THE ECOLOGY, STATUS AND RECOVERY PROSPECTS OF NOOKSACK DACE (*RHINICHTHYS CATARACTAE* SSP.) AND SALISH SUCKER (*CATOSTOMUS* SP.) IN CANADA

by

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ABSTRACT

I studied the ecology and assessed the current status and prospects for recovery of two endangered fishes, the Salish sucker and the Nooksack dace. Salish sucker populations were located in 9 of 45 Fraser Valley watersheds. Distribution is discontinuous and abundance is spatially clumped at the regional and watershed scales. Populations are concentrated in headwaters, especially beaver ponds. The amount of deep pool habitat in a reach is the most powerful predictor of presence, but fish are usually absent if more than 50% of the land within 200 m of a reach is urban. Radio telemetry work showed that Salish suckers are crepuscular, have home ranges averaging 170 m of linear channel, made their longest movements during the spawning period (March to early June) and rarely crossed beaver dams. Relative to closely related Catostomids, they are small, early maturing, and have a prolonged spawning period. Nooksack dace are limited to three watersheds in Canada. Populations are spatially clumped. The amount of riffle habitat in a reach is the most powerful predictor of their presence, while long sections of deep pool are associated with absence. Mark-recapture work suggests that dace typically range over less than 50 m of channel, but that a small number venture further. Spawning is prolonged (April –July). Life history characteristics of both species are likely to impart good resilience to short-term disturbances of limited spatial scale, but not to the chronic, large-scale disruptions that affect their habitat in Canada. I identified eight potential threats and for each assessed species vulnerability, severity in each population's watershed, and the ability of current legislation and policy to address it. In light of these three factors, Salish suckers appear most threatened by acute hypoxia and Nooksack dace are most threatened by lack of water. Both species have been strongly impacted by habitat destruction from drainage and infilling projects and may be vulnerable to introduced predators and habitat fragmentation. Toxicity from urban runoff, sediment deposition and riffle loss to beaver ponds (dace only) threaten individual populations, but are probably not major threats across the range.

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Acknowledgements

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Chapter 1

Introduction

Introduction

Preservation of biodiversity is increasingly recognized as a policy priority by governments. Canada signed the United Nations Convention on Biological Diversity in Rio de Janeiro in 1992. Following this, the federal government and the governments of Canada's provinces and territories signed the National Accord for the Protection of Species at Risk. The federal government also recently enacted the *Species at Risk Act* (S.C. 2002, c. 29), which is intended to prevent indigenous species from becoming extirpated or extinct, to provide for their recovery, and to prevent additional species from becoming at risk (s.6). Provincially, the British Columbia Ministry of Water, Land and Air Protection (MWLAP) continues to highlight biodiversity issues in the objectives and policies of its most recent Service Plan (MWLAP, 2003). Even some municipalities have enshrined goals or objectives related to species at risk and biodiversity in their Official Community Plans (City of Abbotsford, 2000; City of Chilliwack, 1998). These policy and legislative enactments are, no doubt, a response to high and sustained levels of public concern over the issue of declining biodiversity. In the fall of 1999 Environment Canada commissioned a poll by Decima Research, which found that 76% of Canadians felt that governments should do more to protect endangered species and 88% would support legislation to protect the habitat of endangered species (Environment Canada, 1999). A similar poll by Pollara in 2001 found that over 90 percent of Canadians, supported endangered species protection (Jaimet, 2001).

Species at risk are not distributed randomly. Particular regions contain disproportionate densities of species at risk (Myers et al., 2000). Within British Columbia one such place is the Georgia Basin, which contains the Fraser Valley and 26% of British Columbia's 736 Species at Risk (MWLAP, 2002). The Fraser Valley, although only 4000 km^2 in size is currently home to approximately 2.1 million people (BC Stats, http://www.bcstats.gov.bc.ca/data/pop, accessed Feb 6, 2004), is among the fastest growing regions in Canada, produces 50 percent of the province's gross agricultural income and is showing signs of ecosystem distress (Healey et al., 1999).

Conservation initiatives in such a densely settled landscape are complicated by a high degree of private land ownership, multiple and overlapping regulatory jurisdictions, intense and competing pressures for various types of land development, and high land values. Lack of knowledge of population sizes, spatial distribution, habitat needs, and life history attributes further hamper conservation and recovery efforts for many species. In this thesis I use the cases of two endangered fishes, the Salish sucker (*Catostomus* sp.) and the Nooksack dace (*Rhinichthys cataractae* ssp.), to illustrate an approach that integrates ecological research with policy analysis to facilitate conservation planning in such a context.

I start by describing important, but previously unknown, aspects of the life history, distribution, and habitat use of both species (Chapters 2 through 5). Based on this work and on field observations of habitat conditions in the valley, I identify eight possible threats that are potentially driving the observed declines. I analyze the vulnerability of each species to each impact hypothesis by life history stage and assess the existence and degree of threat posed by each impact hypothesis in each watershed to the fish inhabit (Chapter 6). In Chapter 7 I briefly review the jurisdiction and existing legislation and policy of the federal, provincial, and municipal, governments and use the eight threats as a framework to identify opportunities and obligations of each jurisdiction to contribute to conservation efforts. I also identify gaps and conflicts in policy and legislation that will inhibit conservation and recovery. Finally in Chapter 8, I summarize and integrate the major findings and make recommendations for recovery planning for both species.

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Chapter 2

Life-History Characteristics of the Salish Sucker and Their Implications for Management[1]

[1] A version of this chapter has been published. Pearson, M.P. and Healey, M.C. (2003) Life-history of the endangered Salish sucker (*Catostomus* sp.) and their implications for management. Copeia 2003: 759-768.

Introduction

Freshwater fishes are among North America's most threatened faunas (Miller et al., 1989; Moyle and Williams, 1990; Warren and Burr, 1994). Current extinction rates are estimated to be five-fold higher than those of terrestrial vertebrates and over 1000 times background rates estimated from the fossil record (Ricciardi and Ramussen, 1999). The natural history of the vast majority of threatened and endangered fishes is very poorly documented, but can give important insights into extinction risk. For example, diadromy, limited geographic range, reliance on a narrow range of water body sizes, and narrow ecological specialization have been identified as important risk factors (Angermeier, 1995).

The Salish sucker (*Catostomus* sp.) has a distribution limited to a few watersheds in British Columbia's Fraser Valley and northwestern Washington State (McPhail, 1987). It is considered to be an evolutionarily significant unit (sensu Waples, 1995), that evolved from a population of the common and widespread longnose sucker (*C. catostomus* Forster) that became geographically isolated in Washington State's Chehalis River valley sometime during the Pleistocene glaciations (McPhail and Taylor, 1999). The Salish sucker is listed as endangered by the American Fisheries Society (Williams et al., 1989) and by the Committee on the Status of Endangered Species in Canada (Campbell, 2001), but not under the U.S. Endangered Species Act.

Since the 1960s, the Salish sucker has been extirpated from at least two creeks in Canada, and much of their remaining habitat has been degraded by urbanization, agricultural drainage, and sedimentation from gravel mining (McPhail, 1987; Appendix 1). Conservation efforts have been hampered by lack of information on distribution, habitat requirements, and life history and by low levels of public and political awareness of its plight. In this chapter, I report on aspects of life history that have not been previously investigated for this species, including growth, movement patterns, home range size, and spawning periods. I also discuss the implications of my findings for risk of extinction and for conservation and management.

Study Area

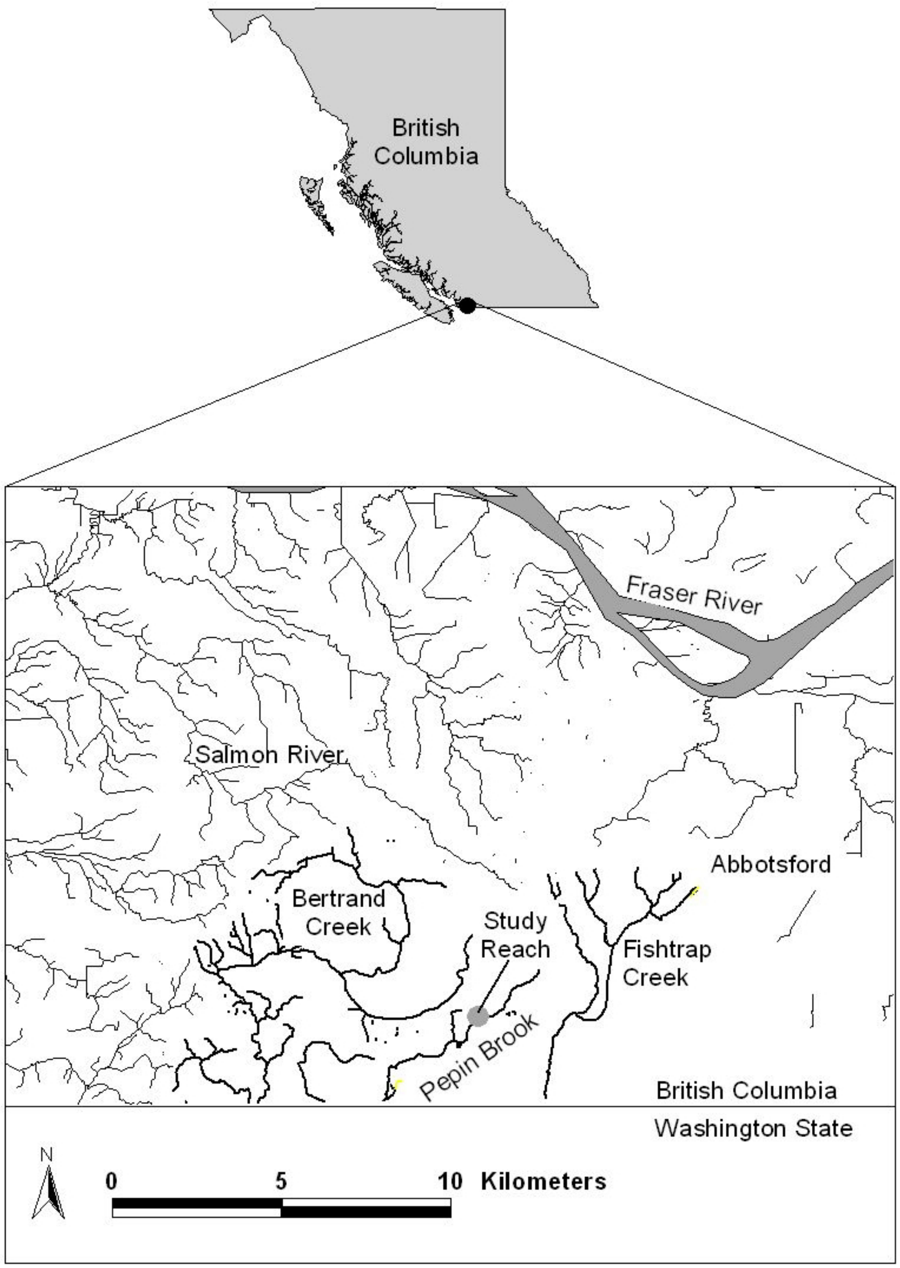
This work was conducted in Pepin Brook, a second order stream in the Fraser Valley of southwestern British Columbia that is tributary to Washington State's Nooksack River (Fig. 2.1). Mean August discharge (base-flow) is 0.171 $\pm$ 0.035 $m^3 \cdot s^{-1}$ (mean $\pm$ S.D). Winter discharge is not measured, but mean January flow in a similar neighboring stream (Fishtrap Creek) exceeds 1.5 $m^3 \cdot s^{-1}$ (Water Survey of Canada, Vancouver). Pepin Brook is largely groundwater fed in summer (Johanson, 1988) and water temperatures rarely exceed 16°C or drop below 2°C (Pearson unpubl.).

Land use within the Canadian portion of the watershed is an approximately even mix of gravel extraction, livestock farming, and parkland. The U.S. portion of the stream is confined to roadside ditches.

I studied a 1.5 km section of the stream that included a 5.8 ha marsh. The area was selected because it contains an exceptionally high concentration of Salish suckers (see Chapter 3). The marsh is a large, aging beaver pond. A single open channel meanders through an otherwise continuous cover of floating mats of reed canary grass (*Phalaris* sp.) and hummocks of cattails (*Typha latifolia* L.). The channel has an average depth of 1.2 m, width of 2 m, and current velocity of ca. 10 $cm \cdot s^{-1}$. A single open water pond (ca. 45 x 30 m), thickly vegetated with submerged macrophytes, is located at its downstream end, immediately upstream of the main beaver dam. A 10 to 50 m wide riparian strip of mature, second-growth deciduous forest buffers the marsh from adjacent gravel pits and a blueberry farm. In addition to Salish sucker, the marsh supports coho salmon (*Oncorhynchus kisutch* Walbaum), cutthroat trout (*O. clarki* Richardson), threespine stickleback (*Gasterosteus aculeatus* L.), and western brook lamprey (*Lampetra richardsoni* Vladykov and Follet; Pearson, unpubl.).

Upstream and downstream of the marsh, the creek flows through swamp. The water in these sections is also deep (>100 cm), slow moving, and periodically impounded by beaver dams; thick tree cover replaces the grass and cattails.

Figure 2.1. Location of the study reach on Pepin Brook in British Columbia's Fraser Valley (Lat 49°00', Long. 122°30'). Bertrand Creek, Pepin Brook and Fishtrap Creek flow south into Washington State's Nooksack River. The remaining drainages shown are tributaries of the Fraser River or drain independently into the Pacific Ocean.



Methods

General Methods

Salish suckers were captured using cylindrical, double-ended funnel traps constructed from galvanized steel mesh (60 x 100 cm with 12 mm mesh). They were baited with dry cat food in perforated canisters and set for approximately 24 h unless nocturnal hypoxia was a concern (August), in which case 6-h daytime sets were used. Catch-per-unit-effort (CPUE) was measured as the mean number of fish per trap on each sampling day. Seasonal patterns in CPUE were examined by analysis of variance with Bonferroni's multiple comparison test of log transformed values ($\propto$=0.05).

Fish were anaesthetized in a solution of tricaine methanesulfonate (MS 222, 70 $mg \cdot l^{-1}$), then weighed (nearest 0.1 g), measured (fork length, nearest mm) and, following recovery from sedation, released at their point of capture. Of the 4,110 suckers captured during the study, 286 were individually marked with subcutaneous injections of fluorescent elastomer (Northwest Marine Technology, Inc., Shaw Island, Washington State). Water temperature was measured hourly in a shaded riffle approximately 100 m downstream of the old beaver dam using a logger (Optic-Stowaway, Onset Corporation, Pocasset , MA).

Growth and Reproduction

Growth rates were calculated from the change in fork length of marked fish between the first and final captures of the sampling season (May 14 to October 12, 2000). Only fish recaptured more than 7 days after marking were included. Growth rates of Salish sucker sexes were compared using analysis of covariance with fork length at time of marking as the covariate as it was significantly and negatively correlated with growth rate for both sexes.

Reproductive condition of all fish was ranked on a qualitative scale (no evidence of reproductive activity, gravid, ripe, very ripe) based on the quantity of eggs or milt extruded from the vent following gentle abdominal squeezing. Salish suckers larger than approximately 100 mm were sexed using the anal fin, which is dimorphic (male large and fan shaped, female rectilinear with thickened leading ray). Size at maturity of Salish suckers was estimated from the proportion of fish in 5 mm length increments that were gravid or ripe during the peak spawning season (March 5 - June 15). Seasonal changes in fish condition were examined using relative condition factor (K_n=(W/W')), where W is the weight of an individual and W' is a length-specific standard weight predicted by the weight-length regression equation (Anderson and Neumann, 1996). Mean monthly K_n values were compared using analysis of variance and Bonferroni's multiple comparison test (α=0.05).

Home Range and Movement

Radio transmitters (Holohil BD-2G, Carp, Ontario), operating in the 148-150 MHz range, were surgically implanted into the body cavities of 12 female and 6 male Salish suckers. Transmitters weighed 1.95 g (16X10X6 mm) or 1.45 g (15X7X4mm); their size limited radio tagging to the largest available individuals (tags=1.1 to 3.1% of body weight). Fish were deeply anaesthetized with clove oil dissolved in creek water (Anderson et al., 1997) and sterilized transmitters were inserted through a 1 - 2 cm midventral incision, which was then closed with 2 - 4 monofilament silk or PDS sutures (3-0, Ethicon Inc.) and sealed with tissue adhesive (3M Vetbond No. 1469). Gills were irrigated with a constant flow of anaesthetic during the 3 - 5 minute procedure and with fresh creek water following surgery until spontaneous gill ventilation resumed. They were then transferred to perforated live boxes in the stream and held for 24 h. Data from the first four days after release were not used in analysis.

The marsh was mapped from bearings and distances to prominent landmarks obtained with a surveying transit and range finder. These relative locations were translated into a Cartesian coordinate system and plotted on a computerized GIS to facilitate base map production.

Fish were located using a portable receiver (Lotek SRX 400) fitted with a two-element Yagi antennae. The relatively shallow water of the marsh allowed me to locate fish precisely by maneuvering a canoe into a position where signal strength was strongest directly below the boat. Fish did not react noticeably to the presence of the boat. The ease of recovering transmitters from dead fish indicated that locational accuracy for fish at rest was within 1 m. Fish locations were either plotted directly on the map or measured using a compass and range finder to obtain distances and bearings from landmarks. Mapping precision was estimated by recording bearings and distances to two different landmarks for a subset of fish locations. The average difference in the two position estimates was 3.76 $\pm$ 0.23 m (mean $\pm$ SEM, n=136, max = 14.6).

I collected locational data at two time scales, daily and hourly. The daily time scale involved locating each fish once every 1 - 3 days during daylight hours while the hourly time scale consisted of locating each fish once every 3 - 4 h over a 24 h period. Hourly data were collected on 18 occasions between April and November of 2000.

Home range sizes for each fish were estimated by calculating the minimum length of channel and the minimum area of channel containing 95% and 100% of location points on the GIS map. Three of the 18 fish were excluded from this analysis. One was located only once and two were found dead less than 10 days after release. The remaining fish were located between 18 and 139 times over 25 to 153 days. I tested for correlation between number of position observations and estimated home range size using the Spearman rank-order correlation coefficient (r_s) with a one-tailed test of significance (Zar, 1999).
Diel activity patterns were examined by calculating the minimum movement rate between successive locations. Each interval's movement rate was placed into the three-hour clock period (beginning at 05:00 Pacific Standard Time) in which the majority of the interval occurred. As the data failed to meet assumptions of normality and homogenous variance necessary for parametric analysis, I used the Kruskal-Wallis method to test for differences among periods and a non-parametric multiple comparison method for unequal sample sizes to identify significant differences (Zar, 1999).

Minimum daily distances traveled were estimated by summing interval distances over each 24-hour session. Fish were used in the analysis only if they were located 5 - 8 times in the session. Over this range, number of locations had no effect on total distance (r^2=0.02, p=0.31).

Results

General

Over three years I captured a total of 4,110 Salish suckers (including recaptures). The largest fish was a 287 mm female weighing 196 g. The largest male was 206 mm and weighed 107 g. Females grew to larger size; only 0.03 % of males but 10 % of females in the sample exceeded 200 mm in length. Modal length of females (136 mm) and males (135 mm) were nearly identical. Regression of weight on length yielded an equation of $W=1.072x10^{-5}xL^{3.01}$ ($r^2=0.96$) for males and $W=8.317x10^{-6}xL^{3.06}$ ($r^2=0.98$) for females. Males matured at a smaller size (50% at 125 mm, 90 % at 140 mm) than females (50 % at 135 mm and 90% at 155 mm). Juvenile fish, particularly young-of-the-year, were poorly represented in my samples, presumably due to sampling bias. Only 10.4% of all Salish suckers captured were less than 120 mm in length, the approximate size of a male in its third year (McPhail, 1987).

Catch per unit effort (CPUE) was strongly influenced by temperature; almost no Salish suckers were caught when water was less than 7^oC and highest catches occurred between 12 and 15^oC (Fig. 2.2). With the exception of August, mean monthly CPUE was significantly higher between May and September than during early spring and late fall (Fig. 2.3).

Growth and Reproduction

Growth rates were negatively correlated with body length in both sexes ($P<0.001$, male $r^2 = -0.64$, female $r^2 = -0.61$). Analysis of covariance revealed that when length effects were removed, male fish grew significantly more slowly (0.071 ± 0.011 mm·day^{-1}; mean $\pm$ SEM; n=35) than females (0.112 ± 0.010 mm·day^{-1}; n=40) between May and October.

The spawning period of Salish suckers appears quite protracted. In Pepin Brook, 80% of mature females (>150 mm fork length) are visibly gravid in March. Spawning begins in early April and continues until mid June or early July. Mature males (>135 mm) follow a similar pattern but appear to begin gametogenesis again in late summer or early fall, as over 60% of them were producing milt during fall sampling.

Figure 2.2. Effect of water temperature on catch per unit effort (CPUE) of Salish suckers in a Pepin Brook marsh. Each point represents the mean of three to six traps set for 24 hours.

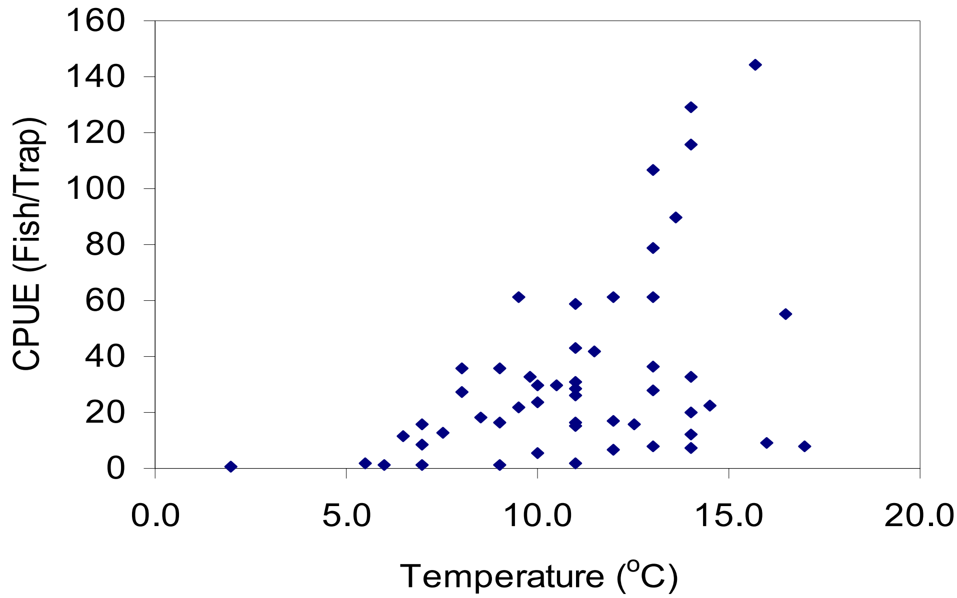
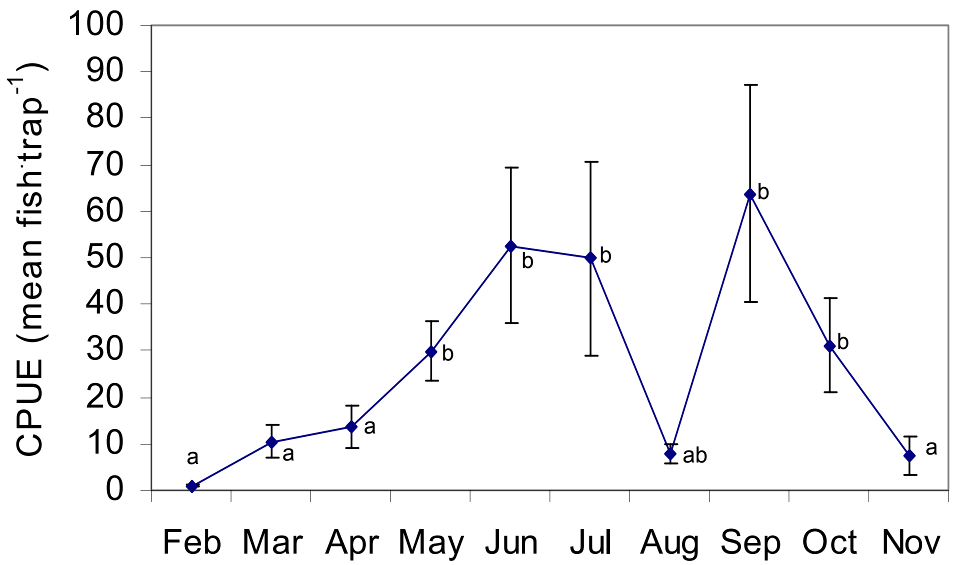


Figure 2.3. Monthly mean catch per unit effort (CPUE) of Salish suckers in Pepin Brook. Vertical bars denote standard errors of means and months flagged with the same letter are not significantly different. Data from all years are pooled and August sets were six rather than 24 hours.



Males and females showed similar seasonal changes in relative condition factor (K_n) within years, but values for both sexes differed sharply between years (Fig. 2.4). In all years K_n was highest in early spring (March or April), declined significantly through the spawning season, and began to increase in late summer and early fall. In 1999, following some recovery in early fall, K_n plummeted in October and November. It remained significantly lower than 1999 levels in all months of 2000. In the spring of 2001 K_n appeared to recover somewhat as peak levels (April) were significantly higher than those of 2000.

Home Range and Movement

Of the 18 fish I tracked, two were still being followed when the study was terminated, batteries expired in four (two of these were recaptured and appeared healthy the following spring), and two were assumed predated. The transmitters from both of these fish were recovered with no sign of a carcass; one badly chewed and one in very shallow water (<10 cm) far from its home range. Three other tagged fish were found dead of unknown causes. The fates of the remaining seven are unknown.

Home range size (95%) of the 15 fish used in the analysis ranged from 42 to 307 m of linear channel and covered between 212 and 1704 m^2 of area (Table 2.1). One hundred percent ranges were much more variable due to a small number of very large movements. Home range size was not correlated with sample size in my data set ($r_s<0.25$, $p > 0.1$). Of the 730 locations in the telemetry data set, all but three were upstream of an old beaver dam, the area in which all fish were initially captured.

Minimum daily distances moved ranged from 1 to 376 m (mean 120, SEM 13.9, median 90). All fish that were followed on multiple occasions showed high variation in distance moved between days, most spanning more than an order of magnitude.

Movement rates of radiotracked Salish suckers were highest at dawn and dusk, significantly greater than between 08:00 and 17:00 Pacific Standard Time (Fig. 2.5). Median movement rates were lower at night than during dawn and dusk, but the difference was not statistically

Figure 2.4. Changes in relative condition factor (K_n) of Pepin Brook Salish suckers between April 1999 and May 2001. Vertical bars denote standard errors of means

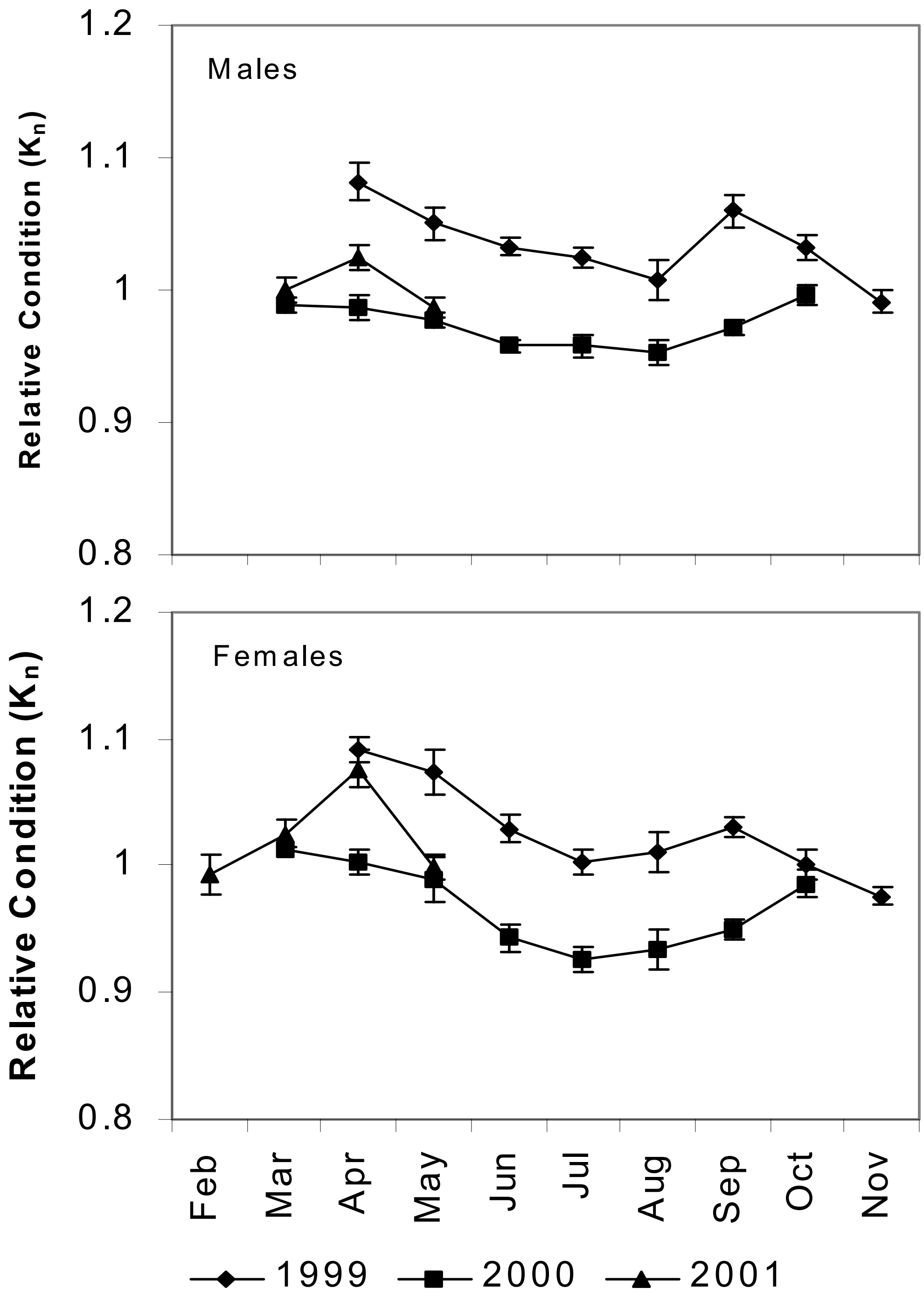


Table 2.1: Characteristics, tracking details, and home range sizes of the 15 Salish suckers used in the radiotelemetry study. Fish are sorted by increasing length and sex.

