies have shown that the Pepin and Salmon River Salish sucker populations are much larger than previously believed, numbering in the thousands rather than in the hundreds (M. Pearson, University of British Columbia, Institute for Resources and Environment, pers com. 2001). Also encouraging is the recent increase in public interest in these species and in the streams they inhabit. Since 1990, MoELP has conducted a series of studies on distribution and habitat preferences (Inglis et al. 1992, 1994), population status (McAdam 1995) and habitat availability (Pearson 1998). Langley Environmental Partners Society, the Bertrand Creek and Salmon River Enhancement Societies, and the newly formed Pepin Brook Stream Keepers have also undertaken several restoration projects in their respective watersheds. These include enhanced fish passage on Cave Creek, numerous cattle fencing and tree planting events, and the focus of this thesis, the creation of new stream habitat on Salish Creek.

Coho salmon and Cutthroat trout:
Life Histories and Habitat Use

In contrast to the scarcity of available information on the Salish sucker and the Nooksack dace, considerable information is available regarding the life history traits and specific habitat use of salmonids. Coho populations are distributed throughout the North Pacific and in other cool temperate areas as a result of introductions (Groot and Margolis 1991). In North America, cutthroat trout occur mostly west of the Rocky Mountains but have also been extensively introduced within their natural range (Scott and Crossman 1998).

Like other salmonids, coho and cutthroat spawn in gravel over upwelling groundwater in freshwater streams. The female digs a redd in the gravel to a depth of 20 to 50 cm. Eggs are deposited in the nest and fertilized by a dominant male. Egg number varies with the size of the female, the area and year. The average fecundity for coho females in British Columbia ranges from 2100 to just under 3000 eggs (Scott and Crossman 1998). Cutthroat fecundity varies from 800 to 1500 eggs.

Both anadromous and resident forms of cutthroat trout commonly coexist in these streams (Scott and Crossman 1998). Cutthroat fry emerge in June and July and the majority of anadromous juveniles rear in their natal stream for 2 to 3 years before migrating to saltwater. Anadromous cutthroat spend 1 or 2 summers in the ocean before returning to spawn for the first time. Mature adults weigh an average of 0.8 kg. They enter spawning streams from October to December and spawn from January to March (Scott and Crossman 1998).

In British Columbia, spawning coho return to freshwater beginning in September to October when the water temperature is between 7.2-15.6°C, the minimum depth is 18 cm and velocities do not exceed 2.44 m/s (Groot and Margolis 1991). This migration pattern allows coho to reach small headwater tributaries, which are favoured as spawning and rearing habitat (Groot and Margolis 1991). Most coho migrate after spending one to two years in the ocean (Scott and Crossman 1998; Groot and Margolis 1991). At this time they weigh between 2.5 and 5.5 kg with an average fork length of 52-69 cm.

The spawning season for most coho is between November and January although this period may extend into March, especially in smaller, shorter streams (Groot and Margolis 1991). After spawning, male and female adults exhibit severe external deterioration and die within days to weeks. The female may guard the nest during this period or until she is too weak (Groot and Margolis 1991).

The duration of incubation and timing of coho fry emergence varies among stocks and is temperature dependent (Scott and Crossman, 1973). In British Columbia, 15-27% of coho eggs will survive to develop and emerge approximately 149-188 days after deposition. At this time they are an average of 30 mm in length. As they grow, they distribute themselves throughout the stream, establishing territories where they may remain for relatively long periods (Groot and Margolis 1991).

Juvenile coho salmon use different types of habitat during different times of the year, but are found most commonly in deep on and off-channel pools with abundant overhead cover during the winter months (Cederholm and Scarlett, 1988; Cederholm et al. 1997). These low velocity areas may provide effective refuge from winter high flows and predation (Murphy et al. 1986; Nickelson et al. 1992) as well as allowing for energy conservation (Cederholm et al. 1997). Studies have found that the availability of suitable winter habitat is a major limiting factor of coho salmon smolt production (Cederholm et al. 1997). Summer nursing habitat generally consists of shallower pool areas of backwaters, side channels and small creeks with abundant instream and overhead cover (Groot and Margolis 1991).

Cutthroat trout often inhabit the same streams as coho salmon, although trout fry seem to utilize shallower, faster flowing riffles more frequently than coho (Groot and Margolis 1991). However, like coho, they rely on deep pools with abundant large woody debris (LWD) to provide important over-winter habitat. A study conducted by Heggenes and co-workers (1991), suggested that cutthroat trout use more slow flowing habitats in streams where they are numerically dominant and thus are prone to habitat displacement in streams where coho salmon are more abundant. Juvenile trout feed primarily on aquatic and terrestrial insects while older fish also eat small fish and fry (Scott and Crossman 1998).

Coho fry also feed on aquatic and terrestrial insects during rearing, although a small amount of zooplankton is also ingested (Groot and Margolis 1991). Like cutthroat trout, the diet of older fish includes salmon fry and small fish. This phase may last for one to two years before they migrate seaward in May and June. In the Lower Fraser Basin, freshwater rearing generally occurs for one year, whereas this period is more protracted in colder, less productive systems. The estimated productive capacity of freshwater systems varies between 8.4 and 141 coho smolts per 100 m^2. However, production from average streams is likely intermediate between these extremes (Groot and Margolis 1991).

Present-day Status

A combination of over-fishing, climate change effects on ocean survival (Beamish et al. 1995) and degradation of freshwater habitat has led to the decline of many west coast salmonid species in North America (Slaney et al. 1996). A 1996 study conducted for the American Fisheries Society (Slaney et al. 1996) showed that of over 10,000 salmon stocks assessed in British Columbia, 3% are extinct and 13% are at moderate to high risk of extinction. Coho and cutthroat stocks were earmarked for particular concern. Cutthroat trout has the greatest percentage of extinct stocks (12%) as well as the highest proportion (80%) of stocks whose status is unknown (MoELP 1998). At least 16% of coho stocks are at moderate to high risk of extinction.

As natural stream ecosystems are required for abundant spawning and rearing habitat of these fish, the maintenance of viable populations is directly related to the existence of healthy stream ecosystems (Murphy and Meehan 1991). Several legislative, regulatory and program measures were implemented by the province of British Columbia and the federal government to address this decline in salmon populations. These included more stringent conservation guidelines (Department of Fisheries and Oceans 1986), Fish Protection Act, the Urban Salmon Habitat Program and measures in the Forest Practices Code to protect wetlands, rivers, streams and lakes (MoELP 1998). However, with the recent changes in government policy with the election of the Liberal government in 2001, with an apparent emphasis on aquaculture has ended many of these programs due to funding cuts.

Introduced Species

Since the time of European settlement and especially within the last century, non-native species have become prevalent in many freshwater ecosystems (Gido and Brown, 1999). An increasing number of introduced species are establishing themselves within the Nooksack tributaries (McAdam, 1995; Inglis, 1992; Pearson, 1998). These include black crappie (*Pomoxis nigromaculatus*), Largemouth bass (*Micropterus salmoides*), brown bullhead (*Ictalurus nebulosus*) and the American bullfrog - some of the most widespread and pervasive invaders of North America (Gido and Brown, 1999). These introductions are cause for great concern.

Bass are implicated in numerous extinctions of endemic species (Miller et al., 1989; Gido and Brown, 1999; Findlay et al., 2000); and brown bullheads are believed to have caused the recent extirpation of the Hadley Lake Stickleback (Cannings and Ptolemy, 1998). While the result has been a net increase in fish species richness in most drainages (because the number of colonizations by alien species has exceeded the number of extinctions of native species), the spread of introduced species tends to reduce global diversity (Gido and Brown, 1999). Although invasions do not necessarily lead to the extirpation of native species, they may lead to shifts in abundance and habitat distributions, alterations of food webs and habitats, and changes in ecosystem processes (Crossman, 1991; Gido and Brown, 1999). Unfortunately, local endemic forms, such as the Salish sucker and the Nooksack dace, tend to be most susceptible (Gido and Brown, 1999).

Design Structures and Habitat Features

Functioning stream ecosystems are a prerequisite for the maintenance of valuable fish populations (Murphy and Meehan 1991). With the loss of natural stream landscapes through various human activities, stream restoration is frequently necessary to aid stream and fish population recovery. The goal of the Salish Creek channel diversion was to produce self-sustaining populations of the target fish species through the use of effective restoration techniques and adaptive management strategies. This included installing physical habitat structures to create suitable rearing and spawning habitat, returning the stream to a pattern of sinuous meanders and substrate characteristics compatible with alternating riffle/pool habitat and incorporating on and off channel pools.

On and Off-Channel Pool Creation

Several large on and off-channel pools with varying volumes, depths and instream cover, were incorporated into the study design in order to examine pool use by Salish sucker (Table 1.0) (Photo 4, Appendix 1). Total cover in pools varied from low (<15%), to medium (15-30%) to high (>30%) with a minimum of 3 replicates, one of each at low (< 0.5 m), medium (0.5 – 0.85m) and high (> 0.85 m) mean depths. Spacing of large and small pools is approximately 5 to 7 channel widths according to Newbury and Gaboury (1993) and constitutes approximately 68% of the new channel area compared to the 11 % of pool habitat by area found in the original channel. These habitat types were included as they are believed critical for adult and juvenile Salish sucker and coho salmon (Inglis, 1992; Cedarholm et al, 1997; Pearson, 1998 and personal communication, 2001). Studies conducted in the Pacific Northwest suggest that availability of low velocity habitat, both within and off the main channel, is often a significant factor in retaining juvenile coho salmon over winter, providing shelter from the effects of winter flood flows (Cedarholm et al, 1997). Nooksack dace young-of-the-year also inhabit shallow lateral pools (McPhail, 1997). Side-channel and lateral pool habitats are frequently lost through channelization (Booth, 1990) and are virtually absent from many of the creeks in the area (Pearson, 1998).

Table 1. Constructed Pool Habitat in the Salish Creek Study Area.

Pool	Area (m2)	Mean Depth	Max. Depth	Boulder	LWD (%)	Undercut (%)	Total cover (%)
Pool 1	60.0	0.43	0.81	8.2	0	0	8.2
Side pool 1	114.5	0.52	0.75	3.4	35.6	0	39.0
Pool 2	88.85	0.71	1.02	20	35	7.3	62.3
Pool 3	170.3	0.87	1.39	7.3	24.5	5.5	37.2
Side pool 2	105.5	0.82	1.2	14	0	0	14
Pool 4	161.7	0.74	1.36	7.5	25	7.5	40
Pool 5	25.3	0.49	0.88	27.3	0	0	27.3
Pool 6	52.6	0.64	0.93	20	28.9	13.3	62.2
Side pool 3	106.4	0.76	1.8	4.1	12.2	0	16.3
Pool 7	197.5	1.13	2.2	3.4	5.7	0	9.1
Pool 8	821.8	1.22	2.03	14.3	14.3	0	28.6

Habitat Complexing

Large woody debris, boulder structures and undercut banks were incorporated into the channel design. Quinn and Petersen (1996) found that coho survival was strongly correlated with the quantity of woody debris. Fausch and Northcote (1992) attributed increased standing crop of coho salmon and cutthroat trout to increased habitat complexity. Salish sucker have been trapped most frequently in areas with instream and overhead cover (Inglis 1992). Such structure serves to maintain high quality pool habitat (Quinn and Petersen, 1996) and increase the storage of gravel, fine sediment and organic matter (Cederholm et al 1997; Adam and Whyte, 1990). Submerged cover such as woody debris and boulders provides refuge from high winter flows and protection from predators. Overhead cover such as undercut banks was also incorporated to allow for both shade and protection from avian predators (Adam and Whyte, 1990). Flood control measures such as removal of in-stream structures, including woody debris and boulders, have simplified much of the stream habitat within the surrounding area (Pearson, 1998).

Riffle Creation

The new channel was designed with approximately 20% (602 m^2) riffle and 12% (369 m^2) glide habitat compared to the original channel which was dominated by these habitat types (89%). A sinuous meander pattern was established during construction to mimic that found in naturally occurring stream systems (Newbury and Gaboury, 1993). This also allowed for an increase in habitat quantity. Several riffle structures with deep pockets of gravel were included within the study area as the quantity of this habitat is limited within many of the local streams (Pearson, 1998) and as all native fish species use the gravel bottom of streams or upwelling groundwater sources for spawning (Adams and Whyte, 1990; McPhail, 1997). Cobble substrates were also used as the highest densities of Nooksack dace adults have been found in association with substrate of this size (Inglis, 1994; McPhail, 1997). Such habitat is also widely utilized by cutthroat trout (Heggenes et al, 1991).

Riparian Planting

Riparian vegetation serves to stabilize banks and reduce erosion, enhance water quality, lower stream temperatures and act as a source of large organic debris to the stream (Murphy, 1995). A

45 m buffer was established throughout the study area. Immediately after construction it was seeded with a local mix of clover and grasses. It was planted with trees, shrubs and cuttings on three different occasions with densities concentrated in the riparian zone. Trees were planted approximately two to five meters apart and shrubs were planted no closer than two meters, according to MoELP specifications.

The majority of the planted vegetation was initially less than one meter. All species planted were native. Willow (*Salix spp*), red-osier dogwood (*Cornus stolonifera*), alder (*Alnus spp.)* and other moisture tolerant species were concentrated along stream banks. Summer rye and other grasses grew quickly and provided some shade within the first year. Other species, such as salmonberry (*Rubus spectabilis*) and thimbleberry (*Rubus parviflorus*) were included due to their value for bird and wildlife grazing. Over 6000 plants and 20 different species, have been planted. The final successional species will likely consist of a mixed forest of western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*) and cottonwood (*Populus ssp.*), as is common to the surrounding area. Douglas fir (*Pseudotsuga menziesii*) and Sitka spruce (*Picea sitchensis*) were also planted in an attempt to mimic their presence historically (Pojar and MacKinnon, 1994). The total number of plants proposed for the area is 20,000, planted over a period of up to ten years.

Conclusion

The need for the evaluation of the effectiveness of projects intended to enhance stream and fish habitat has long been recognized. It is essential that the increasing commitment of resources to stream and river restoration translate to improved fish habitat, production and survival. This thesis represents only a short-term study of habitat recovery. Objective, systematic and long-term evaluation and wide dissemination of the results of such projects is essential if the science of stream restoration is to advance and we are to learn from successes and failures. However, habitat creation or restoration, are not alternatives to conservation nor are they a license to commit further ecological destruction. It is important to acknowledge, for instance, that this newly created stream does not and cannot provide a substitute for the loss of landscape function in this area nor for the loss of function of other streams. There is some fear that attempts will be made to intrude on previously protected areas on the grounds that the restoration process is sufficiently advanced to make this possible (Cairns, 1988). While this may be a risk under some circumstances, the potential benefits of restoration cannot be abandoned on this basis. Instead, the true cost and difficulties of such works should be made clear and responsibility and accountability for them duly assigned.

Chapter 2:

Analysis of the Effectiveness of Channel Construction in Salish Creek, British Columbia

Keywords: anadromous, disturbance, endangered species, habitat restoration, mitigation, Salish sucker, Nooksack dace

Introduction

Widespread habitat degradation, coupled with the recent decline in commercial fish stocks, has prompted renewed concern for the welfare of aquatic ecosystems (Pickett and Parker 1994; Kondolf 1995; Ebersole et al. 1997; Kershner 1997). One out of three fish species are rare or endangered in North America (Maurizi and Poillon, 1992). In British Columbia 40 percent of the 85 recognized native fish taxa are believed to be at risk (Cannings and Ptolemy 1998), and more fish species and freshwater ecosystems have been lost or listed at risk than any other taxonomic group or habitat type (Haas 1999). Anthropogenic disturbance has been identified as the leading cause of species loss, mainly through habitat alteration (Schlosser 1985; Petersen and Bayley, 1993; Ensign et al. 1997; Fraser Basin Council 1997; Healey 1998).

As stream fish communities have become progressively more impoverished, interest has grown in techniques of habitat restoration or enhancement - both as a means to protect remnant populations and to recover populations that have been lost (Gowan and Fausch 1996; Ebersole et al. 1997; Quinn and Kwak 2000). In recent years, many millions of dollars have been spent on stream or watershed restoration in the Pacific Northwest (Cederholm et al 1990; Slaney and Martin 1997). These restoration projects frequently involve alteration of habitat structure in an attempt to reverse declines and increase the number or size of fish populations (Gore and Shields 1995; Bradshaw 1996; Gowan and Fausch, 1996; Ebersole et al. 1997). Yet, studies that examine the effectiveness of such techniques are comparatively rare (Nickelson et al. 1992; Kondolf and Micheli 1995; House 1996; Ebersole et al 1997), despite the acknowledgement that quantifying and understanding community response associated with both habitat disturbance and enhancement is critical to the development of appropriate restoration procedures and the improvement of stream and fisheries management (Peterson and Bayley 1993; Minns et al 1996; Keeley et al. 1996; Quinn and Kwak 2000).

In this chapter, I evaluate the colonization of a newly constructed stream channel in the lower Fraser Valley, BC. The Salish Creek mitigation project involved constructing a new segment of stream channel, 0.96 km long, through a section of a gravel quarry that had been mined to its final elevation. This project provided the opportunity to study, in detail, the colonization patterns of fish species into the new channel. My particular focus was on colonization by two endangered fish species, the Salish sucker (*Catostomus sp.*) and Nooksack dace (*Rhinichthys sp.*) and by local salmonids including cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncorhynchus kisutch*).

The objective of this study was to assess the effect of mitigation efforts based on changes to fish density in the newly created habitat relative to the degraded channel it replaced. Fish densities after restoration efforts will also be compared to densities in adjacent tributaries considered optimal for the target species when possible and to estimates of production benefits for fishes from other stream restoration initiatives (Keeley et al. 1996). I expected post-treatment fish densities to increase within the study area relative to the original channel due to an increase in the area and quality of available habitat. I also expected that habitat suitability of the new channel for each species would mean higher rates of immigration into the study area relative to emigration. These colonization rates would likely depend on species life history characteristics and abundance of the source populations. The endangered Salish sucker and Nooksack dace which have the lowest densities in the surrounding area and relatively small home ranges (Pearson and Healey, 2003), would be expected to have lower study area densities relative to more abundant and mobile populations such as coho salmon and cutthroat trout.

Study Area

The newly constructed stream habitat of Salish Creek, is located in the Municipality of Abbotsford, British Columbia (See Figure 1.0 Chapter 1). Salish Creek is a first order tributary to Pepin Brook, a 16 km^2 watershed draining south across the Canada/United States border into the Nooksack River. The middle and upper reaches of Pepin Brook on the Canadian side of the border are flanked by a mixture of rural residential properties and aggregate mining operations. Most of the lower reaches flow through Aldergrove Lake Regional Park.

Climate in the area is characterized by warm, dry summers and relatively cool, wet weather during the remainder of the year. Mean daily temperatures from 1971 to 2000, were 17.5 + 1.1 (S.D.)°C in July and 2.6 + 2.2 (S.D.)°C in January (Canadian Climate Normals 1971-2000 for Abbotsford Airport Weather Station, Environment Canada). Annual precipitation was 1788.5 mm in 1999 and 1367.4 mm in 2000 (Abbotsford Airport Weather Station, Environment Canada). Average annual precipitation from 1986 to 1996 was 1310 mm, indicating that 1999 was a relatively wet year (Canadian Climate Normals 1986–1996 Environment Canada).

Precipitation is typically high from November to February and low in July to August. However, 2000 was an unusually dry winter (Figure 2.0). Average precipitation in January was 238.1 mm in 1999 and 136 mm in 2000 (Daily Precipitation Records, Abbotsford Airport, Environment Canada). During the winter, variations in flow tend to match precipitation. Between June and September, during periods of drought, evapotranspiration may exceed average seasonal precipitation (Halstead 1986). However, in this area, base flow during dry periods is provided from large unconfined aquifers so these streams continue to flow even during the driest periods. Average precipitation in July was 32.2 mm in 1999 and 53.2 mm in 2000.

Salish Creek is on land owned by Columbia Bitulithic Limited, a national gravel extraction and paving company. The creek was formed in 1992 when gravel mining on property northeast of the Columbia Bitulithic site cut through the water table and allowed an open channel to form. It was subsequently colonized by the aforementioned fish species (excluding Nooksack dace) as well as three-spined stickleback (*Gastersteus aculeatus*), Pacific lamprey (*Entosphenus tridentatus*), and largemouth bass *(Micropterus salmoides)*. Largemouth bass are not native to western Canada. They were introduced into the headwater ponds of Salish Creek, some time after 1992.

Approximately 500 m of the original tributary flowed through land that was still actively mined. Despite the company's efforts to control runoff and sedimentation in the tributary, it was continuously exposed to sediment loading. With approval from federal and provincial regulatory agencies, Columbia Bitulithic funded the construction of a new stream channel across a worked out section of the gravel mine and diversion of the exposed channel into this new channel. This project was part of the company's site reclamation obligations.

Construction began in June of 1999 and was completed 2 months later. The new channel flows south from the upstream diversion point through a 45-m wide corridor (Figure 2.1). It consists of a 225 m steep reach of step pools at the upstream end (maximum slope: 6.5%) and a 735 m low gradient reach (maximum slope: 2.5%) which flows into Pepin Brook. The new habitat consists of approximately 68% pool by area, 20% riffle and 12% glide. The total wetted area is approximately 2965 m^2 with an average wetted width of 5.33 m $\pm$ 0.35 (SEM). The low gradient reach consists of eleven large pools, with average depths ranging from 0.43 m to 1.22 m, maximum depths from 0.8 m to 2.2 m, and total cover (boulder, large woody debris (LWD) and undercut banks) from 8 to 62 % of the pool area. By contrast, the old channel consisted primarily of shallow riffle habitat (59%) with few pools (11%), LWD or off-channel habitat. Average wetted width was 1.98 m $\pm$ 0.48 (SEM) and the total wetted area was approximately $1025 m^2$, less than half that of the new channel.