Fish	Length (mm)	Weight (g)	Sex	Start Date	Days Tracked	Sightings	Linear Home Range (m)		Home Range Area (m^2)	
							95 %	100 %	95 %	100 %
19	191	74.4	F	9/23/00	56	30	42	216	212	830
120	195	72.0	F	9/23/00	62	33	148	167	1238	1302
40	197	80.3	F	9/23/00	62	30	101	155	930	1317
839	197	90.1	F	4/10/00	27	37	240	497	1316	7008
740	200	83.0	F	5/7/00	117	95	218	350	1419	1938
141	203	103.3	F	5/6/00	77	74	307	328	1653	1692
962	205	88.5	F	8/5/00	50	29	164	180	1202	1210
860	209	115.2	F	4/10/00	153	139	113	151	1222	1587
800	214	107.5	F	8/5/00	33	28	307	334	1736	1801
840	231	148.7	F	9/23/00	30	18	251	260	1640	1598
819	243	155.3	F	7/26/00	31	21	289	351	1634	1777
940	166		M	4/11/00	58	65	90	160	1138	1423
119	167	55.0	M	5/6/00	39	46	221	250	1703	1991
18	175	61.2	M	5/7/00	29	34	72	81	1064	1142
822	203	83.5	M	8/4/00	34	29	92	93	995	1006
				Mean			177	238	1273 (107)	1841
				(SEM)			(24)	(32)		(407)
				Median			164	216	1238	1587

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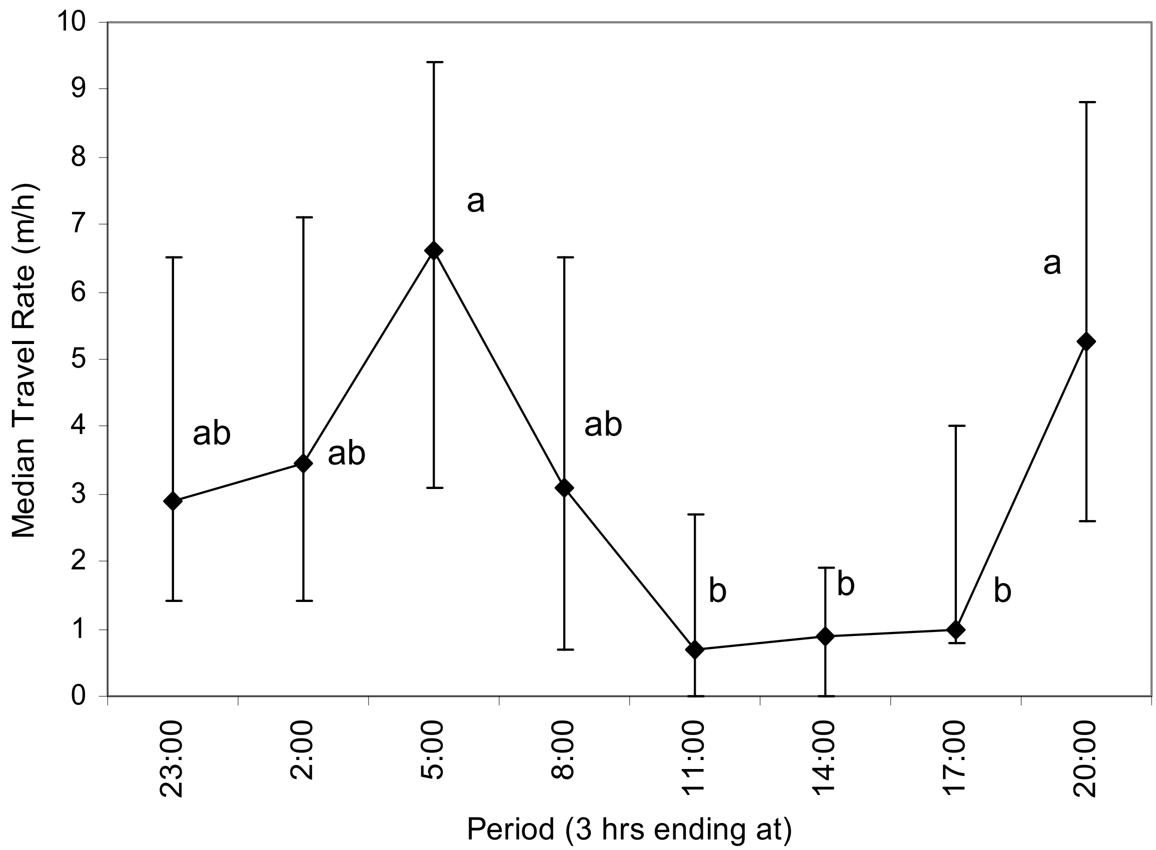
Figure 2.5. Movement behaviour of Salish suckers at different times of day. Values are medians of distance traveled between successive locations with 95 percent confidence intervals. Those marked with the same letter are not significantly different.



significant. During the night, fish were obviously moving and visible (by flashlight) much more frequently than during the day.

Daytime resting positions were usually in heavy cover, often among thick emergent vegetation adjacent to the open channel. Adult Salish suckers showed some fidelity to resting areas. Fish were found at rest within 10 m of their previous days resting location on 50% of occasions. On five of the 80 times individuals were tracked over 24 hours, fish moved from daytime resting positions near the upstream end of the study area to spend the night in the pond more than 200 m downstream, and then returned to spend the next day within 2 m of their original location.

Eight of 265 Salish suckers that were marked in the marsh in October 1999 and two of 103 marked in March 2000 were captured in a weir-trap on Salish Creek, a tributary to Pepin Brook located 1020 m downstream of the study reach. Of the ten fish (fork lengths 135 -222 mm), five were female and three were male. Gender of the other two was not recorded. Six of them, including all the males were in reproductive condition. Seven of the ten were subsequently recaptured in Salish Creek at least once during spring or summer 2000. All were found 450 - 600 m upstream of the weir trap in the largest, deepest pools available. None left Salish Creek by March 2001 when the weir trap was removed (Tyese Patton, University of British Columbia, unpublished data).

Discussion

Life History Strategy

Salish suckers are small, short-lived (McPhail, 1987), and early maturing relative to most populations of *C. catostomus*. The latter are notoriously variable for these traits. Individuals in some populations exceed 500 mm in length and 19 years of age, (Scott and Crossman, 1973) while individuals in ‘dwarf’ populations mature at much smaller size. Among the 1,284 records of occurrence for *C. catostomus* in the University of British Columbia Fish Museum the smallest recorded mature individual is 106 mm (fork length; male, Hart Lake, Peace River drainage, British Columbia; J.D. McPhail, University of British Columbia, pers.

comm.). This is slightly larger than my smallest recorded Salish sucker, a 96 mm mature male.

In most populations *C. catostomus* do not spawn before age 5 (Scott and Crossman, 1973), while Salish suckers spawn at the end of their second year (McPhail, 1987). The Salish sucker spawning period is also very protracted (6 to 8 weeks), relative to longnose sucker (2 to 3 weeks: Scott and Crossman, 1973; Barton, 1980; Schlosser, 1990).

These characteristics suggest that the Salish sucker has evolved an opportunistic life history strategy (sensu Winemiller and Rose, 1992). Protracted or multiple spawning periods increases fecundity in species otherwise limited by small female body size (Burt et al., 1988; Blueweiss et al., 1978). This, especially when combined with early maturation, promotes resilience to frequent disturbance by facilitating rapid population growth and fast recolonization of habitat over short spatial distances (Schlosser, 1990). Small body size and multiple spawnings are common in species inhabiting headwater areas which commonly experience higher rates of disturbance than downstream reaches (Schlosser, 1995a). Unfortunately, these traits provide little resilience to large-scale or chronic disturbances (Winemiller and Rose, 1992), especially in species that have very limited geographic ranges (Angermeier, 1995; Moyle and Williams, 1990).

Sexual size dimorphism with larger females is common among fishes and reflects different equilibrium points for the sexes between opposing selective pressures favoring large and small body size (Blanckenhorn, 2000; Shine, 1989). The major forces favoring large size in most poikilotherms are increased fecundity in females and sexual selection in males (Shine, 1989). Selective pressures favoring smaller body size are more varied (see Blanckenhorn, 2000 for review). Among those likely to be important in Salish sucker life history are reduced mortality risk due to shorter maturation time and advantages associated with greater agility, including improved predator avoidance and possibly sexual selection. Some, but not all, populations of longnose sucker also show sex related size differences (Scott and Crossman, 1973). The resumption of milt production in male Salish suckers in the fall is unusual, but known to occur in some temperate fishes adapted to early spring spawning (J.D. McPhail, University of British Columbia, pers. comm.).

Condition

The seasonal pattern of condition factor was undoubtedly associated with energy loss during spawning and subsequent recovery. The cause of the sharp decline in condition in the fall of 1999 that continued throughout 2000 may have been severe hypoxia as a catastrophic population decline associated with lack of oxygen occurred in this reach in 2002 (see Chapter 3).

Home Range and Movement

The home range sizes I found for Salish suckers were an order of magnitude larger than those of other lotic species reviewed by Minns (1995). All but one of these, however, was studied using mark-recapture rather than telemetry, the former being strongly biased towards finding small home range sizes (Gowan et al., 1994). Home ranges of Salish suckers were comparable in scale (tens to a few hundreds of m of channel) to those of the few other small stream fishes studied by telemetry (Young, 1996; Roberge, 2000; Matthews, 1996). Fish in larger rivers seem to travel much farther (Tyus and Karp, 1990; Swanberg, 1997; Matheney and Rabeni, 1995), although this may be confounded with body size.

The reluctance of radio-tagged fish to cross the beaver dam suggests that Salish sucker distribution and home range size will be strongly influenced by shallow water features like dams and riffles. Salish suckers tend to be associated with long continuous areas of deep pool habitat (see Chapter 3) and their distributions may be constrained by modest barriers like beaver dams. Schlosser (1995b) found that beaver dams had a major influence on the structure of a small stream fish community in Minnesota by limiting dispersal and colonization processes. Fish crossed dams only when discharge exceeded a threshold during critical life history stages.

Salish suckers were capable of crossing the dam. Radio-tagged fish did on three occasions and the marked fish captured in the Salish Creek weir-trap had traveled more than one km downstream crossing the study reach dam and two others en route. These movements occurred during the spring of 2000 and most of the fish were in reproductive condition, suggesting that spawning was the motivation. Salish Creek is a diversion constructed in 1999 to enhance habitat. Fish density within it was still quite low in 2000 and Salish suckers there grew significantly faster than those in the marsh (T. Patton, University of British Columbia, unpubl.), suggesting that it was attractive habitat, which may explain why none left after the spawning season.

Diel Activity

Movement rates of Salish suckers were highest around dawn and dusk. High crepuscular activity rates have been recorded in many species and are usually related to travel between diurnal and nocturnal areas of activity and resting (Matheney and Rabeni, 1995; Helfman, 1981; Bohl, 1980) or to high food availability at these times (Ovidio et al., 2002).

Although some activity was recorded at all times of the day, fish were most often actively moving when located at night. Some other catostomids are nocturnal. Longnose and white suckers (*C. commersoni* Lacepede) feed continuously by night in the shallow waters of lakes, resting in deeper areas by day (Carlander and Cleary, 1949; Campbell, 1971; Emery, 1973) but northern hog suckers (*Hypentelium nigricans* Lesueur) appear diurnal (Matheney and Rabeni, 1995). For most species nocturnal activity is attributed to predator avoidance (Naud and Magnan, 1988; Adam et al., 1988; Hall et al., 1979), but diurnal predation risk for adult suckers appears very low. In the deep, heavily vegetated marsh habitat, avian predators present little threat and no co-occurring predatory fish are large enough to consume them. Mink (*Mustela vison* Schreber), which are common in the study area and are known to prey on Salish suckers (Pearson, pers. obs.), are also nocturnal or crepuscular (Nowak and Pardiso, 1983).

The fidelity to resting areas observed in radio-tagged Salish suckers occurs among many fishes and is thought to improve predator avoidance though familiarity with the local environment (Helfman, 1993). The combination of nocturnal activity and fidelity to daytime resting areas suggests that predation risk may be higher for this species than it appears.

Seasonal Activity

Salish suckers were active at temperatures down to 7^{o}C. Water temperatures in the marsh were above this threshold for at least part of 245 days during 2000. In other systems, Salish suckers are often found in water exceeding 20^{o}C (Pearson, unpublished data). Longnose suckers are similarly eurythermal, often spawning in temperatures of 5^{o}C (Scott and Crossman, 1973), but tolerating temperatures well above 20^{o}C (Black, 1953). CPUE was highest from May to September, when water temperatures were above 10^{o}C. CPUE was very low in August, likely due to the shorter (6 vs. 24 h), daytime-only sets were used in that month to avoid asphyxiating fish overnight. Hypoxic conditions may have also reduced CPUE directly. The relationship between catch rate and temperature was complex with the highest, but also the most variable, catch rates occurring at high temperatures.

Management Implications

The Salish sucker has been in decline in British Columbia since at least the 1970s (McPhail, 1987) and perhaps much longer. The habitats of their native streams have been dramatically altered by human settlement over the past 150 years. In this period approximately 75 % of forest land and 62 % of wetland in the Fraser Valley has been lost, largely to urban and agricultural land uses (Healey et al., 1999). Agricultural and storm drainage combined with irrigation withdrawals have reduced summer low flows, while forest removal, dredging, and channelization have reduced habitat complexity (Boyle et al., 1997), and nutrient loading has reduced water quality (Vizcarra et al., 1997). The risk of Salish sucker extirpation or extinction depends upon the extent and severity of future disturbances to their habitat and on their resilience to and ability to recover from those disturbances.

Local populations of Salish sucker appear confined to relatively small reaches of stream that include deep pools, but also shallow riffles suitable for spawning. Some individuals do explore more widely, however, and are able to colonize unoccupied suitable habitat, as shown by the suckers that invaded Salish creek. Their rapid growth, early maturation, and relatively high fecundity suggest that Salish suckers are capable of recovering from disturbances to their habitat provided the local population is not wiped out. If local populations are extirpated, fish from other local populations may recolonize the area, provided the habitat remains suitable. These factors suggest that conservation of this species can be accomplished by maintaining a number of healthy local populations within a stream system. Such populations would likely be quite resilient to short term local disturbances. Furthermore, the characteristics of the species suggest that reintroduction to stream systems from which they have been eliminated is likely feasible provided habitat characteristics are suitable. The species is not likely to survive continued large-scale degradation of its habitat, such as through the extensive urbanization that is now occurring as metropolitan Vancouver expands eastward. Provided water flow and water quality can be maintained, however, the stream and riparian habitat that must be set aside to maintain healthy sucker populations is relatively small.

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Chapter 3

Habitat Use by the Salish Sucker at Multiple Scales

Introduction

Among taxonomic groups, an exceptionally large proportion of freshwater fish have severely limited distributions (Angermeier, 1995; Warren and Burr, 1994; Sheldon, 1988). The smallest fish ranges are several orders of magnitude smaller than those of the most restricted mammals and birds (Brown et al., 1996). Restricted range size and the limits on abundance associated with it (Gaston, 1999) are considered major determinants of extinction risk and a primary reason that freshwater fishes are among North America's most endangered faunas (Ricciardi and Ramussen, 1999; Miller et al., 1989; Moyle and Williams, 1990). The chance that a single local disturbance event will wipe out all of a local population is simply greater when the population is small and localized than when the population is large and widely distributed. Conservation in these circumstances requires intimate knowledge of the distribution and relative sizes of subpopulations within the range in addition to an understanding of life history and habitat associations over a range of scales.

Population structure within a range can vary from uniform rarity, to local abundance (Brown et al., 1996) with sub-populations absent, insular, linked as classic metapopulations (Levins, 1969), or linked through source-sink dynamics (Pulliam, 1988). Schlosser and Angermeier (1995) proposed a 'hybrid' model in which a cluster of spatially aggregated sub-populations act as a source and peripheral populations act as sinks or behave similarly to classic metapopulations. Understanding these structures is important as different arrangements will frequently lead to different conservation strategies (Wainwright and Kope, 1999; Schlosser and Angermeier, 1995).

Habitats are formed by numerous interacting processes operating at multiple spatial and temporal scales with larger/longer scale processes frequently driving locally observed patterns (Levin, 1992; Frissell et al., 1986; Imhof et al., 1996). Most research on stream fishes has occurred on small spatial and short temporal scales that are poorly linked to pressing management concerns which generally occur on larger and longer scales (Fausch et al., 2002). For restricted-range stream fishes, the reach/decade scale (100s to 1000s of metres spatially, 5 to 50 years temporally) is likely to be critical for conservation. Both human land use management and many of the processes driving fish population dynamics act at this scale

(Fausch et al., 2002). It will also frequently be the largest scale that will allow sufficient replication for statistical analyses (as in this study).

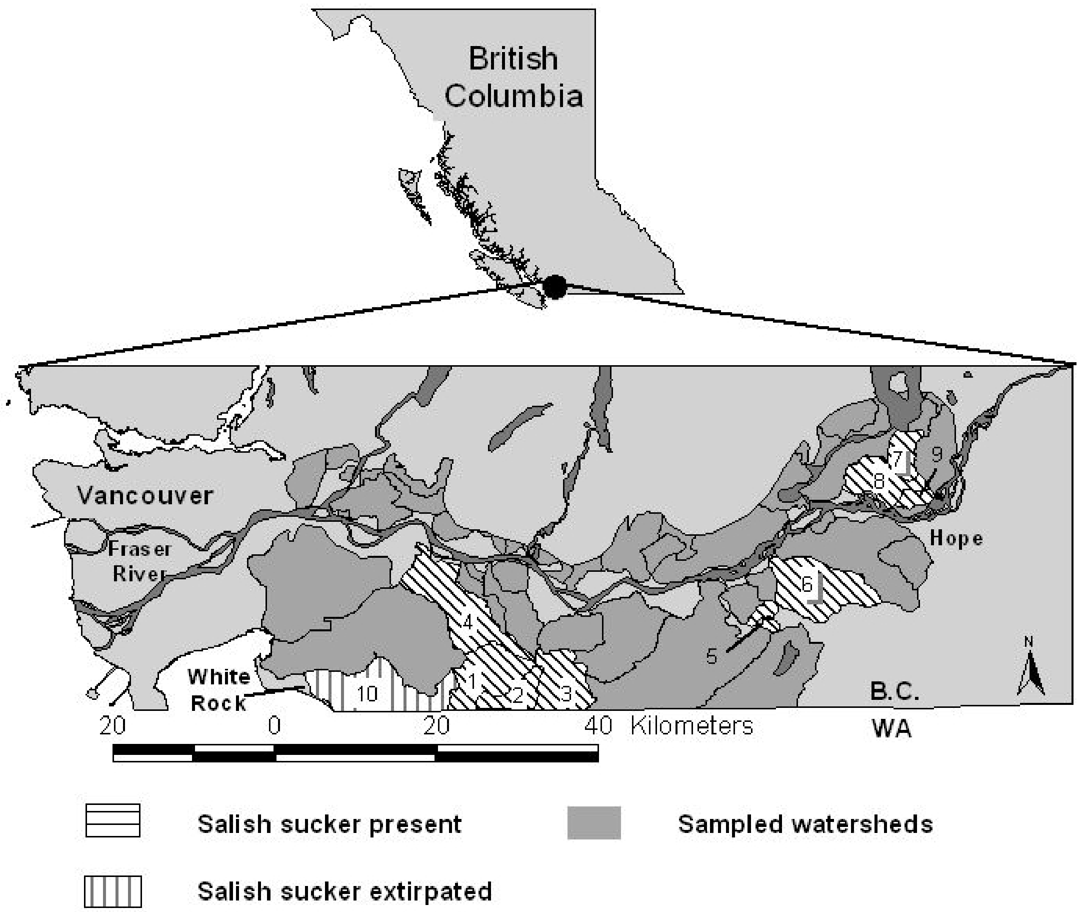
Very few studies have been done on restricted range fishes that include details of internal range structure (Gaston, 1999; Brown et al., 1995). A notable exception is provided by the Labbe and Fausch (2000) study of the Arkansas darter (*Etheostoma cragini* Gilbert) in the dry landscape of southeast Colorado. They found that pool size and distribution at the reach scale controlled population structure but these habitat characteristics were, in turn, created and maintained by rare watershed-scale storm events.

I studied the Salish sucker (*Catostomus* sp.) a fish endemic to northern Washington State and British Columbia's Fraser Valley (McPhail and Taylor, 1999). As with Labbe and Fausch's (2000) study, this is an agricultural landscape, but in a wetter climate and under much more intense pressure from urbanization. The species appears to be in steep decline (McPhail, 1987; McPhail and Taylor, 1999) and is listed as endangered in Canada and by the American Fisheries Society (Williams et al., 1989; Campbell, 2001). It is an evolutionarily significant unit of uncertain taxonomic status (McPhail and Taylor, 1999), but a close relation to the longnose sucker (*C. catostomus)*. In this chapter I describe its distribution in Canada, habitat associations, and population structure over spatial scales ranging from the channel unit to the region and discuss the implications of my findings for conservation and management.

Study Area

In Canada the Salish sucker is limited to small lowland streams in the Fraser Valley (McPhail and Taylor, 1999; McPhail, 1987), which is roughly triangular, 160 km long, 40 km wide at its mouth, 75% within Canada with the remaining quarter in Washington State (Fig. 3.1). Its northwestern corner contains Greater Vancouver and is highly urbanized. The majority of the valley is agricultural, but under increasing development pressure. As recently as 1850, the valley was predominantly forested, much of it by large, old-growth conifers. Extensive wetlands occupied a wide, active floodplain around the Fraser River (North and Teversham, 1984; Boyle et al., 1997). In the ensuing century the original forests were cleared and

Figure 3.1: Study area and currently known Canadian range of the Salish sucker. Numbered watersheds are (1) Bertrand Creek, (2) Pepin Brook, (3) Fishtrap Creek, (4) Salmon River, (5) Salwein Creek/Hopedale Slough, (6) Atchelitz/Chilliwack/ Semmihault Creeks, (7) Miami Creek, (8) Mountain Slough, (9) Agassiz Slough, (10) Little Campbell River.



extensive dyking and drainage projects destroyed most of the wetlands and isolated the lower Fraser from its floodplain (Healey and Richardson, 1996; Boyle et al., 1997). These activities also dramatically altered the channel structure, hydrographs, and nutrient balance of the valley's lowland streams (Fisheries and Oceans Canada, 1998).

The Fraser Valley has cool winters (January mean = 2.6 ^{o}C) and warm summers (August mean = 17.7 ^{o}C). Average annual rainfall is 1,508 mm and is typically highest in November and lowest in August (Abbotsford Airport 1971 - 2000). Hydrographs of streams originating in the valley are rain driven and closely follow seasonal precipitation patterns. Summer base flows in many reaches are maintained by groundwater inflow.

Methods

Fish Trapping

Salish suckers were captured in cylindrical double-ended funnel traps; either commercially available minnow traps (22.5 x 40 cm with 6 mm mesh; 'small traps' hereafter), or 'large traps' constructed from galvanized steel mesh (60 x 100 cm with 12 mm mesh). All were baited with dry cat food in perforated canisters and set for approximately 24 hours unless nocturnal anoxia was a concern, in which case 6-hour daytime sets were used.

Salish suckers were anaesthetized in a solution of tricaine methanesulfonate (MS 222, 70 $mg \cdot l^{-1}$), then weighed (nearest 0.1 g), and measured (fork length, nearest mm). In mark-recapture studies, they were also injected subcutaneously on the ventral surface with fluorescent elastomer (Northwest Marine Technology, Shaw Island, Washington State). Following recovery from sedation, they were released at their point of capture. Other species were counted and released.

Channel Unit Scale (10^0 – 10^1 m)

I recorded substrate, cover, and depth at 463 traps set within reaches known to contain Salish suckers when water temperature exceeded 6^{o}C (species activity threshold, see Chapter 2). Substrate classes (clay, silt, sand, gravel, cobble, boulder (Bain, 1999) and cover classes (large woody debris, overhanging vegetation, boulder, emergent vegetation, submergent vegetation) were recorded as present or absent within a 3 m radius of traps. Depth was recorded to the nearest 5 cm with a metre stick or sounding line. Characteristics of channel units used by Salish suckers were assessed by comparing proportions of traps in which they were captured to the number expected at random in each cover or substrate class using a Chi-square analysis with Yates' correction for one degree of freedom (Zar, 1999). Mean log-transformed depth of traps containing and not containing Salish suckers was compared using a t-test.

Reach Scale (10^2-10^3 m)

Reach scale habitat was surveyed on foot in five streams containing Salish suckers; the Salmon River (tributary to the Fraser River), and the Canadian portions of Bertrand, Cave, Pepin, and Fishtrap Creeks (tributary to the Nooksack River, Washington State). Over the total surveyed distance of 47.9 km, the length (by hip-chain; 2 m resolution) of each channel unit type (riffle, glide, shallow pool, deep pool (>70 cm) was recorded. Reaches were identified as sections at least 20 times longer than channel width that were relatively homogenous with respect to slope, width, substrate, discharge, sinuosity, entrenchment, average depth and riparian vegetation (Arend, 1999). At three pre-determined points on each reach (25%, 50%, and 75% of length) cover was assessed visually on a 5 point scale (0 = no cover; 5 = complete cover) for each of four categories; large woody debris, overhanging vegetation, boulder, and emergent/submergent vegetation. A minimum of 10 traps were set in each reach, between May 1 and Sept 15 in the year surveyed (1999 for Nooksack tributaries, 2000 for Salmon River) to assess presence/absence of Salish suckers.

Proportions of land area in agricultural, forest, urban, and mining use were estimated in a zone adjacent to each reach from polygon areas drawn over high-resolution (pixel size = 1 m on ground), digital, black and white aerial photographs georeferenced to 1:20,000 UTM-projected base maps on a geographic information system (ArcView 3.2). Zones included land within 200 m of each bank and a 200 m-radius semi-circle from each reach endpoint.

Habitat variables were compared between reaches where Salish suckers were present and those in which they were not caught (assumed absent) using either t-tests or, when distributions could not be normalized, Mann-Whitney U-tests (Zar, 1999). A nested series of logistic regression models was used to assess the relative importance of channel unit type, cover, and land use variables in determining the probability of presence or absence. I minimized multicollinearity effects by avoiding inclusion of pairs of highly correlated variables ($|r^2| > 0.7$) in the same model and confirmed logit linearity using the Box-Tidwell test (Tabachnick and Fidell, 2001). I applied reverse stepwise regression (Systat Logit), where the least significant variable of the starting model was excluded in each model iteration using the Wald test with p=0.20. The simplest model contained the combination of channel unit variables that satisfied multicollinearity criteria and maximized fit (highest McFaddens ρ^2). I then expanded the model to include cover and subsequently land use variables. Models were compared using McFadden's ρ^2 and by their ability to correctly predict fish presence or absence in reaches. The significance of improvement in each model expansion was tested for by Chi –square (Tabachnick and Fidell, 2001). I also tested (Chi-square) for positive or negative associations between presence of co-occurring fish or amphibians and Salish suckers at 149 reaches/sites located in watersheds containing known populations.

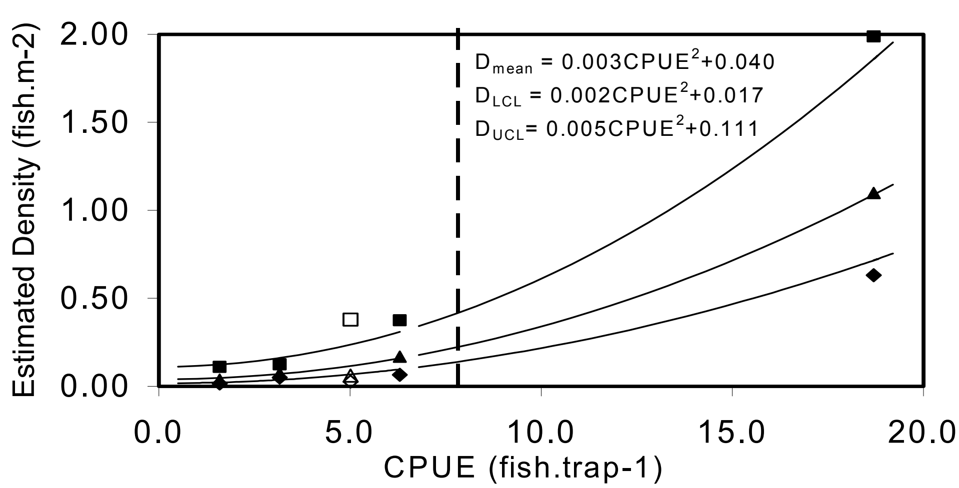
Reach scale adult population estimates were made using an equation relating CPUE to population density estimates from mark-recaptures studies of four sites in 3 streams (Table 3.1). Each site was trapped one to 4 times over periods of 5 to 37 days following initial marking sessions. Mean population sizes with confidence limits were calculated using Schnabel or Petersen methods (Krebs, 1989) and site density was estimated by dividing by the area trapped. Areas for these calculations were bounded at the closer of 85 m from the terminal trap location (50% mean Salish sucker home range size) or at beaver dams (which Salish suckers rarely cross, see Chapter 2).

Catch-per-unit-effort (CPUE, mean number of fish per trap) was calculated for each site and plotted against estimated fish density. Equations relating site density to CPUE were fit as squared functions by regression (Fig. 3.2) and used to estimate densities for each reach of the six watersheds for which I had adequate CPUE data. Reach population estimates were obtained by multiplying density estimates by the area of deep pool (The primary habitat of

Table 3.1: Details of mark-recapture studies used in calculating the relationship between Salish sucker density and catch-per-unit-effort. 'S' and 'P' denote Schnaebal and Petersen methods respectively and bracketed values denote number of samples. LCL and UCL are the lower and upper confidence limits for the mean population estimate.

Site (Watershed)	Sampled Area (m^2)	Start Date	Duration (days)	Method	Total Marks	Total Recap	Pop. Estimate		
							Mean	LCL	UCL
1 (Pepin)	1420	11/10/99	36	S (5)	265	51	1679	1209	2746
	1420	3/29/00	37	S (3)	103	27	1266	896	1940
	1420	5/14/00	22	S (3)	149	33	1711	1247	2461
2 (Salmon)	736	7/5/00	30	P (2)	12	7	54	37	92
3 (Salmon)	1660	5/4/01	6	P (2)	17	2	281	109	623
4. (Miami)	2500	6/9/02	5	S (3)	24	6	94	39	275

Figure 3.2: Relationship of Salish sucker density to catch-per-unit-effort (CPUE). Equations are based on mean, lower confidence limit and upper confidence limits of density estimates. Unfilled points are independent values obtained from a separate reach by another investigator (T. Patton, UBC) using similar methods. The dashed line indicates the maximum CPUE used in calculating density in reaches without mark-recapture data.



adult Salish suckers) in the reach. Reaches were classified based on inflection points in the frequency distribution of reach CPUE as ‘absence’ (CPUE=0), low density (0<CPUE<1), moderate density (1<CPUE<3), or high density (CPUE>3) and plotted on GIS maps to allow examination of the spatial distribution of abundance.

Watershed Scale

I searched for previously unknown populations of Salish suckers by trapping 429 sites in 45 watersheds (size range 0.23 to 708 km^2) across the Fraser Valley. A minimum of one large and two small traps were set at each site. Only the low gradient downstream portions of watersheds originating in the mountains surround the Fraser Valley were sampled while sites along the entire length of streams that originated on the valley floor were sampled. Sites were selected at easily accessible points along creeks, rivers and sloughs between White Rock and Hope (Fig. 3.1). Where possible traps were set in water depths of 70 cm or greater and near or in heavy cover as analysis at the reach and channel unit scales showed that these features are associated with high trapping success for Salish suckers. Sampling was conducted between May 1 and August 31,1999 to 2002, with the majority occurring in 2000. Voucher specimens from previously unknown populations were deposited in the University of British Columbia Fish Museum.

Population sizes in watersheds containing Salish suckers were estimated by summing reach scale estimates (see above). Mean densities ($\text{fish}\cdot\text{km channel}^{-1}$) were plotted against land use, cover and channel unit based variables and assessed graphically, as sample size was too small (8) to permit statistical analysis. The percentage of land in the entire watershed and in a zone within 200 m of the portion of channel believed to contain water year round were estimated for all drainages known to presently or historically contain Salish suckers using methods previously described for the reach scale analysis. Watershed cover scores (C_w) were estimated, by category, from reach scale data as,

$$C_w = \frac{\sum_{n}^{k} (L_n * C_n)}{\sum L_n},$$

where L_n is the length in metres and C_n is the cover score of reach n of k reaches in the watershed.

Methodological Limitations

A tradeoff between extent and resolution of coverage is rarely avoidable in biological surveys. One can sample many sites superficially, or can sample fewer sites more thoroughly. If the goal is to detect pattern and change at larger spatial scales, sampling more sites at the expense of effort per site, as I have done at the regional and reach scales, is generally the best strategy (Strayer, 1999). In adopting this approach, however, one is left with low confidence in declarations of Salish sucker absence at any particular site. Nevertheless, I was able to detect broad scale spatial patterns and these provide a suitable baseline for future surveys attempting to detect range wide population trends. At the reach scale I collected coarse grained but spatially continuous data on both habitat type (pools, riffles etc.) and surrounding land use. This allowed analysis of spatial pattern, provided unbiased estimates of reach scale parameters, and suggested mechanisms of population regulation (Fausch et al., 2002).

My population estimates are most usefully viewed as indicators of relative abundance. They rely on the transferability among populations and habitats of the equations relating CPUE to density. Independent data collected by another investigator collected using similar methods fit them well (Fig. 3.2) and their parameter estimates are very typical of CPUE-abundance relationships in fisheries (Harley et al., 2001) suggesting that they are robust. My reach scale population estimates from these equations will have low precision because of small sample sizes and populations in low-density reaches are likely to have been systematically underestimated was they will be frequently recorded as ‘zero’ (Gaston, 1999). My density estimates are also based on closed population models and will be overestimated in proportion to the extent that the assumptions of zero immigration and emigration were violated. Even though some mark-recapture studies lasted over 30 days, these rates were likely low. Salish suckers have summer home ranges averaging under 200 m of channel length and rarely cross beaver dams (see Chapter 2), which bounded most of my population estimate reaches. My ability to detect high-density hot-spots, however, is probably quite good as the traps used are very efficient for Salish sucker (Pearson, unpubl.) and high density greatly increases detectability (Strayer, 1999; Gaston, 1999).

Results

Channel Unit Scale

Salish sucker capture probabilities were unaffected by substrate size within 3 m of traps, but were significantly lower than expected when overhanging vegetation or undercut banks were present and marginally higher near emergent plants (Table 3.2). Traps capturing Salish suckers were set significantly deeper than those that did not. CPUE of fish over 70 mm was near zero in water shallower than 70 cm, while young of the year fish were rarely caught at depths greater than 40 cm (Fig. 3.3). Of the nine other species of fish and amphibians I was able to test, only coho salmon (*Oncorhyncus kisutch*) were captured at sites with Salish suckers significantly more often than expected by chance ($p=0.029$; Table 3.3).

Reach Scale

Univariate analysis showed that reaches where Salish suckers were captured were characterized by greater bankfull width, a lower proportion of riffle and a higher proportion of deep pool habitat (Table 3.4). They also had significantly more in-stream vegetation and less boulder cover, but did not differ with respect to the proportion of land in agriculture or forest within 200 m of the streambank. The mean percentage of urban land within 200 m was marginally less around reaches containing Salish suckers and Chi-square analysis showed that they were found significantly less often than expected ($p=0.045$) when over 50 percent of the land within 200 m was urban. Salish sucker presence in a reach was strongly associated ($p<0.001$) with the presence of beaver colonies, as indicated by dams or lodges.

The simplest logistic regression model, containing only channel unit variables, was highly significant (Table 3.5), showed adequate fit (McFadden's $\rho^2 > 0.2$), and moderate predictive ability (Tabachnick and Fidell, 2001). The percentage of reach length occupied by deep pool

Table 3.2: Comparison of channel-unit-scale variables among traps that caught Salish sucker and those that did not. Only traps from reaches known to contain Salish suckers that were set in water warmer than 6 °C were used in the analysis. Substrate and cover class variables were recorded as present or absent within 3 m traps and were analyzed by comparing numbers of traps observed with and without a species to those expected if the variable had no effect.

	Salish Sucker					
	Traps With		Traps Without			
	Mean	Range	Mean	Range	P	Test
Trap Depth (cm; n=1312)	125	60 - 255	100	20 - 200	<0.001*	ts
Substrate Class (n=1309)	Obs	Expected	Obs	Expected		
Cobble	31	25	35	41	0.160	y
Gravel	52	59	100	93	0.207	y
Sand	1	2	4	3	0.694	y
Silt	116	114	180	182	0.742	y
Clay	8	12	23	19	0.187	y
Cover Class (n=1105)						
Submergent Macrophyte	78	77	127	129	0.838	y
Emergent Macrophyte	92	82	129	139	0.064	y
Overhanging Vegetation	20	32	65	53	0.005*	y
Large Woody Debris	16	22	42	36	0.132	y
Undercut	1	5	13	9	0.036*	y

t = Student's t-test * significantly different at $\alpha = 0.05$
s = square root transformed
y = Chi Square with Yates correction for continuity (Zar 1999)

Figure 3.3: Catch-per-unit-effort (CPUE) of young-of–the-year (YOY; top) and older (bottom) Salish suckers at increasing water depth. Fish less than 70 mm (fork-length) were considered YOY.

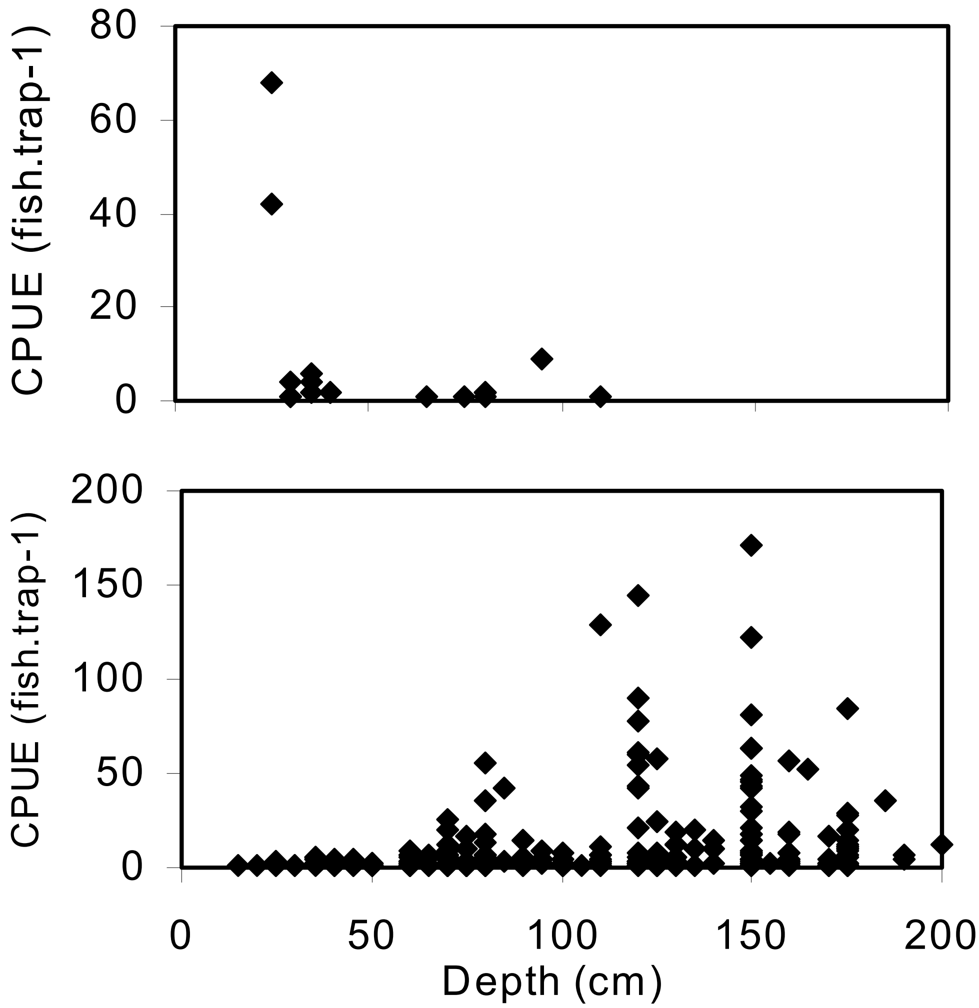


Table 3.3: Expected and observed frequencies of fish and amphibian species captured in the same reach as Salish sucker. 'N' indicates that Chi-square could not be applied because the expected frequency was too low.

Common Name	Species	Obs.	Exp.	p
Native Species				
Coho salmon	*Oncorhynchus kisutch* Walbaum	42	35.6	0.029*
Cutthroat trout	*Oncorhynchus clarki* Richardson	29	27.9	0.841
Steelhead/RainbowTrout	*Oncorhynchus mykiss* Walbaum	12	12.6	0.98
Nooksack dace	*Rhinichthys cataractae ssp.*	9	10	0.788
Northern pikeminnow	*Ptychocheilus oregonensis* Richardson	5	4.5	N
Redside shiner	*Richardsonius balteatus* Richardson	3	1.7	N
Largescale sucker	*Catostomus macrocheilus* Girard	2	1.7	N
Prickly sculpin	*Cottus asper* Richardson	1	4.5	N
Threespine stickleback	*Gasterosteus aculeatus* L.	52	47.1	0.16
Lamprey	*Lampetra spp.*	11	7	0.076
Northwestern salamander	*Ambystoma gracile* Baird	8	7	0.793
Introduced Species				
Brown bullhead	*Ameiurus nebulosis* Lesueur	3	3.5	N
Pumpkinseed	*Lepomis gibbosus* L.	2	5.2	0.118
Largemouth bass	*Micropterus salmoides* Lacepede	6	3.5	N
Fathead minnow	*Pimephales promelus* Rafinesque	1	1.7	N
Bullfrog tadpoles	*Rana catesbeiana* Shaw	12	10.5	0.659

Table 3.4 : Comparison of habitat variables in reaches with and without Salish sucker. Bracketed numbers indicate sample size. All lengths are in m, areas in m^2 and cover variable values are sums of three subjective scale estimates from predetermined locations within each reach.

	Reaches With (35)		Reaches Without (51)			
	Mean	SEM	Mean	SEM	P	Test
Reach Length	589	94	455	51.4	0.124	tl
Bankfull Width	14.3	2.6	8.4	1.4	0.007*	tl
Total Riffle Length	42.3	10.2	75.1	14.7	0.068	tl
Percent Riffle	7.8	2.1	18.2	2.4	0.004*	m
Large Substrate Length	3.4	1.2	13.7	3.4	0.037*	tl
Percent Dry	2.7	1.4	3.2	1.6	0.210	m
Total Deep Pool Length	353	83	109	23.5	<0.001*	tl
Percent Deep Pool	54.7	5.3	22.3	3.5	<0.001*	m
Max. Deep Pool Length	175	35	59.3	19.3	0.005*	tl
Mean Deep Pool Length	85.2	24.1	38.6	18.2	0.127	tl
Large Woody Debris	6.3	0.7	6.1	0.5	0.844	m
Boulder	0.6	0.2	2.0	0.4	0.003*	m
Overhanging Vegetation	9.8	0.6	9.4	0.4	0.411	m
In-stream Vegetation	10.2	0.6	8.1	0.5	0.008*	tu
Total Cover	26.9	1.0	25.6	0.7	0.282	tu
Area of 200 m Zone	36.3	4.4	28.8	1.7	0.125	tl
Percent Agricultural	53.3	4.7	46.5	4.3	0.180	ta
Percent Forest	37.3	4.2	32.7	3.2	0.518	ta
Percent Urban	6.1	3.3	20.4	4.7	0.075	m

t = parametric t test
m = Mann-Whitney U test
u = untransformed
l = log transformed
a = arcsine transformed
* significantly different at $\alpha = 0.05$

Table 3.5: Nested logistic regression models examining the effects of habitat type, cover, and land use on the probability of presence and absence of Salish sucker in reaches. Coefficients are followed by p-values in parentheses. Dashes indicates that the variable was eliminated during the reverse stepwise procedure. Correct classification values are percentage of reaches correctly re-classified by the model for presence/absence of Salish sucker. McFadden's Rho-squared is an R^2 analog with values >0.2 considered satisfactory.

	Habitat Type	Habitat Type + Cover	Habitat Type + Cover +Land use	Habitat Type +U50
Reach Length	--	--	--	
Bankfull Width	--	--	0.826 (0.180)	
% Deep Pool	1.147 (0.001)*	1.038 (0.002)*	0.825 (0.022)*	1.121 (0.001)*
Mean Deep Pool Length	--	--	--	
% Riffle	-0.561 (0.028)*	-0.551 (0.036)*	-0.535 (0.052)	0.549 (0.028)*
Total Riffle Length	0.584 (0.021)*	0.603 (0.021)*	0.595 (0.060)	0.530 (0.122)
Large Woody Debris		--	--	
Overhanging Vegetation		1.054 (0.168)	1.587 (0.089)	
In-Stream Vegetation		0.106 (0.180)	0.149 (0.097)	
Boulder		--	--	
% Agricultural within 200 m			-2.715 (0.172)	
% Forest within 200 m			-3.448 (0.076)	
% Urban within 200 m			--	
>50% Urban within 200m			-4.489 (0.040)*	-1.620 (0.115)
Intercept	-5.895 (0.001)	-8.920 (0.001)	-6.774 (0.117)	-4.904 (0.009)
McFadden's rho	0.284	0.306	0.368	0.308
Correct Reclassification	60/74	61/75	65/78	62/75
P of Model Improvement	<0.001	0.138	0.126	0.089

habitat was the most significant predictor of Salish sucker presence or absence. Adding cover variables did not improve the model's performance significantly nor did any of them make a significant individual contribution. Including land use variables also failed to significantly improve the models overall fit, but identified a predominantly urban landscape within a 200 m radius of the reach as a significant predictor of Salish sucker absence.

The distribution of CPUE was extremely skewed, equaling zero in the majority of reaches (54 of 88), exceeding one fish$\cdot$trap^{-1} in 10 reaches and three fish$\cdot$trap^{-1} in three reaches (Fig. 3.4). It was extraordinarily high in one reach (7.8 fish$\cdot$trap^{-1}; n=521), a 1.2 km-long, heavily vegetated marsh in Pepin Brook (see Chapter 2 for detailed description of habitat). Reaches containing moderate and high densities of Salish sucker were highly aggregated spatially. The most populous five reaches across all creeks accounted for 55 percent of the total combined population estimate while the least populous 10 reaches accounted for only 1.8 percent. Mean density varied from 0 to 1.54 adults$\cdot$ m channel^{-1} at the reach scale.

Watershed Scale

Salish suckers were caught at 61 of the 429 sampled sites confirming the continued existence of populations in six watersheds, rediscovering one that was believed extirpated (Salwein Creek, McPhail and Taylor, 1999), and finding two that were previously unknown (Miami Creek and Hopedale Slough; Fig. 3.1). I did not capture Salish suckers in the Little Campbell River where they have not been captured since the mid 1960's (McPhail, 1987), although apparently suitable habitat at previously inhabited sites was trapped on several occasions.

I was able to estimate population size in six of these watersheds. They ranged over an order of magnitude from low hundreds to low thousands of adults (Table 3.6). One creek, Pepin Brook contributed 40 percent of the total and 54 percent of its population was found in the 1.2 km marsh mentioned above. In Atchelitz Creel and Hopedale Slough, Agassiz Slough and Mountain Slough CPUE was too low to permit density estimates and in Bertrand

Figure 3.4: Spatial distribution (bottom) and frequency (top) of catch-per-unit-effort (CPUE) of Salish suckers among reaches in the Nooksack tributaries and the Upper Salmon River (n=88). In most reaches (54) CPUE was zero. High and moderate density reaches were spatially clumped. CPUE was very high (> 3 fish·trap^{-1}) in three reaches (circled).

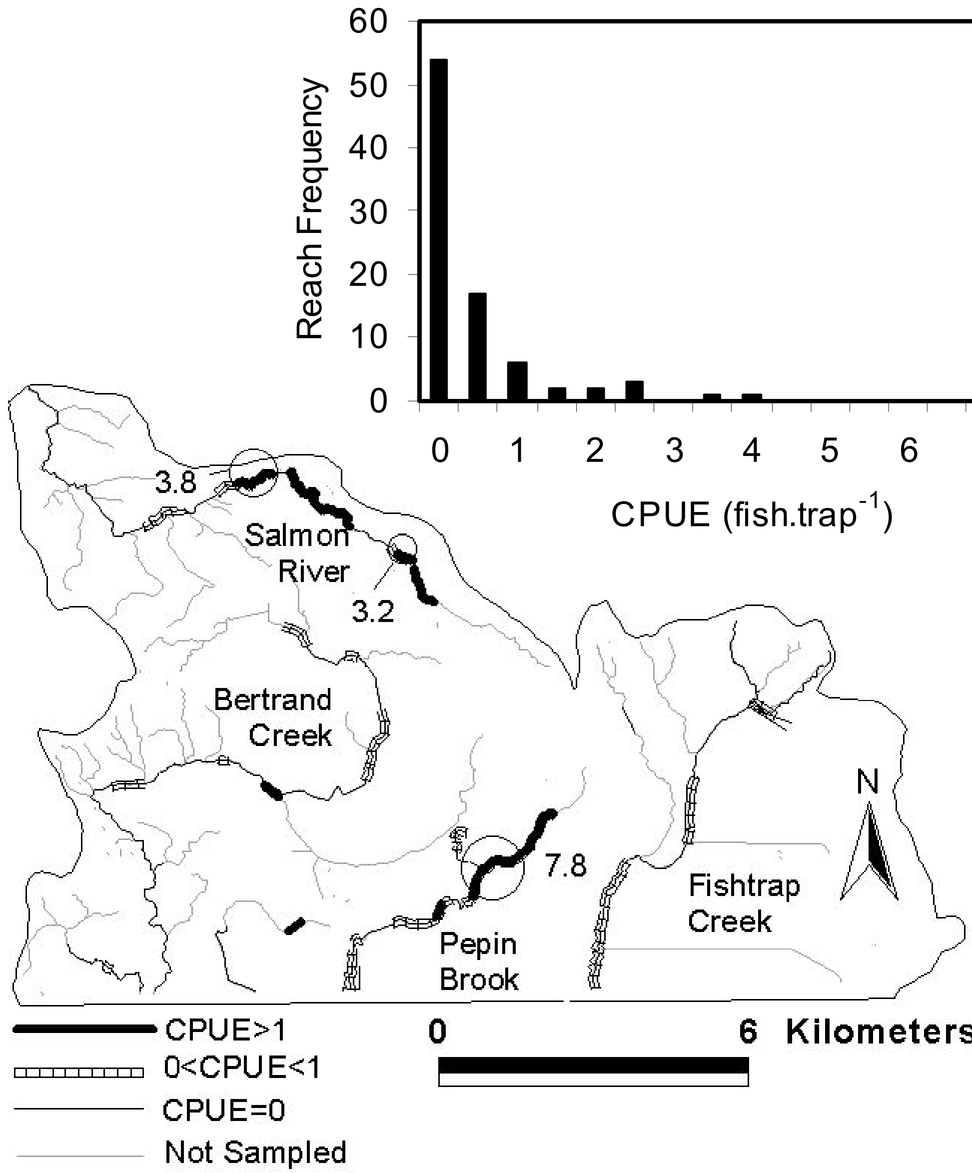


Table 3.6: Population estimates for watersheds containing Salish sucker in Canada. Estimates are sums of reach scale estimates calculated from catch-per-unit effort (CPUE) data. CPUE was too low to allow estimation in four watersheds.

	Population Estimate		
Watershed	Mean	Minimum	Maximum
Salmon River	1390	650	3580
Bertrand Creek	240	100	670
Pepin Brook	2860	1990	9200
Fishtrap Creek	490	210	1370
Salwein Creek	1290	550	3580
Miami Creek	850	350	2480
Hopedale Slough	?	?	?
Atchelitz/Chilliwack	?	?	?
Mountain Slough	?	?	?
Agassiz Slough	?	?	?
Canada	>7120	>3850	>20880

and Fishtrap Creeks the total adult population is estimated below 500.

Mean density in Pepin Brook was more than double that of any other watershed, exceeding 450 fish·km^{-1} (Fig. 3.5). Among watersheds it also scored highest for large woody debris, overhanging vegetation and in-stream vegetation cover, had the highest percentage of deep pool and riffle, the lowest proportion of shallow pool and the largest proportion of forest within 200 m of the channel. Watersheds with high densities of Salish sucker (>100 fish·km^{-1}) lacked urban area and in-stream boulder cover and generally had less shallow pool and dry channel. Proportion of land within 200 m of the channel that was in agriculture or forest showed no trends in relation to population density.

Discussion

Regional and Watershed Scale Distribution

The restriction of the Salish sucker to northwestern Washington State and the Fraser Valley in Canada appear to be the result of post-glacial dispersal limitations (McPhail, 1987). The strikingly discontinuous distribution of populations among Fraser Valley watersheds and their absence from many watersheds with suitable physical habitat is more difficult to explain. Their absence from the Sumas watershed, between the Nooksack and Chilliwack populations, is almost certainly the result of large-scale habitat destruction. Historically, the Chilliwack River entered the Fraser River through a large delta that included the large, marshy Sumas Lake (Fig. 3.6). In 1875 settlers blocked off the main distributaries feeding the delta to reduce flooding of agricultural lands. This forced the entire river through Sumas Lake, which was in turn drained in 1920 to provide additional farmland (Schaepe, 2001). Salwein Creek and Hopedale Slough, which still harbour small, remnant populations, are former tributaries of Sumas Lake and Atchelitz Creek formed part of the delta. Salish suckers were last seen in Little Campbell River in 1976 (McPhail, 1987), although it still contains large quantities of apparently suitable habitat (Pearson, pers. obs.). Low water quality (Krista Payette, Ministry of Water, Land, and Air Protection, Surrey, BC, pers. comm.) and high densities of the introduced brown bullhead (*Ameiurus nebulosis*; Pearson, unpubl.) may be responsible for their extirpation.

Figure 3.5: Mean Salish sucker population density (line) in relation to relative abundance of habitat types (top), level of cover (middle), and land use within 200 m of the channel (bottom). Watershed cover scores are corrected for reach and total channel length (see text for details).