Salish Creek extends an additional 500 m upstream from the start of the newly constructed channel. The headwaters drain three large ponds between 1 and 2 ha in total size near the center of an open hay field. I sampled these locations with minnow traps for presence/absence in the spring and summer of 1999. The upstream channel and ponds sustained populations of Salish sucker, cutthroat trout, stickleback, largemouth bass and American bullfrog (*Rana catesbeiana),* all sources of colonists for the new channel. Like bass, bullfrogs are not native to the area. No Nooksack dace, coho salmon or rainbow trout were trapped in Salish Creek upstream of the study area prior to the diversion in 1999. Largemouth bass and cutthroat trout were the most numerous species with the greatest abundance of bass located in the ponds at the tributary headwaters. Cutthroat trout were distributed throughout and suckers were mainly in the headwater ponds.

At its downstream end, the new channel discharges into Pepin Brook, which was a source of colonists for coho salmon, cutthroat trout, rainbow trout (*Oncorhynchus mykiss*), Salish sucker, Nooksack dace, largemouth bass, three-spined stickleback and Pacific lamprey (Inglis et al, 1992; McAdam 1995; Pearson 1998; Pearson unpublished data). However, the number of rainbow trout, Nooksack dace and largemouth bass in the mainstem of Pepin Brook is believed to be small. Furthermore, the nearest Nooksack dace population was 1 km downstream from the confluence of Salish Creek with Pepin Brook and the nearest rainbow trout population is 4 km downstream (Pearson 1998, Pearson and Healey, 2003). The largest known Canadian population of Salish sucker, lies within a marshy reach of Pepin Brook, approximately 1 km upstream of the confluence of Salish Creek (Pearson and Healey, 2003).

Figure 2.0. Environment Canada Monthly Precipitation Records at the Abbotsford Airport, British Columbia 1999-2000 (mm).

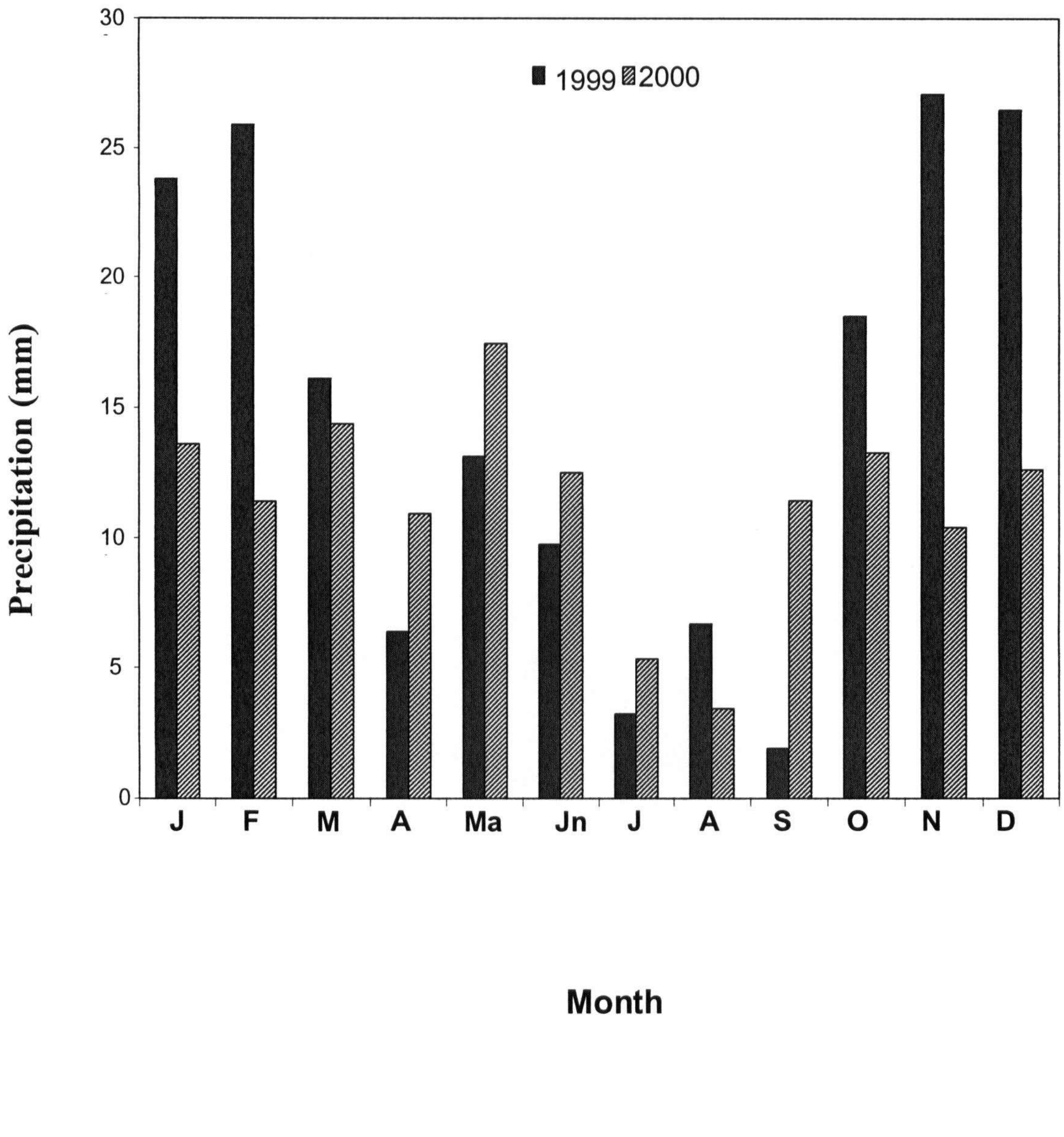
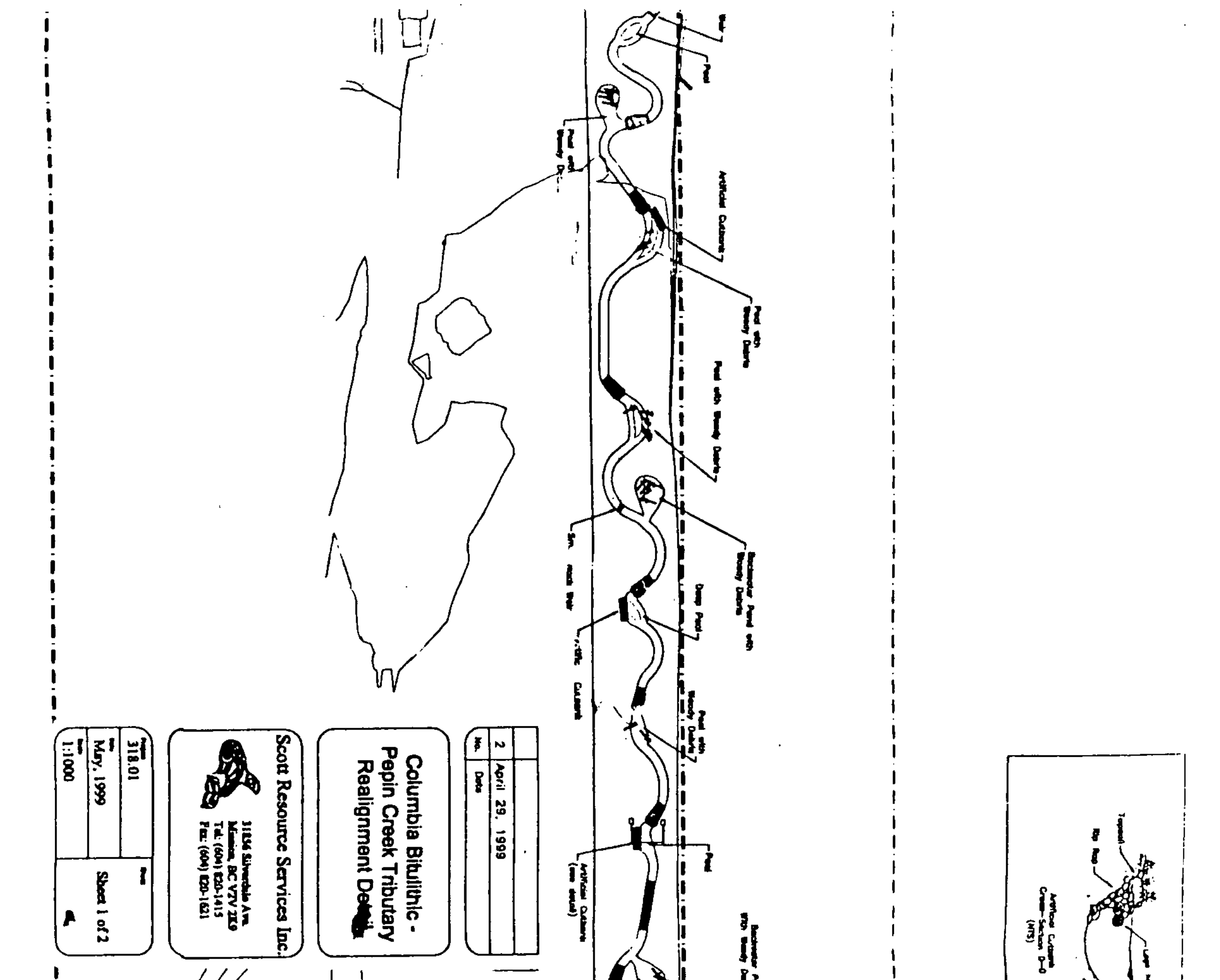


Figure 2.1. Constructed Stream Habitat on Salish Creek.



Methods

The effectiveness of the constructed habitat was examined from three perspectives:

- the balance of immigration and emigration for each species over the period of intensive study;
- the abundance and density of each species in the new channel compared to the original channel, optimal habitat and expected densities based on existing literature where possible and,
- additional measures of habitat quality including Salish sucker condition factor, growth rate, coho smolt production and survival of coho salmon, cutthroat trout and Salish sucker.

Immigration and Emigration

I monitored movement of fish into and out of the study section in detail from September 1999 to August 2000. Less detailed information was collected by volunteers from September 2000 to March 2001. To monitor movement of fish, I placed fish fences approximately 15 m below the upstream end of the constructed channel and 20 m above its confluence with Pepin Brook. The fences were operational from September 1st, 1999, two weeks after the constructed channel was connected at upstream and downstream ends. Prior to installing the fences, I placed gravel berms and fine mesh seine nets across the channel to prevent fish from entering the study area, but these barriers may not have been completely fish proof.

Fences consisted of 0.6 cm (quarter inch) mesh vexar screen weirs, approximately 3.65 m in length, and 1 m in height that spanned the width of the channel and incorporated upstream and downstream fish traps. The upstream trap consisted of a convex V-shaped funnel leading to a live box. Fish moving downstream were funneled through an O-ring and down a 27 cm diameter tube into a live box. Live boxes were approximately 1.0 m in length and 0.65 m wide and deep. Large holes with vexar mesh screens (three, 20x15 cm in the upstream boxes and nine 20x13 cm in the downstream boxes) allowed fresh water to flow through. Fish had to swim actively into the upstream trap but could enter the downstream trap passively. These trapping fences were similar to those used by Zorn and Seelbach (1995) in a study on habitat availability and fish distribution.

I removed fish from the traps on 305 days of the 365 day intensive study period, with no more than 2 days between sampling dates, except for December 15th to 27th, 1999, when the fences were closed for repairs and experimenter absence. On 8 days in the winter, during periods of high flow when a great deal of leaf litter accumulated on the fence, the downstream trap at the upstream fence overflowed and became inoperative.

The counts of fish captured at the fish fences, allowed me to portray the overall colonizing activity of each species in terms of the total number of individuals moving into and out of the study channel, in both an upstream and a downstream direction. Each fish captured was identified to species, weighed to the nearest 0.1 gram and fork lengths measured to the nearest millimeter. Suckers, dace, cutthroat and coho entering the study area were marked with a fluorescent elastomer dye (Northwest Marine Technology Inc., Shaw Island, Washington State) injected with a 25cc, 27 gauge syringe just beneath the skin on the ventral surface. Four fluorescent dye colours (red, green, yellow and orange) and four to eight marking positions, allowed for the possibility of 4096 (8^4) individual markings. Prior to marking, the fish were anaesthetized with MS22, and after recovery, returned to a calm area of the stream directly above or below the fences in the direction that they were moving. The exception to this procedure was with the largemouth bass and American bullfrogs, which were euthanized at the time of capture to help reduce their spread into Pepin Brook.

Each Salish sucker and Nooksack dace received an individual mark. Coho salmon and cutthroat trout were initially given individual marks but after November 2nd were batch marked by day of entry due to their large numbers. Large numbers of YOY coho entering the study area from April 2nd to May 18th , 2000 and cutthroat entering from April 25th to May 27th , 2000, were not marked, nor were lamprey and stickleback. Salish sucker > 100 mm long were sexed using the anal fin which is dimorphic. Spawning condition of suckers was also noted. Other species could not be sexed or the stage of maturity determined.

Fish fence operation continued from September 2000 to March 19th, 2001, with a different protocol. Fish were not marked during this time and were not allowed to go upstream out of the study area due to plans for bass eradication in the headwaters. Also fish were erroneously not allowed to move out of the study area downstream to Pepin Brook between September 2nd, 2000 and December 26th, 2000. Due to these limitations, these data will only be used to examine immigration trends of the target species to compare with the first fall and winter of the channel's existence.

Density Comparisons

Densities of the different species in the channel in August 2000, one-year after its creation, was estimated in two ways. The first was by simply subtracting the total number of emigrants from the total number of immigrants using the counts at the fence traps. This estimate fails to account for mortality within the channel and for any fish that may have entered or left without going through the traps. The second estimate was from a Jolly-Seber (J-S) analysis of marked fish recaptured in the channel. The data for the J-S estimates were obtained from minnow trapping the new channel on 16 occasions, at least once monthly, from September 1999 to August 2000. J-S population estimates for Salish sucker were calculated according to Pollock et al. (1999) using data gathered on each trapping date. As the number of coho and cutthroat recaptures were small (less than 50) these numbers were pooled and included in J-S calculations of overall fish density. To increase recapture numbers, trapping data was combined with fish fence data for salmonid species. Individuals entering the fences were counted as marked and included in the data for the subsequent trapping date. Only trapping dates before April, when large numbers of unmarked coho and cutthroat entered the study area, were used. Average J-S survival rates calculated from September 1999 to February 2000 for coho and cutthroat were multiplied by the total number of fish remaining within the study area after the one-year period to get an estimate of population size.

Trapping was conducted using standard minnow traps (MT) and larger traps (LMT) constructed from hardware cloth (60 x 100 cm with 12 mm mesh). I baited traps with dry cat food in perforated canisters and left them over night for a minimum of 15 hours and a maximum of 24 hours. The larger minnow traps were used only in areas with sufficient water to completely immerse the trap opening (minimum of 30 cm). The study area was visually stratified into pool, riffle, glide and step-pool habitat types for a total of 73 units. The entire length of the study area was trapped on each date but the location of individual traps was randomly assigned with the constraint that each of the 11 large pools was sampled on each trapping date. An average of 53 $\pm$ 2.91(SEM) traps was used on each trapping date 37 $\pm$ 2.88(SEM) small and 16 $\pm$ 1.07(SEM) large for an overall average trapping density of 1trap/16 m, or 1 trap/13.4 m in the low gradient reach. . As few salmonids or juvenile sucker were caught using this technique, riffle and glide areas were also randomly electro-shocked at the end of the study period. All fish were identified to species and marked individuals were noted. Fork lengths were taken to the nearest millimeter and weights to the nearest 0.1 gram. Any unmarked fish were assigned a new, individual mark.

On August 13th and 14th, 1999, fish within the original channel were captured by electro-shocking and abundance estimated using the 3-pass removal method (Zippen 1956). All fish were weighted to the nearest 0.1 gram. The final estimate of the number of each species served as a basis for comparison with the population in the new channel in August 2000. All native fish captured in the original channel were released into the mainstem of Pepin Brook, approximately 100 m upstream of the new tributary tie-in. Any fish remaining after the channel had run dry following diversion were also collected. Non-native species were destroyed.

Species densities within the study area were compared to densities in the original channel, nearby systems that contained high quality habitat and densities found in the restoration literature. Comparisons were made in order to determine where the population in Salish Creek lies on a range of habitat qualities.

For Salish sucker, species density (measured as catch-per-unit-effort (fish/trap/hour)), was compared to the same measure in marsh habitat on the Pepin Brook mainstem (Pearson and Healey 2003). No data were used for comparison if the trapping dates were greater than 7 days apart and CPUE calculations included only those from larger traps as only larger traps were used in Pepin Brook. In Pepin Brook, traps were set for approximately 24 hours unless nocturnal hypoxia was a concern in late summer in which case 6-hour daytime sets were used. This analysis does not include the months of January and February due to lack of available data from the main-stem (Pearson and Healey, 2003). Nooksack dace densities were compared to those found in Bertrand Creek, another local tributary to the Nooksack and with a similar species composition to Pepin Brook.

Coho densities were compared to those found within the Salmon River (Giannico and Healey 1998) and from estimates of production for coho from stream restoration initiatives (Keeley et al. 1996). The Salmon River is an important coho-producing river and for the past 17 years, has served as an index of freshwater coho production for the Department of Fisheries and Oceans. The Salmon River watershed is relatively undeveloped and has a similar species composition to Pepin Brook, although it contains no Nooksack Dace.

Cutthroat densities were compared to those expected in natural stream habitat using an equation calculated by Rosenfeld and others (1999), based on average bankfull width, where density = $1.65 \times 1.78 \times bfw^{-1.36}$. Comparisons were also made to post-treatment densities in the restoration literature (Keeley et al. 1996).

For the purpose of data analysis, Salish sucker were grouped into juveniles (<100 mm fork length) and adults (> 100 mm fork length). Coho salmon were categorized as fry (less than 40 mm), parr (41-79 mm) and smolts (greater than 80 mm) according to Adams and Whyte (1990). Cutthroat trout were divided into three size classes (small: <80 mm; medium: 80-110 mm; and large: > 100 mm) which roughly correspond to 0+, smaller 1+ and larger 1-2+ or older year classes (Rosenfeld 2000).

Condition factor, Growth and Survival

Average survival rates of Salish sucker, coho salmon and cutthroat trout were calculated using Jolly-Seber population estimates. Salish sucker growth (mm/day, based on the recapture of marked individuals) and condition factor (weight/length^3) were also calculated and compared to those found on the Pepin Brook main stem.

Results

Immigration and Emigration

Salish sucker, Nooksack dace, coho salmon, cutthroat trout, three-spine stickleback, Pacific lamprey, largemouth bass, American bullfrog and crayfish were all captured within the fish fences during the study period. From September 1999 to August 2000, 5730 individuals were captured in the live traps at the upstream and downstream fences. This includes 4897 fish (and 123 bullfrog tadpoles) found in the traps entering the study area, and 710 fish exiting, for a daily average of 16.5 entering and 2.5 individuals exiting. Based on the trap counts, 2593 fish remained within the Salish Creek study area after one year of colonization (total immigration – emigration – euthanized bass and bullfrogs). (Table 2.0).

With the exception of Nooksack dace, all fish began moving into the study area immediately. Unmarked fish trapped within the study area on September 19th, 1999 indicate that a maximum of 60 Salish sucker, 34 coho salmon and 33 cutthroat trout moved into the study area prior to the operation of the fish fences (Jolly-Seber estimates with 95% confidence limits minus numbers entering through fences: SSU – $29<39>66$; CO – $9<15>43$; CT-$1<2>36$).

Movement into and out of the study area was distributed evenly between the mainstem and headwaters. Approximately 2537 (44%) individuals moved upstream into Salish Creek from Pepin Brook, 2483 (43%) colonized the study area from the headwaters, 306 (5%) left to Pepin and 404 (7%) left to the headwaters. The proportion of sucker, cutthroat and lamprey colonizers leaving the study area to those remaining after one-year were similar (sucker: 1:3.4; cutthroat: 1:3.9; lamprey 1:3.9). This proportion was significantly higher for coho salmon with 1 leaving for every 5.6 coho remaining **(X^2=15.65, d.f.=3, $P<0.001$).**

The study area was colonized by all species in greater numbers than were found in the original channel. The total fish population of the original channel was estimated to be 978 $\pm$ 59 fish where cutthroat trout were numerically dominant followed by largemouth bass, coho salmon and Salish sucker. In contrast, coho salmon was the most abundant species in the study area after one year, followed by cutthroat trout, Pacific lamprey and Salish sucker. No Nooksack dace were found within the original channel. Eighteen dace colonized the study area from the mainstem but only four remained after one year. A total of 211 $\pm$ 11(SE) largemouth bass were found in the original channel compared to 1539 which could have colonized the study area if permitted. It is unknown how many of these individuals would have remained within the study area or moved downstream into Pepin Brook. The 21 bass leaving the study area may have entered from upstream when the fences overflowed or they may have entered from Pepin or upstream prior to the operation of the fish fences. The 11 bass entering from Pepin Brook confirms their presence there although numbers appear to be small. A total 123 bullfrog tadpoles were captured in the fences and destroyed throughout the one-year study period (Table 2.0).

Table 2.0. Population Estimates of Species in the Original Channel in August of 1999 When it Was De-watered and Salish Creek One Year After it Was Watered Using Jolly-Seber Population Estimates When Possible and Fish Fence Data (Total Immigration Minus Emigration).

Species	Salish Sucker	Coho Salmon	Cutthroat Trout	Nooksack Dace	Large-mouth Bass	Stickle-back	Pacific Lamprey	Bull-frogs	*TOTAL*
Original Channel (95% C.L.)	108 ± 8.0	173 ± 9.0	373 ± 16.0	0	211 ± 11.0	53 ± 8.0	60 ± 8.0	0-	978 ± 60.0
Jolly-Seber Estimates	62 (27<N>386) (95% C.L.)	1217 (1004<N> 1431) (SEM)	388 (319<N> 458) (SEM)	NA--	NA	NA	NA	NA	NA
Fish Fence Data									
Entering From Pepin	125	2058	227	18	11	73	25	0	***2537***
Leaving To Pepin	7	129	65	14	11	0	80	0	***306***
Leaving To Headwaters	43	244	105	0	10	0	2	0	***404***
Entering from Headwaters	45	15	441	0	1549	14	296	123	***2483***
Total	**220**	**2446**	**838**	**32**	**1581**	**87**	**403**	123	***5730***
Entering	**170**	**2073**	**668**	**18**	**1560**	**87**	**321**	123	***4897***
Leaving	**50**	**373**	**170**	**14**	**21**	**0**	**82**	0	***710***
Total Remaining	**120**	**1645**	**498**	**04**	**0***	**87**	**239**	0*	***2593***

*euthanized

Immigration and Emigration September 2000 to March 2001

Only three additional Salish sucker moved into the study area from September 2000 to March 19th, 2001 - two from the headwaters and one from the mainstem. All three were greater than 100 mm fork length.

During this period, 58 additional coho entered the study area – fifty-four from the mainstem and 4 from the headwaters. The majority (N=43) were greater than 80 mm. Smolts began to form aggregations in December 2000 in the pool and glide immediately upstream of the downstream fish fence. An estimated 893 entered the downstream traps in large schools between December 21st, 2000 and January 5th, 2001. Because these fish were not permitted to leave from this fence until after December 26th, this number probably includes some double counts. However, 430 smolts did attempt to exit on the 21st of December, and this represents the minimum number for smolt migration. As 59 and 75 coho were found dead in the downstream box on December 22nd and 26th, respectively, the true number of smolts cannot be estimated from those leaving after December 26th, 2000. Smolts ranged in size from 80 to 160 mm.

Cutthroat trout were observed in mixed schools with coho salmon from late December 2000 to early January, 2001. On December 23rd and 26th, and on January 5th, forty-three, one-hundred and eighteen, and thirty-six trout respectively, attempted to move downstream into the mainstem. Sizes ranged from 78 to 174 mm. Fifty-eight cutthroat trout colonized the study area from the headwaters from September 2000 to March 19th, 2001 (< 80 mm: 14; 81-110: 28; >110 mm: 9). Twenty-eight individuals < 80 mm and 41 trout 81-110 mm attempted to move upstream to the headwaters in September 2000 with similar numbers in October and November. As these fish could not be individually identified and size ranges were similar, these may have been the same fish repeatedly attempting to leave to the headwaters. Only 18 trout colonized from the mainstem during these months (< 80 mm: 8; 81-110 mm: 7; > 110 mm: 3).

In August of 2002, after removal of the fish fences, additional gravel spawning habitat was added at three riffle sites in the lower reaches of the study area as part of a continuing management strategy. These areas were electroshocked prior to instream works and a total of 16 unmarked Nooksack dace were found during the fish salvage. It is assumed that these fish entered the study area after the fences were removed some time after March 2001.

Approximately 17,815 bullfrog tadpoles were captured at the upstream fish fences from October, 2000 to March, 2001. Over 13,000 were captured from November 4^{th} to the 16^{th}. During this same period 463 largemouth bass juveniles were captured migrating from the headwaters and 4 adults were emigrating from the study area to move upstream on January 5^{th}, 2001. These adult bass likely entered the study area when the upstream fences overflowed. All bass and tadpoles were euthanized.

Density Comparisons

Using fish fence data, the overall fish density within the study after one year was 0.88 fish/m^2 $\pm$ 0.085 (1SE) and was not significantly greater than densities of 0.75 fish/m^2 $\pm$ 0.06 (1SE) in the original channel ($t=0.25$, d.f.=2, $P=0.25$). In general, species densities within the study area after one year were less than those in the original channel (Figure 2.2). Coho salmon and Pacific lamprey were the only species with significantly higher densities than in the original channel using fish fence data and Jolly-Seber estimates where available.

For all species, the densities within the study area after one year were significantly less than the mean and lowest densities found both in more established systems and in the restoration literature (Figure 2.2). Coho salmon densities of 0.56 fish/m^2 $\pm$ 0.11 (1 S.E) using fish fence data and 0.41 fish/m^2 $\pm$ 0.02 (SE) using J-S estimates were lower than average densities of 0.87 fish/m^2 based on a summary of post-restoration densities found in the literature (Keeley et. al. 1996) and densities of 5-6 fish/m^2 found within the Salmon River. Cutthroat trout densities within the study area using fish fence data and J-S estimates were approximately half of those expected in natural stream habitat using the equation of Rosenfeld and others (1999), based on an average bankfull width 5.5 m (density = $1.65 \times 1.78 \times \text{bfw}^{-1.36} = 0.30$ fish/m^2).

Salish sucker Habitat Use

Salish suckers were almost exclusively trapped only within the pools of the new channel. Juvenile data from Salish Creek ($N=16 < 70$ mm) and adult catches from other pools or riffle habitat ($N=1$), was not analyzed due to the small number captured throughout the study period using trapping or shocking techniques. The two largest pools with the largest volumes had significantly greater densities than all other pools within the study area ($F=15.358$, d.f.=10, $P<0.005$) but were not significantly different from one another (Figure 2.3).

Species Reproduction

Two unmarked young-of–the–year (YOY) Salish sucker left the study area in June and July of 2000, indicating that at least one successful spawning event had occurred. Thirteen male and one female adult coho migrated into the study area in the fall of 1999. The female was found spawned out at the downstream fence shortly afterwards. Visual identification of schooling coho and cutthroat juveniles and subsequent capture of unmarked fingerlings smaller than those that had moved in through the fences indicated that both species spawned successfully within the study area. On July 25^{th}, 65 young-of-the-year stickleback were minnow trapped within the study area indicating that reproduction was also playing a role in increasing numbers of this species.

Condition Factor, Growth and Survival

The average monthly condition factor for the Salish sucker populations found within the study area were significantly greater than those of the Pepin Brook marsh population ($t = -3.198$, $d.f.=7$, $p<0.006$) (Pearson and Healey 2003) (Figure 2.4). These differences appeared to be more pronounced in the summer months when the condition factor within the mainstem marsh was lowest at 1.06×10^{-5} compared to 1.20×10^{-5} in July within the study area.

The condition factor for Salish sucker within the study area decreased slightly from April to May and was highest in the fall and summer months, at the beginning and end of the study period. In contrast, the condition factor within the mainstem marsh tended to decrease gradually over this one-year period (Figure 2.4). There was a significant difference in the condition factor between months within Salish Creek ($F=6.74$, $p<0.005$) and Pepin Brook ($F= 7.22$, $p<0.005$). Due to the small number of fish trapped within Pepin Brook, the winter months of December through February were absent from the comparative analysis.

Condition factor of Salish sucker within the study area, was initially calculated for both males and females as it was expected that size differences would occur beginning with the spawning season in May (due to increased relative mass of gravid females). However, no significant differences were found between the two sexes within the study area ($t=-0.502$, $P>0.05$) so the data were pooled.

Figure 2.2. Species Densities (fish number · m^{-2} + 1 SE) in the Salish Creek Study Area One Year After Construction using Fish Fence and Jolly-Seber Population Estimates, Densities in the Original Channel and the High, Mean and Low Densities of Optimum Habitat and in the Restoration Literature (I—O—I).

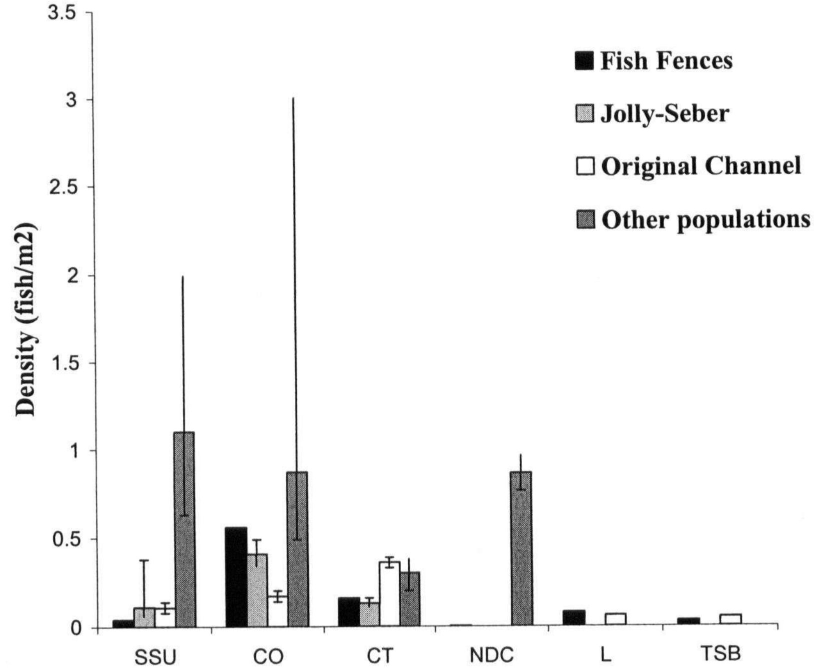
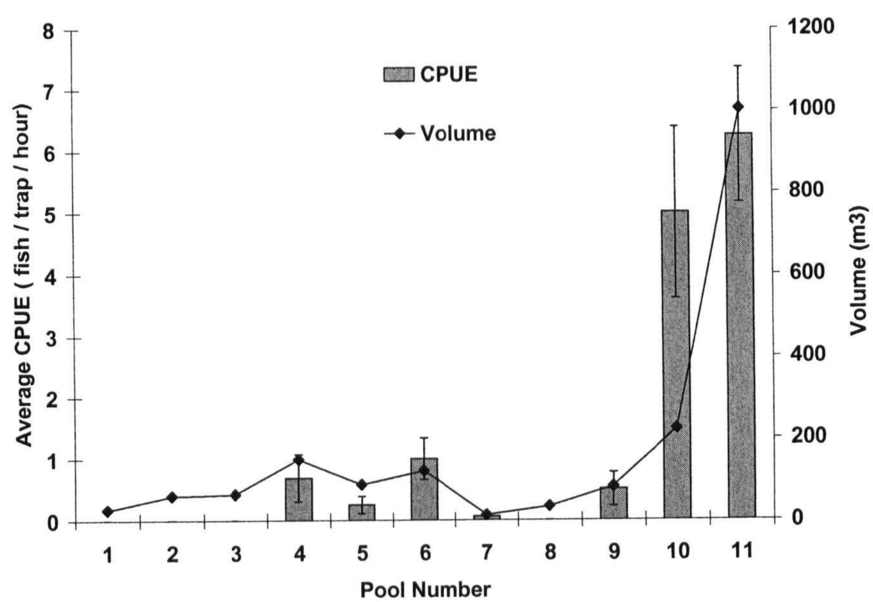


Figure 2.3. Average Catch Per Unit Effort (fish/trap/hour) for Adult Salish sucker and Volume (m3) in Constructed Pools One to Eleven of the Salish Creek Study Area from September, 1999 to August, 2000.



During the growing season from March to October, males recaptured within the study area (N=70), grew an average of 0.124 mm/day $\pm$ 0.019 (1 SEM). Female growth rates within the study area (N=21) were consistently higher than males, for an average of 0.214 mm/day $\pm$ 0.041 (1SEM). The average growth rate of Salish sucker found within the study area was also greater than that in the Pepin Brook marsh with male growth rates of 0.071 mm/day $\pm$ 0.011 (1 SEM) (N=35) and 0.112 mm/day $\pm$ 0.01 for females (N=40)(Pearson and Healey, 2003) (Figure 2.5).

J-S survival estimates for Salish sucker, coho salmon and cutthroat trout were high, Average survival of Salish sucker over the one-year period was calculated at 0.92 $\pm$ 0.03 (1 SEM) and ranged from 0.69 to 1.0. Average coho survival from September 1999 to March 2000 was 0.70 $\pm$ 0.15 (1 SEM) and ranged from 0.20 in February to 1.0 in the fall. Average cutthroat survival during this period was 0.78 $\pm$ 0.14 (1 SEM) and ranged from 100% to 16% at the end of February. The lower survival in February likely reflects emigration between trapping periods from February 26th to March 26th (N=13) and the relatively few colonizers compared to those in the previous trapping period (N=19 versus N=62) rather than mortality within the study area.

Figure 2.4. Comparison of the Condition Factor (g/mm^3) of Salish sucker Found In Pepin Brook Mainstem (Pearson and Healey, 2003) to those within the Salish Creek Study Area.

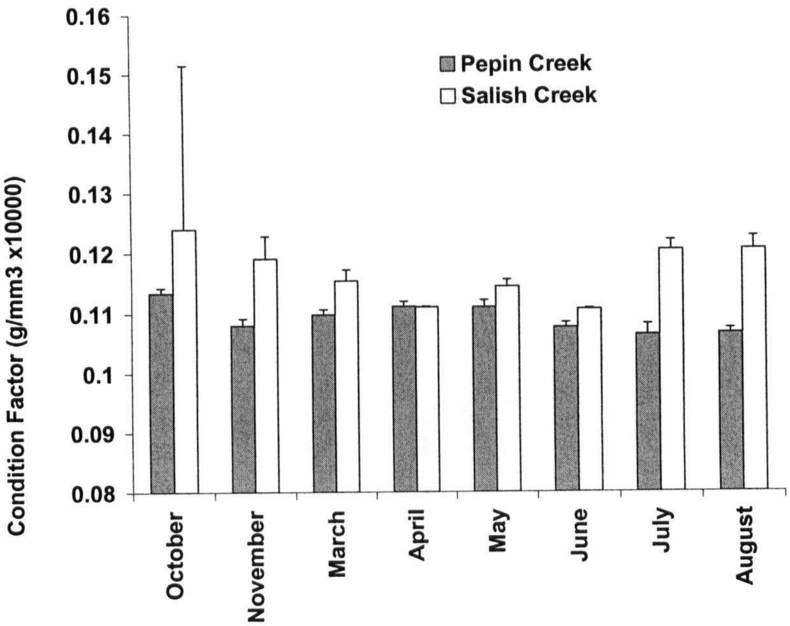
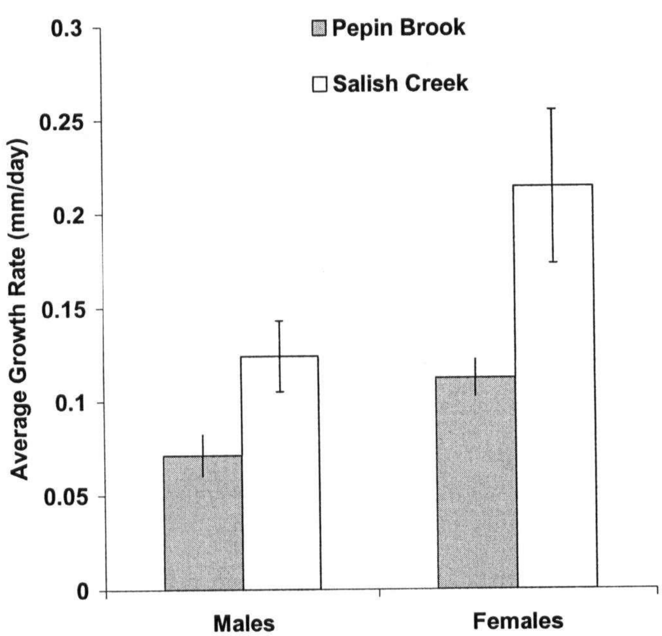


Figure 2.5. Average Daily Growth Rate (mm/day) for Male and Female Salish sucker in the Study Area and Pepin Brook Marsh.



Discussion

All of the fish species commonly found in Pepin Brook and headwaters of Salish Creek actively colonized the new channel of Salish Creek from the moment it was connected. In comparison with the channel it replaced, after one year, the Salish Creek study area contained more of all species except bass, which were prevented from colonizing. Populations of most species exceeded the numbers found in the original channel within the first nine months of the study period. Coho salmon achieved the highest numbers in the shortest period followed by cutthroat trout and Salish sucker. Most coho salmon suckers, dace and stickleback colonized the study area from the mainstem whereas most cutthroat trout and lamprey colonized from the tributary headwaters. Most bass attempted to enter from the headwaters.

During the first year, the new tributary was populated mainly through colonization although suckers, coho salmon, cutthroat trout and sticklebacks were known to have spawned within the study area during the study period. This is consistent with case studies of stream manipulation and disturbance in which migration or re-colonization were identified as the main mechanisms of early stream recovery (Larimore 1955; Niemi et al. 1990; Bryant et al. 1999).

The majority of fish that entered the Salish Creek study area remained there for the duration of the study (86%) with the exception of Ocean-bound coho smolts, spawning Salish sucker and the small number of Nooksack dace colonizers. The ratio of immigration to emigration was similar for all species except coho, which had a higher ratio. The total number of immigrants and emigrants was similar at upstream and downstream fish fences. Previous studies have also reported higher immigration and lower emigration after habitat manipulation (Burgess and Bider, 1980; Gowan and Fausch, 1996). In this case, low emigration may be due to the lack of competition encountered by colonizers inhabiting empty habitat or habitat that is not densely populated. This may simply be a result of the increased quantity of available habitat as the new channel exceeded that of the original by almost three times. Enhanced condition factor and growth of the Salish sucker populations in the study area (compared to populations found within optimum main-stem habitat), and the high survival rates of coho, cutthroat and Salish sucker, indicate that habitat quality was also high in the new channel.

The target species that returned most rapidly and in highest densities included the two most common and widespread species, coho salmon and cutthroat trout. The observed rapid rate of colonization of the study area by coho salmon and cutthroat trout is consistent with salmonid life history strategies, which support highly mobile populations that exploit newly accessible habitats (Bryant et al. 1999). Our findings support a review by Niemi et al (1990), which found that immigrant species densities reflect the relative densities of the greater fish community from surrounding source populations, as well as species life history characteristics including mobility.

Salish sucker and Nooksack dace had the smallest densities within the study area and were also the least common species upstream and downstream of the study area. Salish sucker home ranges average approximately 170 m^2 of channel with longer movements known to occur during the spawning season (Pearson and Healey 2003), when the majority of movement into and out of the study area took place. Although the largest known Canadian population of sucker is found within Pepin Brook approximately one kilometer upstream of the tributary tie-in (Pearson, 1998), few fish (N=10) colonized the study area from this distance. As the diversion occurred in August, shortly after completion of Salish sucker spawning, this may also have increased the recovery time relative to the salmonid species whose fry would have emerged several months prior to diversion. This is consistent with previous studies in which the timing of disturbance relative to spawning season was related with time to recovery of fish densities (Detenbeck et al. 1992). However, there was no pulse of juvenile suckers moving into the study area for the entire sixteen-month study period. Thus, it may be reasonable to assume that sucker explore less than coho and cutthroat. Coupled with their lower overall abundance this would account for the limited colonization.

Further, unlike coho salmon and cutthroat trout species, where juvenile dispersion accounted for the majority of colonization, few young-of–the-year sucker were captured throughout this study period. This is consistent with other studies which captured very few YOY Salish sucker and is why little is known of juvenile sucker ecology (Inglis 1992; Pearson 1998; Pearson and Healey, 2003). Dispersion mainly by adults would increase the relative recovery time of the Salish sucker due both to the smaller available number of colonizers of this endangered species and the limitations imposed by longer migrations primarily by adults during spawning. As few Salish sucker colonized the study area following the initial one-year period, maturation of additional young-of–the-year within the mainstem and study area may be required, followed by subsequent spawning migrations and additional spawning in the study area itself. Thus, it will take longer for suckers to establish higher population densities within the tributary.

Trapping of the majority of sucker within two of the deepest and largest volume pool areas within the study area is consistent with the findings of recent studies on habitat use (Pearson and Healey 2003). Pearson and Healy (2003) found that adult Salish sucker were trapped mainly within areas of deep continuous pool with depths over 0.70 m. Only one sucker was trapped within habitat other than pools throughout the one-year study period.

The low numbers of Nooksack dace colonizers, may be due in part to the relative scarcity of source populations in general and in relation to the location of the new stream habitat, together with known Nooksack dace ecology and placement of the fish fences. No dace are found above the tributary tie-in and the closest known population in Pepin Brook is small and almost 1 km downstream (Pearson, 1998). Pearson (2003) found that the majority of Nooksack dace remained within a few metres of their initial capture location for periods of up to one-year indicating that this species does not explore widely. Although recovery literature has found that cyprinids from headwater regions are well adapted to colonize variable environments under stressful conditions (Niemi et al. 1990) the relatively stable hydrology of Pepin Brook may make an adaptation of this kind unnecessary. Like other small benthic fishes that occupy riffle habitats, characteristics of these populations may be determined more by recruitment, growth and survivorship and much less by immigration and emigration (Coon 1987).

A number of dace (N=16) were also found in the study area in August 2002, during a fish salvage prior to placement of additional spawning gravel. These dace entered the study area from Pepin Brook after the removal of the fences in March of 2001. The small number of dace colonizers during the study period may have been due to possible selectivity of the fish fences against this species. As dace are riffle specialists, they may have encountered the fish fences and surrounding pool habitat and left before capture. This does not explain why those dace that did colonize the study area, emigrated shortly afterwards. This may be due to a lack of riffle habitat with suitable substrate in the immediate vicinity of the downstream fish fence or perhaps to the presence of known predator species such as cutthroat trout and coho salmon. He and Kitchell

(1990) experimentally demonstrated the importance of the indirect effect of predators on prey fish in small ponds by increasing emigration rates of cyprinids. As no dace were found in the original channel, however, the small number of this species within the study area represents a gain in species richness.

Enhanced coho densities relative to the original channel may also be partially explained by improved habitat conditions which discouraged emigration of juveniles. Coho in the original channel were likely limited by the lack of pool habitat and streambed instability. In the original channel, most coho salmon (and Salish sucker) were found in the one large off-channel pool as well as the few small deeper pool areas. Construction of the new stream habitat was designed to overcome these limitations. The increased density of coho salmon relative to the densities in the original channel suggests that the rehabilitation structures resulted in greater supportive capacity for coho. This has been demonstrated in other studies which found that habitat structure may affect community recovery, with increased coho density or survival following enhancement of instream cover and/or pool quantity (Canton et al. 1984; Cederholm et al. 1988; Nickelson et al. 1993; Peterson and Bayley 1993; Quinn and Peterson 1996; Cederholm et al. 1997; Quinn and Kwak 2000).