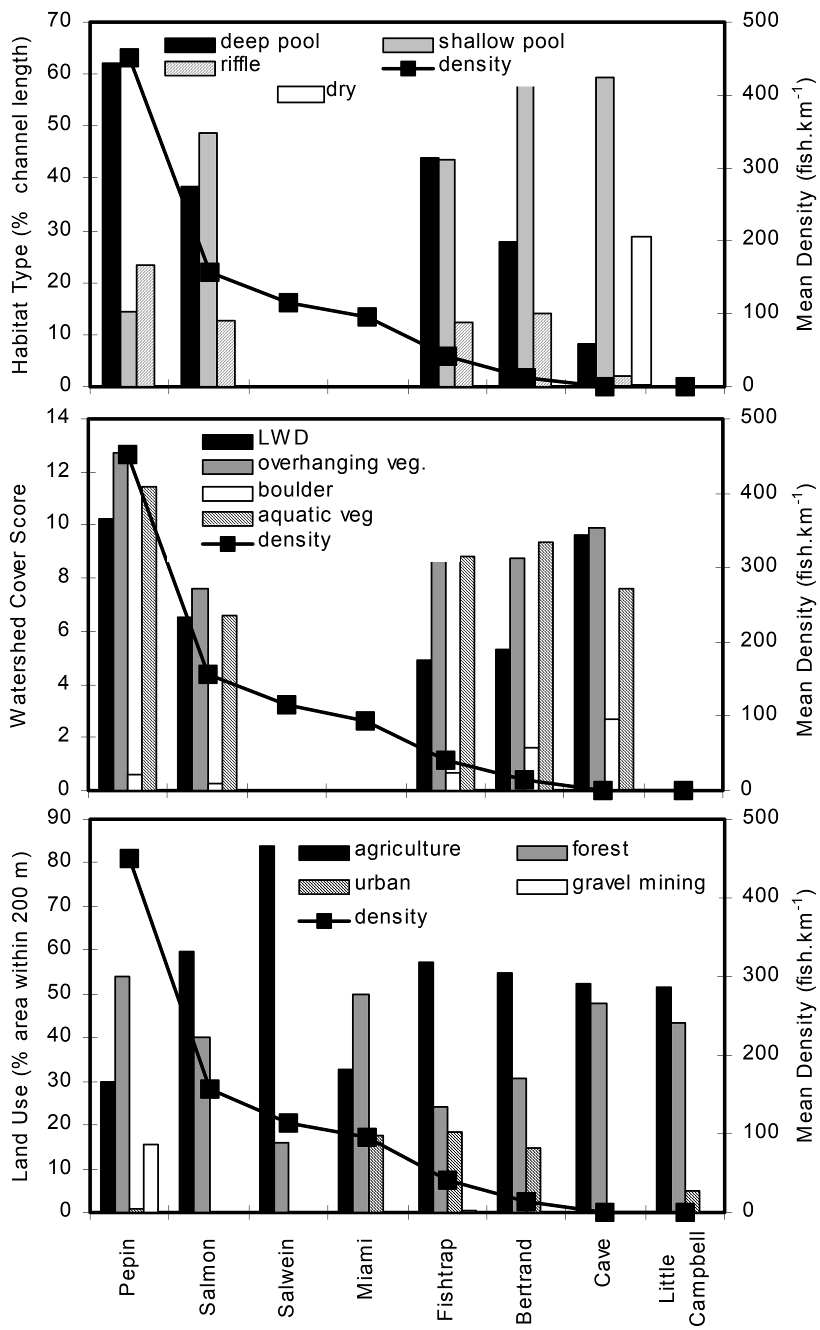
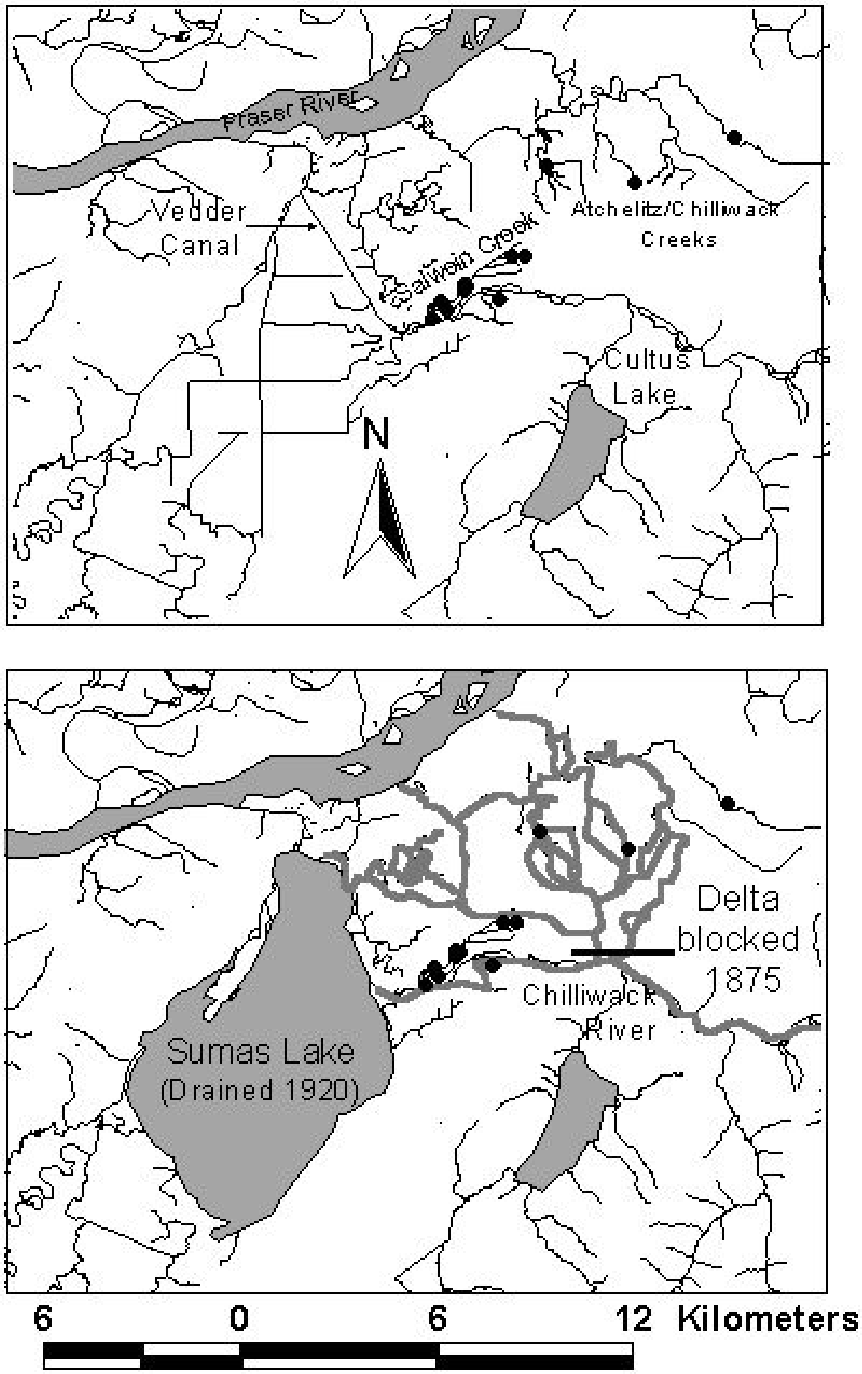


Figure 3.6: Map of the Sumas-Chilliwack area in the present (top) and prior to 1875 (bottom). Black dots indicate current distribution of Salish suckers.



Many of the sloughs and larger rivers sampled also contained habitat physically similar to the headwater marshes where Salish suckers were abundant, yet did not appear to contain populations. This may indicate that biotic interactions (perhaps predation) in these more diverse, large river communities limit distribution to headwater systems. After glaciation, Salish suckers probably recolonized the Fraser Valley at least 1000 years prior to the formation of the modern Fraser River when Columbia River species gained access to the area (McPhail, 1987). The current distribution may also be a relic of invasion patterns by these faunas.

Reach Scale Distribution

Salish sucker distribution among reaches appears to be largely controlled by the quantity of deep pool habitat, which in turn is heavily influenced by beaver activity. Logistic regression showed that although their presence was positively associated with the presence of riffle in a reach, they were not found when the percentage of riffle was high. This is consistent with their need for a limited amount of riffle for spawning (McPhail, 1987). Superimposed on these patterns are the negative impacts of human activities. Reaches in predominantly urban areas were unlikely to contain Salish suckers regardless of the amount of deep pool habitat they contained.

Salish suckers may also be limited in some reaches by periods of anoxia. Asphyxiation of fish in traps was a recurrent problem in late summer in many marsh/beaver pond reaches. Dwindling summer low flows due to water withdrawal, gravel extraction, and agricultural and urban drainage are likely in these watersheds. In combination with nutrient loading from agriculture and urban runoff, reduced discharge is likely to exacerbate hypoxia problems. The large subpopulation of fish that I studied in the Pepin Brook marsh (see Chapter 2) may be one such casualty. A major algae bloom occurred August-October of 2002. In the summer of 2003 four sampling sessions yielded only 3 Salish suckers (CPUE = 0.13 $fish.trap^{-1}$), all of which asphyxiated in the traps. Dissolved oxygen at midday was measured on 9 occasions between June 11 and September 23 2003 at the surface and substrate (depth 1 m) in the centre of the marsh. Only two of the 18 readings exceeded 2 $mg{\cdot}l^{-1}$ with the majority being less than 1 $mg{\cdot}l^{-1}$ (Krista Payette, BC MWLAP, unpubl. data.)

Channel Unit Scale Distribution

Adult Salish suckers were largely restricted to deep pool habitats. Their apparent lack of association with a particular substrate size may be an artifact of baited traps drawing fish from surrounding areas. I suspect that the strong negative associations with overhanging vegetation and undercut banks simply reflect the absence of these features in the deep-water zones of the marshes and beaver ponds where most fish were found.

Population Structure and Stability

Salish sucker populations are extremely clumped, with a few sites harboring a large proportion of adult individuals. This was evident at both the watershed and reach scales. Similar patterns characterize most common, widespread species across taxonomic groups, although patterns in the distribution of rare species are poorly known (Brown et al., 1995; Gaston, 1999). Brown (1995) used the multi-dimensional niche concept (Hutchinson, 1958) to explain the phenomenon, showing that when four to 10 independent environmental factors limit abundance, at least one will tend to be unfavourable at most sites. In the rare circumstances when all key factors are near optimal levels for the species, a 'hot spot' in which it is very abundant results. For Salish suckers critical factors may include large continuous areas of deep pool, with nearby spawning riffles and shallow nursery habitat, the absence of large piscivorous fish, and adequate water quality. The clumping of high and moderate density reaches is likely due to spatial autocorrelation in these factors and to limits on the frequency and range of dispersal (Ives and Klopper, 1997). Most Salish sucker movement is restricted to within a reach or to adjacent reaches, although occasional longer distance movements do occur (see Chapter 2). Outlying low-density reaches may be reproductive sinks (sensu Pulliam, 1988). Although few have been studied, some other stream fish populations appear to be organized similarly, with a group of highly productive source habitats feeding migrants to surrounding lower abundance, sink habitats (see Schlosser and Angermeier, 1995).

The stability of hotspots will depend on the rate of change in the key environmental factors. Spatial and temporal autocorrelation in factor levels will tend to produce relatively stable hot spots that move slowly through the range over time but occasionally disappear *in situ* when a critical factor changes abruptly (Ives and Klopper, 1997). The data suggest that urbanization and sudden degradations in water quality are likely to be such agents of such changes. Urbanization is known to have major impacts on the abundance and community structure of both fish (Weaver, 1994; Wang et al., 2001) and benthic macroinvertebrates (Walsh et al., 2001; Karr, 1998) and is implicated in a substantial number of extinction case histories (Frissell, 1991; Williams et al., 1989).

Beaver ponds stabilize the otherwise highly variable environments of headwater streams (Hanson and Campbell, 1963; Naiman et al., 1986). Some aspects of this stability are clearly beneficial to fish. Ponding greatly increases benthic invertebrate biomass (McDowell and Naiman, 1986) and buffers low-flow impacts on habitat volume. Indeed, during late summer low-flow periods beaver ponds provided the only wetted habitat in a number of reaches inhabited by Salish sucker in the study area. However, beaver ponds also tend to be chronically hypoxic (Snodgrass and Meffe, 1998; Schlosser and Kallemyn, 2000) and beaver dams create significant barriers to movement of stream fishes (Schlosser, 1998) including the Salish sucker (see Chapter 2). This combination of a physical barrier to escape with critically low dissolved oxygen levels is likely to produce occasional, localized catastrophic mortality, the most plausible explanation for the sudden decline in abundance I observed in the Pepin Brook marsh.

The small size, early maturation and protracted spawning period of Salish suckers (see Chapter 2) will promote relatively rapid recovery from localized catastrophic events (Winemiller and Rose, 1992). However, this capacity could easily be overwhelmed if their frequency of occurrence increased sufficiently. Decreases in stream baseflow, increases in water temperature and elevation of limiting nutrient levels are known to exacerbate hypoxia . They are also well-documented consequences of agricultural and urban development in watersheds (Welch et al., 1998).

In conclusion, my data suggest that the current distribution and abundance of Salish sucker is the result of factors operating predominantly at the regional and reach scales. At the regional scale, the pattern of deglaciation limited dispersal opportunities from the glacial refuge in which the fish evolved, leading to a restricted distribution. The absence of Salish sucker from apparently suitable habitat in sloughs connected to the Fraser River suggests that biotic or abiotic interactions with large river habitats and/or fauna may have fragmented their original range. The species persists in reaches of Fraser Valley streams characterized by low gradient and large areas of deep pool habitat, especially beaver ponds. Over the past century, direct habitat destruction has drastically reduced the amount of suitable habitat across the Fraser Valley, particularly in the Chilliwack-Sumas area. More recently, urbanization and nutrient contamination of surface and groundwater may be increasing the frequency of fish kills and local extinctions due to reduced base flow and late summer anoxia.

Management Implications

Conservation priority should be given to aggregations of high and moderate density reaches within watersheds that are likely acting as major source habitats. This will involve protection of landscape attributes that preserve water quality through maintenance of adequate base flow, shading, and limitation of nutrient loads in addition to the preservation of physical habitat.

Salish sucker life history attributes should facilitate rapid response to habitat restoration (see chapter 2), but projects should be located close to high and moderate density reaches to expand existing source populations (see Huxel and Hastings, 1999). Reestablishment of extirpated populations through introductions may also be possible where suitable habitat exists, but close attention must be given to water quality and introduced species as potentially limiting factors.

The spatial association of Salish sucker with coho salmon (also of major management concern) suggests that habitat conservation and restoration projects designed for one are likely to benefit the other.

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Chapter 4

Movement, growth, and spawning period in a population of Nooksack dace

Introduction

The current extinction rate of North American freshwater fishes is estimated to be five times higher than that of terrestrial vertebrates and approximately 1000 times that inferred for fishes from the fossil record (Ricciardi and Ramussen, 1999). They are considered to be one of the continent's most threatened faunas (Miller et al., 1989; Moyle and Williams, 1990; Warren and Burr, 1994). Little is known of the life history of most imperiled fish despite the importance of this information in assessing extinction risk or effecting conservation (Angermeier, 1995).

The global distribution of the Nooksack dace (*Rhinichthys cataractae* ssp.) is limited to three streams in British Columbia's Fraser Valley (Bertrand, Pepin and Fishtrap Creeks) and to streams on the eastern side of Puget Sound and the western side of the Olympic Peninsula in Washington State (McPhail, 1997). Based on morphological and genetic evidence, this small riffle-dwelling cyprinid is considered to be an evolutionarily significant unit (sensu Waples, 1995, Don McPhail, University of British Columbia, pers. comm.). It is believed to have evolved from a population of longnose dace (*R. cataractae*) that became isolated in Washington State's Chehalis River valley sometime during the Pleistocene glaciations (McPhail, 1997). It is listed as endangered in Canada (Campbell, 2001) and by the American Fisheries Society (Williams et al., 1989), but not under the U.S. Endangered Species Act.

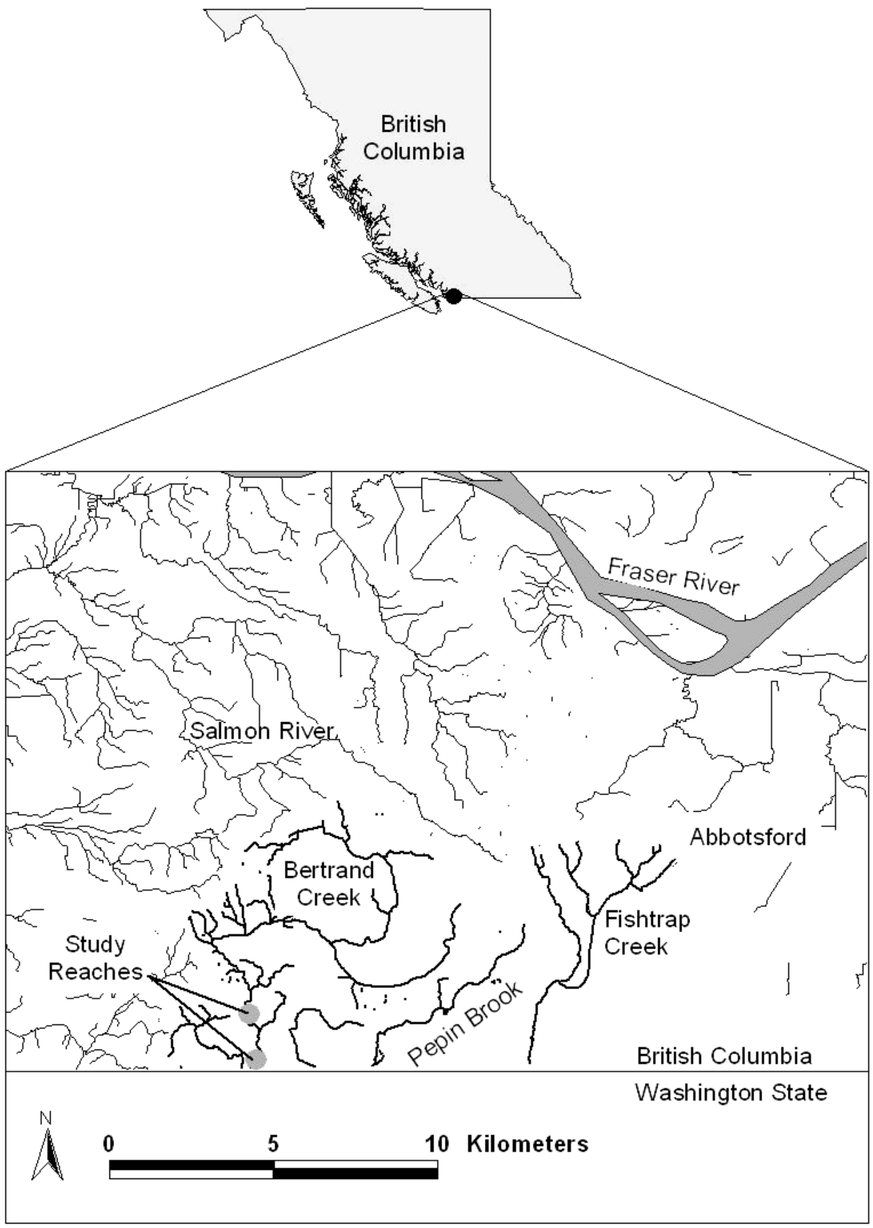
The Nooksack dace appears to be in steep decline in Canada. It remains abundant only in a 5 km section of Bertrand Creek (see Chapter 5), is now rare in Fishtrap Creek where it was common until recently, and has been extirpated from some tributaries and headwater reaches in both of these watersheds (McPhail, 1997). Conservation efforts to date have been hampered by lack of information on life history and by low levels of public and political awareness. In this chapter I report on previously uninvestigated aspects of Nooksack dace life history including growth, spawning period, and activity patterns. I discuss my findings in relation to extinction risk, conservation and management.

Study Area

I studied the Nooksack dace of Bertrand Creek, a tributary to Washington State's Nooksack River located in the Fraser Valley of southwestern British Columbia (Fig. 4.1). Mean August discharge (base flow) is 0.067 $\pm$ 0.158 $m^3 \cdot s^{-1}$ (mean $\pm$ S.D.), but following major storms can exceed 9 $m^3 \cdot s^{-1}$. Winter discharge is not measured, but is usually close to that of neighboring Fishtrap Creek (mean January Discharge, 1.5 $m^3 \cdot s^{-1}$; Water Survey of Canada, Vancouver). Groundwater inputs to the stream are minimal (Johanson, 1988) and water temperatures range from slightly below 0^oC to over 22^oC annually (Pearson, unpubl.). Land use in the watershed is primarily agricultural and low-density rural-residential although the headwaters are urbanized, lying within the town of Aldergrove.

I worked in two reaches in lower Bertrand Creek because this area contains the largest known Canadian population of Nooksack dace (see Chapter 5). Each was approximately 200 m long and comprised 4 riffle-pool sequences. The reaches are separated by approximately 2.2 km of stream channel. Both have gradients between 1 and 2%, gravel/cobble substrates, bankfull widths of 5 to 8 m and riparian buffers (5 to 20 m) of mature deciduous trees. Land use beyond the buffer is low density rural-residential. Co-occurring native species (in decreasing order of relative abundance) are steelhead trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*), threespine stickleback (*Gasterosteus aculeatus)*, cutthroat trout (*O. clarki*), western brook lamprey (*Lampetra richardsoni*) and prickly sculpin (*Cottus asper*). Pumpkinseed (*Lepomis gibbosus*) have been introduced and, although not abundant, appear to be established. Salish sucker (*Catostomus sp*.), largescale sucker (*Catostomus macrocheilus*) and brown bullhead (*Ameiurus nebulosus,* also introduced and established) occur in Bertrand Creek, but not in the study reaches (Pearson, unpubl.).

Figure 4.1: Location of study reaches on Bertrand Creek in British Columbia's Fraser Valley (Lat 49°00', Long. 122°30'). Bertrand, Pepin, and Fishtrap Creeks constitute the entire Canadian distribution of the Nooksack dace. They flow south into Washington State's Nooksack River. Other drainages shown are tributaries of the Fraser River or drain independently into the Strait of Georgia.



Methods

Capture and Marking of Dace

Fish were trapped in commercially available double-ended funnel minnow traps (22.5 x 40 cm with 6-mm-mesh) baited with dry cat food in perforated canisters. Trapping sessions were conducted approximately twice monthly during the summers of 2000 and 2001 (Reach 1, n=13, Reach 2, n=10). Six to eight traps were set at standard locations in each of the four pool-riffle complexes contained in each reach. Traps were set in all channel unit types (riffles, pools, and glides) as CPUE does not differ among them when baited traps are used (see Chapter 5). In most sessions traps were emptied after 24 hours then reset for a further 24, although in several sessions a single 24-hour set was used. Additional data from fish caught in preliminary work during 1999 using similar trapping methods is included in analyses not involving mark-recapture. Catch-per-unit-effort (CPUE) was calculated as the mean number of fish per trap on each sampling day. Monthly changes in CPUE (April – September) were examined using analysis of variance with Bonferroni's multiple comparison test on log-transformed values.

Following capture, Nooksack dace were anaesthetized in tricaine methanesulfonate (MS 222, 70 $mg \bullet l^{-1}$), weighed (nearest 0.1 g), and measured (fork length, nearest mm). Reproductive condition of all fish was ranked on a qualitative scale (no evidence of reproductive activity, gravid, ripe, very ripe) based on the quantity of milt or eggs extruded from the vent in response to gentle pressure on the abdomen. Nooksack dace could not be reliably sexed in the field unless very gravid or ripe. Following recovery in fresh water, fish were released in a calm area within 5 m of their point of capture. Nine hundred eighty-seven of the 1,331 Nooksack dace captured were individually marked (935 in the study reaches, 52 in adjacent areas) with subcutaneous injections of fluorescent elastomer (Northwest Marine Technology Inc., Shaw Island, WA) on the ventral surface (Hill and Grossman, 1987a). Only fish larger than approximately 50 mm (fork length) were marked. Other species captured with dace were counted and released. Water temperatures were measured hourly in a shaded riffle using a recording logger (Optic Stowaway, Onset Computer Corporation, Pocasset, MA).

Growth and Condition

Growth rate (mm•day^{-1}) was calculated for each marked fish from the fork length when marked and at the final recapture within the sampling season (April to September). Only fish that were at large for more than 7 days between marking and final capture were used to estimate growth rate. I used a separate variance t-test to assess differences in growth rates between years and regressed growth rate on length at first capture to assess effects of fish size.

Seasonal changes in fish condition were examined using relative condition factor (K_n=(W/W')), where W is the weight of an individual and W' is a length-specific standard weight predicted by the weight-length regression equation (Anderson and Neumann, 1996). Mean monthly K_n values were pooled across years, as no significant differences between the same months in different years were identified (Bonferroni adjusted t-tests). Pooled monthly means were compared using analysis of variance and Bonferroni's multiple comparison test (α=0.05). A two factor ANOVA could not be used as some months were only sampled in a single year.

Movement

Movement was calculated as the distance (in metres) between successive trapping locations. On four occasions at the end of summer 2001, I extended the trapping area to include two additional pool-riffle complexes immediately upstream and downstream of both study reaches (approximately 100 m in each direction) to assess emigration rates. Effects of time since previous capture (log transformed) and fork length on distance moved (log transformed) were examined by linear regression. Body length, K_n, and log-transformed growth rates of fish that were recaptured at the location where they were marked (stayers) were compared (t-test) to those that moved more than 20 m between captures (movers).

To assess the pattern of Nooksack dace movements I compared the observed distribution of individual movements to the distribution expected if movement was random with respect to trap location (Chi-Square; all distances rounded to nearest 5 m). Expected numbers of recaptures for each distance (R_{ED}) were calculated as:

$$R_{ED} = \left[\frac{T_D}{T_T}\right] \bullet R_{OD},$$

where T_D is the number of pairs of traps separated by distance D, T_T is the total number of pairs of traps that were set on different dates within the same reach, and R_{OD} is the total number of observed Nooksack dace movements over distance D.

Results

Population Characteristics

I captured 1,331 Nooksack dace over three field seasons. The largest individual was 114 mm and weighed 16.1 g. The smallest, a young-of–the-year fish captured in July, measured 19 mm. Modal length and weight were 75 mm and 4.1 g respectively. Small fish, particularly young-of-the-year, were poorly represented in the samples. Only 2.2 % of the Nooksack dace caught were less than 50 mm in length although large numbers of such fish were observed in marginal pools of the stream. Regressing weight on length yielded the equation $W=6.339 \times 10^{-6} \times L^{3.11}$ ($r^2=0.950$).

CPUE of Nooksack dace was temperature dependent (Fig. 4.2). Only one fish was captured when water temperature was less than 11^{o}C, but catch rates increased rapidly as temperatures rose. Maximum CPUE was 1 to 2 fish per trap when temperature was between 15 and 20^{o}C. The upper thermal tolerance of Nooksack dace remains unknown, but fish were frequently sighted foraging in temperatures of up to 22^{o}C (Pearson, pers. obs.).

Seasonally, CPUE was negligible before May, increased to a maximum of about 1.5 fish•trap^{-1} in July and declined to negligible values again after October. At least some adult dace appear to over-winter in riffles, where they were caught by kick-netting in February.

Growth and Condition

Nooksack dace growth rate averaged 0.07 $\pm$ 0.01 mm•day^{-1} (mean$\pm$SE; n=52) between April and September, did not differ between the two sampling years (t=1.729, p=0.090), and had a weak negative relationship with fish length (F=3.524, p=0.066). Relative condition factor

(K_n) was highest in May, declined significantly in June and July, and increased again in August and September (Fig. 4.3).

Spawning

A very small proportion (3.1%) of captured dace were in reproductive condition. Most gravid females were caught between April and June, although a few were captured as late as July (Fig. 4.4). The smallest male in reproductive condition was 68 mm long (n = 9) and the smallest female was 75 mm (n = 34).

Movement

Of the 935 dace that were marked within the study reaches, 90 individuals (9.6 %) were recaptured. Thirteen of these fish were recaptured a second time and one was recaptured on three occasions. Intervals between captures ranged from 1 to 397 days.

Movement between captures ranged from 0 to 205 m, but 52 % were caught within 5 m of their previous capture position and 92 % were found within 50 m of their starting location (Fig. 4.5). Many (33) were recaptured in exactly the same location, some after more than a year had lapsed since the previous capture. Fish were as likely to move upstream (34 fish) as downstream (33 fish). Time since previous capture (T in days) had a significant positive relationship on distance moved (D in metres ; Log D=0.117•Log$T$ +0.466; r^2=0.132, p<0.001) although fish length (L) over the range examined did not (Log$D$=0.0001•L+0.74; r^2=0.0001, p=0.93). Individuals that were recaptured where they were marked (n = 33) did not differ from those that moved more than 20 m between captures (n = 25) in growth rate (t=0.712, p = 0.48), K_n (t=0.268, p = 0.790) or length (t=0.10, p=0.92). Recapture rates upstream and downstream of the study reaches at the end of the second summer were lower than recapture rates within the study reaches on the same days (Table 4.1).

The distribution of Nooksack dace movements was extremely leptokurtotic (biased towards short distances) relative to the distribution of detectable movement distances in this study (X^2=493, p<0.0001; Fig. 4.6).

Figure 4.2: Effect of water temperature on catch per unit effort (CPUE) of Nooksack dace in Bertrand Creek. Each point represents the mean catch of seven to 64 traps set for approximately 24 h. Data from 1999, 2000 and 2001 are included.

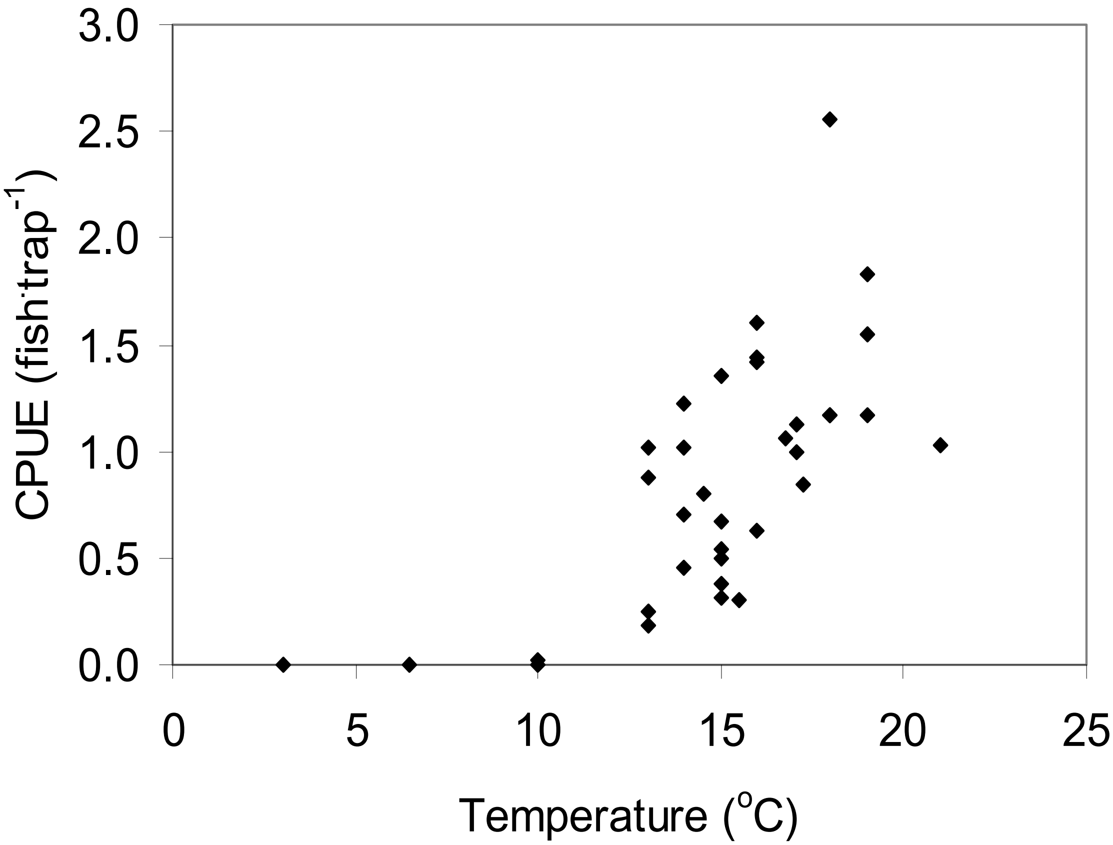


Figure 4.3: Changes of relative condition factor (K_n) in Nooksack dace from Bertrand Creek. Months with the same letter are not significantly different (F=16.27, p<0.0001). Data from 1999, 2000, and 2001 are pooled as there was no significant difference between years.