Lower densities of cutthroat trout within the study area relative to coho salmon and the original channel may also be partially influenced by habitat structure. The low pool to riffle ratio in the original channel appeared to be more conducive to cutthroat trout numbers than to coho salmon. Further, as the majority of trout colonization occurred from above the study area, the large number of exotic predator species in the Salish Creek headwaters compared to Pepin Brook, may also limit trout populations.

Habitat manipulation may also positively affect survival of fish that do not enter the study area. Although survival in response to habitat enhancement was not measured directly in this study, manipulation may have increased survival at a larger scale according to Gowan and Fausch (1996). If immigrants left unsuitable habitat and had not discovered the new channel, they may have died. This is especially true for the juvenile fish entering the stream as they are more vulnerable to the elements and predation than adults. By dispersing from conditions of relatively high population density near hatching and emergence areas, fish that migrate may find the space and food they need to avoid competition and grow, thus increasing size to avoid vulnerability to predators (Northcote 1984). Alternatively, if the habitat immigrants left was favorable, subordinate individuals could then fill these locations, thereby increasing their survival. Both processes would entail more than the simple redistribution of individuals but would also result in an increase in total fish biomass within the watershed.

Although, this project has successfully created additional habitat for a greater number of fish then that which existed prior to diversion, and hence there is no net loss of fish, it has clearly not reached the density levels of well-established main-stem habitat. The observed rapid rate of colonization of the study area by naturally occurring anadromous salmonids has positive implications for colonization of restored habitats by these populations and to watersheds where populations have been locally extirpated. However, the same may not be said for freshwater species with limited home ranges and numbers. Recovery seemed to be affected by the distance to and availability of a source of colonizers.

The small number of native colonizers after the first year indicates that Pepin Brook and the Salish Creek headwaters may not yet have the number of colonizers needed to inhabit the additional area in higher densities. With the exception of the non-native bass and bullfrogs, numbers of colonizers decreased substantially after the first year of colonization. This has important implications for the invasion of natural systems by exotic species, which are difficult to extirpate once they have been introduced.

As illustrated by Nooksack dace populations in this study, source populations must be available for colonization, life history characteristics must be compatible and habitat must be suitable. In these cases, restoration efforts on their own would be insufficient in increasing species survival but must be accompanied by conservation efforts as a mechanism of ensuring that suitable habitat and source populations remain. With limitations on available funds or sites for restoration, non-random restoration practices which restore only habitat that is adjacent to those occupied by the target species should be emphasized where possible (Huxel and Hastings 1999). This also accentuates the need for regional restoration plans that acknowledge the often patchy distributions and possible extirpation of endangered species.

Chapter 3:

Fish Colonization of a Newly Diverted Channel In Relation to Discharge, Temperature and Season

Keywords: British Columbia, movement, restoration, Salish sucker, Nooksack dace, Coho salmon and cutthroat trout

Introduction

Stream dwelling organisms depend largely on the seasonal variation in hydrologic conditions to complete their life cycles successfully. Three inter-related stream variables that are known to have major effects on temporal variation, abundance and distribution of fish, are temperature, flow regime and season (Schlosser 1990 and 1995; Richter et al. 1996; Modde and Irving 1997; Giannico and Healey 1998; Snedden et al. 1998; Bjorgo et al 2000; McKinney et al. 2000; Workman et al 2001). High temperatures, for example, can be acutely lethal, promote disease caused by induced stress, adversely impact spawning and reproductive success, and impede growth and migrations (Armour et al. 1991). Modifications to flow regimes can affect chemical, physical and thermal characteristics of stream habitats and, thereby indirectly affect the structure and function of stream ecosystems (Richter et al 1996). High discharge events may play an important role in organizing populations of fish in small streams as they provide unique opportunities for movement to other stream locations (Schlosser 1995; David and Closs 2002), can displace smaller fish (Cederholm et al. 1997), or increase movement as fish seek refuge from higher velocities (Giannico and Healey 1998). A variety of adult and juvenile fish also often show distinct seasonal pulses such as spawning migrations (Schlosser 1995; McDowall, 1995) or movement to over-wintering stream habitat (Brown and Hartman, 1988). Consequently, responses of fish to changes in the flow regime, stream temperature or season, may alter population dynamics (Schlosser, 1985; 1990; Heggenes 1989; Heggenes et al. 1991; Richter et al. 1996).

Fish species differ greatly in their ability to cope with environmental variability (Starett 1951; Larimore et al. 1959; Schlosser 1985). Both juvenile and adult fishes can be affected. In a study of a warm water fish assemblage Schlosser (1985) found that stream flow and temperature had a greater effect on the abundance, species richness and species composition of juveniles than adults. Giannico and Healey (1998) have also shown that a moderate increase in winter flow resulted in increased emigration of juvenile coho salmon but that downstream movement decreased as winter temperatures decreased. Among adult fishes, Modde and Irving (1997) found that movement of male razorback suckers to spawning areas was influenced primarily by discharge. By contrast, Workman et al. (2001) found that upstream migration of adult steelhead that was relatively unaffected by stream flow increased with increasing water temperatures above a movement threshold. Temperature and discharge in one season can also affect movement and distribution in subsequent seasons. For example, an increase in both water temperature and river stage in the spring was associated with greater median movement rates and larger home ranges of spotted gar than during the fall, winter and summer months (Snedden et al. 1998).

In this chapter I examine the effect of temporal change in discharge and temperature on the colonization of fish in a newly constructed stream channel, Salish Creek in Abbotsford, B.C. Salish Creek was watered and connected to potential upstream and downstream sources of colonists in August 1999. A variety of fish species began to invade the new habitat immediately including coho salmon (*Oncorhynchus kisutch*), cutthroat trout (*Oncorhynchus clarki*), largemouth bass (*Micropterus salmoides*) and the endangered Salish sucker (*Catostomus sp.*). I was able to monitor colonization, discharge and temperature in the newly constructed channel on virtually a daily basis from September 1999 to August 2000. By means of these observations, I attempted to evaluate the role of discharge, temperature and season in regulating the structure of the fish community. It was expected that movement would occur primarily during periods of elevated discharge, especially downstream movement of juveniles; and that temporal variation in temperature would affect each species according to life history characteristics and tolerance levels. For instance, largemouth bass, a non-native warm water species would be expected to move more during the summer months with warmer temperatures than salmonid species with lower optimum temperature regimes.

Study Area

See Chapter 2.

Methods

Fish Capture and Handling

See Chapter 2.

Data Analysis

Seasonal Movement Patterns

Seasonal movement patterns were assessed by summing immigration and emigration over periods of time that reflected different seasons. For this analysis, data gathered from the fish fences was divided into four seasons corresponding to fall (September – November), winter (December - February), spring (March - May) and summer (June – August). Chi-squared analyses for each species, was undertaken to determine if there was a significant difference in the number of each size class that colonized the study area over the one year period between and among seasons and locations.

Temperature and Discharge Measurements

A staff gauge was installed in a pool just upstream from the study reach on February 14th, 1999 and a second was installed in the most downstream side-pool of the study area on November 15th, 1999. With the assistance of Columbia Bitulithic staff, we recorded water levels to the nearest centimeter on 305 days at the upstream site and 225 days at the downstream site. We estimated missing values using staff gauge readings from the previous and next day combined with precipitation records from Environment Canada (1999 - 2000). For example, if no precipitation had occurred during a recording period and flow readings were the same on the dates following and preceding a date with a missing value, the same reading would be interpolated for the missing value. Water velocity and cross sectional area were measured at a stable cross section over a wide range of flows throughout the study period. Water velocities were measured to the nearest 0.01 m/s with a Marsh-McBirney Model 2000 flow meter at a depth equal to 0.6 times the total water-column depth. Cross-section was calculated by multiplying the measured channel width by depth measurements recorded every 15 cm across the stream channel. Stream discharge was then calculated by multiplying cross-section (m^2) by velocity. Daily discharge was estimated from the curve of discharge against staff gauge.

Two temperature data loggers were installed in the tributary. One was located at the lower fish fence and one at the headwaters downstream of the pond outlet. Temperature data were also used from the Pepin Brook mainstem at 0 Avenue from October 19th, 1999. These loggers recorded temperatures at one-hour intervals. Regular temperature readings were also taken at the upstream and downstream fish fences with a Centigrade mercury thermometer. The logger at the downstream fish fence stopped recording on April 2^{nd}, 2000 due to equipment malfunction. Temperature was estimated at this location from April 3^{rd} to August 31^{st}, 2000 using pond outlet temperatures and regression equation T (adjusted) = 3.106 + (0.714 x T(pond outlet)) (R^2=0.9632).

To determine if there was a significant relationship between movement, temperature and discharge, univariate and multivariate ANOVA was performed using SYSTAT 9 software (2000). The daily number of coho salmon, cutthroat trout or Salish sucker by size class, entering or leaving the study area in each direction, at each of the fish fences served as the dependent variables according to the model:

Species Movement by Size class (1…3) = CONSTANT + season + discharge + temperature + season*discharge + season*temperature + discharge*temperature + error

Season was treated as a categorical grouping factor due to its possible effect on movement patterns. Discharge and temperature were treated as continuous variables. Largemouth bass were included in the analysis at the upper fences only.

Univariate analysis was used to test for within size class differences in movement with a separate test of the effect of each variable/factor/interaction on individual size classes. The univariate F-test for the movement for each size class and temperature effect, for example, is computed from the hypothesis mean square divided by the error mean square (SYSTAT 9 2000). Between size class responses were tested using multivariate statistics and the Pillai's trace F-statistic (SYSTAT 9, 2000). Dependent variables (size classes of each species) are grouped, with separate tests for the effect of each variable in the ANOVA model, as well as tests of all interactions between those factors. Multivariate tests with a significant F-statistic (alpha < 0.05) indicate that the differences between subject means is large compared to the within subjects means.

The movement data did not satisfy the ANOVA assumption of compound symmetry due to the presence of a large number of zeroes on the days when no colonization occurred. However, because the single-degree-of-freedom polynomial contrasts, which do not require compound symmetry, were in agreement with the F-statistic and associated probability derived from the univariate analysis, its use was justified (SYSTAT 10 Statistics I, 2000). A preliminary test for homogeneity of slopes (that there is no significant interaction between the covariate(s) temperature and discharge, and the treatment between seasons) was performed prior to the ANOVA hypothesis test. The general linear model was used for this purpose according to SYSTAT 10 (2000). A plot of the residuals versus the estimated variables indicated that the data for the movement to Pepin Brook, failed to meet the homogeneity assumption. However, as ANOVA is relatively robust, particularly when groups are of equal sample size as in this case, failure to meet this assumption is not fatal to the analysis (Garson 2001).

Results

Statistical results using univariate and multivariate ANOVA did not consistently demonstrate a significant effect of season, temperature and/or discharge across species, sizes, location or direction of movement (Tables 3.0, 3.1 and 3.2). Seasonal effects were significant most often followed by discharge and temperature. However, these main effects must be interpreted with caution due to the large number of significant interaction effects.

Seasonal Movement

The majority of movement into the study area by all species took place during the spring months while most emigration occurred during the spring and summer (Figures 3.0 and 3.1). Chi-squared analysis of species movement indicates that immigration and emigration differed significantly between seasons for sucker, coho and cutthroat at each fence location with the exception of sucker moving to Pepin (N=7) (X^2=7.3, d.f.=3, P>0.05).

Coho salmon

A total of 2434 coho were captured in the traps. Overall movement of coho was significant by size class (X^2=2368, d.f.=2, <0.001). The majority were parr (N=1935), 41-79 mm in size (Figure 3.0). Almost all of these (1777), entered from Pepin Brook (X^2 = 1945, d.f. 1, P< 0.001).

A total of 150 parr left during the study period. Most of these left during spring (N=67) and summer (N=79) (X^2=137, d.f.=3, P<0.001) and most moved to the headwaters (N=137)(X^2=103, d.f.=1, P<0.001) (Figure 3.1). Recapture of marked coho indicated that the parr moving upstream were mainly parr that had entered the study area from Pepin in May and June.

The majority of the 112 smolts entering the study area came from Pepin Brook (N=103) (X^2=79, d.f.=1, P<0.001). Most immigration occurred during the fall (N=50) rather than the spring (N=37) with few entering during the summer (N=5) (X^2=42, d.f.=3, P<0.001).

A total of 270 smolts left Salish creek compared to the 112 that entered so, presumably, many represent growth of parr to smolt size. Most left in spring (N=175) and summer (N=74) and seasonal variation was highly significant (X^2=257 df=3, P<0.001). Significantly more parr and smolts emigrated to the headwaters (N=234) than to Pepin (N=131) and the interaction between season and direction of movement of émigrés was significant (X^2=14, d.f. 3, P<0.01) mainly due to the relatively large number of smolts moving to headwaters in summer (N=131)(Figure 3.1). Smolts moving to Pepin were significantly larger than those moving to the headwaters (t-test = -8.155, P<0.005)(Table 3.3).

Cutthroat trout

A total of 819 cutthroat trout were captured in the traps. The majority were 0+ (N=549), less than 80 mm in size; trout 81-110 mm (1+) and > 110 mm (1-2+) were significantly less abundant (163 and 107 respectively) (X^2=425, d.f.=2 ,P<0.001).The majority of all movement occurred in the spring (N=464) and summer (N=158) months (X^2=450.3, d.f.=3, P<0.001). Immigration of 0+ trout from upstream and downstream sources (X^2 = 150, d.f. 1, P< 0.001) were both highly significant with most entering from upstream (N=324). In contrast, 120 1+ trout parr migrated into Salish Creek during the study period, over half of these (N=67) entering from Pepin Brook (Figure 3.0). Seasonal variation in immigration (X^2 = 63, d.f. 3, P< 0.01) and variation in immigration from upstream and downstream sources (X^2 = 52, d.f. 1, P< 0.01) were both significant.

Table 3.0. Summary of F and P Values for Univariate ANOVA Examining the Effect of Season, Temperature and Discharge on Upstream Movement of Salish sucker, Coho salmon and Cutthroat trout from September 1999-2000 in Salish Creek, British Columbia. Significant Values in Bold (critical value: P<0.05).

Upstream From Pepin Brook									
		Species							
		Salish sucker		*Coho salmon*			*Cutthroat trout*		
Variable Entered		**< 100 mm**	**> 100 mm**	**< 40 mm**	**41-79 mm**	**> 80 mm**	**< 80 mm**	**81-110 mm**	**> 110 mm**
	F	0.626	1.683	0.936	2.35	**2.782**	**2.837**	0.541	0.540
Season(S)	**P**	0.599	0.171	0.424	0.073	**0.042**	**0.039**	0.654	0.655
	F	0.543	1.074	1.652	2.294	**8.108**	1.521	0.241	0.90
Temperature(T)	**P**	0.462	0.301	0.200	0.131	**0.005**	0.219	0.624	0.344
	F	0.227	**3.319**	1.32	0.083	0.166	0.116	1.65	0.204
Discharge(D)	**P**	0.634	**0.07**	0.253	0.958	0.684	0.734	0.2	0.652
SXT		0.577	1.609	0.205	**6.028**	**2.978**	1.6	1.781	0.428
		0.630	0.188	0.891	**0.001**	**0.032**	0.19	0.151	0.733
SXD		0.150	**2.898**	**3.531**	1.092	2.258	1.881	2.563	0.614
		0.929	**0.036**	**0.015**	0.353	0.082	0.133	0.055	0.607
TXD		0.296	1.394	**4.654**	1.313	0.118	1.945	0.096	0.125
		0.587	0.239	**0.032**	0.253	0.732	0.164	0.83	0.724
Upstream to headwaters									
	F	**5.209**	**6.533**	NA	**7.199**	**5.989**	2.431	0.772	**4.545**
Season(S)	**P**	**0.002**	**0.000**		**0.000**	**0.001**	0.66	0.510	**0.004**
	F	5.116	**4.118**		0.690	0.752	0.241	0.583	2.846
Temperature(T)	**P**	0.025	**0.043**		0.407	0.387	0.624	0.446	0.093
	F	**4.612**	1.502		0.044	0.006	1.35	0.338	2.588
Discharge(D)	**P**	**0.033**	0.222		0.834	0.941	0.246	0.562	0.109
SXT		1.603	**5.218**		**9.265**	**5.602**	**3.975**	0.578	1.503
		0.189	**0.002**		**0.000**	**0.001**	**0.009**	0.63	0.214
SXD		**15.03**	**4.271**		0.344	**2.982**	0.539	0.211	**9.478**
		0.000	**0.006**		0.794	**0.032**	0.656	0.888	**0.000**
TXD		**9.378**	3.549		0.223	0.990	1.874	0.271	**7.553**
		0.002	0.061		0.637	0.321	0.172	0.603	**0.006**

Table 3.1. Summary of F and P Values for Univariate ANOVA Examining the Effect of Season, Temperature and Discharge on Downstream Movement of Salish sucker, Coho salmon and Cutthroat trout from September 1999-2000 in Salish Creek, British Columbia. Significant Values in Bold (critical value: P<0.05).

		Salish sucker		*Coho salmon*			*Cutthroat trout*		
Downstream To Pepin Brook		*Species*							
Variable Entered		**< 100 mm**	**> 100 mm**	**< 40 mm**	**41-79 mm**	**> 80 mm**	**< 80 mm**	**81-110 mm**	**> 110 mm**
Season(S)	**F**	NA		NA	0.391	0.233	0.025	6.769	2.013
	P	(N=7)		(N=1)	0.532	0.637	0.876	0.100	0.157
Temperature(T)	**F**				2.721	1.462	0.407	1.622	**9.139**
	P				0.100	0.228	0.524	0.204	**0.003**
Discharge(D)	**F**				**5.628**	**7.241**	0.407	1.622	**9.139**
	P				**0.018**	**0.008**	0.524	0.204	**0.003**
SXT					0.225	0.007	0.065	**6.026**	0.638
					0.636	0.933	0.799	**0.015**	0.425
SXD					0.014	0.286	**4.545**	3.110	**4.771**
					0.904	0.593	**0.034**	0.079	**0.030**
TXD					**14.38**	**2.397**	**9.403**	0.072	**6.993**
					0.000	**0.001**	**0.002**	0.789	**0.009**
Downstream from headwaters									
Season	**F**	2.249	0.394	NA			0.576	0.723	1.685
	P	0.083	0.757	(N = 15)			0.631	0.539	0.170
Temperature	**F**	0.509	0.609				0.017	0.041	0.847
	P	0.476	0.436				0.897	0.840	0.358
Discharge	**F**	0.546	0.017				0.058	0.395	0.51
	P	0.460	0.295				0.810	0.529	0.476
SXT		2.001	0.970				**3.243**	0.495	0.324
		0.114	0.407				**0.022**	0.686	0.808
SXD		0.606	0.069				0.099	0.564	0.290
		0.612	0.976				0.961	0.639	0.833
TXD		0.782	0.027				0.028	0.370	0.348
		0.377	0.871				0.866	0.543	0.556

Table 3.2. Summary of F and P Values for Multivariate ANOVA Examining the Effect of Season, Temperature and Discharge on Upstream and Downstream Movement of Salish sucker, Coho salmon and Cutthroat trout from September 1999-2000 in Salish Creek, British Columbia. Significant Values in Bold (critical value: P<0.05).

	Species					
	Salish sucker		**Coho salmon**		**Cutthroat trout**	
	Upstream From Pepin					
Variables	**F**	**P**	**F**	**P**	**F**	**P**
S	1.118	0.351	**1.966**	**0.041**	1.306	0.230
T	0.741	0.478	**3.796**	**0.011**	0.834	0.476
D	0.358	0.699	0.339	0.747	0.139	0.691
SXT	1.058	0.387	**3.109**	**0.001**	1.237	0.269
SXD	1.516	0.171	**2.210**	**0.020**	1.778	0.069
TXD	0.789	0.456	2.004	0.114	0.716	0.543
	Upstream to Headwaters					
S	**4.650**	**0.000**	**4.917**	**0.000**	**2.593**	**0.006**
T	2.921	0.056	0.523	0.593	1.202	0.309
D	2.298	0.102	0.022	0.978	1.390	0.246
SXT	**3.470**	**0.002**	**5.267**	**0.000**	**2.034**	**0.033**
SXD	**7.016**	**0.000**	1.493	0.178	**3.203**	**0.001**
TXD	**4.677**	**0.010**	0.499	0.608	**3.181**	**0.024**
	Downstream to Pepin					
S	NA	NA	0.627	0.598	**3.059**	**0.029**
T	NA	NA	1.077	0.359	**2.608**	**0.052**
D	NA	NA	**2.792**	**0.041**	**3.732**	**0.012**
SXT	NA	NA	0.610	0.609	2.401	0.068
SXD	NA	NA	0.250	0.861	**4.715**	**0.003**
TXD	NA	NA	**5.789**	**0.001**	**4.413**	**0.003**
	Downstream from Headwaters					
S	1.242	0.283	1.735	0.111	1.159	0.318
T	0.610	0.544	0.130	0.878	0.286	0.836
D	0.291	0.747	3.561	0.030	0.271	0.846
SXT	1.327	0.222	**3.790**	**0.001**	1.370	0.191
SXD	0.328	0.922	**2.293**	**0.034**	0.366	0.951
TXD	0.418	0.658	2.058	0.130	0.208	0.890

The majority of the 78 1-2+ trout entering the study area came from the headwaters (N=45). Most immigration occurred during the winter (N=51) rather than the spring (N=16) with few entering during the summer (N=1) (X^2=74, d.f.=3, P<0.001).

A total of 43 1+ and 29 1-2+ trout left during the study period and a similar number of both age classes moved to the headwaters and to Pepin (Figure 3.1). Most of these left during spring (N=13) and summer (N=20) (X^2=15, d.f.=3, P<0.01).

Salish sucker

A total of 224 Salish sucker were captured in the traps. The majority were > 100 mm (N=180) (X^2=83, d.f.=1, P<0.001). Seasonal movement patterns did not differ significantly between size classes (X^2=7.6, d.f.=3, P>0.05) but most movement occurred in the spring (N=131) and summer (N=56) months (X^2=153, d.f.=3, P<0.001). The majority of sucker entered the study area from Pepin Brook (N=125) (X^2 = 34.3, d.f.=1, P<0.001) and were > 100 mm (N=137) (X^2 = 59.0, d.f. 1, P<0.001). The dye marks on ten of these sucker, indicate that they moved in from the mainstem marsh, located approximately 1 km upstream from the confluence of Pepin Brook and Salish Creek (Pearson and Healey 2003).