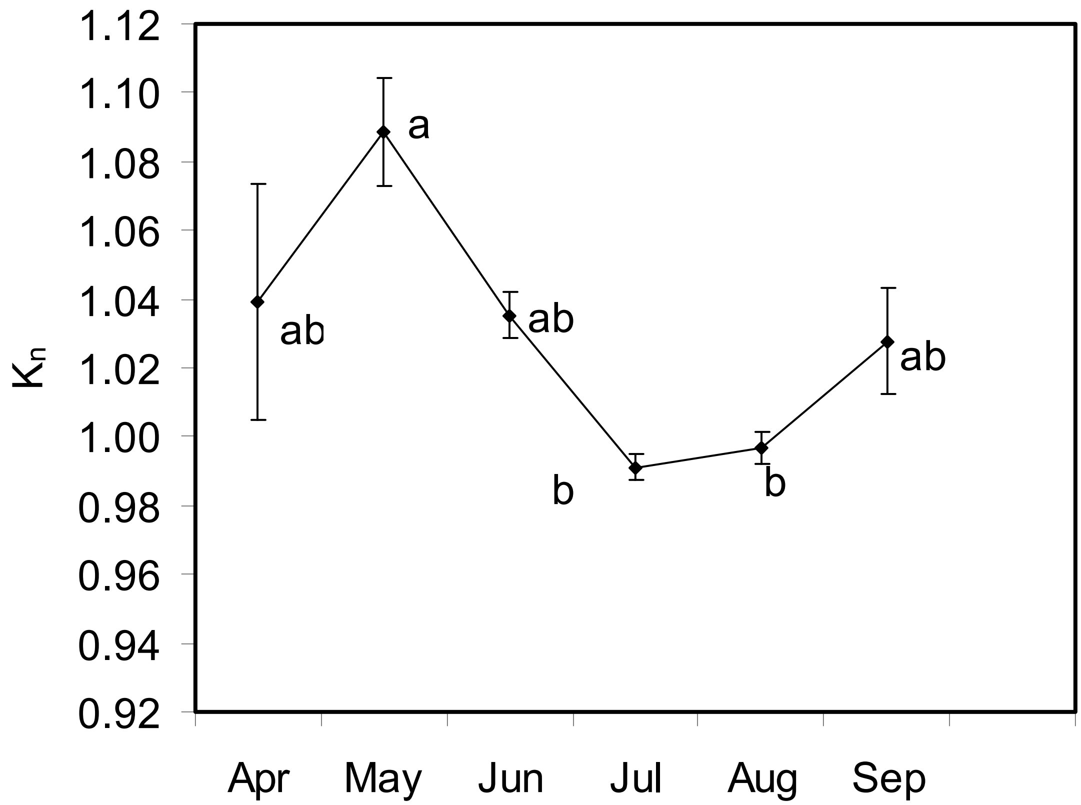


Figure 4.4: Monthly catch of female (F) and male (M) Nooksack dace in spawning condition in Bertrand Creek. Due to difficulty in sexing fish not in spawning condition, data are expressed as percent of total catch. Bracketed numbers indicate n. Condition was subjectively rated as obviously gravid (females) or according to the amount of eggs or milt released with gentle pressure on the abdomen.

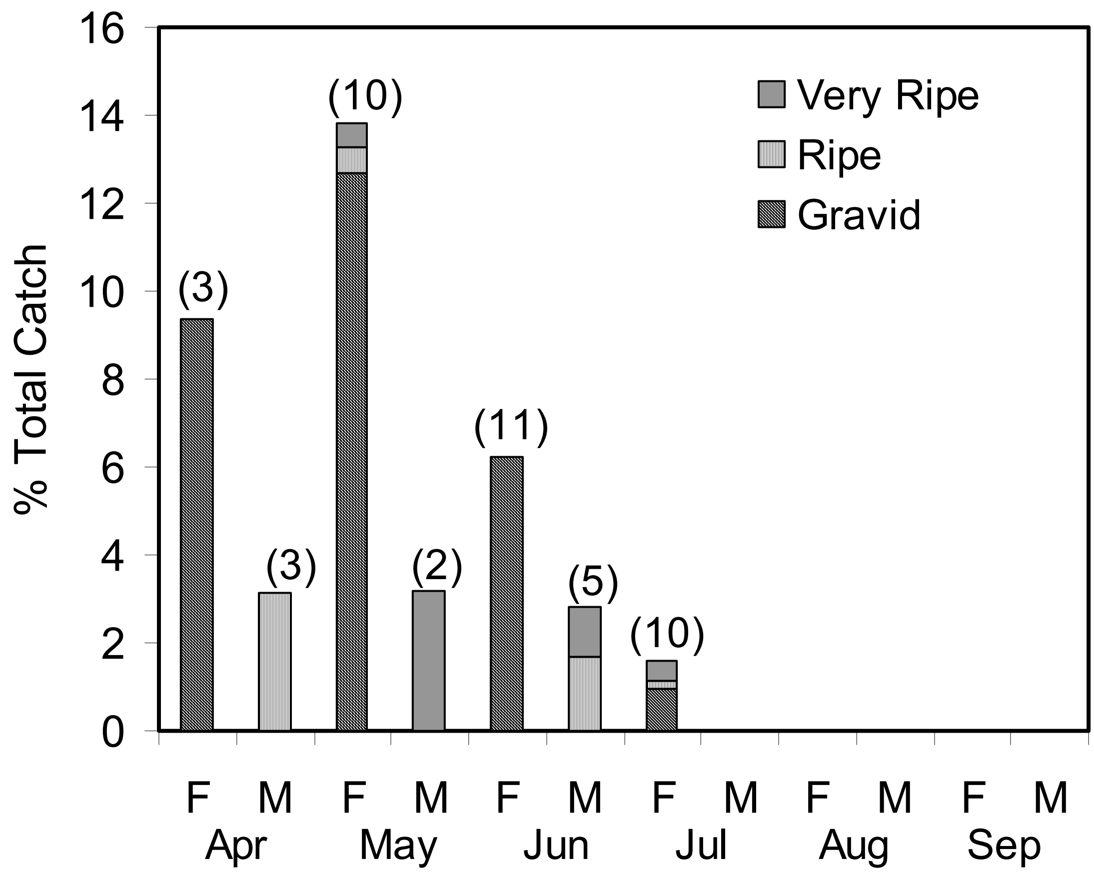


Figure 4.5: Distances moved by marked Nooksack dace in relation to time since previous capture (n=105). Negative distances indicate downstream movement.

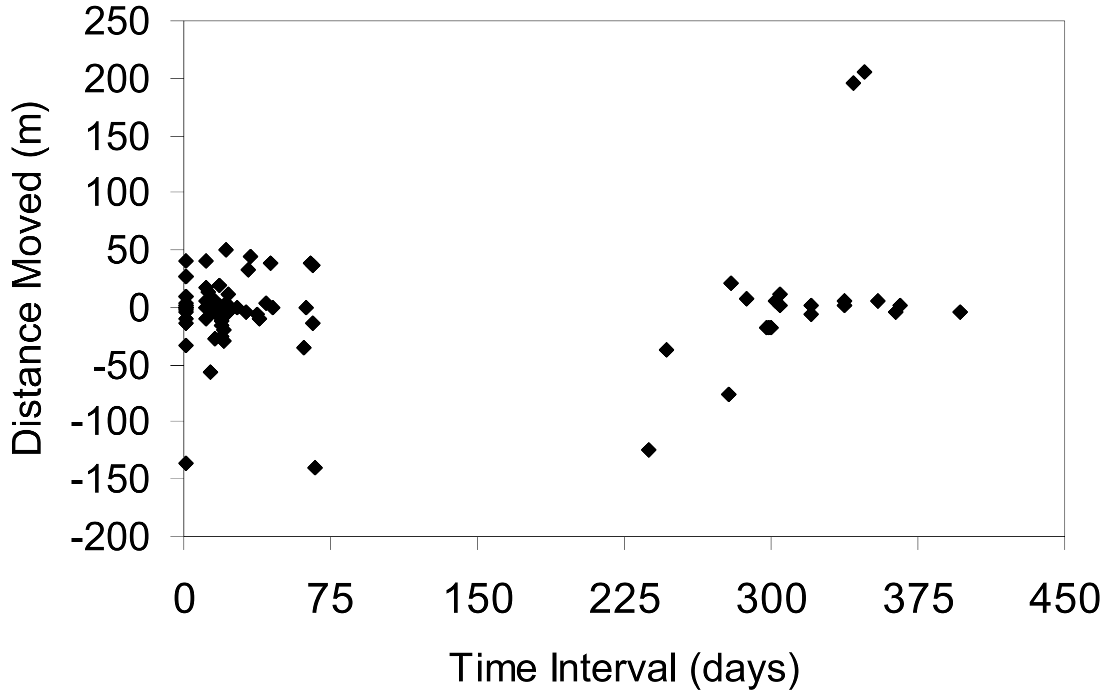
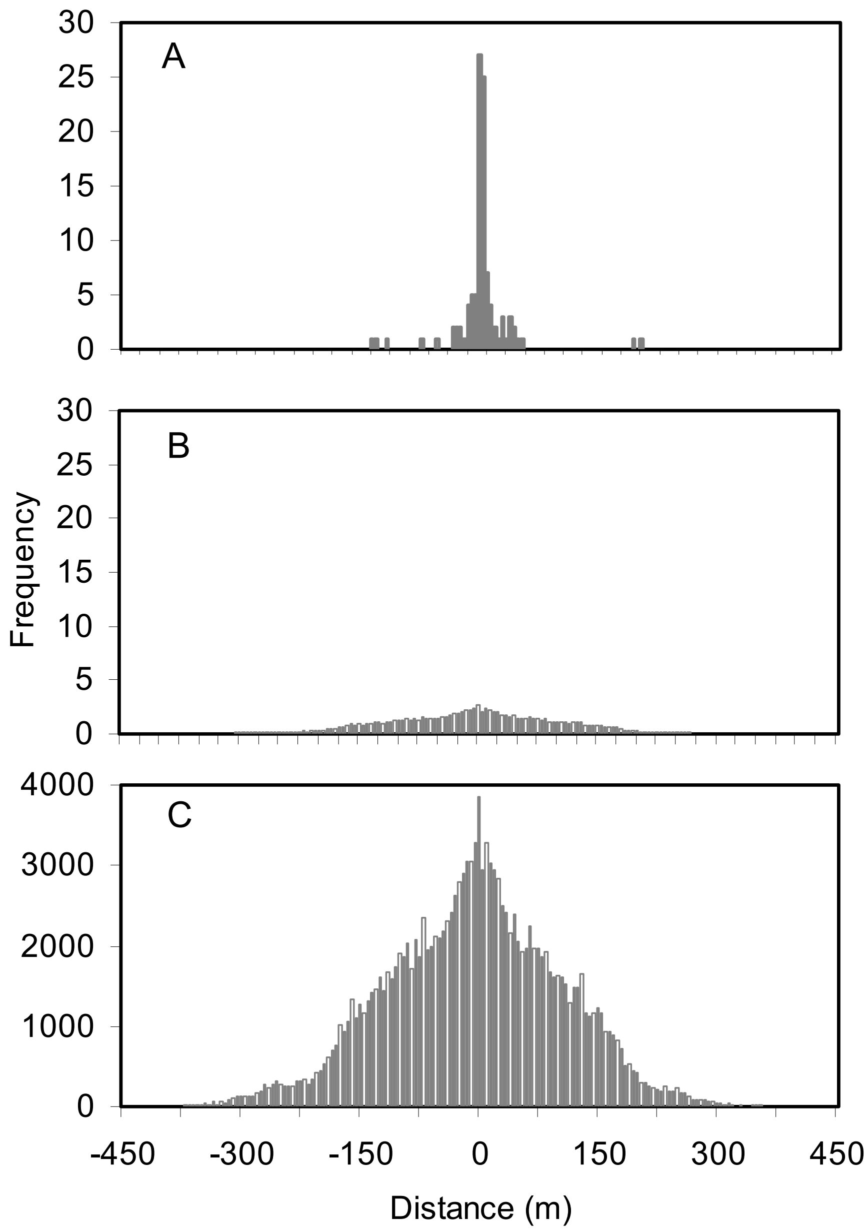


Table 4.1: Comparison of the percentage of previously marked Nooksack dace in samples from the two study reaches and in the 100 m of channel immediately upstream (u/s) and downstream (d/s) of them. All samples were collected late in the study in 2001. Bracketed values indicate number of fish caught on the two consecutive days comprising each sampling period.

Sample	Reach 1	R1 u/s	R1 d/s	Reach 2	R2 u/s	R2 d/s
Mid July	4.2 (71)	0.0 (16)	1.5 (67)	6.0 (64)	3.7 (27)	0.0 (27)
Late July	11.8 (68)	0.0 (23)	0.0 (50)	8.0 (50)	0.0 (11)	2.7 (37)

Figure 4.6: Frequency distributions of (A) observed distances moved by Nooksack dace between captures, (B) expected distances moved calculated from (C) all movements detectable given trap locations and set dates. The observed movement distribution is extremely leptokurtotic relative to that expected at random. Negative distances indicate downstream movement.



Discussion

Spawning

Nooksack dace spawn over an extended period and, like some other *R. cataractae* populations (Roberts and Grossman, 2001), may spawn more than once in a season. This tactic increases reproductive potential in species limited by small female body size (Burt et al., 1988; Blueweiss et al., 1978).

The very small proportion of Nooksack dace in breeding condition in my samples is likely due to territorial spawning behaviour. Spawning *R. cataractae* are spatially concentrated in clusters of tiny territories that they rarely leave even to feed (Bartnik, 1972; 1973), a situation which would reduce trap catches of spawning fish to near zero. Since only a portion of the adult population is spawning at any one time, however, pre or post-spawning adults continue to be caught throughout the spawning season, as indicated by the early summer peak in K_n.

Movement

The short distances moved by most recaptured Nooksack dace, the low recapture rates in adjacent reaches, and the extremely leptokurtotic distribution of observed movements relative to that expected at random with respect to trap locations strongly suggest that a large fraction of the population is sedentary. Hill and Grossman (1987b) also report small home range size (mean 13.7 m) for *R. cataractae*. The relatively long movements (circa 200 m) of a few individuals, however, suggests that a lesser fraction of the population exhibits relatively unrestricted movement and may travel considerable distances from the home patch. This pattern has been found in a number of other stream fishes. In some species individuals appear to change tactics in response to food availability, growth rates or body size , while in others individuals appear to be permanently mobile or sedentary (Nakamura et al., 2002). The lack of differences in growth rate, condition (Kn), and size between ‘movers’ and ‘stayers’ in this study suggest that movers and stayers may be discrete fractions of the population, although the strong dependence of my K_n values, on reproductive status may have masked an effect of fish condition.

None of the recaptured fish moved the 2.2 km between study reaches, although the probability of detecting such movements was low. Nooksack dace colonists (n=9) did penetrate 560 m into a newly constructed 960 m tributary diversion within 15 months. (T. Patton, University of British Columbia, unpublished data), suggesting that maximum annual range may be less than 1 km.

My recapture rate was very low at 9.6 %. This suggests that mortality was high, sampling efficiency was low, or that large numbers of marked fish moved outside the study reaches (Gowan et al., 1994). CPUE showed no decline in the study reaches over two summers of frequent sampling, as would be expected if mortality was high. The strongly leptokurtotic distribution of movements suggests that relatively few fish left the study reaches. Consequently, I believe the explanation lies in the poor efficiency of my trapping method. Unfortunately, more efficient methods may not be suitable for capture of rare species. The method used represents a compromise. Electroshocking would likely been more efficient, but is inappropriate for repeat sampling of a listed species due to impacts on fish health (Kocovsky et al., 1997; Ruppert and Muth, 1997). Kick seining, also likely to be more efficient, would have damaged spawning sites.

Life History Overview

McPhail (1997) reports that Nooksack dace spawn, and forage as adults in fast flowing riffles over course substrate while young-of-the-year emerge in mid-summer and inhabit shallow, marginal pools with sand or mud substrates until moving into riffle habitat when approximately 45 mm long. He also reports a lifespan of four to six years and attainment of sexual maturity at the end of the second summer of life. These features, when combined with small body size and the prolonged spawning period I observed suggest that Nooksack dace follow an opportunistic life history strategy (sensu Winemiller and Rose, 1992). In aggregate these traits should allow rapid recovery from intermittent, small–scale disturbances that inflict high adult mortality (Detenbeck et al., 1992) and should facilitate successful re-introductions into suitable habitat. These attributes, however, will provide little resilience in the face of large scale or chronic disturbances (Winemiller and Rose, 1992; Detenbeck et al., 1992).

Management Implications

The Nooksack dace of Bertrand Creek may be vulnerable to low flows, which during very dry years are near zero in late summer The lowest recorded discharge (0.001 m^3 •s^{-1} August 1985, Water Survey of Canada), would have completely eliminated riffle habitat in the study reaches. In 10 of the last 18 summers (including both study years) discharge was less than 0.025 m^3·•s^{-1} for at least 5 consecutive days in late summer. In these conditions wetted riffle area is reduced by 50 to 75% relative to typical flows in May and June (Pearson, pers. obs.). During these periods adult Nooksack dace are frequently observed in pools (Pearson pers. obs.). Other studies have shown that *R. cataractae* are sometimes forced out of riffles by conspecifics defending spawning territories (Bartnik, 1973) or competing for sheltered locations (Mullen and Burton, 1998). Displacement into pools, which frequently contain relatively large resident salmonids, likely increases predation risk for Nooksack dace. Increased urbanization and water withdrawals in the drainage basin will exacerbate the problem and may reduce flows below critical levels earlier in the year, during the spawning period.

Populations in all three of their Canadian watersheds are susceptible to large-scale chemical spills or siltation events, which although unlikely to happen, could devastate an entire population, and to chronic degradation of water quality from urban runoff, which is likely to increase as local human populations increase. These threats are exacerbated by the fact that habitat downstream in Washington is seriously degraded (McPhail, 1997). The lack of a productive source of colonists downstream means that Canadian habitats would probably not be recolonized naturally following a catastrophic event.

The risk of Nooksack dace extirpation is likely to be minimized by implementing a management strategy that emphasizes three elements. First adequate baseflows should be maintained during dry periods by preventing illegal water withdrawals, preventing wetland loss, and increasing permeable area in urbanized sections of watersheds containing Nooksack dace. Second, land use management should minimize the chances of catastrophic events and chronic water quality degradation from non-point source pollution. Third, Nooksack dace protection areas where habitat and water quality can be maintained should be established. These areas could provide source individuals for future reintroductions.

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Chapter 5

Habitat Associations and Population Structure of the Nooksack Dace

Introduction

Limited geographic range is one of the strongest correlates of species endangerment and is particularly prevalent in the freshwater fishes of western North America (Warren and Burr, 1994; Sheldon, 1988) rendering them one the continent's most threatened faunas (Moyle and Williams, 1990; Ricciardi and Ramussen, 1999). British Columbia's Fraser Valley contains a number of fishes with restricted ranges that are considered at risk. One of these, the Nooksack dace (*Rhinichthys cataractae* ssp.), is an evolutionarily significant unit (sensu Waples, 1995) of the longnose dace (*R. cataractae*) genome. It is listed as endangered in Canada (Campbell, 2001) and by the American Fisheries Society (Williams et al., 1989). A number of its life history traits were characterized in Chapter 4, but details of habitat requirements, particularly at scales larger than the channel unit remain poorly understood.

The reach scale (100s to 1000s of metres) is likely to be critical for conservation of stream fishes, because both human settlement patterns and most of the processes driving their population dynamics occur at this scale (Fausch et al., 2002). It is also the scale least frequently included in habitat studies because doing so usually requires collection of spatially continuous data over kilometres of habitat (Fausch et al., 2002).

The influence of beaver activity on stream fish communities is complex affecting different species and life history stages differently. Dams are barriers to movement and migration (Chapter 2; Schlosser, 1995). Ponds alter habitat patch distribution and quality (Naiman et al., 1986) in ways that dramatically alter species presence and relative abundance, depending upon the surrounding landscape and successional processes which are non-linear and complex. (Schlosser and Kallemyn, 2000; Snodgrass and Meffe, 1998).

In this chapter I report on the population structure and habitat associations of Nooksack dace at the watershed, reach and channel unit scales and examine the impact of beaver activity on their habitat. I then discuss the management implications of my findings.

Study Area

I studied Nooksack dace throughout their Canadian range, which consists of three adjacent lowland streams in British Columbia's Fraser Valley: Bertrand, Pepin and Fishtrap Creeks (McPhail, 1997, Fig. 5.1). All are 2nd to 3rd order tributaries of the Nooksack River in Washington State.

Land use in the catchments of these creeks is predominantly agricultural, with small, isolated forest patches. The headwater regions of Bertrand and Fishtrap Creeks are urbanized, and the Pepin Brook watershed contains substantial aggregate mining. Surface soils in the Bertrand Creek watershed are primarily glaciomarine tills with high clay content and poor permeability, while those of Pepin and Fishtrap are the thick gravel deposits of a glacial moraine (Johanson, 1988). Consequently, Bertrand Creek receives much less groundwater influx and has more extreme temperatures and discharges than either Fishtrap or Pepin.

Methods

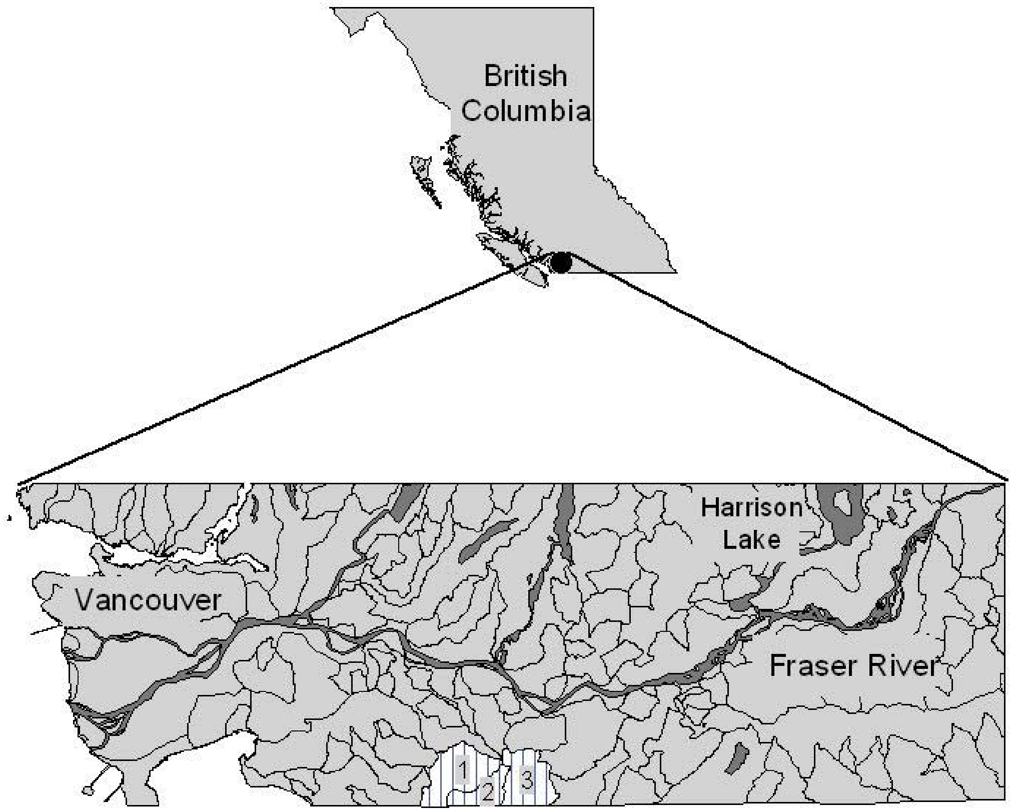
Fish Trapping

Fish were captured in commercially available, cylindrical, double-ended funnel traps (22.5 x 40 cm with 6 mm mesh). Traps were baited with dry cat food in perforated canisters and set for approximately 24 hours. Fish were anaesthetized in a solution of tricaine methanesulfonate (MS 222, 70 $mg \cdot l^{-1}$), weighed (nearest 0.1 g), measured (fork length, nearest mm) and released at their point of capture following recovery from sedation. Other fish were counted and released.

Channel Unit Scale

To examine habitat associations at the channel unit scale (metres to tens of metres) I recorded channel unit type, substrate, cover, and depth characteristics at 1,343 trap sites. Channel units were defined as riffle, glide, deep pool (>70 cm depth), shallow pool, or marginal pool (shallow pools lateral to riffles). Substrate classes (clay, silt, sand, gravel, cobble, boulder (Bain, 1999) and cover classes (large woody debris, overhanging vegetation, boulder, emergent vegetation, submergent vegetation) were recorded as present or absent

Figure 5.1: Location of the three study watersheds; Bertrand Creek (1), Pepin Brook (2) and Fishtrap Creek (3). All are tributaries of Washington State's Nooksack River.



within a 3 m radius of traps. Depth was recorded to the nearest 5 cm with a metre stick or sounding line. Only traps set in water warmer than 11°C (Nooksack dace trapping threshold, see Chapter 4), in reaches known to contain the species were used in the analysis.

Preference for different habitat characteristics was inferred by comparing the number of traps containing Nooksack dace to the number expected by chance for each cover or substrate class using Chi-square with Yates' correction for comparisons with 1 degree of freedom (Zar, 1999).

Reach Scale

Continuous reach-scale habitat surveys were conducted on foot in all three streams at low-flow. Reaches were identified as sections of channel at least 20 times longer than channel width that were relatively homogenous with respect to slope, width, substrate, discharge, sinuosity, entrenchment, average depth and riparian vegetation (Arend, 1999). The length (by hip-chain, 2 m resolution) of each channel unit type (deep pool, shallow pool (<70 cm), riffle, glide) was recorded over the entire 39.1 km of surveyed stream. At three pre-determined points on each reach (25%, 50%, and 75% of reach length) cover was quantified using a subjective 5-point scale (0= no cover; 5 = complete cover) for each of four categories; large woody debris, overhanging vegetation, boulder, and emergent/submergent vegetation. The locations of beaver dams and length of their associated ponds were recorded in these surveys (1999) and in earlier surveys in 1997. A third beaver dam survey of Pepin Brook was conducted in 2001. In conjunction with the 1999 survey, a minimum of 10 traps were set in each of 74 surveyed reaches to assess Nooksack dace presence and density.

Percentage areas of different land uses (agricultural, urban, forest, gravel mining) were measured in a zone around each reach extending 200 m from each bank and through a 200 m radius semi-circle from each reach endpoint. Polygons for each land use were drawn over high resolution (pixel size=1 m on ground), digital, black and white aerial photographs and georeferenced to 1:20,000 UTM-projected base maps using a geographic information system (ArcView 3.2).

Means of habitat variables in reaches with and without Nooksack dace were compared using either a t-test or Mann-Whitney U-tests, when distributions could not be normalized (Zar, 1999). A nested series of stepwise logistic regression models (Systat Logit) was used to quantify relationships between the presence of Nooksack dace and reach scale habitat variables. The least significant variable was identified by a Wald test and excluded in each successive model iteration until all remaining variables were significant at p=0.20. Multicollinearity was minimized by avoiding inclusion of highly correlated variables (|r| >0.7) in the same model and logit linearity was confirmed using the Box-Tidwell test (Tabachnick and Fidell, 2001). The simplest model contained the combination of channel-unit variables that maximized fit (highest McFadden's ρ^2) and satisfied multicollinearity criteria. I added cover variables to form a second model and then added land use variables individually (because of collinearity problems) to subsequent models. Models were compared using McFadden's ρ^2 and by their ability to correctly predict fish presence or absence in reaches. The significance of improvement with each model expansion was tested using chi-square. I also tested (chi-square) for positive or negative associations between Nooksack dace and presence of other fish and amphibian species at 92 sites (all surveyed reaches plus 18 sites in unsurveyed tributaries).

Catch-per-unit-effort (CPUE, mean number of Nooksack dace per trap) was calculated for each reach and plotted in descending order of magnitude to yield a curve with an inflection point at 0.25 fish·trap^{-1} (Fig. 5.2). Reaches were categorized as high density (CPUE > 0.25), low density (0<CPUE<0.25) or zero density (CPUE=0) and mapped to examine spatial patterns of abundance.

Watershed Scale

I assessed relative density (D') of Nooksack dace among watersheds by summing the product of relative fish density and length of riffle habitat at the reach scale over a watershed as:

$$D' = \left(\frac{\sum_{n}^{k} \left(\left(\frac{CPUEn}{CPUE\max} \right) \bullet Ri \right)}{\sum Ln} \right) * 1000$$

where $CPUE_n$ is the CPUE and L_n is the length in metres of reach *n* of k reaches in the watershed, $CPUE_{max}$ is the maximum CPUE observed in any reach in the study, and *Ri* is the length of riffle (m) in the reach. I scaled *D'* to riffle length rather than reach length because Nooksack dace were occasionally caught in small, isolated riffle patches surrounded by long stretches of pool habitat in which they were absent. Here, using reach length inflated *D'* to unrealistic values. My calculation of *D*' assumes a linear relationship between Nooksack dace density and CPUE, which is unlikely. With most species and gears CPUE is hyperstable, staying relatively high as density decreases through its mid-range (Harley et al., 2001). This property would result in an overestimate of D' for medium density reaches.

I compared *D'* to watershed scale land use, stream habitat, and hydrographic characteristics graphically, as the sample size (n=3) precluded statistical treatment. Land use proportions were estimated for the entire watershed and in a zone within 200 m of the portion of channel containing perennial flow using the same method as in the reach scale studies. The amount and proportions of channel unit types were summed by watershed from the reach scale data, and watershed cover scores (C_w) were calculated as:

$$C_w = \frac{\sum_{n}^{k} (L_n \bullet C_n)}{\sum L_n},$$

where C_n is the cover score of reach *n* of *k* reaches in the watershed.

Summer discharge data (May 1 to Oct 31) are available for all three creeks beginning in 1984 and year-round data are available for Fishtrap Creek after 1988. I calculated mean 'summer' discharge (May 1 to October 31), the five-year minimum mean daily flow, and the coefficient of variation in summer discharge (Poff and Allan, 1995; Dunne and Leopold, 1978) using the entire available record for Bertrand Creek and Pepin Brook. Only post-1991 data were used for Fishtrap Creek as preliminary analysis revealed substantial increases in baseflow following this year when 5 km of the mainstem were dredged and large headwater detention ponds were constructed. Water temperatures were measured hourly between June 19, 1997 and June 19, 1999 using loggers (Optic-Stowaway, Onset Corporation, Pocasset , MA) placed in shaded riffles or glides at the downstream end of the study area in each stream. Temperature duration curves were constructed for each creek and used to assess the proportion of the year that temperatures exceeded the trapping threshold for Nooksack dace (11^{o}C, see Chapter 4).

I also mapped and examined watershed scale changes in the number, distribution and extent of inundation due to beaver dams identified in the surveys. The number of beaver colonies was counted assuming that contiguous series of ponds with less than 330 m between consecutive dams corresponded to a single colony (equivalent to maximum recorded colony density of 3 per km (Naiman et al., 1986).

Results

Channel Unit Scale

The probability of capturing dace was significantly higher when gravel was present and lower when silt was present within 3 m of a trap. Other substrate size classes and the presence of particular cover types had no apparent effect (Table 5.1) and depth of traps with (42 $\pm$ 1.4cm, mean+SEM, n=315) and without (44$\pm$ 0.9 cm, n=967) Nooksack dace were not significantly different (p=0.472). Nooksack dace were captured more often than expected in riffles and their adjacent marginal pools, but this was not statistically significant (Table 5.1).

Reach Scale

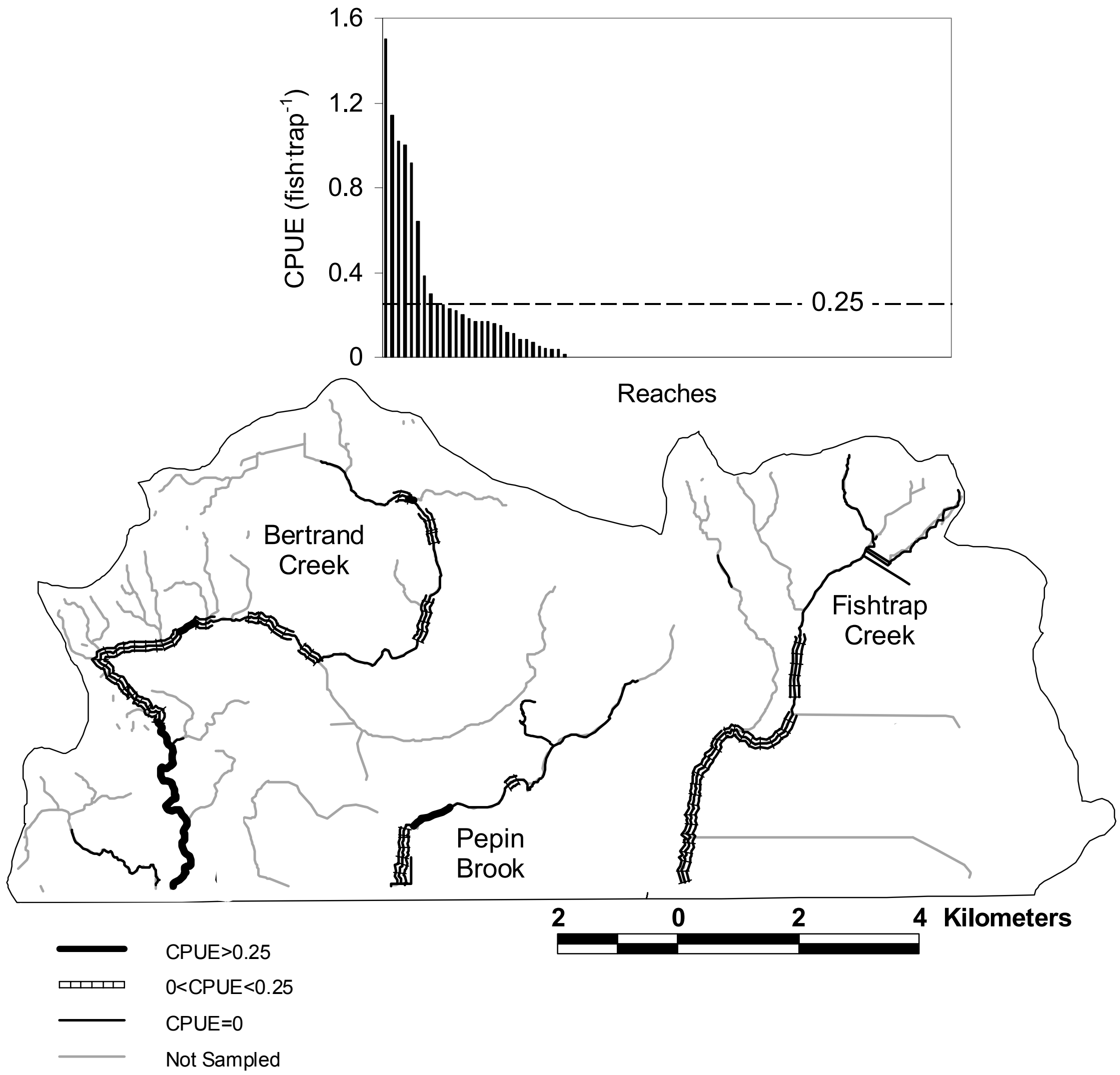
CPUE was zero in most reaches (41 of 72), peaked at 1.5 fish$\cdot$trap^{-1}, but exceeded 0.25 fish$\cdot$trap^{-1} in only eight reaches, all of which were in Bertrand Creek (Fig. 5.2). These reaches were highly aggregated with six being contiguous. Univariate comparisons showed that reaches inhabited by Nooksack dace had significantly more riffle habitat and shorter deep pools than those that did not, although the overall proportion of deep pool did not differ

Table 5.1: Observed and expected (at random) frequencies of traps containing Nooksack dace in different channel unit types and in relation presence of different substrate and cover classes within 3 m of the trap. Only traps from reaches known to contain a species in water warmer than 11°C (trapping threshold for the species, see Chapter 2) were used in the analysis. The significance of channel unit differences were tested using an overall chi-square. Substrate and cover classes were analyzed individually and tested with Yates correction for one degree of freedom to chi-square (Zar 1999) as more than one class applied to most traps.

	Obs	Expected	n	p
Channel Unit Type				
Deep Pool	69	70	263	0.191
Shallow Pool	138	156	584	
Marginal Pool	67	57	215	
Riffle	68	58	217	
Glide	12	12	44	
Substrate Class (n=1309)				
Boulder	38	40	150	0.804
Cobble	92	86	326	0.462
Gravel	337	325	1228	0.004*
Sand	20	23	87	0.519
Silt	4	15	57	0.001*
Clay	29	36	134	0.214
Cover Class (n=1105)				
Submergent Macrophyte	1	2	9	-
Emergent Macrophyte	65	74	277	0.198
Overhanging Vegetation	140	127	475	0.091
Large Woody Debris	111	101	381	0.191
Undercut	9	12	44	0.442
Rock	35	32	120	0.574

* significantly different at $\alpha = 0.05$

Figure 5.2: Spatial distribution and frequency of catch-per-unit-effort (CPUE) of Nooksack dace among reaches (n=72). In most (41) reaches CPUE was zero. High density reaches were extremely clumped spatially.



(Table 5.2). They also had significantly less overhanging vegetation, but did not differ in amounts of large woody debris, in-stream vegetation, or boulder cover. Reaches with and without dace did not differ in proportions of land use type within 200 m of the channel.

The simplest logistic regression model predicting Nooksack dace presence contained only channel unit variables. It showed excellent fit and good predictive capability (Table 5.3). The total length of riffle habitat in a reach was the most significant predictor or Nooksack dace presence. The probability of dace presence decreased significantly as mean deep pool length increased, but was also positively associated with the percentage of deep pool habitat in a reach. When cover variables were added to form the second model, only a negative association with the amount of overhanging vegetation significantly improved overall model fit. No land use variables significant improved the model fit.

Nooksack dace were present in reaches containing beaver dams and lodges on fewer occasions than expected, but this was not statistically significant (p=0.09). They were found with cutthroat trout (*Oncorhynchus clarki*), steelhead/rainbow trout (*O. mykiss*) and crayfish (*Pacifastacus* sp.) more frequently than expected by chance (Table 5.4) but showed no significant pattern in relation to other species of fish or amphibians in the traps.

Watershed Scale

The Nooksack dace density index (*D'*) of Bertrand Creek was more than seven fold higher than in Pepin Brook and 18 times higher than Fishtrap Creek (Table 5.5). Bertrand Creek also had almost twice as much riffle, in proportion to its length, as Pepin and more than four times as much as Fishtrap. Summer temperatures were higher in Bertrand, exceeding the thermal threshold for trapping Nooksack dace (11^{o}C, see Chapter 2) for 232 days compared to 160 and 195 days for Pepin and Fishtrap respectively (Fig. 5.3). Minimum discharges were also more variable and lower in Bertrand Creek than in either of the other stream, but Nooksack dace density showed no consistent pattern in relation to watershed or riparian landuse variables (Table 5.5).

Table 5.2: Means, standard errors and significant differences between habitat variables in reaches with and without Nooksack Dace. All lengths are in m, areas in m^2 and cover variable values are sums of three visual estimates (1-5 scale) from predetermined locations within each reach.

	Reaches With (n=30)		Reaches Without (n=44)			
	Mean	SE	Mean	Range	p	Test
Reach Length	607	111	426	51	0.083	tl
Bankfull Width	6.5	0.5	14	3	0.093	tl
Total Riffle Length	108	17	34	11	<0.001*	tl
Percent Riffle	22	3	11	3	<0.001*	m
Riffle Area	384	104	57	23	<0.001*	m
Large Substrate Area	132	44	13	4	0.002*	tl
Large Substrate Length	18.6	4.6	3.2	1.3	0.000*	m
Percent Dry	0	0	4	2	0.092	m
Total Deep Pool Length	205	83	201	48	0.351	tl
Percent Deep Pool	26	4	41	6	0.349	m
Max. Deep Pool Length	57	16	137	32	0.029*	tl
Mean Deep Pool Length	19	5	94	28	<0.001*	m
Large Woody Debris	5.3	0.7	6.6	0.6	0.174	m
Boulder	1.9	0.4	1.5	0.4	0.163	m
Overhanging Vegetation	8.7	0.6	10.6	0.5	0.012*	m
In-stream Vegetation	9.3	0.6	9.0	0.6	0.779	tu
Total Cover	25.1	0.8	27.7	0.9	0.036*	tu
Area of 200 m Zone	0.35	0.05	0.29	0.02	0.266	tl
Percent Agricultural	49.0	5.3	43.5	4.9	0.928	ta
Percent Forest	37.0	4.7	31.6	3.6	0.427	ta
Percent Urban	13.3	6.2	20.3	4.6	0.145	m
Percent Gravel Mine	0.7	0.7	2.8	1.2	0.092	m

t = parametric t test
m = Mann-Whitney U test
u = untransformed
l = log transformed
a = arcsine transformed
* significantly different at $\alpha = 0.05$

Table 5.3: Nested logistic regression models examining the effects of habitat type, cover and land use on the probability of presence and absence of Nooksack dace in reaches. Values listed for variables are coefficients followed by bracketed p-values. 'E' indicates that the variable was eliminated during the reverse stepwise procedure. Prediction values denote percentage of reaches correctly identified by the model for presence/absence of Nooksack dace. McFadden's rho is an R^2 analog with values >0.2 considered satisfactory(Tabachnick and Fidell, 2001). Landuse variables were added individually to separate models due to multi-collinearity problems.

	Habitat Type	Habitat Type + Cover	Habitat Type + Cover +Land use
Reach Length	E	E	E
Bankfull Width	E	E	E
% Deep Pool	1.358 (0.012)	1.502 (0.014)	1.494 (0.016)
Mean Deep Pool Length	-1.348 (0.026)	-1.528 (0.039)	-1.638 (0.030)
% Riffle	E	E	E
Total Riffle Length	1.269 (<0.001)	1.329 (<0.001)	1.277 (0.001)
Large Woody Debris		E	E
Overhanging Vegetation		-2.709 (0.026)	-3.327 (0.018)
In-Stream Vegetation		E	E
Boulder		E	E
Area of Riffle .Cobble/Boulder		E	E
% Agricultural within 200 m			E
% Forest within 200 m			1.690 (0.197)
% Urban within 200 m			E
Intercept	4.959	-3.840	1.960
McFadden's rho	0.439	0.510	0.529
Prediction	71/78	75/81	76/82
P of Model Improvement	<0.001	0.011	0.180

Table 5.4: Expected and observed frequencies of fish and amphibian species captured in the same reach as Nooksack dace. 'N' indicates that Chi-square could not be applied because the expected frequency was too low.

Common Name	Species	Obs.	Exp.	p
Native Species				
Coho salmon	*Oncorhynchus kisutch*	23	19.2	0.120
Cutthroat trout	*Oncorhynchus clarki*	24	17.3	0.005*
Steelhead/RainbowTrout	*Oncorhynchus mykiss*	15	7.9	0.001*
Salish sucker	*Catostomus* sp.	9	9.1	1.000
Largescale sucker	*Catostomus macrocheilus*	1	1.6	N
Prickly sculpin	*Cottus asper*	3	0.9	N
Threespine stickleback	*Gasterosteus aculeatus*	29	26.5	0.107
Lamprey	*Lampetra spp.*	4	3.5	N
Northwestern salamander	*Ambystoma gracile*	2	4.4	N
Crayfish	*Pacifastacus* sp.	28	17.6	<0.001*
Introduced Species				
Brown bullhead	*Ameiurus nebulosis*	1	1.9	N
Pumpkinseed	*Lepomis gibbosus*	2	2.8	N
Largemouth bass	*Micropterus salmoides*	0	3.2	N
Fathead minnow	*Pimephales promelus*	0	0.9	N
Bullfrog tadpoles	*Rana catesbeiana*	4	6.3	N

Figure 5.3: Temperature duration curves for Pepin, Bertrand and Fishtrap Creeks. The horizontal line at 11^{o}C marks the trapping threshold of Nooksack dace (see Chapter 4).

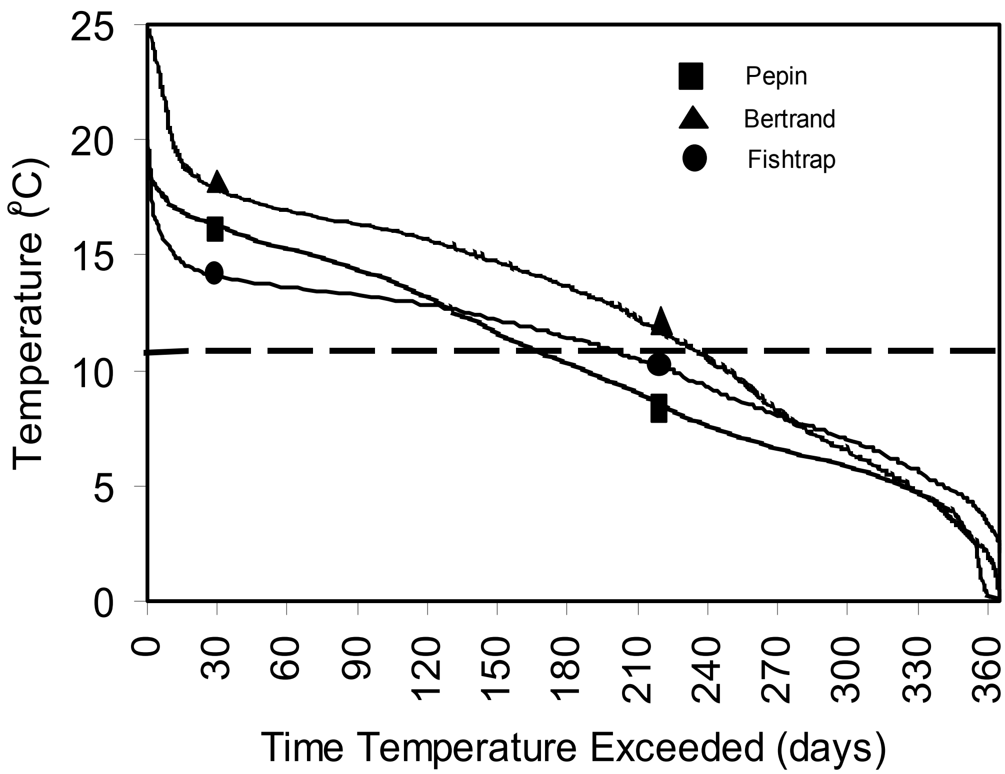


Table 5.5: Nooksack dace density index (*D'*) and watershed scale characteristics of Bertrand, Pepin, and Fishtrap Creeks. Cover scores are corrected for reach and total channel length (see text for details). Land use proportions for the entire watershed are followed by bracketed values for proportions within 200 m of the channel.

	Bertrand Creek	Pepin Brook	Fishtrap Creek
D'	34.0	4.8	1.8
Riffle (% channel length)	8.7	2.0	4.8
Deep Pool (% channel length)	27.8	67.8	52.4
Shallow Pool (% channel length)	58.1	9.8	36.9
Maximum Temperature (^{o}C)	24.7	20.0	19.3
Large Woody Debris Cover	5.3	10.3	4.9
Overhanging Vegetation Cover	8.7	12.7	8.7
In-stream Vegetation Cover	9.3	11.4	8.8
Boulder Cover	1.6	0.6	0.7
Mean Summer Discharge ($m^3 \cdot s^{-1}$)	0.295	0.359	0.294
5 Year Return Minimum Flow ($m^3 \cdot s^{-1}$)	0.015	0.090	0.037
CV of Discharge	2.24	0.49	1.21
Percent Urban	9.1 (14.7)	1.5 (0.6)	17.7 (18.5)
Percent Agricultural	65.9 (54.8)	56.4 (29.8)	70.1 (57.1)
Percent Forest	24.4 (30.5)	24.7 (54.0)	11.2 (24.1)
Percent Gravel Mine	0.6 (0.0)	17.3 (15.5)	0.9 (0.2)

The number of beaver dams and colonies increased in all streams between 1997 and 1999 and in Pepin between 1999 and 2001, but the amount and proportion of stream length affected differed greatly (Table 5.6). In Pepin Brook, the most affected stream, approximately 690 additional metres of channel was flooded between 1999 and 2001. This eliminated approximately 10% of the total riffle area as measured in 1999 (938 m).

Table 5.6: Beaver activity in Bertrand, Pepin and Fishtrap Creeks during the study period. Clusters of dams within 330m of channel were considered to house single colonies.

		Bertrand Creek	Pepin Brook	Fishtrap Creek
Number of Dams (Colonies)	1997	11 (8)	13 (8)	3 (2)
	1999	24 (12)	22 (9)	5 (3)
	2001		30 (10)	
Colony Density (per km)	1997	0.50	1.26	0.19
	1999	0.76	1.42	0.19
	2001		1.58	
Km of Channel Flooded (%)	1999	2.42 (15.3)	2.97 (46.9)	0.54 (5.1)
	2001		3.66 (57.7)	

Discussion

Watershed Scale

Although the restriction of Nooksack dace to just three Canadian watersheds precluded statistical analysis of habitat associations at this scale, the large differences in population densities among these streams (as indicated by D') suggests that watershed scale effects are important. The probable overestimation of medium densities using my method would lead to conservative estimates of watershed scale differences. The large proportion of riffle in the watershed with the greatest density of dace is likely an important factor given its strong impact at the reach scale. Temperature may also play a role with the warmer waters of Bertrand Creek permitting faster growth, shorter egg incubation periods, and longer growing seasons. Bartnik (1970) reports that *R. cataractae* from Manitoba's Mink River that over-wintered in the laboratory did not spawn until maximum daily water temperatures exceeded 15 ^oC. In a correlative study of fish community structure in Michigan streams, Wherly et al. (2003) found that few *R. cataractae* populations were found in streams having maximum weekly average temperatures below 20 ^oC. Bertrand creek falls above this threshold, but both Pepin and Fishtrap Creeks are below it.

The increase in beaver activity over the course of the study was dramatic, particularly in Pepin Brook. The increase mirrors the recent trend across North America, which is attributed to reduced trapping, and an abundance of second growth deciduous forest on the landscape (Remillard et al., 1987; Howard and Larson, 1985; Johnston and Naiman, 1990; Naiman et al., 1988). Although further impoundment of Pepin Brook is likely, some areas will likely remain dam-free due to extreme floodplain width (Johnston and Naiman, 1990) and dam removal by agencies and residents concerned about flooding. Consequently I expect Nooksack dace habitat loss due to beaver impoundment to come to an end in the near future. I remain concerned about fragmentation of the remaining population by recently constructed ponds, however. Beaver activity, although expanding, is much less prevalent in Bertrand and Fishtrap Creeks. Neither creek has the wide riparian forest characteristic of Pepin Brook, a major determinant of colony longevity (Howard and Larson, 1985). Furthermore, high winter flows in Bertrand and Fishtrap regularly wash out dams in the reaches where most Nooksack dace are found (Pearson pers. obs.).

D' was unrelated to watershed scale land use in this study, which may result from the lack of variation in land use among watersheds. Land use within 200 m of the permanently wetted channel was also similar in Bertrand and Fishtrap Creeks. In comparison, Pepin Brook, had a high proportion of forest and lesser proportion of agriculture near the stream. Any direct effects of land cover on Nooksack dace in Pepin Brook, however, were likely overwhelmed by the prevalence of beaver pond habitat (and lack of riffle) in the channel.

Reach Scale

Nooksack dace abundance among reaches appears to be controlled primarily by the amount of riffle habitat present. This is not surprising as *R. cataractae* is considered a riffle specialist (McPhail, 1997; Facey and Grossman, 1992; Gibbons and Gee, 1972; Thompson et al., 2001). The influence of deep pool habitat on the probability of presence was complex, increasing with the proportion present in a reach, but decreasing with the mean length of each unit. Deep pool presence may benefit Nooksack dace by acting as refugia during periods of critically low flow, especially in Bertrand Creek, where most Nooksack dace reaches were located, but predation risk is likely elevated there due to the presence of adult salmonids. Long deep pools may effectively fragment patches of riffle habitat within reaches, thereby reducing the probability of Nooksack dace presence. Greater overhead cover reduced the probability of presence, which is difficult to explain. Given the very small difference in means (Table 5.2), this result may not be biologically significant. Land use was unrelated to Nooksack dace distribution at the reach scale, probably because the proportion of riffle habitat in reaches is a function of channel gradient (Church, 2002) or dredging history rather than land use.

Channel Unit Scale

I found adults in both pools and riffles and at a variety of water depths. In contrast, McPhail (1997) reports them favouring shallow riffle habitats. This discrepancy is probably due to the baited traps I used drawing fish from surrounding habitats and/or because low summer flows in Bertrand Creek (where over 90 % of traps capturing Nooksack dace were located), forced fish out of riffles and into pools. The avoidance of silt and preference for gravel substrates by Nooksack dace is consistent with the results of other studies (Gibbons and Gee, 1972; Grossman and Freeman, 1987; Mullen and Burton, 1995; Glozier. et al., 1997; McPhail, 1987).

Population Structure

Spatially, the distribution of Nooksack dace was clumped at both the reach and watershed scales. The vast majority of individuals appear to inhabit the lower 5 km of Bertrand Creek. This pattern, which is suggestive of source-sink population dynamics (Pulliam, 1988), appears to be common among many species (Brown et al., 1996; Gaston, 1999) including other stream fishes (Gotelli and Taylor, 1999; Schlosser, 1995). Brown (1995) explained it using Hutchison's

(1958) multi-dimensional niche concept, showing that when more than four independent habitat variables limit abundance they will rarely all be at optimal levels simultaneously. When they are, local 'hot spots' of very high abundance occur. For Nooksack dace an abundance of uncompacted riffle habitat, warm summer water temperatures, and the absence of long continuous deep pools may be such variables.

In the absence of anthropogenic habitat degradation or extensive beaver ponding, these factors are likely to be temporally stable in lower Bertrand Creek as they are primarily products of watershed-scale geomorphological features. The 1.5-2% slope of this section of stream will naturally maintain a pool-riffle structure (Church, 2002). Winter floods cause dramatic changes in channel structure at the local scale with pools and riffles appearing and disappearing annually, but the relative amount of these habitats remains constant at the reach scale (Pearson unpubl.). The high clay content of the watershed's surface soils will continue to limit groundwater inputs and produce relatively warm summer water temperatures.

Beaver are active in lower Bertrand Creek, but riffle loss from flooding appears to be localized and short lived due to regular dam washouts during high discharge events. At least four of the eight dams that occurred in these reaches in 1999 were washed out in floods during the winter of 2000 (Pearson, pers. obs.). Dace persistence in the presence of beaver likely depends upon the frequency, duration, and especially the spatial extent of impoundment (i.e. distance from riffles containing potential colonists).

Management Implications

Management strategies should emphasize the preservation of riffle habitat and the processes that form it. Base flow in late summer should be adequate to keep riffles wetted and stream access to sources of erodable gravel should be maintained. Riparian vegetation should be of sufficient width to control water temperatures and limit the entry of sediment, which can clog riffles. Protection of base flow, in Bertrand Creek is probably the most pressing concern as it appears to contain the majority of the Canadian population but lacks flow (and riffle) in the late summer of many years. Baseflows are currently adequate in Pepin Brook and Fishtrap Creek but the extensive gravel mining currently underway in these watershed may compromise them in future.

In Pepin Brook beaver have eliminated a significant amount of riffle habitat and may need to be controlled in some reaches. This is not recommended unless the Nooksack dace population is threatened, however, because pond habitat is likely to benefit a co-occurring endangered fish, the Salish sucker, *Catostomus* sp. (see Chapter 3). In Fishtrap Creek, the low densities I found contrast sharply with those prior to the elimination of most riffle habitat by municipal dredging in 1990-91 (J.D. McPhail, University of British Columbia, pers. comm.). Here restoration of riffle habitat may be required.

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Chapter 6

An Analysis of Threats to the Nooksack Dace and the Salish Sucker

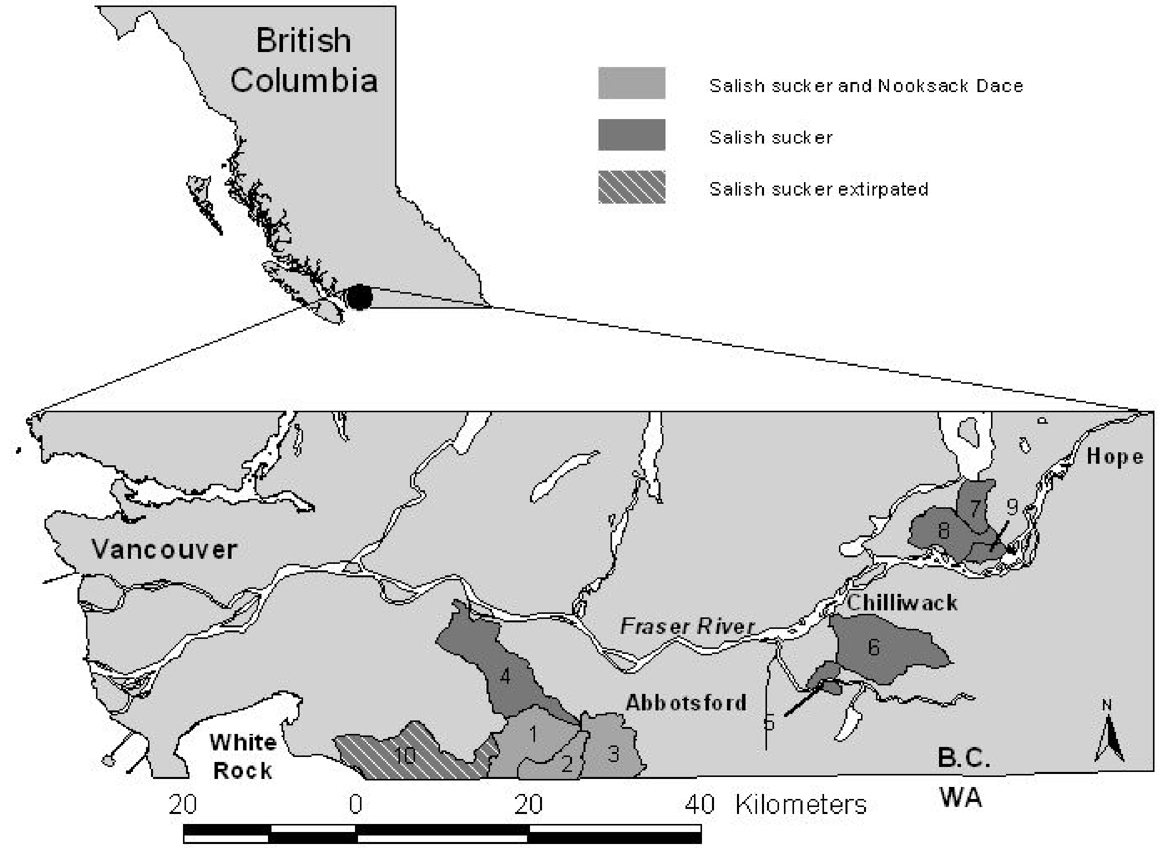
INTRODUCTION

The Salish sucker (*Catostomus* sp.) and Nooksack dace (*Rhinichthys cataractae* ssp.) were listed by COSEWIC in 1986 and 1996 respectively (Campbell, 2001). They occur together in the Canadian portions of Bertrand, Pepin, and Fishtrap Creeks, which are in British Columbia's Fraser Valley and flow south into Washington State's Nooksack River (Fig. 6.1). These three creeks constitute the entire Canadian range of the Nooksack dace. The Salish sucker is found in six additional Fraser River tributaries and is believed recently extirpated from the Little Campbell River (McPhail, 1987; Chapter 3). The current distribution is likely the product of limited opportunities for post-glacial dispersal (McPhail and Taylor, 1999), unrecorded anthropogenic extirpations, and perhaps biotic interactions with fauna in the Fraser River, which entered the valley more recently than Salish sucker and Nooksack dace (Chapter 3).