Immigration of <100 mm sucker occurred mainly from the headwaters (N=28) while sucker > 100 mm entered mainly from Pepin Brook (N=117) (Figure 4). The interaction of size and location was significant (X^2 = 56.7, d.f. 1, P<0.001). In contrast to coho salmon and cutthroat trout immigration, the majority of Salish sucker movement into the study area was by adults. A total of sixteen juveniles less than 70 mm were captured in the fish fences throughout the one-year study period. Among all sucker large enough to sex, males (91) outnumbered females (33) by approximately 3 to 1.

Forty-nine sucker left the study area throughout the one-year period. Most were > 100 mm leaving to the headwaters (N=40) (Figure 3.1). These sucker were predominantly adults of spawning size and in spawning condition. Most emigration took place during the spring (N=17) and summer (N=29) (X^2=45, d.f.=3, P<0.001) (Figure 3.1).

Figure 3.1. Coho salmon, Cutthroat trout and Salish sucker Entering The Salish Creek Study Area versus Season.

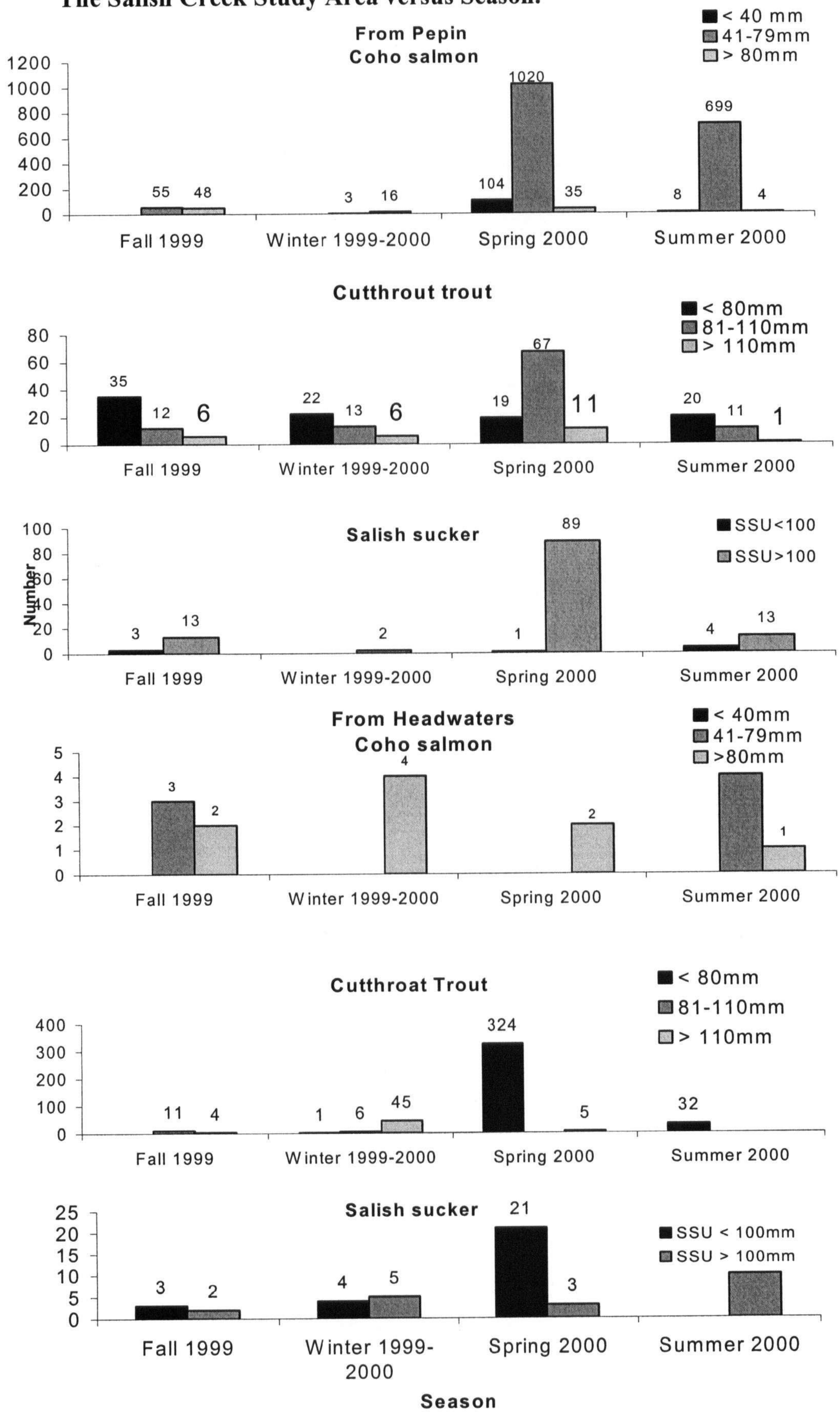
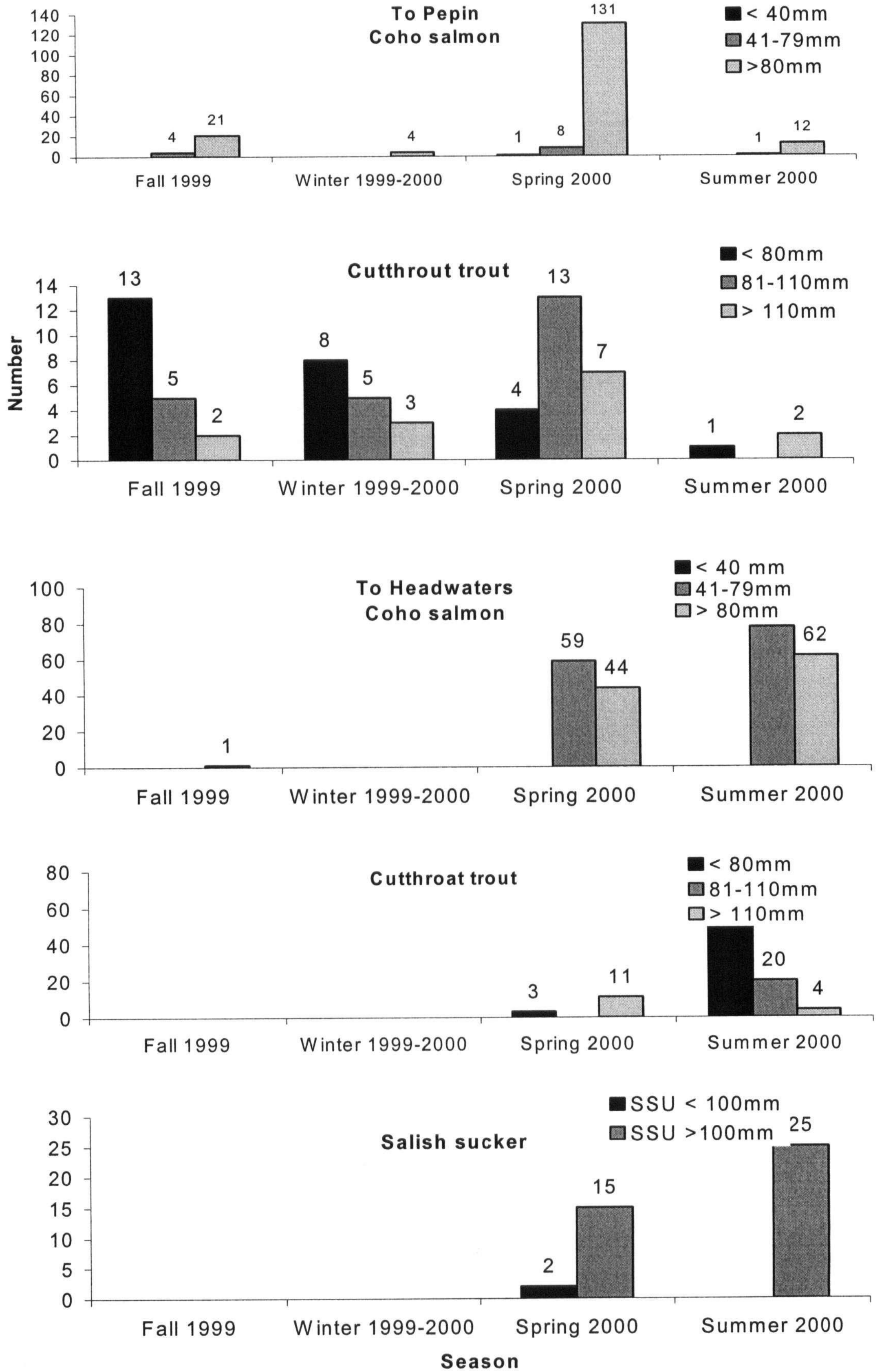


Table 3.3. Mean Length of Coho salmon Parr and Smolts Migrating

Month	To Pepin	Mean Length (mm +SEM)	Size Range	To Headwaters	Mean Length (mm+SEM)	Size Range
November	25	94.9 (3.6)	74-130	0		
December	3	122.5(1.0)	122-123	0		
February	2	86.5(1.00)	86-87	0		
March	7	99.4(11.1)	69-150	0		
April	17	125.7(4.2)	87-155	7	142.9(4.8)	134-169
May	64	114.7(4.5)	71-174	96		
June	13	89.3(5.6)	69-152	131	78.1(1.2)	55-151
TOTAL	**131**	**109(2.7)**	**69-200**	**234**	**80.9 (1.5)**	**55-166**

Figure 3.2. The Number of Coho salmon, Cutthroat trout and Salish sucker Leaving the Study Area versus Season.



Discharge

Available stream discharges ranged from 2.2 x 10^{-2} m^3/s to 18.28 x 10^{-2} m^3/s over the one-year study period. Low and mid-range discharges were available more frequently than higher discharges (Figure 3.2).

Coho salmon

Most coho movement occurred over a very short time interval with the exception of > 80 mm coho from Pepin Brook (Figures 3.3 to 3.5). For instance, over the one year intensive sampling period 64% (N=72) of movement of < 40 mm coho occurred over 12 days from April 4^{th} to 15^{th}, 2000 and 76% (N=1476) of coho 41-79 mm moved from May 1^{st} to 31^{st}, 2000 (Figure 3.5). During shorter time intervals, many of these fish appeared to increase movement during periods of high discharge (Figure 3.5). This relationship was not consistent however with fish fluxes occurring during periods of both high and low flows.

Both univariate and multivariate ANOVA indicate a significant effect of discharge on downstream movement to Pepin Brook with a significant interaction effect between temperature and discharge. Discharge was also significant when all size classes were considered for coho moving downstream from the headwaters (Tables 3.1 and 3.2). At this location there was also a significant interaction with both season and temperature. Thus the effect of discharge may vary with stream temperature and season.

Cutthroat trout

In general, cutthroat trout movement occurred over longer time intervals than coho salmon with the exception of trout moving in from the headwaters (Figures 3.6 to 3.8). There was a significant relationship between discharge and downstream movement for trout > 110 mm to Pepin with significant temperature and season interaction effects (Table 3.1). These effects were also significant when all size classes were considered (Table 3.2). Therefor the effect of discharge on trout movement to Pepin changes with seasons and temperature.

It was common for a large number of 0+ trout to move downstream from the headwaters during or shortly after a rain event (Figure 3.8). During shorter time intervals, there appeared to be fluxes of trout < 80 mm and > 100 mm from Pepin during periods of higher discharge. However, there was no significant relationship between discharge and movement at this location.

Figure 3.3. Frequency Histogram of Available Discharges ($x10^{-2}$ m^3/s) n Salish Creek From September 1999 to 2000.

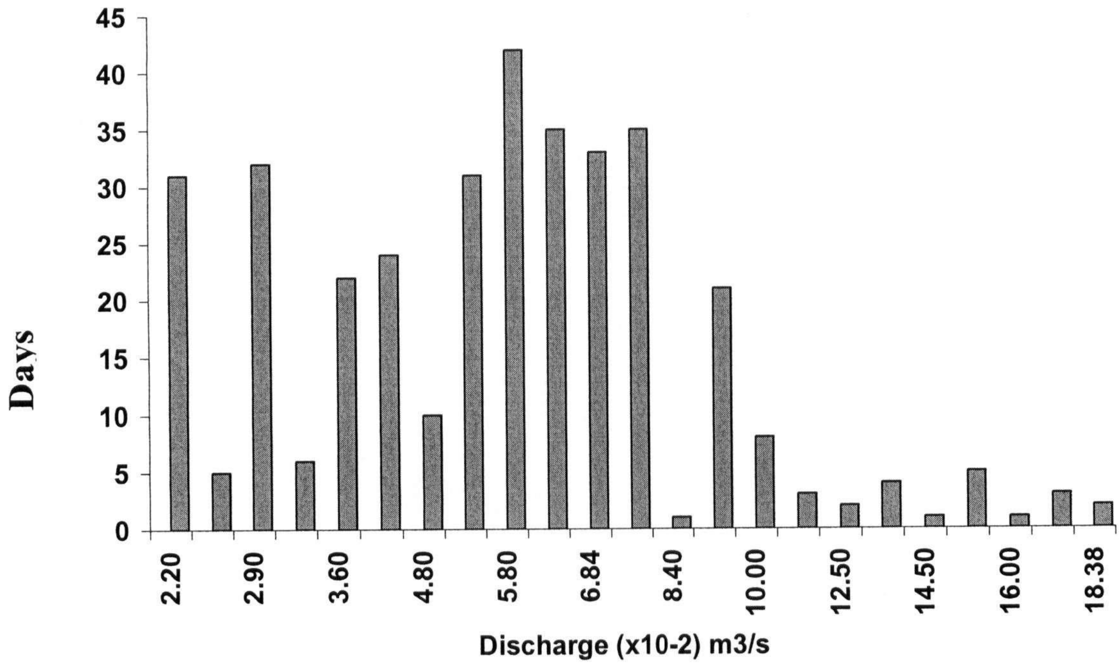


Figure 3.4. Coho salmon Entering the Study Area Upstream From Pepin Brook and Discharge (10^{-2} m^3/s) from September 1999-2000.

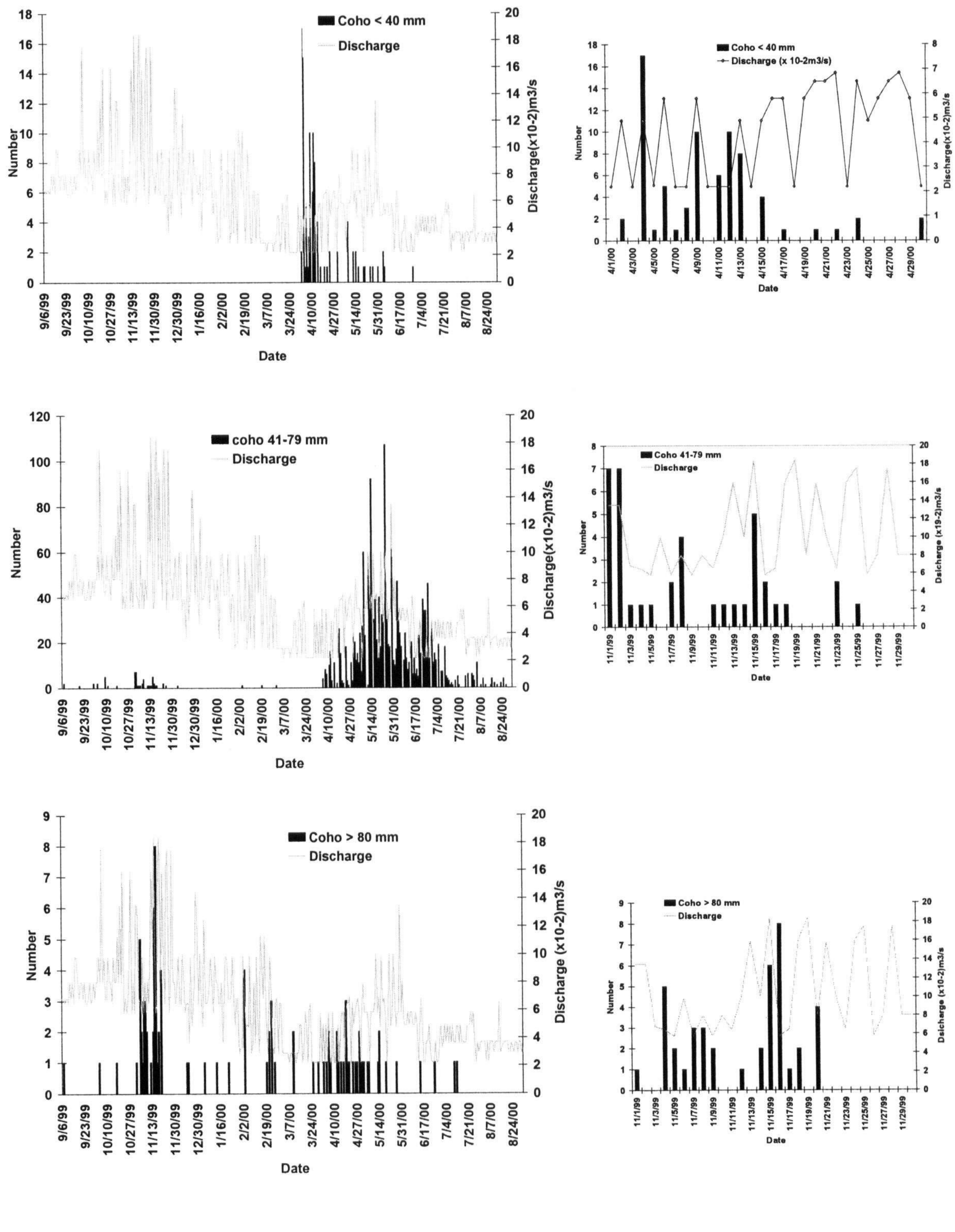


Figure 3.5. Coho salmon Exiting the Study Area Upstream Toward the Headwaters and Discharge ($10^{-2}m^3/s$) of Salish Creek, September 1999-2000.

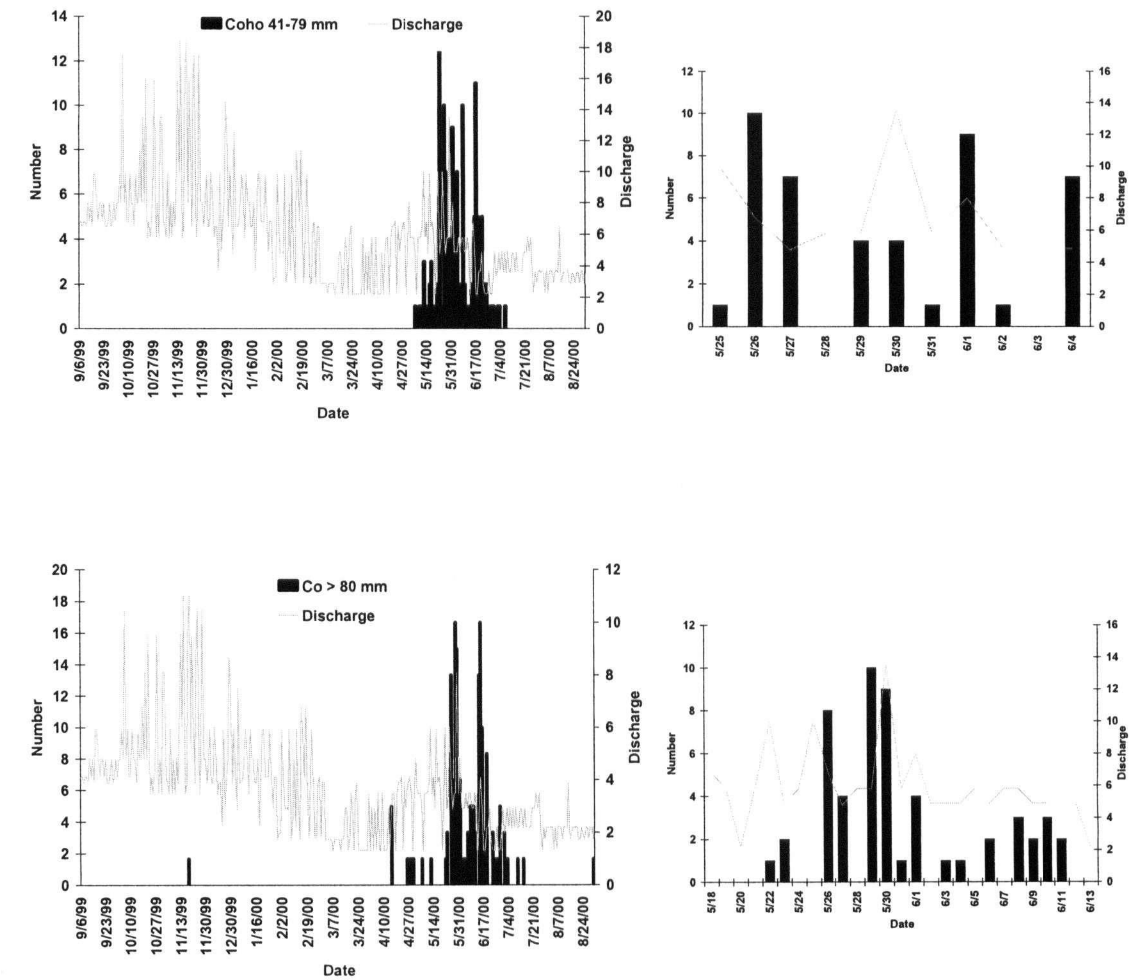
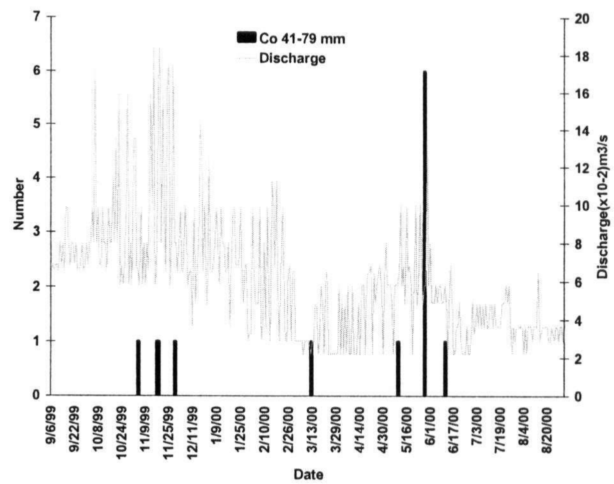
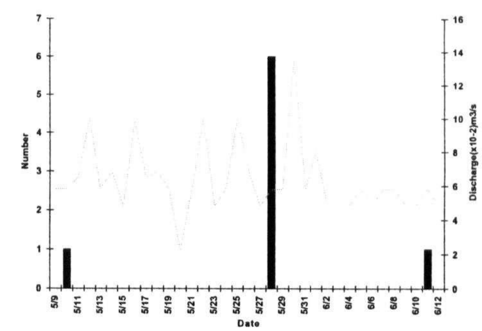
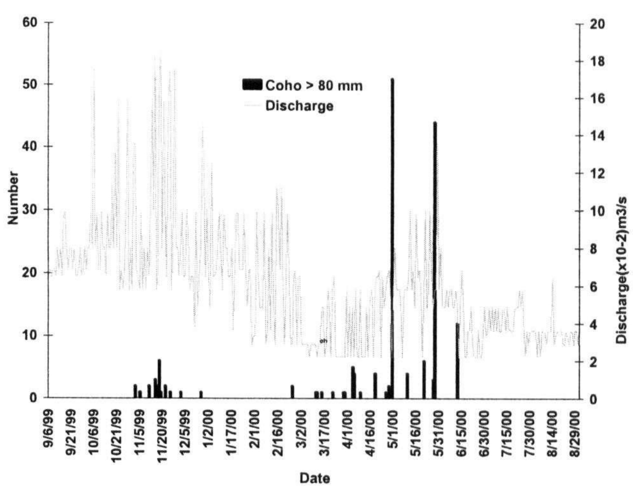
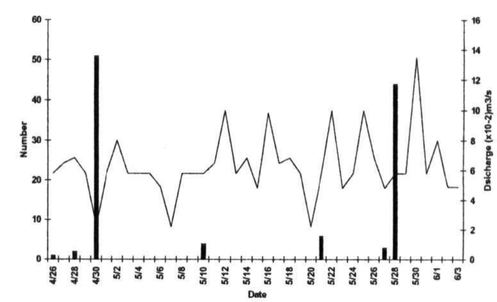


Figure 3.6. Coho salmon Exiting the Study Area Downstream To Pepin Brook and Discharge ($10^{-2}m^3/s$), September 1999-2000.