Both species are small bodied, have prolonged spawning periods (Chapters 2,4), mature early (1-2 years), and have and short life spans (5-6 yrs, McPhail, 1997; McPhail, 1987). These life history traits tend to produce a capacity for rapid population increase, enabling relatively rapid recovery from short-term, small-scale disturbances (Winemiller and Rose, 1992). Chronic or cumulative impacts, however, may overwhelm their capacity for recovery, and are likely to occur within their small range.

Large-scale physical habitat destruction, altered flow regimes, impaired water quality, sediment deposition, and introduced species are common in streams throughout the Fraser Valley (Boyle et al., 1997; Healey and Richardson, 1996). These and other threats may interact with one another, act on more than one scale, and/or act through multiple pathways. For example, drainage of agricultural land permanently destroys habitat by eliminating wetlands. It also reduces base flow during dry periods, which can fragment habitat by drying portions of the channel or degrade it by aggravating hypoxia. Additional nutrients entering stream channels from agriculture increase productivity and the risk of hypoxia and pesticides degrade water quality. Hypoxia and low levels of toxicity may, in turn, increase the impacts of introduced species by altering predator-prey dynamics.

Figure 6.1: Canadian distributions of Salish sucker and Nooksack dace



1. Bertrand Creek
2. Pepin Brook
3. Fishtrap Creek
4. Salmon River
5. Salwein Creek/Hopedale Slough
6. Atchelitz/Chilliwack/Semmihault Creeks
7. Miami Creek
8. Mountain Slough
9. Agassiz Slough
10. Little Campbell River (believed extirpated)

Such complexity can be usefully described in a variety of ways. Here, eight possible agents of decline are proposed as hypothesized 'threats'(Table 6.1). Most focus on direct causes of mortality, fitness loss, or habitat destruction (e.g. hypoxia, introduced predators, wetland drainage). One, habitat fragmentation, proposes that permanent or seasonal barriers to movement between populations, subpopulations or critical habitats produce declines at larger spatial scales.

Following a brief description of each threat that identifies the factors that drive or trigger it, each is assessed for its potential effects on Salish sucker and Nooksack dace (vulnerability assessments) and for its significance within each watershed in the range (watershed assessments). In the vulnerability assessments, the various life history stages are assessed separately and then combined for an overall rating. In the watershed assessments, each threat is evaluated systematically using a range of metrics. Watersheds are then ranked in terms of risk, and threats are ranked in terms of severity and ubiquity across the range. In the interests of readability only summary information on watershed assessments is presented in this Chapter, detailed rationale for all ratings appear in Appendix 1.

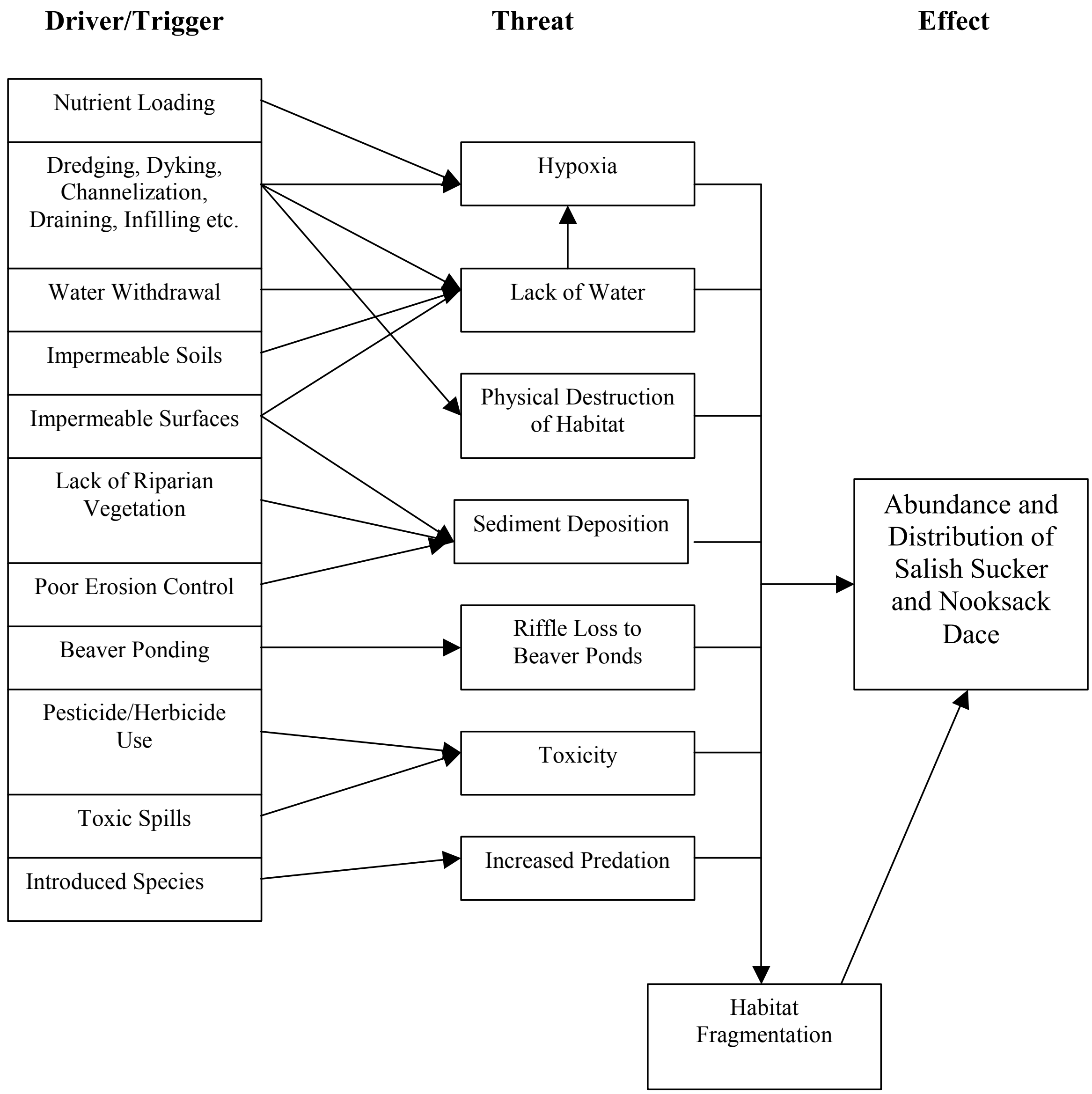
DESCRIPTION OF THREATS

Each of the eight threats is driven or triggered by one or more factors (Fig. 6.2). Most of these have potential to be regulated or influenced by legislation, policy and/or stewardship activities. In the following sections I briefly discuss each threat in terms of these factors.

Table 6.1: Potential threats to Salish sucker and Nooksack dace in Canada.

Threat	Hypothesis
1. Hypoxia	Episodes of extreme hypoxia are causing acute mortality or reduced fitness.
2. Lack of Water	Low flows in late summer eliminate critical habitat, reducing fitness or survival.
3.Physical Destruction of Habitat:	Drainage, dyking, channelization and infilling of waterbodies destroys critical habitat.
4. Riffle Loss to Beaver Ponds:	Beaver ponds are flooding critical riffle habitat.
5. Sediment Deposition:	Deposited sediment is degrading critical habitat.
6. Increased Predation	Introduced species are consuming individuals or reducing their fitness by inducing behavioural change.
7. Toxicity:	Toxic discharges from point or non-point sources are significantly reducing survival or fitness.
8. Habitat Fragmentation:	Fish are prevented or inhibited from traversing some stream reaches by permanent or temporary barriers. This restricts access to critical habitats and/or alters metapopulation dynamics to increase extinction risk.

Figure 6.2: Factors known or suspected to drive or trigger threats to Nooksack dace and Salish sucker.



Hypoxia

Hypoxia is ultimately caused by the cumulative effects of local and watershed scale impacts. Increased nutrients result in algal blooms and associated decomposition that strip the water of oxygen, especially at night. Elevated nutrients in Fraser Valley groundwater and streams are primarily a consequence of overapplication of manure and fertilizers to agriculture lands (Schreier et al., 2003; Lavkulich et al., 1999), but are also associated with urban stormwater runoff and poorly maintained septic tanks (Lavkulich et al., 1999). Lack of riparian vegetation eliminates shade and increases daytime oxygen levels through increased primary production. It also allows water temperatures to rise. Warmer water has less capacity for dissolved oxygen and increases the metabolic demand for it by fish. Reduced water movement impairs reoxygenation of water and may be caused by channelization (Schreier et al., 2003), beaver ponds (Schlosser and Kallemyn, 2000; Fox and Keast, 1990), or lack of water.

Lack of Water

During late summer, when rainfall is lowest, Fraser Valley stream flows are maintained by groundwater alone. Streams vary widely in their groundwater base-flow due to variations in soil characteristics. Watersheds with large unconfined aquifers maintain steady flows of cold water throughout this critical period, whereas surface flows in watersheds with impermeable surface soils may cease completely. Unfortunately this low flow period coincides with peak demand for water withdrawal for irrigation. Land use patterns can exacerbate problems with lack of water. Gravel mining reduces the size of the aquifer contributing to baseflow, urban development increases the area of impermeable surfaces, reducing infiltration to the aquifer, and agricultural drainage lowers water tables further reducing low flows. Beaver ponds are a stabilizing force, maintaining water levels in reaches that would otherwise dry out. Climate change is also likely to exacerbate water shortages in the future.

Physical Destruction of Habitat

Approximately 77% of pre-settlement wetland areas in the Fraser Valley have been drained or infilled (Boyle et al., 1997). Fifteen percent of the area’s streams no longer exist, having been paved over or piped (Fisheries and Oceans Canada, 1998). A large, but unknown proportion of the length of those that remain have been channelized and/or repeatedly dredged in agricultural drainage or urban development projects. It is difficult to overstate the historical extent of fish habitat loss due to these activities. Permitted and/or illegal dredging of ditches and stream channels for flood control and agricultural drainage still occurs annually in all watersheds included in this study.

Riffle Loss to Beaver Ponds

Following their near extinction around 1900 (Johnson and Chance, 1974; Naiman et al., 1986), beaver have recovered to near historical densities in streams across much of North America (Broschart et al., 1989; Howard and Larson, 1985; Johnston and Naiman, 1990), although their total population remains much reduced due to habitat loss (Naiman et al., 1988). Lack of predators, depressed fur prices, and an abundance of second growth deciduous trees in riparian zones are believed to be driving the recovery (Naiman et al., 1988). Beaver ponds have been shown to influence fish populations in many ways, both positively and negatively (Keast and Fox, 1990; Hanson and Campbell, 1963; Schlosser, 1995), but the impacts of riffle loss through ponding has received scant attention. A large proportion of freshwater fish species require riffles for some stage of their life history, particularly spawning. Population level impacts are likely to occur primarily when riffles are already scarce or when beaver impound long continuous stretches of channel, but both conditions occur in a number of streams in the study area (Pearson, pers. obs.).

Sediment Deposition

Sediment deposition is controlled by the balance between the rate of sediment delivery to the channel and capacity of the stream to mobilize and carry it downstream. Sediment delivery may be increased by direct discharges, from storm drain runoff, or by bank erosion exacerbated by lack of riparian vegetation or increased peak flows. All of these sources are likely to increase to varying degrees with urban, agricultural and mining development in a watershed.

Toxicity

Toxic compounds enter Fraser Valley streams through urban and agricultural runoff, contaminated groundwater, direct industrial discharges, sewage treatment plant effluents, aerial deposition, and accidental spills (Hall et al., 1991). Some contaminants, particularly heavy metals, bind to sediments where they may be taken up and bioaccumulated by aquatic invertebrates and subsequently fish. Concentrations in the water column are widely variable over time because inputs are often strongly pulsed as in the first flush of stormwater following a long dry spell, and dilution varies with streamflow (Hall et al., 1991).

Increased Predation

Introduced predators are implicated in the extirpation and extinction of a large number of freshwater fishes (Gido and Brown, 1999; Miller et al., 1989; Richter, 1997). Most introduced predators are game fish elsewhere, suggesting that recreational fishers are a major vector in their spread. Most non-native species that are established in the Fraser Valley prefer warm, lentic environments (e.g. brown bullhead, *Ameiurus nebulosis*, bullfrogs, *Rana catesbeiana,* and largemouth bass *Micropterus salmoides*), and probably benefit from human caused habitat changes, which tend to convert faster flowing, cold water habitats to slow moving warm water ones (Weaver, 1994; Castleberry and Cech., 1993).

Habitat Fragmentation

Any of the threats discussed above could effectively fragment habitat by prohibiting or curtailing movement of individual fish through affected reaches. In addition, physical barriers such as hanging culverts, beaver dams, and agricultural weirs commonly prevent movement between habitats for all or part of the year in Fraser Valley streams. On a larger scale, connections between watersheds during floods were undoubtedly more common prior to the extensive dyking and drainage works of the past century.

ASSESSMENT METHODS

Species Vulnerability Assessments

The vulnerability of Salish sucker and Nooksack dace to each potential threat was assessed and data gaps were identified. In the assessments, four life history stages (eggs/spawning, young-of-the-year, adult summer, adult winter) were rated for vulnerability using existing information on life history traits. These ratings are listed graphically below each species-threat assessment using the following four-stage subjective scale:

+++	major concern	+	minor concern
++	moderate concern	-	not a concern

The highest level of concern assigned to a life history stage was used as the overall rating for each threat.

Watershed assessments

Overview of Method

Threats were assessed separately in each watershed, as their prevalence varies widely among streams. A two-stage process was used (Fig. 6.3). In the first stage, metrics were identified to indicate the state of each of the drivers and triggers discussed above (Table 6.2). Quantitative metrics were preferred, but qualitative ones were included, either to supplement quantitative ones or to suffice when none were available. Each driver/trigger was rated in each watershed using the four-level scale described above (major concern, moderate concern, minor concern, no concern) based on the observed state of the chosen metric(s). The rationale for the ratings in each watershed is given in the tables of Appendix 1. Five direct measures of threats were also included in this analysis. These were dissolved oxygen (for hypoxia), hydrographic data (for lack of water), observations of riffle sediments (for sediment deposition), population isolation (for habitat fragmentation) and habitat fragmentation within the watershed (for habitat fragmentation). In the second stage, an overall assessment of each of the eight potential threats in each watershed using the same four-level scale was made based on the ratings assigned to its drivers and triggers. Median values were used unless direct measures of the threat (e.g. dissolved oxygen levels for hypoxia) indicated a different assessment level.

Details of Metric Calculations

Water quality: Concentrations of dissolved oxygen, dissolved nitrate (as N), dissolved ammonia (as N), and fecal coliform counts were obtained from a provincial government database (http://wlapwww.gov.bc.ca/sry/p2/eq/wat_qual_data/index). Data were not available for all watersheds and only from one or two locations within watersheds. The total available record (various years between 1971-2002) for each station was plotted by month to show seasonal patterns and to illustrate the extent of variance among years. Values recorded after 1999 were highlighted to allow comparison with older ones. Levels were compared to the federal and provincial objectives for freshwater aquatic life (CCREM, 1987; MELP, 1994).

Figure 6.3: Schematic diagram of the two-stage threats assessment applied to each watershed. In the first stage, measurable metrics were used to rate factors identified as drivers or triggers of each of the eight identified threats (only one is shown). Ratings for drivers/triggers were combined to produce an overall rating for each threat in each watershed.

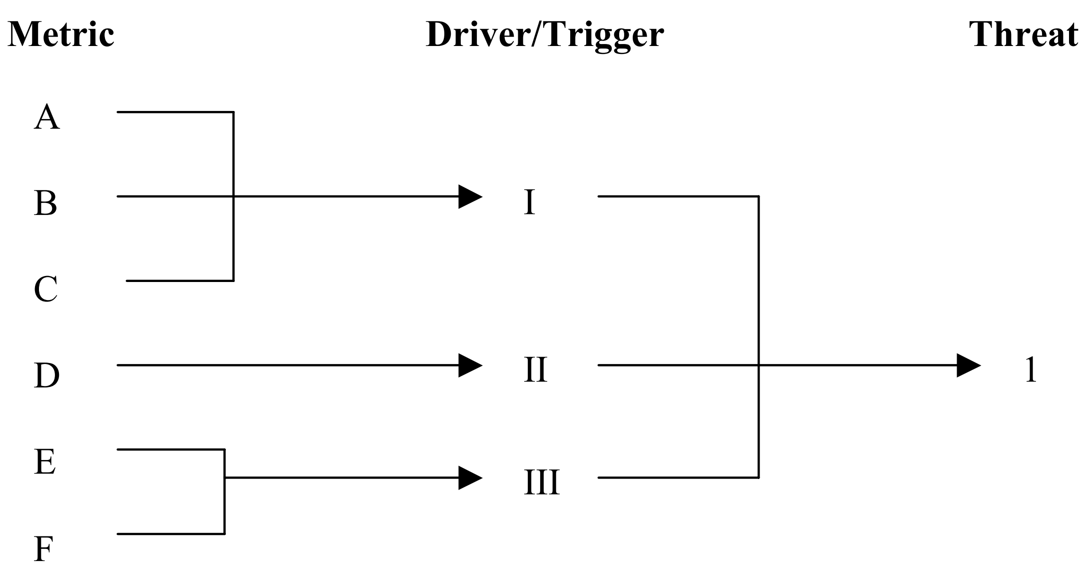


Table 6.2: Metrics used in assessment of watershed condition.

Driver/Trigger	Metric	Methods and Data Sources
Dissolved Oxygen	Dissolved Oxygen	Data from Provincial database (1) Unpublished data.
Lack of Riparian Vegetation	Width and continuity of riparian forest.	Inspection of aerial photographs.[2] Field observations.
Nutrient Loading	Dissolved Nitrate & Ammonia Fecal Coliforms Percent Watershed in Agriculture	Data from Provincial database (1) Unpublished data. GIS measurement of aerial photographs [2]
Hydrograph	Mean summer flow (April 1-Oct 1) 5-year minimum daily flow Coefficient of variation of discharge. Channel dryness in late summer	Discharge data from gauged creeks (Water Survey of Canada, Vancouver) Field observations
Beaver Activity	Presence of Dams	Field observations. Various cited reports.
Soils	Presence and extent of impermeable soils	Geological maps Various cited reports
Impermeable Surfaces	Percent watershed urban	GIS measurement of aerial photographs [2]
Physical Destruction of Habitat	Percent watershed urban Percent land in agriculture Existence of Dyke/Pumping Station Linearity of stream course	GIS measurement of aerial photographs [2]. Inspection of aerial photographs
Water Withdrawal	Flow reduction potential (FRP) of water licenses. Amount of unlicensed pumping	Calculated as reduction in discharge produced by maximum legal withdrawals over a set period of time (3). Field observations
Riffle sedimentation	Fines and compaction in riffles	Field observations
Erosion	Presence of large scale erosion Percent of land in mining Percent of land in agriculture	Field observations GIS measurement of aerial photographs [2]
Increased Predation	Presence of introduced predator in watershed	Trapping (Pearson unpubl.) FISS database (http://srmapps.gov.bc.ca/apps/fidq/)
Pesticide/Herbicide Use	Percent watershed in agriculture Percent watershed urban	GIS measurement of aerial photographs [2]
Toxic Spills	Percent watershed urban Number of major road crossings	GIS measurement of aerial photographs [2]
Isolation of Population/Subpopulation	Number of populations with which there is constant or periodic surface flow connection	Inspection of aerial photographs [2] Field observations.
Fragmentation Within Watershed	Number, severity, and seasonality of barriers within a watershed.	Various cited reports. Field observations.

1. see *water quality* in text   *2.* see *land use* in text   *3.* see *water withdrawal* in text

Land use: Proportions of land area in agricultural, forest, urban and gravel mining uses were measured as areas of polygons drawn over high-resolution (pixel size = 1 m on ground), digital, black and white aerial photographs georeferenced to 1: 20000 UTM projected base maps on a geographic information system (ArcView 3.2).

Water withdrawal: The flow reduction potential (FRP) of licensed water withdrawal was calculated as the reduction in stream discharge that would be caused by pumping at the maximum permitted rate. In British Columbia, water licenses vary in the units of water measurement and time restrictions on withdrawal. Some permit a certain number of gallons per day throughout the year. Others are measured in acre-feet, and have annual volume limitations. The latter are primarily for irrigation systems that only operate during the growing season. Here the FRP is calculated under two scenarios. In the first, pumping rates for irrigation were set at the constant rate that would withdraw the total annual permitted volume in180 days (i.e. April-September). In the second scenario, total annual irrigation withdrawals were assumed to take place over a period of 120 days (i.e. June-September or May-August). Licenses with daily limits were assumed to be pumping at the constant rate required to remove the permitted volume in both cases. Fish hatchery licenses were not included in calculations as the water is returned to the stream. All units were converted to constant units ($m^3 \cdot s^{-1}$) in the calculations. The FRP of water licenses on a stream are only meaningful in relation to base flows. I compare them to mean summer discharge (April – October) and to the five-year minimum daily flow where data is available. This metric is useful in identifying watersheds that are oversubscribed but actual withdrawals probably differ dramatically from permitted amounts (see chapter 7).

Salish Sucker and Nooksack Dace Populations

The known distributions and relative densities of Nooksack dace and Salish sucker within each watershed (from Chapters 3 and 5) were plotted on orthographic photographs to allow visual assessment of their spatial configuration relative to land use and other features.

RESULTS AND DISCUSSION

Species Vulnerability Assessments

Hypoxia Hypothesis:

Episodes of extreme hypoxia are causing acute mortality or reduced fitness.

Salish sucker

Acutely lethal concentrations of dissolved oxygen will vary with water temperature, duration of exposure and fish size, but are probably below 3 $mg \cdot l^{-1}$ (Pearson pers. obs.). In some fish species smaller individuals are able to tolerate lower levels of dissolved oxygen (Tonn and Paszkowski, 1986; Fox and Keast, 1990), while in others the reverse appears to be true (Danylchuk and Tonn, 2003). The relative vulnerability of juvenile and adult Salish sucker is unknown. Many of the reaches with the highest densities of Salish sucker experience seasonal periods of hypoxia (D.O. <3 $mg \cdot l^{-1}$). Local refuges of oxygenated water (e.g. tributary plumes) are available in some areas but not in others. Salish suckers are occasionally found dead in traps set in severely hypoxic water (Pearson pers. obs.), which may indicate that they temporarily venture into these environments to forage (Rahel, 1994). Hypoxia induced kills of Salish sucker may occur. A marsh in Pepin Brook that contained an extraordinarily high density of Salish suckers between 1999 and 2002 (Over 1000 fish in 1420 m^2 of habitat) was near anoxic (D.O. <1.5 $mg \cdot l^{-1}$) and apparently devoid of fish in 2003 (Chapter 3). A beaver dam maintains the marsh, but Salish suckers rarely cross it (Chapter 2). The combination of a physical barrier to escape with occasional episodes of severe hypoxia is the most plausible explanation for the sudden decline in abundance I observed in the Pepin Brook marsh. Sub-lethally, chronic hypoxia is likely to reduce growth, fecundity, and condition. Condition of Salish suckers in the marsh declined significantly in the years prior to the collapse (Chapter 2). Severe hypoxia generally occurs in late summer in streams inhabited by Salish sucker suggesting that impacts on eggs, larvae, and overwintering fish are minimal.

Eggs/Spawning	Young of Year	Adult Summer	Winter
+	+++	+++	--

Nooksack dace

Acutely lethal concentrations of dissolved oxygen are unknown, but as riffle specialists, Nooksack dace are unlikely to be well adapted to hypoxia. In the absence of better information, the federal guideline for the protection of aquatic life (5mg$\cdot$l^{-1}, CCREM 1987) is probably a useful benchmark. Severe hypoxia (0-3 mg$\cdot$l^{-1}) occurs in the pools of many reaches in the Nooksack watersheds during the summer months (Pearson unpubl.). Adult dace inhabiting riffles below these pools and young-of-the-year, which are found in shallow pools are likely to be affected. In hypoxic reaches, where surface flow ceases and riffles desiccate in late summer, fish may be forced into hypoxic pools. Spawning occurs in spring and early summer before the lowest flows. Sublethally, chronic hypoxia is likely to reduce growth, condition, and fecundity.

Eggs/Spawning	Young of Year	Adult Summer	Winter
+	++	++	--

Data Gaps and Uncertainties

- Extent, severity and impact of hypoxia in all watersheds.
- Relative contributions of sources to nutrient loading (agriculture, septic tanks, urban sources etc.) in each watershed that ultimately contribute to anoxia.
- Thresholds for nutrient inputs/concentrations above which water quality degrades and populations decline
- Interactive effects of beaver ponding, reduced baseflow, and channel shading on dissolved oxygen levels.
- Extent of pool use by Nooksack dace during drought conditions

Lack of Water Hypothesis

Low flows in late summer eliminate critical habitat, reducing fitness or survival.

Salish sucker

Adult Salish suckers are associated with deep pools (>70 cm), the habitats least affected by low flows. Young-of-the-year use shallower habitats (<40 cm, Chapter 3), and as a result are probably somewhat more vulnerable to problems with lack of water than are adults. Salish suckers spawn in spring and early summer, when water is plentiful.

Eggs/Spawning	Young of Year	Adult Summer	Winter
+	++	++	--

Nooksack dace

Adult Nooksack dace inhabit riffles and young-of-the-year school in nearby shallow pools (McPhail, 1997). These habitats are the first to be affected by lack of water and dry completely in many reaches in the range. Adults also spawn in riffles, but during spring and early summer when water is plentiful. The response of Nooksack dace to riffle drying is uncertain. They may move into pools, burrow into the hyporheic zone or vacate the reach.

Eggs/Spawning	Young of Year	Adult Summer	Winter
+	+++	+++	--

Data Gaps and Uncertainties:

- Extent of drying in some watersheds
- Extent to which lack of flow contributes to hypoxia in the creeks.
- Extent of water withdrawals (both licensed and unlicensed).
- Relative influence of factors driving base flow reductions (urbanization, gravel mining, water withdrawals)
- Effects of riffle drying on Nooksack dace fitness and predation risk.
- Frequency and duration of future drought periods given global warming.
- Threshold levels of flow (minimum acceptable baseflows) below which Salish sucker and Nooksack dace are negatively impacted

***Physical Destruction of Habitat* Hypothesis**

Drainage, dyking, channelization and infilling of waterbodies destroys critical habitat.

Salish sucker

The highest densities of Salish suckers are found in reaches containing long continuous areas of deep pool habitat, primarily headwater marshes and beaver ponds (Chapter 3). Remnant populations of Salish suckers near Chilliwack currently inhabit streams that were once tributaries to the now drained Sumas Lake. Nearby they occur in severed distributaries of the former Chilliwack River delta (Chapter 3). Dredging and channelization work have destroyed a number of known Salish sucker spawning riffles (J.D. McPhail, UBC, pers. comm.).

Eggs/Spawning	Young of Year	Adult Summer	Winter
+++	+++	+++	+++

Nooksack dace

Nooksack dace are riffle specialists. As the 'high spots' in a stream, their habitat tends to be targeted in drainage projects. Channelization and drainage projects also tend to eliminate shallow backwater areas preferred by young of the year.

Eggs/Spawning	Young of Year	Adult Summer	Winter
+++	+++	+++	+++

Uncertainties and Data Gaps

- Historical extent of habitat destruction
- Current extent of unauthorized tributary and ditch dredging.

Riffle Loss to Beaver Ponds Hypothesis

Beaver ponds are flooding critical riffle habitat.

Salish sucker

Salish suckers use riffles to spawn (McPhail, 1987), but their presence in a reach is negatively associated with the amount of riffle present and positively associated with beaver presence (Chapter 3). So long as the relatively small amount of riffle habitat necessary for spawning remains intact, riffle loss to beaver ponds is unlikely to impact Salish sucker populations. By stabilizing the otherwise highly variable environments of headwater streams (Hanson and Campbell, 1963; Naiman et al., 1986), beaver pond creation is likely to benefit Salish suckers. Indeed, during late summer low-flow periods beaver ponds provide the only wetted habitat in a number of reaches they inhabit.