Salish sucker

Salish sucker movement occurred over longer time intervals with the exception movement to the headwaters (Figure 3.9). At this location 76% (N=32) of movement occurred over a 20 day time interval from May 29th to June 17th, 2000. Here a significant relationship between discharge and movement of sucker < 100 mm was found along with significant interactions with temperature and season (Table 3.0).

During the period of April 28th to May 6th, 2000 fluxes of sucker moving upstream from Pepin Brook appeared to enter the study area during periods of increased discharge. This trend was not observed for any other time period or location (Figure 3.9). Very few sucker moved at discharges greater than $10x10^{-2}m^3/s$.

Largemouth bass

Large mouth bass movement downstream took place at all discharges below 11.27×10^{-2} m^3/s (Figure 3.12). More than 59% (N=924) of the large mouth bass that attempted to move into the study area from the headwaters, did so at a low flow discharge of 3.30×10^{-2} m^3/s. This discharge occurred on only 32 days of the year and corresponds to warmer summer temperatures. As with cutthroat trout, a large number of juveniles seemed to move downstream during or after a rain event. There was no significant relationship between bass movement and discharge.

Figure 3.7. Cutthroat trout Entering the Study Area Moving Upstream from Pepin Brook and Discharge ($10^{-2}m^3/s$), September 1999-2000.

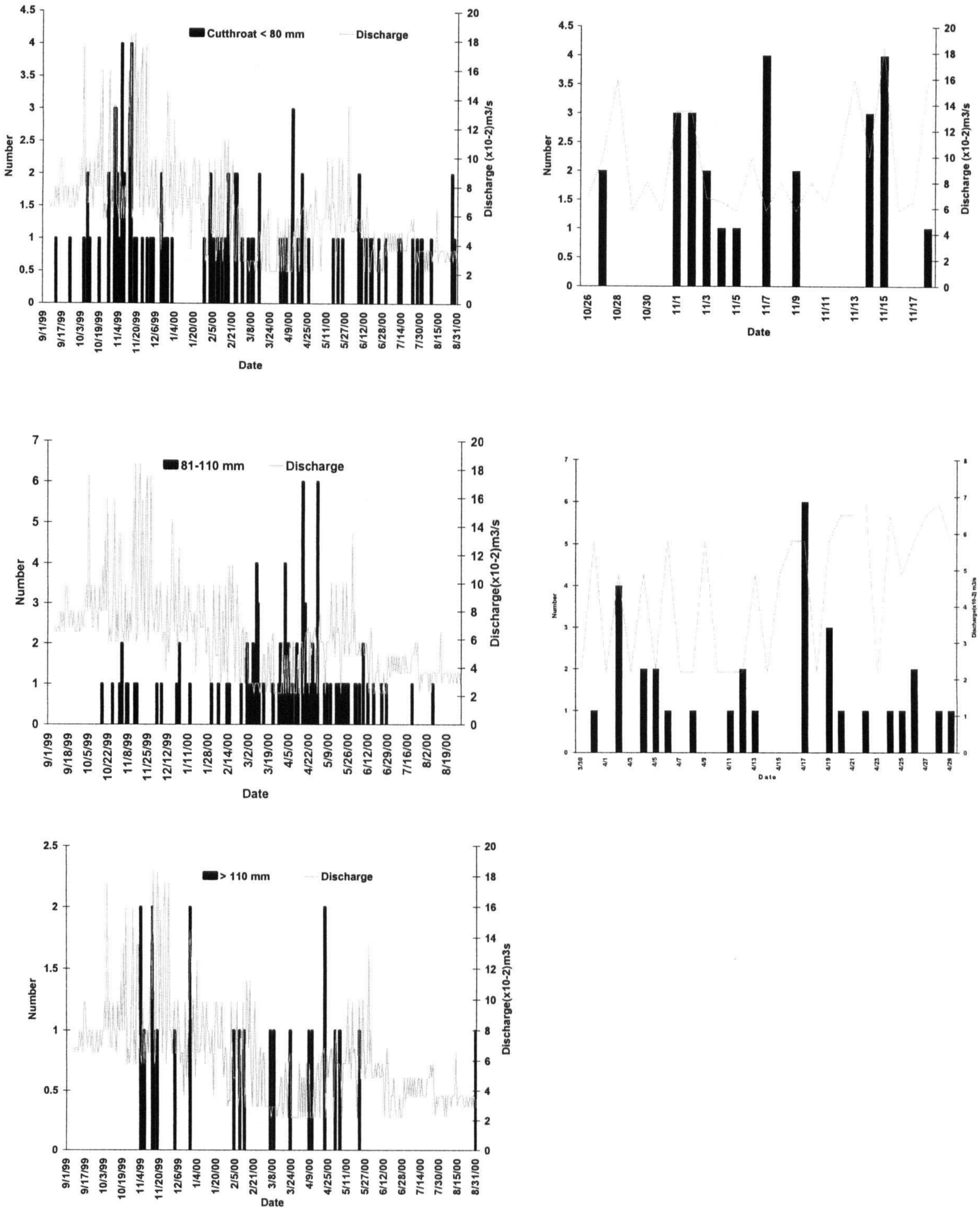


Figure 3.8. Cutthroat trout Exiting the Study Area Moving Upstream Toward the Salish Creek Headwaters and Discharge ($10^{-2}m^3/s$), September 1999-2000.

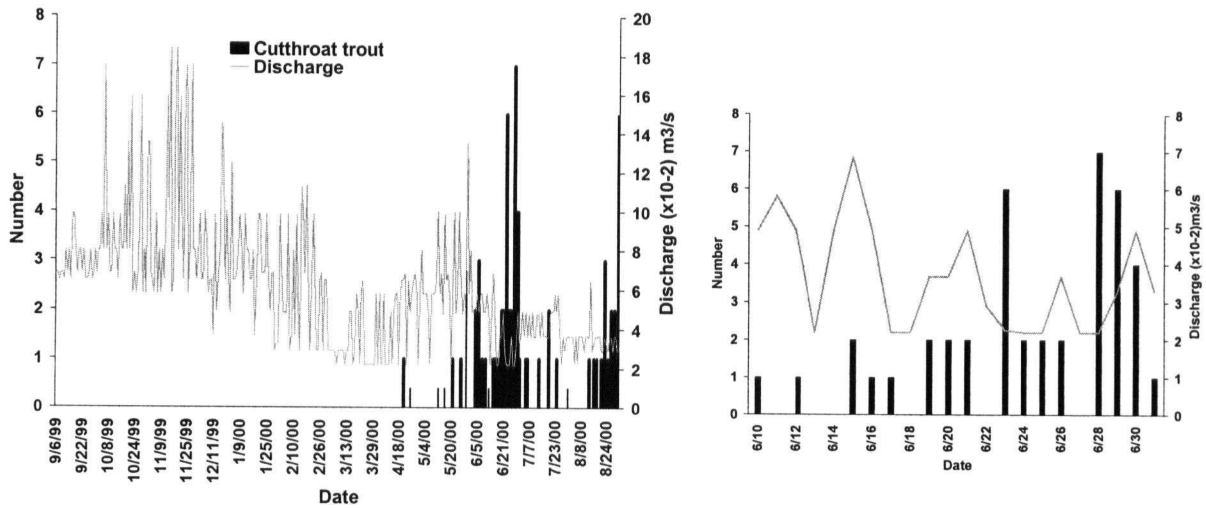


Figure 3.9. Cutthroat trout Exiting the Study Area Moving Downstream To Pepin Brook and Discharge ($10^{-2}m^3/s$), September 1999-2000.

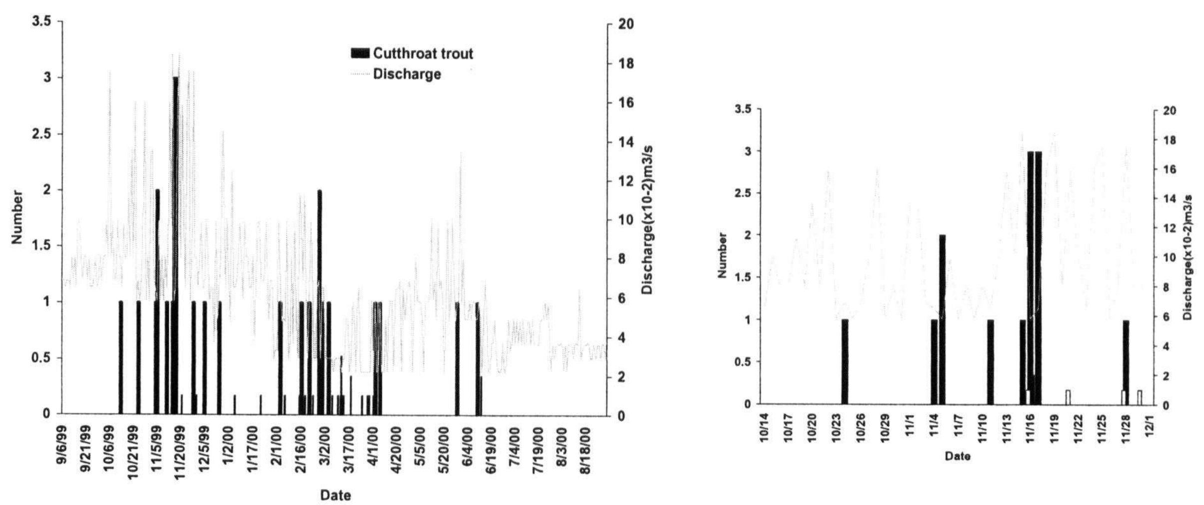
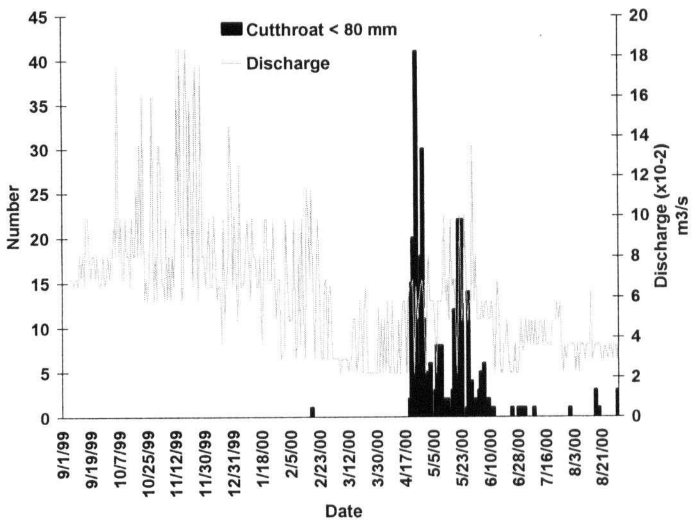
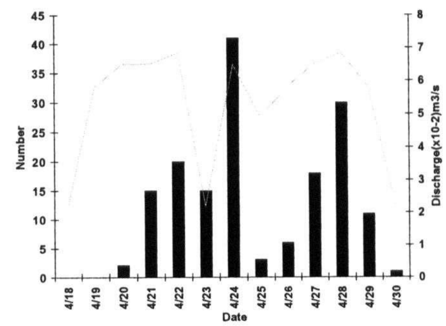
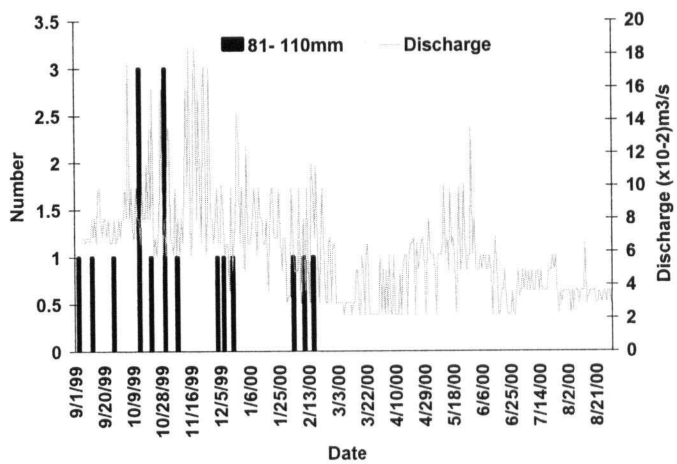
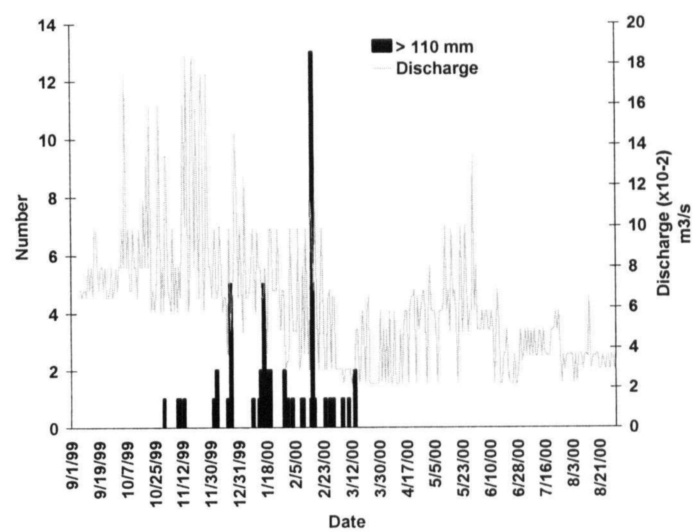


Figure 3.10 Cutthroat trout Entering the Study Area Moving Downstream From the Headwaters of Salish Creek and Discharge ($10^{-2}m^3/s$), September 1999-2000.









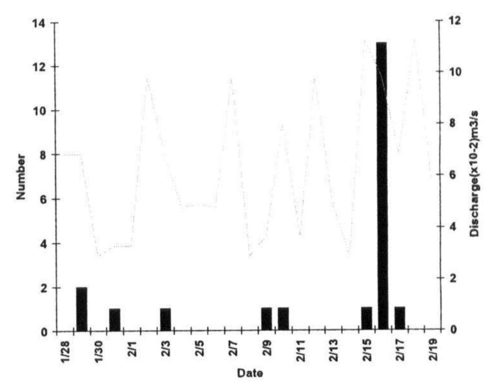
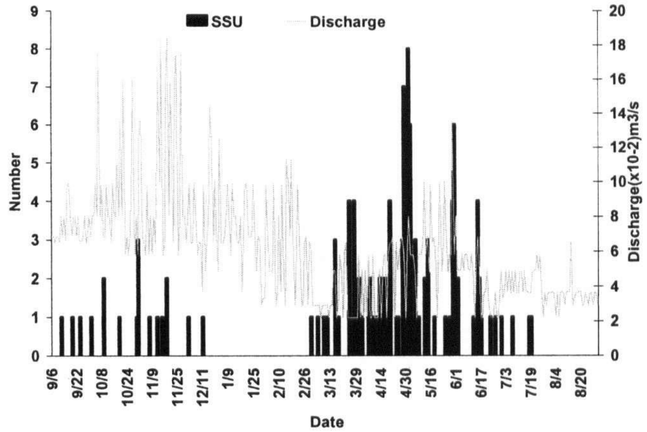
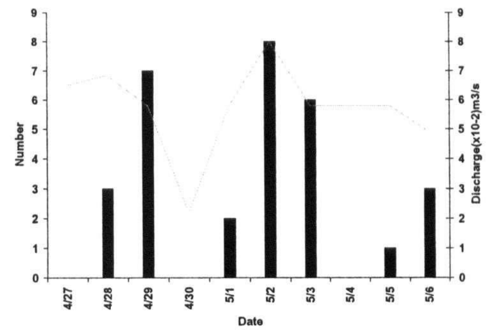


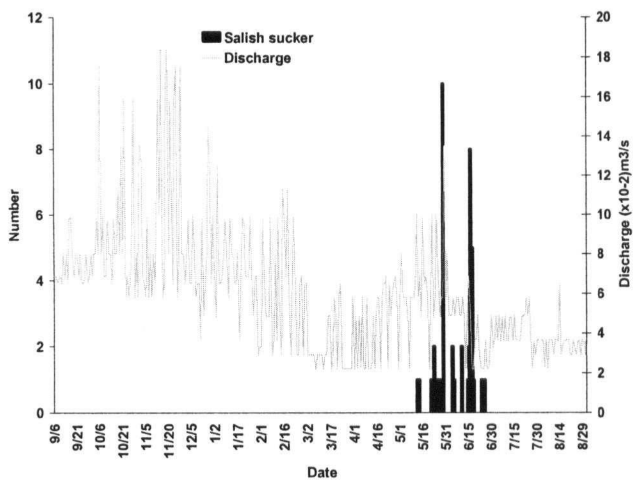
Figure 3.11. Salish sucker Entering or Exiting the Study Area of Salish Creek and Discharge ($10^{-2}m^3/s$), September 1999-2000.

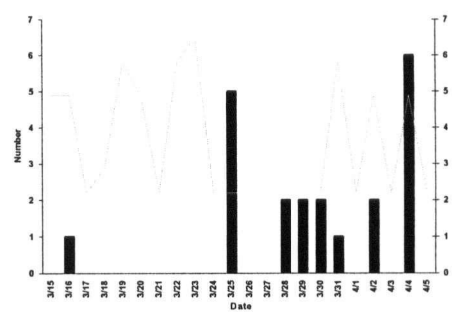
From Pepin Brook



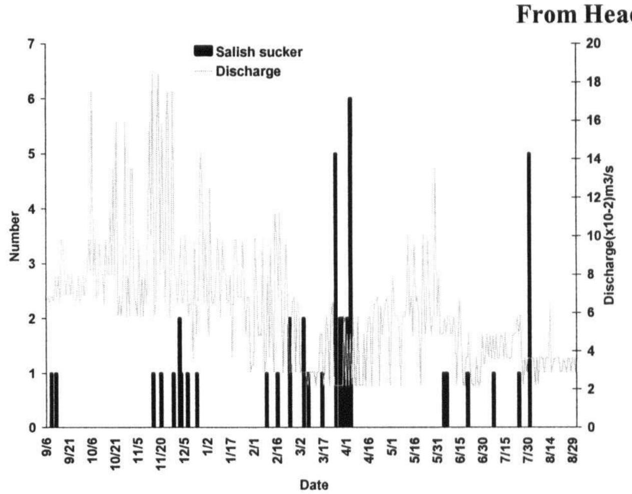


To Headwaters





From Headwaters



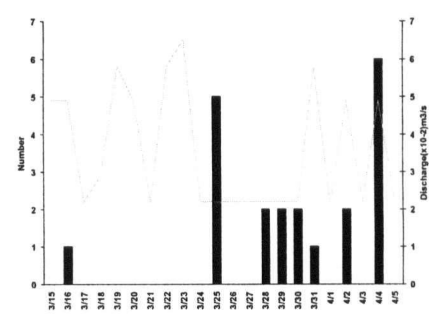
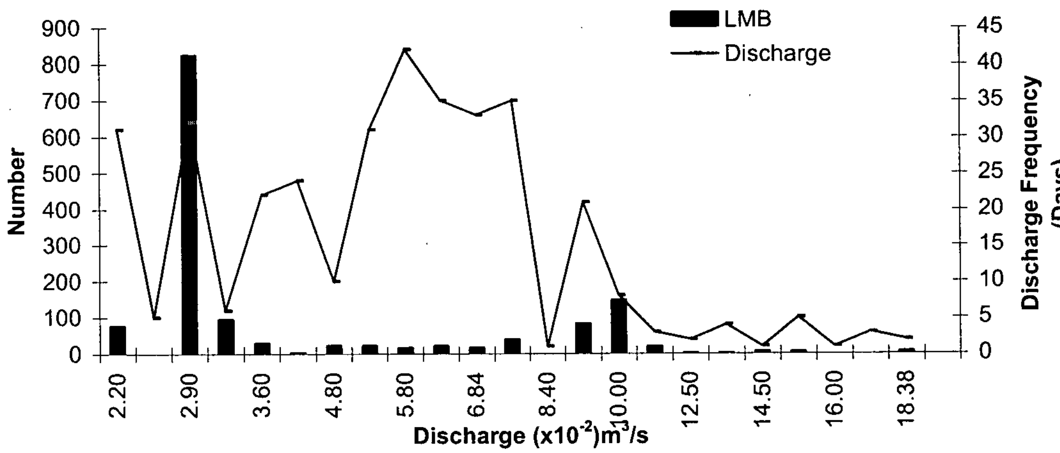


Figure 3.12. Large mouth Bass Entering the Salish Creek Study Area from the Headwaters versus Discharge ($x10^{-2}$ m^3/s)



Temperature

Average daily stream temperature within the study area ranged from 5.25 to 20.77°C with a yearly average of 12.20 $\pm$ 4.57°C. This was 3°C higher than the average temperature within the Pepin Brook mainstem and 0.48°C lower than the average headwater temperature (Figure 3.12). Headwater temperatures were lower during the winter and higher during the summer months due to the influence of the large headwater ponds. Headwater temperatures exceeded 20°C on 62 days or 17% of the one-year study period and were below 5°C on 42 days. By contrast, Salish Creek exceeded 20°C on only seven days and was below 5°C for nine days. During the late spring and summer, the difference in temperature between Pepin Brook and the headwaters of Salish Creek was typically 5-10°C with the study reach in between. Fall and winter differences in temperature were seldom more than 2°C.

Coho salmon

Movement of coho salmon took place at a broad range of available temperatures from 2 to 19°C. Ocean bound coho moving downstream to Pepin Brook moved at lower temperatures while smaller colonizers moved at higher temperature ranges (Figure 3.13). Most immigration took place when temperatures ranged from 10 to 13°C, temperatures which were available 21% (N=66 days) of the year, primarily during the spring months. As only 15 coho entered the study area from the headwaters, no statistical or graphical analyses was performed.

No coho movement toward the headwaters was recorded until April of 2000. Movement out of the study area to the headwaters occurred at temperatures between 13 and 20°C, about 10°C higher than emigration to Pepin (Figure 3.13).

Graphical analysis shows increasing movement with increasing headwater temperatures from 13 to 16°C and a gradual decrease in movement at temperatures greater than 16°C (Figure 3.13). Coho moving upstream to the headwaters were moving to an area of higher temperatures. In general, coho tended to move upstream when temperatures were relatively high and increasing, and downstream when temperatures were low and decreasing.

Figure 3.13. Average Daily Stream Temperatures of the Salish Creek Study Area, Headwaters and Pepin Brook Mainstem from September 1999 to August 2000.

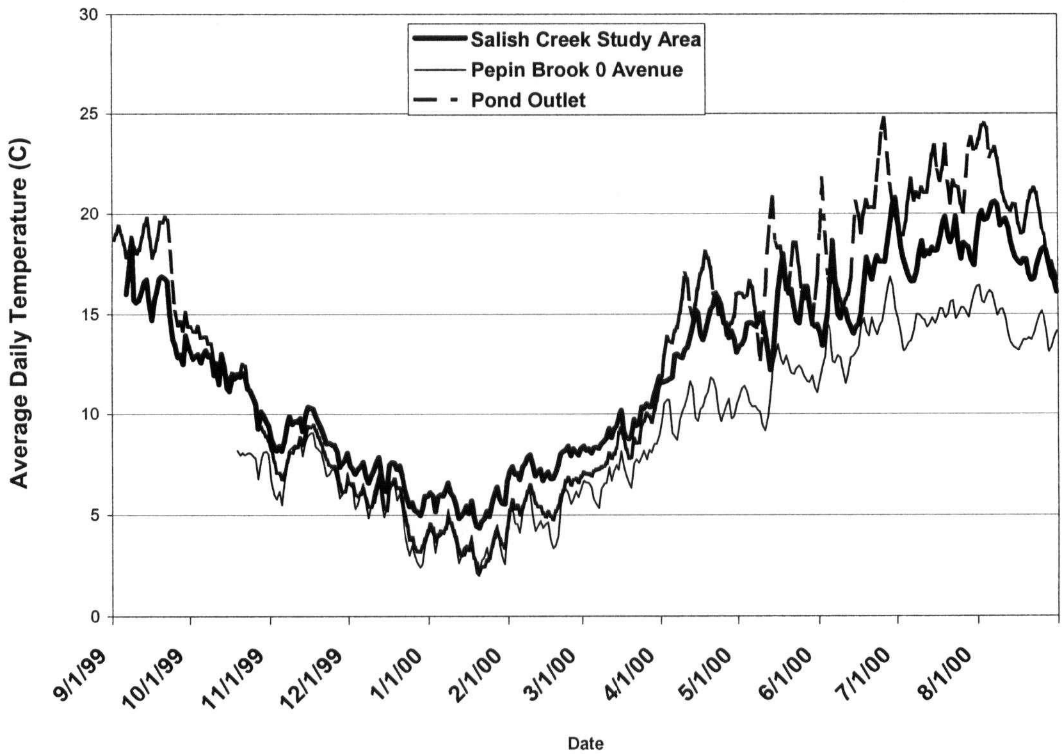
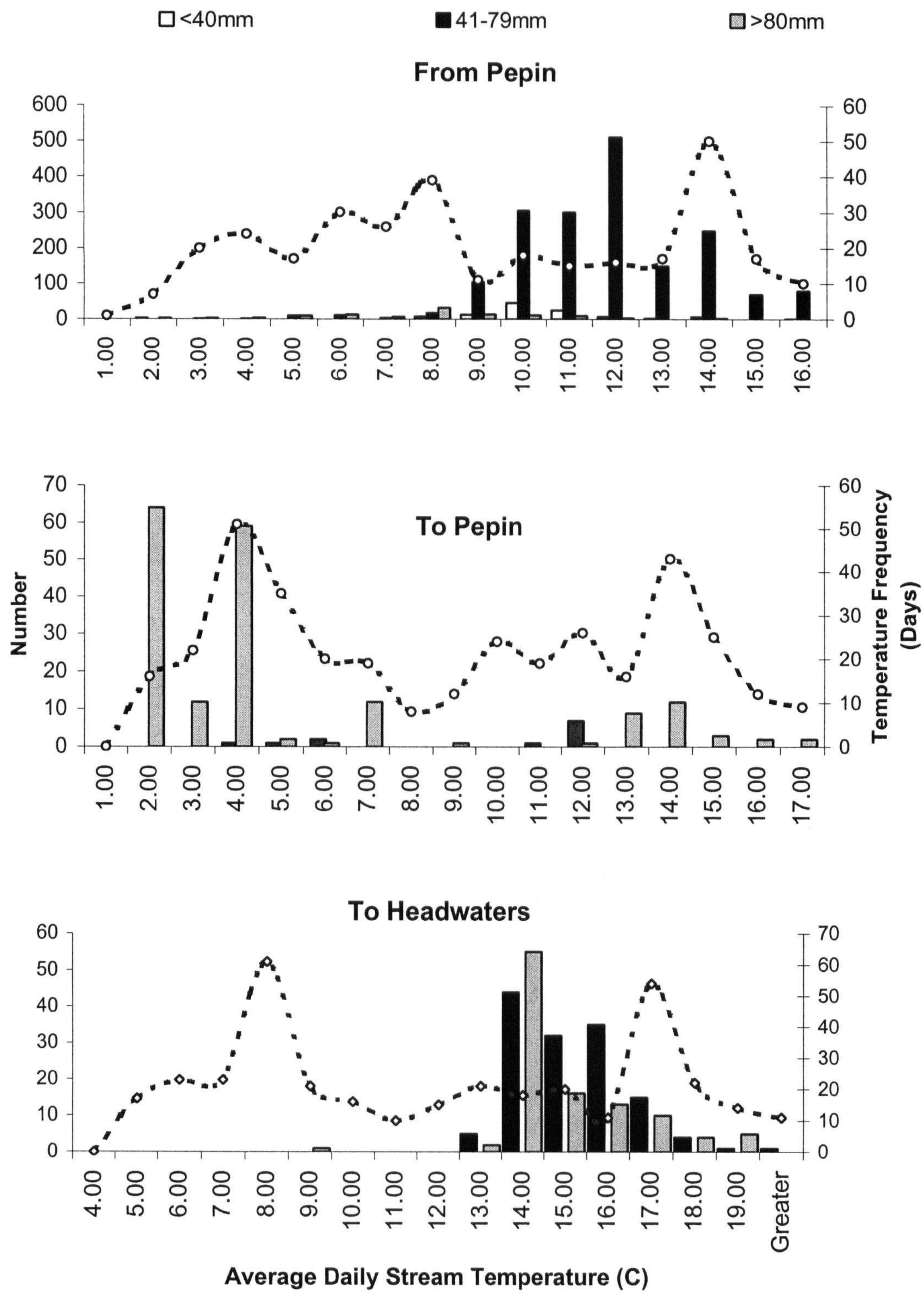


Figure 3.14. The Number of Coho Salmon Moving Through the Fish Fences Versus Average Daily Stream Temperature.



Cutthroat Trout

Cutthroat trout appear to show similar movements to coho with some variations. Movement was distributed over a wide range of temperatures with most movement occurring between 8 and 17°C (Figure 3.14).

Emigration to Pepin appeared to decrease with an increase in study area temperatures (Figure 3.14). Over 50% of individuals moved into the mainstem at temperatures between 5 and 9°C with no movement occurring when temperatures exceeded 15°C ($F=2.608$, $p=0.05$).

The majority of trout moving to the headwaters were in the smallest size category and these fish moved above study area temperatures of 13°C. A small number of trout in the larger size categories moved to the headwaters but movement of larger fish was primarily at temperatures below 9°C. Like coho, trout movement to the headwaters appeared to increase as the temperatures at the headwaters increased, meaning fish were leaving cooler study area temperatures to move upstream (Figure 3.14).

Salish sucker

Sucker movement occurred over a broad range of temperatures (Figure 3.15). Graphical analysis shows that movement of fish larger than 100 mm increased with an increase in headwater temperatures, while movement of the smaller size class occurred only between 5 and 12°C. Sixty percent (N=27) of the total movement downstream from the headwaters was recorded at temperatures between 14 and 18°C. These temperatures occurred on 87 days or 24% of the year. Most movement from Pepin Brook took place at mainstem temperatures below 9°C. As only seven sucker left the study area to the mainstem, no analysis was possible. Like coho and trout, movement of adult sucker to the headwaters occurred at higher headwater temperatures.

Largemouth Bass

More than 56% (N=857) of the large mouth bass attempted to move downstream at headwater temperatures above 17°C (Figure 3.16). These temperatures occurred on 121 days or 33% of the one-year study period. However, movement was recorded throughout the year at temperatures as low as 3.35°C. There was a significant relationship between bass movement from the headwaters and temperature ($F=7.404$, $p<0.05$).

Figure 3.15. The Number of Cutthroat Trout Moving Through The Fish Fences Versus Average Daily Stream Temperature.

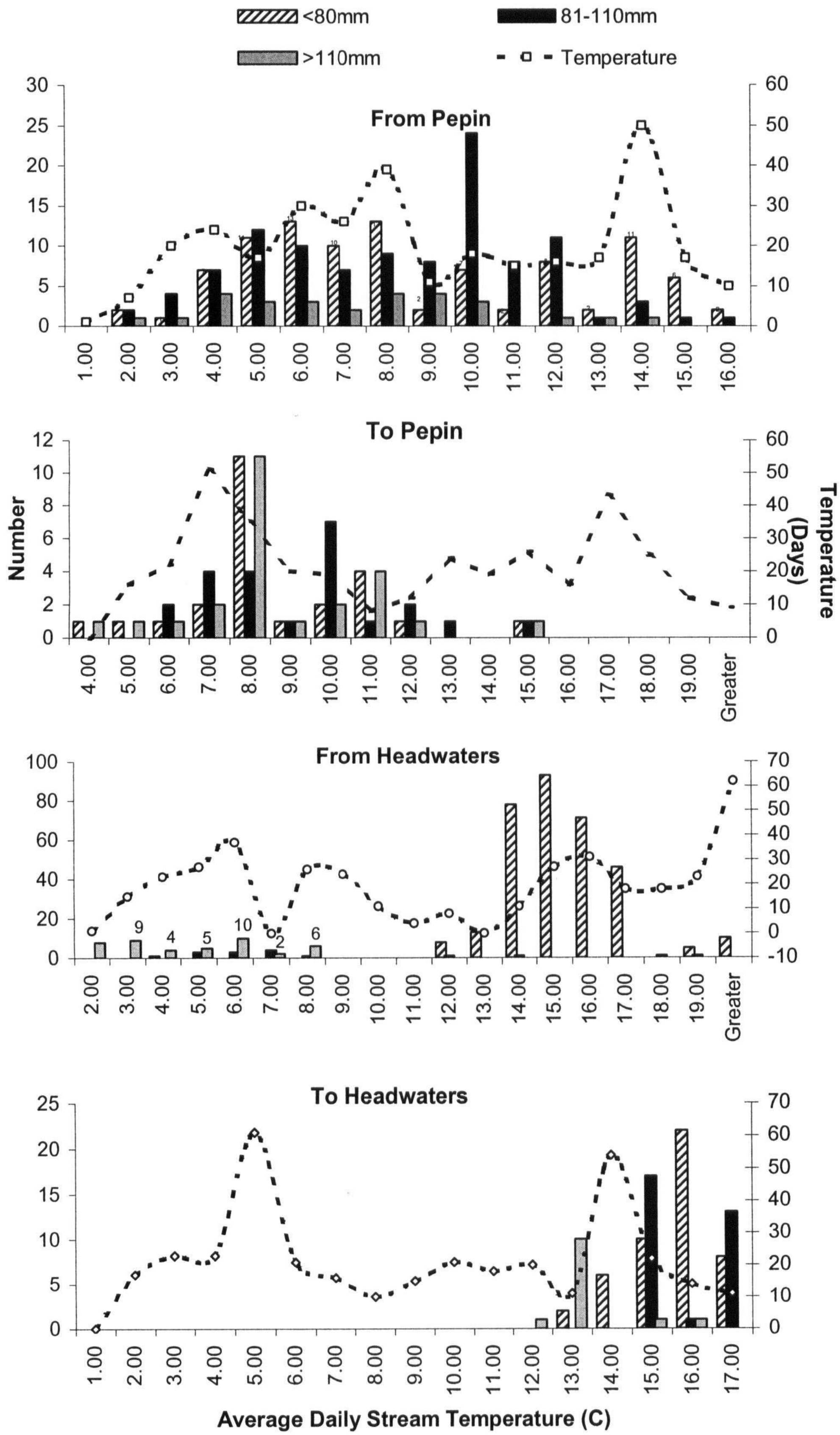


Figure 3.16. The Number of Salish sucker Entering and Leaving the Salish Creek Study Area versus Average Daily Stream Temperature (°C).

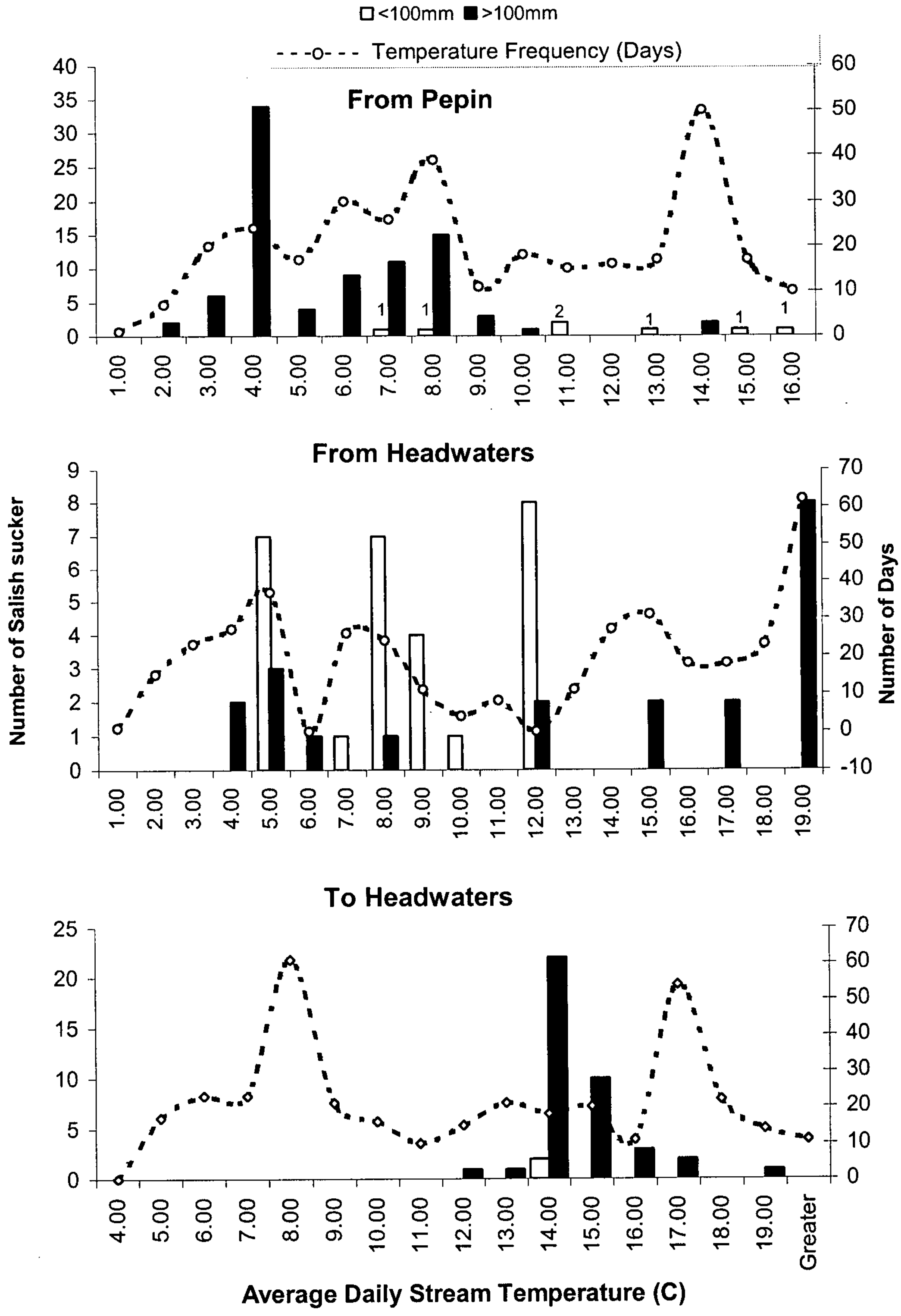
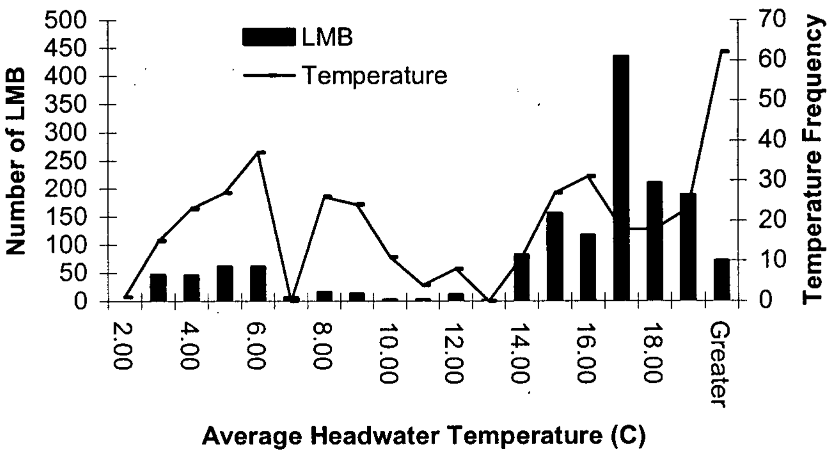


Figure 3.17. The Number of Largemouth bass Attempting to Enter the Salish Creek Study area from the Headwaters versus Average Daily Stream Temperature (C).



Discussion

Coho salmon, cutthroat trout and Salish sucker all exhibited rapid colonization of the study area. For these three species, movement into the study area was most active in spring followed by movement during the summer. Immigration was lowest in winter. Emigration was also highest in spring and summer lowest in winter, but was considerably lower than immigration throughout the year. Size structure of fishes captured at the fences indicated predominantly younger age classes (< age 1+) of fish were dispersing along the stream with the exception of spawning adult Salish sucker.

The majority of coho entered the study area from Pepin in spring and summer. Most of these fish were parr and so represent coho that had emerged some weeks prior to moving into Salish Creek. Few recently emerged fry less than 40 mm, were among the immigrants. This indicates considerable exploratory behaviour on the part of coho parr in Pepin Brook. Very few of the many hundreds of parr that entered Salish creek emigrated, indicating that the habitat was suitable within Salish creek. Few parr were caught in the traps in fall and winter.

Most smolt sized coho (N=50) entered Salish Creek in fall although about 2/3 as many (37), also entered in spring. By far the majority that entered came from Pepin Brook. Most smolts emigrated in spring, moving downstream into Pepin, however, more than 200 also moved upstream into the headwaters in spring and summer. Movement of substantial numbers of smolt size fish upstream into Salish Creek throughout the year and to the headwaters in spring and summer is contrary to expectation, as these fish should be moving downstream toward the estuary. These fish may represent a component of the population that spends 2 years in freshwater exploring for suitable nursery habitat during different seasons. This is supported by the fact that they were significantly smaller than those moving downstream.

More than two times as many smolts emigrated from Salish creek as immigrated, presumably reflecting growth of parr to smolt size. However, the number of smolts and parr emigrating over the year was only about 20% of those that immigrated into Salish Creek (365/1719), suggesting either substantial mortality within Salish Creek or that many were holding over for an additional year. The large number of emigrating smolts in the winter of 2000 (See chapter 2) would also seem to support the later assumption (minimum of 430 smolt emigrants). Assuming the majority of the coho that are not accounted for died, the mortality rate in Salish Creek was on the order of 54%, lower than fry to smolt mortality in other systems (Keeley et al. 1996).

More than twice as many sucker entered from Pepin as from the headwaters. Most immigrants from Pepin were adults in spawning condition whereas most from headwaters were immatures less than 100 mm. Ten of these, were suckers that had originally been tagged in Pepin marsh, 1 km upstream from the confluence of Salish Creek with Pepin Brook. The seasonal pattern of immigration and emigration of suckers differed significantly as did the patterns of immigration and emigration between size classes. Few suckers left Salish Creek after they entered, however, 40 of the 137 adult sucker that entered Salish creek moved upstream to the headwaters in spring and summer, with more moving in summer. The majority of these sucker were in spawning condition.

Patterns of immigration and emigration of suckers suggest that adult dispersal occurs mainly in spring and summer and involves gravid fish looking for suitable spawning habitat. Such fish will move considerable distances, in search of such habitat – up to two km in this case. A significant component of dispersal by adult sucker appears to be movement upstream. However, there was also downstream movement of adult fish from the headwaters into Salish Creek throughout the year. These fish did not move out of the reconstructed channel, however, but took up residence in the pools in Salish Creek (Chapter 2). This suggests that this movement is exploratory in search of high quality habitat and that these fish found the habitat they wanted in the deeper pools of the study area.

Most Salish sucker were adults entering from Pepin Brook at temperatures between 4 and 10°C and discharges between 4.8 and 8.0 x 10^{-2} m^3/s. The majority of movement was by adults in spawning condition. This is consistent with other studies of Salish sucker (Pearson and Healey 2003) and of catostomids in general, which found that the greatest distances traveled occurred in relation to spawning (Modde and Irving 1997). Modde and Irving (1997) also found that movement of spawning male razorback suckers to spawning areas was influenced primarily by discharge. In contrast to other studies (Schlosser 1995), the majority of all fish movement in Salish Creek occurred at mid-range discharges between 3.85 and 10.0 x 10^{-2} m^3/s rather than during periods of highest flow. However, mid-range discharges occurred more frequently than higher flows.

Juvenile dispersal of suckers, by contrast is primarily downstream, with young suckers moving into Salish Creek from upstream but few entering from downstream. As with the non-breeding adults, juveniles that entered Salish Creek apparently found suitable habitat because they remained within the constructed channel. Few sucker less than 70 mm (N=16) were caught throughout the study period and little is known about movement of this size class. Sucker of this size may not move much from their emergence location until larger or the scale of the study may have been too large compared to the distance moved.

Other than smolt migration, little movement of coho salmon took place at temperatures below 9°C although these temperatures occurred over 51% (N=164 days) of the year. Most movement took place when temperatures ranged from 10 to 15°C, temperatures that roughly correspond to preferred stream temperatures between 12-15°C (Groot et al, 1996). Immigration of cutthroat trout from Pepin Brook occurred at a wide range of temperatures from 2°C to over 20°C. Emigration to Pepin Brook was mainly at temperatures between 6 and 12°C.

Movement from the headwaters may have been a general response to an increase in temperature there, as downstream movement appeared to increase with rising headwater temperatures. However, trout also moved to the headwaters at high temperatures and, when the movement occurred the fish were moving into habitat where temperatures were warmer than Salish Creek. Emigration to the headwaters for all species increased over the one-year study period.

Largemouth bass showed the greatest movement at temperatures above 17°C, consistent with life history characteristics of this warm water species. Movement was also significantly positively related to temperature within seasons in the analysis. Similar to other studies of bass species, movement appears to be strongly influenced by temperature (Bjorgo et al. 2000). However, there was movement at all temperatures even as low as 2°C. Like juvenile cutthroat trout, movement at these lower temperatures often occurred during or shortly after high flow events and may have been passive dispersal.

Previous studies have found that flow regimes and changes in stream temperature play an important role in defining biotic composition (Richter et al, 1996; Giannico and Healey, 1998). There is also strong evidence that climatic or seasonal change is marked during colonization or succession in streams (Fisher, 1990; Schlosser 1995). Movement in relation to temperature and discharge was complex in this study, and varied with season, species and size class of fish. Although ANOVA indicated several cases with significant main effects of season followed by discharge and temperature, there was always an interaction between season and/or temperature and discharge in these analyses. These relationships were not consistent across species, locations or direction of movement. As these variables were inter-related they were confounded in the data and it was difficult to separate individual effects. Hence, the ultimate reasons for dispersal were not established in this study.

In this study, the area surrounding the tributary is characterized by high subsurface storage capacities, where groundwater flow predominates, leading to less extreme high and low-flow conditions. The temperature regimes of this system were also not extreme, and the stream habitat within the study area was physically stable. Therefore, these abiotic factors may have exerted less of an influence on movement then other less stable systems (Milner 1987; Sidle and Milner 1989). In streams where more subtle changes in environmental quality occur, it may be difficult to sort out autogenic changes from those imposed by an external or seasonal influence (Schlosser, 1995; Coon, 1985).

Variability in movement may be influenced by a number of physical and biological factors interacting to influence fish dispersal (Schlosser 1995). Due to the combination of environmental conditions together with differential life histories and tolerances of individuals and species, it may be difficult to distinguish the exact influences of these parameters on variation in fish community structure over time. The relatively short time frame of movement for the vast number of fishes probably reflects the need for appropriate physiological, developmental and/or reproductive states of the fish to coincide with appropriate stream conditions for movement to occur together with an attempt to colonize new, unexploited habitat (Schlosser 1995). Long-term monitoring of fishes throughout the drainage basins is critically needed to establish more precisely the natural range of variation in community structure.

REFERENCES

Adams, M.A. and I.W. Whyte. 1990. Fish Habitat Enhancement A Manual for Freshwater Estuaries and Marine Habitats. Department of Fisheries and Oceans Canada. DFO 4474. 330 p.

Anonymous. 1996. Conserving our fish resources: Fisheries program strategic plan 1996-2000. BC Environment. 10p.

Armour, C.L., D.A., Duff and W. Elmore. 1991. The effects of livestock grazing on riparian and stream ecosystems. American Fisheries Society. January-February: 7-11.

Becker, D. and R.G. Genoway. 1979. Evaluation of the critical thermal maximum for determining thermal tolerance of freshwater fish. Env. Biol. Fish. 4: 245-256

Bjorgo, K.A., J.J. Isely and C.S. Thomason. 2000. Seasonal Movement and Habitat Use by Striped Bass in the Combahee River, South Carolina. Transactions of the American Fisheries Society.129(6): 1291-1287.

Bradshaw, A.D. 1996. Underlying principles of restoration. Canadian Journal of Fisheries and Aquatic Sciences 53 (supplement 1): 3-9.

Brown, T.G. and G.F. Hartman. 1988. Contribution of seasonally flooded lands and minor tributaries in the production of coho salmon in Carnation creek British Columbia. Transactions of the American Fisheries Society. 117:546-551

Bryant, M.D., B.J. Frenette and S.J. McCurdy. 1999. Colonization of a Watershed by Anadromous Salmonids following the Installation of a Fish Ladder in Margaret Creek, Southeast Alaska. North American Journal of Fisheries Management. 19:1129-1136.

Burgess, S.A. and J.R. Bider. 1980. Effects of stream habitat improvements on invertbrates, trout populations, and mink activity. Journal of Wildlife Management 44: 871-880.

Burrell, K.H., J.J. Isley, D.B. Bunnell Jr., D.H. Van Lear, and C.A. Dolloff. 2000. Seasonal Movement of Brown Trout in a Southern Appalachian River. Transactions of the American Fisheries society. 129(6): 1373-1379.

Cannings, S.G. and J. Ptolemy. 1998. Rare freshwater fish of British Columbia. B.C. Ministryo of Environment Lands and Parks. Conservation Data Centre. Victoria B.C. 214 pp.

Canton, S. P., Cline, L. D., Short, R. A. and J. V. Ward. 1984. The macro-invertebrates and fish of a Colorado stream during a period of fluctuating discharge. Freshwater Biology. 14:311-16.

Cederholm, C.J. and W.J. Scarlett. 1988. Low-cost Enhancement Technique for Winter Habitat of Juvenile Coho Salmon. North American Journal of Fisheries Management. 8:438-441.

Cederholm, C.J., Bilby, R.E., Bisson, P.A., Bumstead, T.W., Fransen, B.R., Scarlett, W.J. and J.W. Ward. 1997. Response of Juvenile Coho Salmon and Steelhead to Placement of Large Woody Debris in a Coastal Washington Stream. North American Journal of Fisheries Management. 17:947-963.

David, B.O. and G.P. Closs. 2002. Behaviour of a Stream-Dwelling Fish before, during, and after High-Discharge Events. Transactions of the American Fisheries Society. 131(4): 762-771.

Coon, T.G. 1987. Responses of benthic riffle fishes to variation in stream discharge and temperature. Chapter 10 in Comments and Evolutionary Ecology of North American Stream Fishes.

Detenbeck, Naomi E, Devore, Philip, W., Niemi, Gerald J, and Ann Lima.1992.Recovery of Temperate-Stream Fish Communities from Disturbance: A Review of Case Studies and Synthesis of Theory. Environmental Management. 16(1): 33-53.

Ebersole, J.L., W.J. Liss and C. A. Frissell. 1997. Restoration of Stream Habitats in the Western United States: Restoration as Re-expression of Habitat Capacity. Environmental Management . 21(1):1-14.

Ensign, William E, Leftwich, Kevin N, Angermeier, Paul, L, and C. Andrew Dolloff. 1997. Factors Influencing Stream Fish Recovery Following a Large-Scale Disturbance. Transaction of the American Fisheries Society. 126:895-907.

Fausch, K.D. and T.G. Northcote. 1992. Large woody debris and salmonid habitat in a small coastal British Columbia stream. Canadian Journal of Fish and Aquatic Sciences. 49: 682-693.

Fraser Basin Council. 1997. Salmon River Watershed: Land and Water Use Management Plan: An Initiative of the Salmon River Watershed Management Partnership. 18 p.

Frissel, C. A. and Lanzarich, D.G. 1996. Habitat Use and Competition Among Stream Fishes (Book) Hauer, F.R., Lamberti, G.A.:Eds. Methods in Stream Ecology. 493-510.

Garson, G.D. 2001. Anova review in Guide to writing empirical papers, thesis and dissertations. North Carolina State university, Raleigh, NC.

Giannico, G.R. and M.C. Healey. 1998. Effects of Flow and Food on Winter Movements of Juvenile Coho Salmon. Transactions of the American Fisheries Society. 127:645-651.

Gido, K.A. and J. H. Brown. 1999. Invasion of North American drainages by alien fish species. Freshwater Biology. 42:387-399.

Gore, J.A. and F.D. Shields, Jr. 1995. Can large rivers be restored? Bioscience 45: 142-153.

Groot, C., and L. Margolis. (eds.). 1991. Pacific salmon life histories. University of /British Columbia Press, Vancouver, B.C., 564 p.

Haas, G. R. 1999. British Columbia's Freshwater Fish, Species and Ecosystems Are More at Risk and Less Protected. 561-576.

He, X. and J.K. Kitchell. 1990. Direct and indirect effects of predation on a fish community: a whole lake experiment. Transactions of the American Fisheries Society 119: 825-835.

Healey, M. 1998. Prospects for Sustainability. Integrative Approaches to Sustaining the Ecosystem Function of the Lower Fraser Basin. Final Report on the Tri-Council Funded Eco-research project at UBC.

Heggenes, Jan. 1989.Comparisons of habitat availability and habitat use by an allopatric Cohort of juvenile Atlantic salmon Salmo salar under conditions of low competition in a Norwegian Stream. Holarctic Ecology. 14:1. p 51-62.

Heggenes, J., T.G.Northcote and A. Peter. 1991. Seasonal Habitat Selection and Preferences by Cutthroat Trout (Oncorhynchus clarki) in a Small, Coastal Stream. Can. J. Fish. Aquatic Sci., 48: 1364-1370.

House, Robert. 1996. An Evaluation of Stream Restoration Structures in a Coastal Oregon Stream, 1981-1993. North American Journal of Fisheries Management. 16:272-281.

Huxel, G.R. and A. Hastings. 1999. Habitat Loss, Fragmentation and Restoration. Restoration Ecology. 7(3): 309-315.

Inglis, Susan, Lorenz, A. and M.L. Rosenau. 1992. Distribution and habitat of the endangered Salish sucker (Catostomus sp.). Regional Fisheries Report No. LM230. Fish and Wildlife management, B.C. Ministry of Environment, Lands and Parks, Surrey, B.C.

Inglis, Susan , S.M. Pollard and M.L. Rosenau. 1994. Distribution and Habitat of Nooksack Dace (Rhinichthys sp.). in Canada. Regional Fisheries Report No. 237. Fish and Wildlife management, B.C. Ministry of Environment, Lands and Parks, Surrey, B.C.

Jackson, L.L., Lopoukhine, N. and D. Hillyard 1995. Ecological Restoration: A definition and Comments (Commentary). Restoration Ecology 3(2): 71-75.

Keeley, E.R. P.A. Slaney and D. Zaldokas. 1996. Estimates of production benefits for salmonid fishes from stream restoration initiatives. British Columbia Watershed Restoration Program: Ministry of Environment Lands and Parks and Ministry of Forests. Watershed Restoration Management Report No. 4.

Kondolf, G.M. and E. R. Micheli. 1995. Evaluating stream restoration projects. Environmental Management 19: 1-15.

Krebs, C. J. 1996. Ecology The Experimental Analysis of Distribution and Abundance. Harper Collins College Publishers. 4th ed.

Lavkulich, L.M., K.J. Hall and H. Schrier. 1999. Land and water interactions: Present and future in M.C> Healey, editor. Seeking sustainability in the lower Fraser Basin: Issues and Choices. Institute for Resources and Environment , Westwater Research, University of British Columbia, Vancouver.

Maurizi, Susan and Florence Poillon (eds). 1992. Restoration of Aquatic Ecosystems. The National Academy of Sciences.

McAdam, S. 1995. MS. Unpublished Manuscript. Available from Ministry of Environment Lands and Parks, Fisheries Research, 2204, Main Mall, University of British Columbia.

McDowall, R.M. 1995. Seasonal pulses in migrations of New Zealand diadromous fish and the potential impacts of river mouth closure. New Zealand Journal of Marine and Freshwater Research. 29: 517-526

McKinney, T., D.W. Speas, R.S. Rogers and W.R. Persons. 2000. Rainbow Trout in a Regulated River below Glen Canyon Dam, Arizona, following Increased Minimum Flows and Reduced Discharge Variability. North American Journal of Fisheries Management. 21(1): 216-222.

McPhail, J.D. 1967. Distribution of Freshwater Fishes in Western Washington. Northwest Science 41:1-11.

McPhail, J.D. and C.C. Lindsey. 1986. Zoogeography of the freshwater fishes of Cascadia (the Columbia and rivers north to the Stikine), p 615-637. In C.H. Hocutt and E.O. Wiley (ed.) Zoogeogrpahy of North American Freshwater Fishes. John Wiley and Sons, new York.

McPhail, J. D. 1987. Status of the Salish sucker, Catostomus sp., in Canada. Canadian Field Naturalist. 101:231-236.

McPhail, J.D. and R. Carveth. 1993. A foundation for conservation: The nature and origin of the freshwater fauna of British Columbia. B.C. Environment. 39pp.

McPhail, J.D. 1997. Status of the Nooksack Dace (Rhinichthys sp.). in Canada. Canadian Field Naturalist. 111:258-262.

McPhail, J. D., and E. B. Taylor. 1999. Morphological and genetic variation in northwestern longnose suckers, Catostomus catostomus: the Salish sucker problem. Copeia. 1999:884-893.

Miller, R. R., J. D. Williams, and J. E. Williams. 1989. Extinctions of North American fishes during the past century. Fisheries. 14:22-38.

Minns, C.K., J.R.M. Kelso and R.G. Randall. 1995. Detecting the response of fish to habitat alterations in freshwater ecosystems. Canadian Journal of Fisheries and Aquatic Science. 53 (Suppl 1): 403-414.

Modde, T. and D.B. Irving. 1997. Use of Multiple Spawning Sites and Seasonal Movement by Razorback Suckers in the Middle Green River, Utah. North American Journal of Fisheries Management. 18)2): 318-326.

Murphy, M.L., J. Heifetz, S.W. Johnson, K.V. Koski and J.F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams. Canadian Journal of Fish and Aquatic Sciences. 43-1521-1533.

Murphy, M.L. and W.R. Meehan. 1991 Stream ecosystems. American Fisheries Society Special Publication 19: 17-46.

Newbury, R.W. and M.N. Gaboury. 1993. Stream Analysis and Fish Habitat Design A Field Manual. Newbury Hydraulics Ltd. The Manitoba Habitat Heritage Corporation Manitoba Fisheries Branch. 262 pp.

Nickelson, T.E., M.F. Solazzi, S.L. Johnson and J.D. Rodgers. 1993. Effectiveness of Selected Stream Improvement Techniques to Create Suitable Summer and Winter Rearing Habitat for Juvenile Coho Salmon (Oncorhynchus kisutch) in Oregon Coastal Streams

Niemi, G.J., P. DeVore, N. Detenbeck, A. Lima, J. Pastor. J. D. Yount and R.J. Naiman. 1990. Overview of Case Studies on Recovery of Aquatic Systems from Disturbance. Environmental Management 14(5): 571-587.

Pearson, M. 1998. A Review of the Distribution, Status, and Biology of the Endangered Salish Sucker (*Catostomus sp.*) and Nooksack Dace (*Rhinichthys sp.*). Fisheries Technical Circular No. 101.

Pearson, M and M. Healey. In press. Life History Characteristics of the Endangered Salish sucker (Catostomus sp.) and their Implications for Management. Copeia.

Peterson, James T. and Peter B. Bayley. 1993. Colonization rates of fishes in experimentally defaunated warmwater streams. Transactions of the American Fisheries Society. 122: 199-207.

Pojar, J. and A. MacKinnon (eds.). 1994. Plants of coastal British Columbia including Washington, Oregon and Alaska. B.C. Ministry of Forests and Lone Pine Publishing.

Pollock, K.H., J.D. Nichols. C. Brownie and J.E. Hines. 1999. Statistical Inference for Capture-Recapture Experiments. Wildlife Monographs. 107: 1-97.

Precision Identification Biological Consultants. 1198. Wild, threatened, endangered and lost streams of the lower Fraser valley summary report. Lower Fraser Valley Stream Review, Volume 2. Fraser River Action Plan. Habitat and Enhancment Branch. Department of Fisheries and Oceans Canada.

Quinn, Thomas, E. and N. Phil, Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile Coho salmon (Oncorhynchus kisutch) in Big Beef Creek, Washington. Can. J. Fish. Aquat. Sci. 53:1555-1564.

Quinn, J. E. and T. J. Kwak. 2000. Use of Rehabilitated Habitat by Brown Trout and Rainbow Trout in an Ozark Tailwater River. North American Journal of Fisheries Management 20:737-751.

Ricciardi, A., and J. B. Ramussen. 1999. Extinction rates of North American freshwater fauna. Conservation Biology. 13:1220-1222.

Richter, B.D., Baumgartner, J.V.., Powell, J. and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology. 10(4): 1163-1174.

Rosenfeld, J.S., M. Porter and E. Parkinson. 2000. Habitat Factors Affecting the Abundance, and Distribution of Juvenile Cutthroat trout (Oncorhynchus clarki) and coho salmon (Oncorhynchus kisutch). Canadian Journal of Fisheries and Aquatic Sciences 57: 766-774.

Schlosser, Isaac, J. 1990. Environmental variation, life history attributes and community structure in stream fishes: Implications for environmental management and assessment. Environmental Management, 14(5): 621-628.

Schlosser, I. J. 1995. Dispersal, Boundary Processes and Trophic-Level Interactions in Streams Adjacent to Beaver Ponds. Ecology 76(3): 905-925.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Fisheries and Oceans Canada, Ottawa.

Scott, W. B., and E. J. Crossman. 1998. Freshwater fishes of Canada. Fisheries Research Board of Canada, Fisheries and Oceans Canada, Ottawa.

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

Snedden, G.A., W.E. Kelso and D.A. Rutherford. 1998. Diel and Seasonal Patterns of Spotted Gar Movement and Habitat Use in the Lower Atchafalaya River Basin, Louisiana. Transactions of the American Fisheries Society. 128(1): 144-154.

Trexler, J.C. 1995. Restoration of the Kissimmee River : A Conceptual Model of Past and Present Fish Communities and its Consequences for Evaluating Restoration Success. Restoration Ecology. 3(3): 195-210.

Vannote, R.L., G.W. Mensal, K.W. Cummins, J.R. Seder and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 37: 130-137.

Warren, M. L., and B. M. Burr. 1994. Status of freshwater fishes of the United States. Fisheries. 19:6-18

Workman, R.D., D.B. Hayes and T.G. Coon. 2001. A Model of Steelhead Movement in Relation to Water Temperature in Two Lake Michigan Tributaries. Transactions of the American Fisheries Society. 131(3): 463-475.

Zorn, T. G. and P. W. Seelbach. 1995. The Relation between Habitat Availability and the Short-Term Carrying Capacity of a Stream Reach for Smallmouth Bass. North American Journal of Fisheries Management. 15:773-783.

Photo Appendix 1

Photo 1. Ponds at headwaters to Salish Creek, 2000.

Photo 2. Columbia Bitulithic channel resulting from flooding on adjacent landowners property facing upstream, 1992.

Photo 3. Aerial of Salish Creek before diversion, 1999.

Photo 4. Salish Creek study area prior to watering – pool with boulders.