Eggs/Spawning	Young of Year	Adult Summer	Winter
++	--	--	--

Nooksack dace

Nooksack dace are strongly associated with riffle habitat, and the amount a reach contains is the most powerful predictor of their presence. Long sections of continuous deep pool, like beaver ponds, are associated with their absence, even when riffle is present (Chapter 5). Riffle loss to beaver ponds is likely to negatively impact Nooksack dace populations before Salish sucker populations.

Eggs/Spawning	Young of Year	Adult Summer	Winter
+++	+++	+++	+++

Data Gaps and Uncertainties:

- Historical extent of Beaver impoundment
- Optimal location and extent of beaver ponds that will maximize Salish sucker populations while minimizing impacts on Nooksack dace.

Sediment Deposition Hypothesis

Deposited sediment is degrading critical habitat.

Salish sucker

Salish suckers spawn in riffles (McPhail, 1987) between April and early July (Chapter 2) and are probably most susceptible to sedimentation in these habitats during this period. Chronic, large-scale releases of fine sediment associated with gravel mining that fill in pools and largely eliminate instream cover and food sources have occurred, but fortunately are rare. Salish suckers are less likely to be found in reaches where land use within 200 m of the channel is predominantly urban (Chapter 3). Sediment deposition on riffles from storm sewer outfalls may partially explain this.

Eggs/Spawning	Young of Year	Adult Summer	Winter
+++	+	+	+

Nooksack dace

Adult dace spawn, forage and rest in the crevasses between and under coarse riffle substrate (McPhail, 1997). Sedimentation clogs these spaces and inhibits the flow of oxygenated water through the substrate.

Eggs/Spawning	Young of Year	Adult Summer	Winter
+++	++	+++	++

Data Gaps and Uncertainties

- Critical levels of sediment in riffles for both species
- Assessment of riffle compaction and sedimentation in Nooksack tributaries

Increased Predation Hypothesis

Introduced predators are consuming individuals or reducing their fitness by inducing behavioural changes.

Salish sucker

Brown bullheads, bullfrogs and/or largemouth bass are present in all creeks within the range. All three species are likely to prey upon juvenile Salish suckers, and largemouth bass become large enough to consume adults. Impact may vary with habitat attributes, particularly summer water temperatures. All of the predators listed above thrive in warm water littoral zones and the brown bullhead is also extremely tolerant of hypoxia (Scott and Crossman, 1973). Habitat changes that increase water temperatures or the frequency and severity of hypoxia are likely to exacerbate the impacts of these predators by providing more favourable habitat conditions for them (see Jackson et al., 2001).

Eggs/Spawning	Young of Year	Adult Summer	Winter
+	+++	++	+

Nooksack dace

Brown bullhead, bullfrogs and/or largemouth bass are present in all creeks within the range. Each of these species may threaten young of the year dace in shallow pools, but are unlikely to be found at high densities in the pool-riffle reaches where Nooksack dace are most abundant. None of these introduced species are typically found in riffles, where they would encounter adult Nooksack dace. Seasonal drying of riffles may force Nooksack dace into pools, however, and may exacerbate impacts of introduced species.

Eggs/Spawning	Young of Year	Adult Summer	Winter
+	++	+	+

Data Gaps and Uncertainties

- Distribution and densities of introduced predators in each watershed.
- Predation rates for different life stages over a range of habitats and temperatures.
- Effects of introduced predators on Salish sucker and Nooksack dace habitat use and the fitness consequences of any changes.
- Potential for predator presence to prevent successful re-introduction of Salish suckers to the Little Campbell River.
- How to minimize habitat changes that favours the growth of predator populations

Toxicity Hypothesis

Toxic discharges from point or non-point sources are significantly reducing survival or fitness.

Salish sucker

Salish suckers are less likely to be found in reaches where land use within 200 m of the channel is predominantly urban (Chapter 3). This is conceivably due, at least in part, to toxic materials originating from storm sewer outfalls. Levels of copper, lead and zinc in stream sediments of urban watersheds are commonly elevated (Hall et al., 1991) and copper and zinc levels in the sediments of Agassiz slough, which is inhabited by Salish sucker, exceed levels recommended for aquatic life (Schreier et al., 2003). Pesticides and herbicides, which are frequently used in some watersheds, have contaminated groundwater in the Fraser valley (Lavkulich et al., 1999). The range of compounds that could enter creeks from spraying, negligent waste management, and accidental spills is enormous. Toxicity is likely to impact some Salish sucker populations.

Eggs/Spawning	Young of Year	Adult Summer	Winter
++	++	++	++

Nooksack dace

Nooksack dace are exposed to the full range of toxic compounds that enter their habitats from urban agricultural and industrial lands. The information detailed for Salish suckers above applies equally to Nooksack dace.

Eggs/Spawning	Young of Year	Adult Summer	Winter
++	++	++	++

Data Gaps and Uncertainties

- Extent of pesticide and herbicide contamination of creeks.
- Extent of stormwater-derived contamination in urban reaches.
- Vulnerability of species to toxins of concern.
- Vulnerability of Salish sucker and Nooksack dace relative to co-occurring species i.e. can other species be used as indicators of water quality.

Habitat Fragmentation Hypothesis

Fish are prevented or inhibited from traversing some stream reaches by permanent or temporary barriers. This restricts access to critical habitats and/or alters metapopulation dynamics to increase extinction risk.

Salish sucker

Salish sucker movement is limited in spatial scale. Mean summer home range size of 15 radio tagged suckers was 177 m of channel (range 42-307). Most fish covered a large portion of their home range each night, and tended to return to the same resting area each day. They avoided crossing a beaver dam. A few individuals traveled more than one km during the spawning season (Chapter 2). Newly available habitat is colonized within weeks when it is in close proximity to an occupied reach (Patton, 2003).

In the populations that have been studied, a few core reaches contain most individuals while density in outlying reaches is very low. This pattern, in combination with the limited movement described above, suggests that each watershed is inhabited by loosely connected subpopulations. Movement between core areas requires traversing several km of stream or crossing watershed boundaries during occasional high-water connections (Chapter 3). These occur annually in some systems (e.g. Miami Creek with Mountain Slough) and at least every few years in others (e.g. Bertrand Creek with the Salmon and Little Campbell Rivers).

The current distribution is clearly fragmented relative to historical conditions. At the regional scale, dyking, and channelization have severed connections between Agassiz Slough and its adjacent watersheds (Miami Creek and Mountain Slough). In Chilliwack, diversion and drainage eliminated the connection between Salwein Creek and Atchelitz/Chilliwack/Semmihault Creeks, and the drainage of Sumas Lake reduced the frequency of high water connections between the Fraser and Nooksack systems. Most of these changes occurred between 50 years and 130 years ago, and surviving populations have shown some persistence. The effects of less movement between subpopulations and reduced ability to colonize new habitat, however, may occur over even longer time frames. Within watersheds, physical barriers and degraded habitat have likely affected movement patterns between subpopulations. The extent and importance of this to the long-term persistence of individual subpopulations and to recolonization following local extinctions of subpopulations is also unclear.

Eggs/Spawning	Young of Year	Adult Summer	Winter
++	++	++	++

Nooksack dace

Most Nooksack dace move very little, but a small proportion venture further. In a mark-recapture study, the distribution of movement distances relative to trap placement was highly skewed. Just over half of 90 recaptured fish were caught within 5 m their original capture location, many after more than a year. Over 90% of recaptures were within 50 m of the marking location. Maximum displacement was 205 m. (Chapter 4).

Populations show a clumped distribution, which in combination with the limited movement described above, suggests that each watershed is inhabited by weakly connected subpopulations. A 5 km section of Bertrand creek comprises only 13 % of channel length within the Canadian range, yet harbours an estimated 70 percent of the its population (Chapter 5). The Canadian populations of Nooksack dace may be isolated from one another by poor habitat conditions in the Washington State portion of their watersheds (McPhail, 1997). Within watersheds, physical barriers and degraded habitat have likely affected movement patterns between subpopulations. The extent and importance of this to the long-term persistence of individual subpopulations and to recolonization following local extinctions of subpopulations is also unclear.

Eggs/Spawning	Young of Year	Adult Summer	Winter
++	++	++	++

Data Gaps and Uncertainties:

- Minimum viable population size.
- Present and past frequency of reach-scale extirpations.
- Frequency of migration between subpopulations within watersheds.
- Frequency of movement between watersheds.
- Identification of types of permanent and seasonal barriers (beaver dams, culverts, hypoxic reaches etc.) and the ability of different life history stages to cross them.

Summary of Vulnerability Assessments

Salish sucker:

Salish suckers appear most acutely at risk from hypoxia and direct habitat destruction through drainage, channelization and infilling (Table 6.3). Juvenile Salish suckers are also likely to be highly impacted by introduced predators.

Toxic contamination and habitat fragmentation are both are widespread and likely to have impacts on at least some populations, but insufficient data exists to assess their importance properly. At present they may be considered moderate concerns. Riffle loss to beavers may limit spawning when riffles are rare and sediment deposition may impact populations if severe, but these threats along with lack of water appear to be relatively minor concerns for Salish suckers (but see watershed assessments for local exceptions).

Nooksack dace

As riffle specialists, Nooksack dace are most threatened by lack of water, riffle loss to beaver ponds, sediment deposition and direct habitat destruction through dredging and channelization activities.

Introduced predators are probably a lesser concern for Nooksack dace because habitat overlaps are less likely than with Salish sucker. As with Salish suckers, habitat fragmentation and toxic contamination likely have some impacts, but insufficient information exists to properly assess them. These three threats are considered moderate concerns. Hypoxia is unlikely to affect large areas of Nooksack dace habitat but may interact with lack of water. At present it is considered a minor concern.

Recommendations

Salish sucker

1. Initial recovery efforts should focus primarily on preventing further habitat destruction, restoring habitat in areas likely to be recolonized and on reducing the incidence of hypoxia by decreasing nutrient loading to streams.

2. Research should focus on increasing knowledge of the extent and duration of hypoxia in all watersheds and of the impacts and pervasiveness of introduced predators, toxic contamination and habitat fragmentation.

Nooksack dace

1. Initial recovery efforts should focus on maintaining or increasing the quality and quantity of riffle habitat by increasing base flows where necessary, preventing sediment deposition, and riffle loss to dredging and channelization.
2. Riffle loss to beaver ponding should be monitored in streams inhabited by Nooksack dace and management plans developed that explicitly consider the habitat tradeoffs between Salish sucker and Nooksack dace that are associated with beaver activity.
3. Research should focus on increasing knowledge of the impacts and pervasiveness of introduced predators, toxic contamination and habitat fragmentation.

Table 6.3: Summary of vulnerability assessments.

Salish Sucker	Overall	Eggs/ Spawning	Young of Year	Adult Summer	Winter
Hypoxia	+++	+	+++	+++	--
Lack of Water	++	+	++	++	--
Physical Destruction of Habitat	+++	+++	+++	+++	+++
Riffle Loss to Beaver Ponds	++	++	--	--	--
Sediment Deposition	++	++	+	+	+
Introduced Predators	+++	+	+++	++	+
Toxicity	++	++	++	++	++
Habitat Fragmentation	++	++	++	++	++

Nooksack Dace	Overall	Eggs/ Spawning	Young of Year	Adults Summer	Winter
Hypoxia	+	+	++	++	--
Lack of Water	+++	+	+++	+++	--
Physical Destruction of Habitat	+++	+++	+++	+++	+++
Riffle Loss to Beaver Ponds	+++	+++	+++	+++	+++
Sediment Deposition	+++	+++	++	+++	++
Increased Predation	++	+	++	+	+
Toxicity	++	++	++	++	++
Habitat Fragmentation	++	++	++	++	++

+++	major concern	+	minor concern
++	moderate concern	-	not a concern

Watershed Assessments

Bertrand Creek

General Description

Bertrand Creek is a tributary of Washington State's Nooksack River. The Canadian portion of its watershed includes just over 50 km^2 of land and 18 km of mainstem channel (Table 6.4, Fig. 6.4). Detailed reach scale descriptions along with temperature data from a number of sites are given in Pearson (1998). With the exception of the urbanized headwaters, land use in the watershed is predominantly agricultural and low-density rural residential. The riparian zones of some reaches are well forested while others lack woody vegetation completely. The upper reaches flow through the town of Aldergrove where channel gradient is low and there are some deep pools. The middle reaches contain long continuous sections of deep pool habitat. The Lower reaches have a steeper gradient and pool-riffle structure. Here, dramatic changes in local channel morphology occur every winter when high flows scour and fill the gravel substrate (Pearson, pers. obs.). Surface soils in the watershed are primarily glaciomarine till with high clay content and poor permeability (Johanson, 1988). Consequently, the creek receives little groundwater influx and is characterized by warm summer temperatures and highly variable discharge (Table 6.4).

Salish Sucker Distribution

Salish suckers densities are generally low throughout the watershed, although medium densities were recorded near the Howe's Creek confluence (Fig. 6.4). Of the six streams in which population estimates have been made, Bertrand Creek is the smallest at fewer than 250 adults (see Chapter 3). They have never been caught in the lower reaches despite heavy trapping.

Nooksack Dace Distribution

Nooksack ace are found throughout the watershed but are only at high densities in the lower reaches (Fig. 6.5). Despite comprising only 13 % of the Canadian range, this 5 km section of stream is estimated to contain over 70 percent of the its population (see Chapter 5).

Table 6.4: Summary characteristics of streams and watersheds containing Nooksack dace and/or Salish sucker. Bracketed values for land use variables indicate the percentage within 200 metres of the channel.

	Bertrand Creek	Pepin Brook	Fishtrap Creek	Upper Salmon River	Salwein Creek	Hopedale Slough	Atchelitz/ Chilliwack/ Semmihault	Miami Creek	Mountain Slough	Agassiz Slough	Little Campbell
Watershed Area (km^2)	51.3	20.9	44.2	19.0	7.0	3.1	70.8	18.3	36.8	8.0	72.7
Channel Length (km)	17.97	6.35	12.08	8.84	10.37	3.77	54.9	12.0	14.5	5.9	
Riffle (% channel length)	8.7	2.0	4.8	8.4	--	--	--	--	--	--	--
Deep Pool (% channel length)	27.8	67.8	52.4	38.5	--	--	--	--	--	--	--
Maximum Temperature (^oC)	24.7	20.0	19.3	22.4	ca. 15	--	--	--	--	--	21.2
Mean Summer Discharge ($m3 \cdot s^{-1}$)	0.295	0.359	0.294	--	--	--	--	--	--	--	0.29
5 Year Minimum Daily Flow ($m3 \cdot s^{-1}$)	0.015	0.090	0.037	--	--	--	--	--	--	--	0.042
CV of Discharge	2.24	0.49	1.21	--	--	--	--	--	--	--	1.40
4 Month Water License FRP*	.029	.030	.034	.037	--	0.00	.096	--	--	.002	.063
Percent Urban	9.1 (14.7)	1.5 (0.6)	17.7 (18.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	17.9 (17.2)	7.5 (17.4)	0.8 (0.0)	16.6 (3.7)	12.5 (4.8)
Percent Agricultural	65.9 (54.8)	56.4 (29.8)	70.1 (57.1)	59.4 (58.9)	92.1 (84.0)	56.9 (69.9)	58.0 (73.5)	22.0 (32.7)	46.3 (66.8)	75.7 (93.3)	55.7 (51.5)
Percent Forest	24.4 (30.5)	24.7 (54.0)	11.2 (24.1)	40.6 (41.1)	7.9 (16.0)	42.3 (30.1)	22.8 (9.3)	70.4 (49.9)	51.5 (32.4)	7.7 (3.0)	29.8 (43.6)
Percent Gravel Mine	0.6 (0.0)	17.3 (15.5)	0.9 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.4 (0.0)	0.0 (0.0)	1.3 (0.8)	0 (0.0)	1.5 (0.1)

**Flow reduction potential: decrease in flow predicted under maximum permitted pumping rates calculated over 4 months (see methods section for details).*

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Figure 6.4: Catch per unit effort of Salish suckers (CPUE, mean number of fish per trap) in Bertrand Creek. The photograph is from 1999 and the catch data is from 1999-2002. Data from water sampling sites is given in appendix 1.

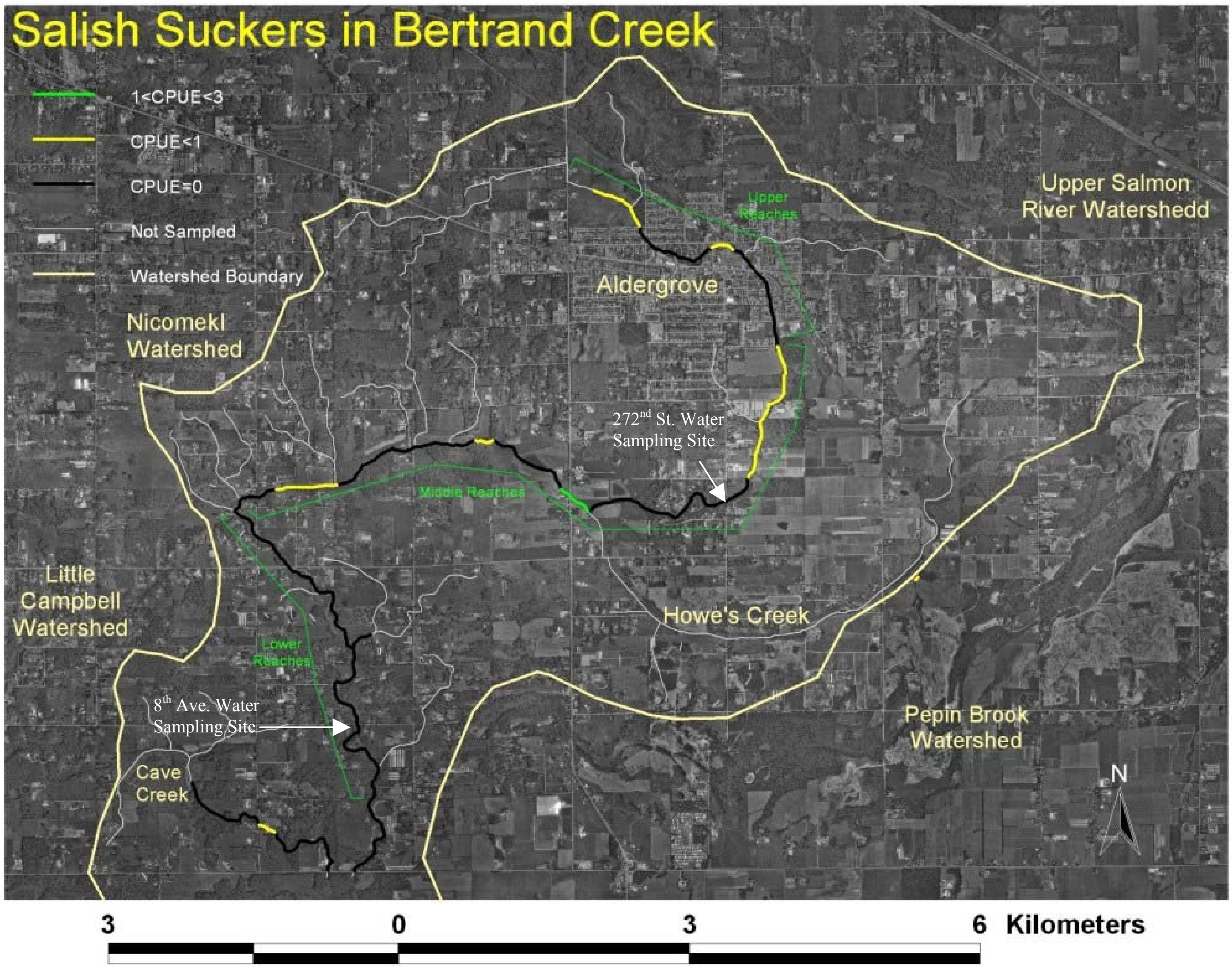
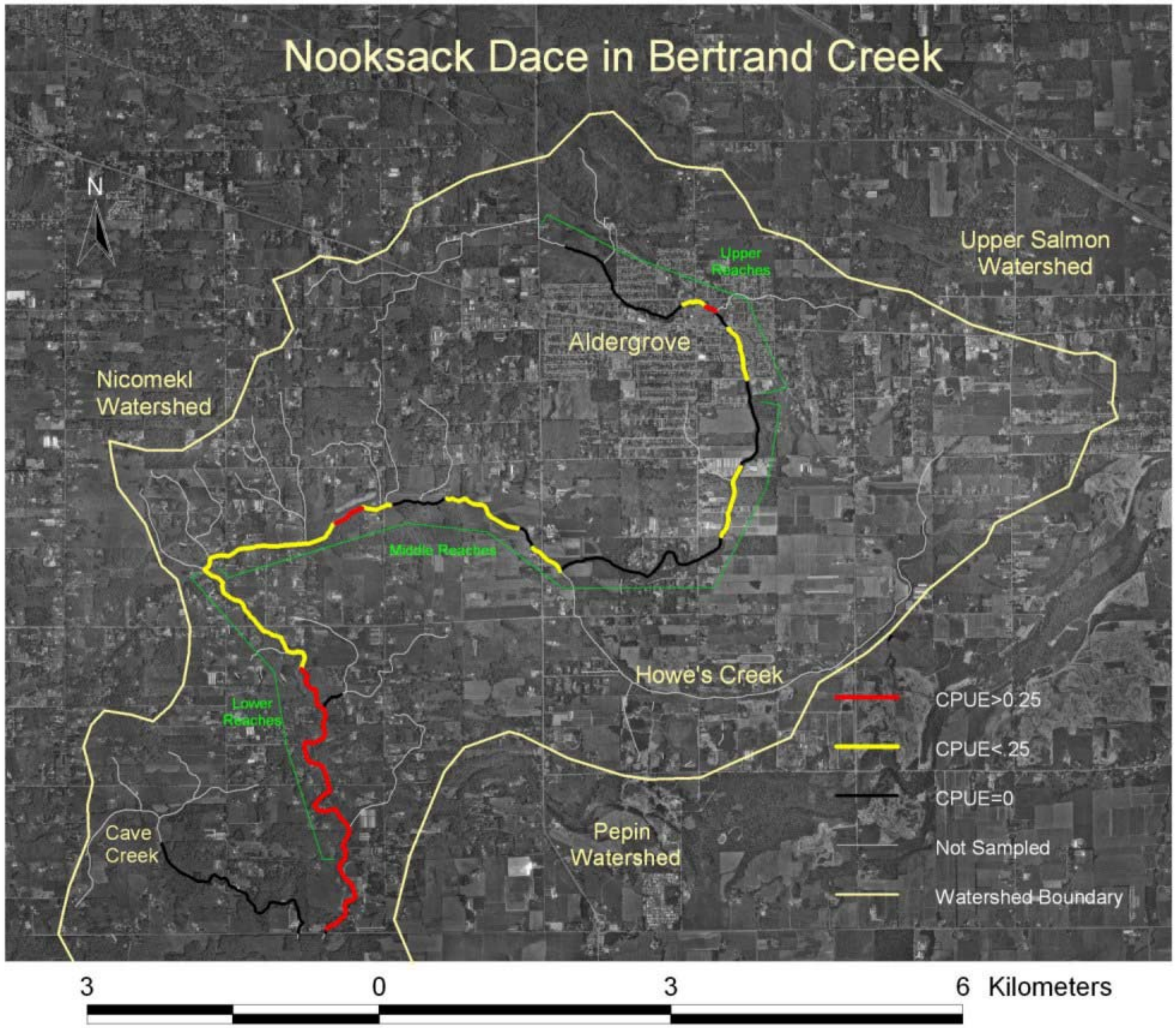


Figure 6.5: Catch per unit effort of Nooksack dace (CPUE, mean number of fish per trap) in Bertrand Creek. The photograph is from 1999 and the catch data from 1999-2002.



Assessment

Lack of water and habitat fragmentation are major concerns for Nooksack dace and Salish sucker conservation in Bertrand Creek. Most other impact hypotheses are of moderate concern, but sediment deposition and the impact of beaver on riffle habitat appear to be minimal (see Appendix 1 for details).

Lack of Water	+++		Riffle Loss to Beaver	+
Physical Destruction of Habitat	++		Increased Predation	++
Hypoxia	++		Toxicity	++
Sediment Deposition	+		Habitat Fragmentation	+++

Pepin Brook

General Description

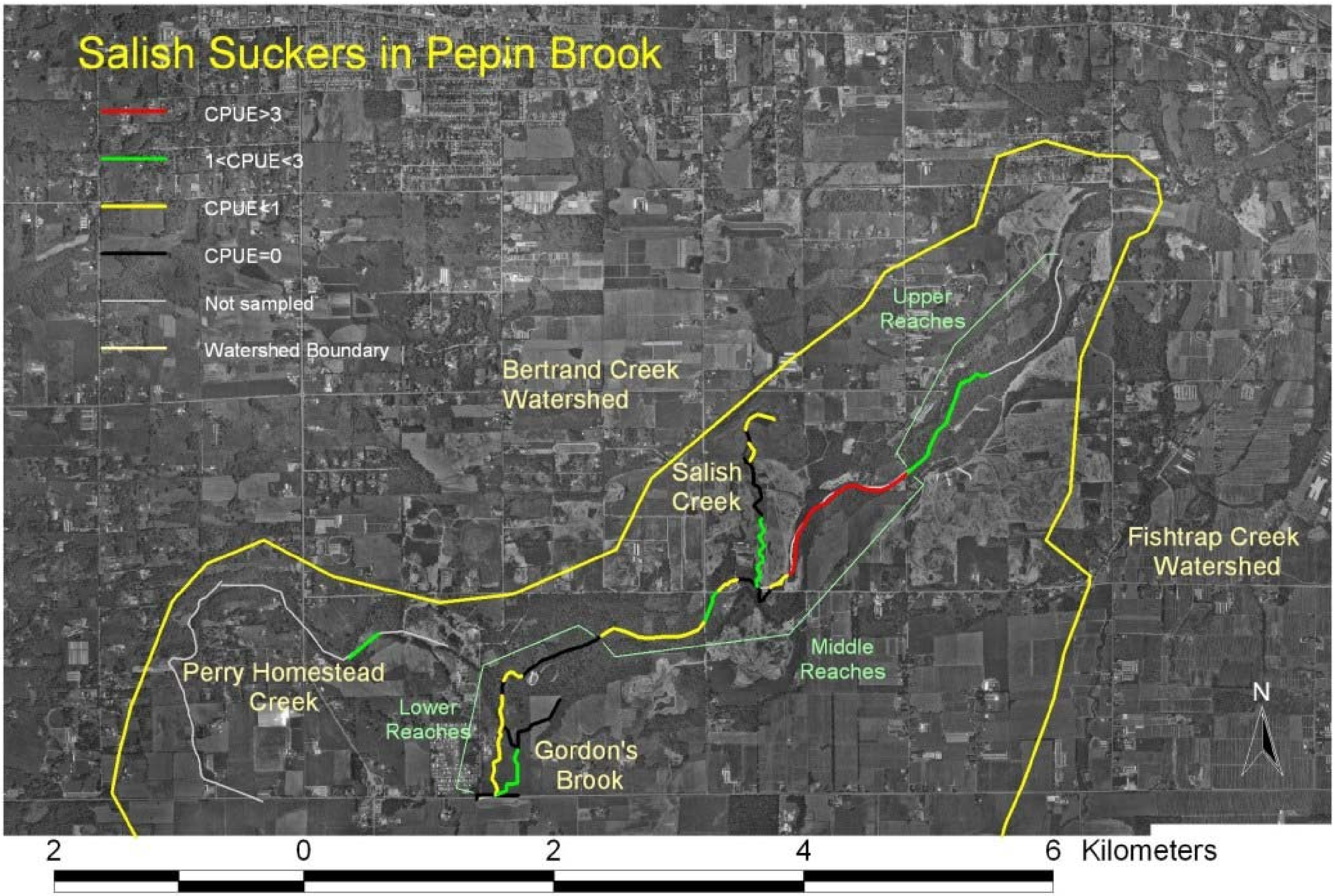
Pepin Brook is a tributary of Washington State's Nooksack River. The Canadian portion of its watershed includes approximately 21 km^2 of land and 6.4 km of channel. The entire watershed drains a glacial moraine. Surface soils are gravel deposits well over 30 m thick (Johanson, 1988). Consequently the creek is fed by abundant groundwater inflows and maintains high base flows and cool temperatures year round (Table 6.4).

The watershed is a mix of parkland, agricultural land and gravel mines (Fig. 6.6). The upper reaches flow through a forested ravine and are almost completely impounded by beaver. The middle reaches are also largely impounded by beaver, but contain more riffle. Gravel mining is encroaching on riparian areas in both of these sections. The lower reaches flow through Aldergrove Lake Regional Park and are surrounded by mature deciduous forest. Detailed reach scale descriptions along with temperature data from a number of sites are given in Pearson (1998).

Salish Sucker Distribution

Salish sucker are found throughout the creek and its tributaries (Fig. 6.6). Densities were extraordinarily high in a marsh in the middle reaches between 1999 and 2002, but appear to have crashed in 2003 (Chapter 3). Reach scale habitat enhancement projects have been completed on both Salish Creek and Gordon's Brook and now contain medium densities of Salish sucker (1<CPUE<3, Pearson unpubl.).

Figure 6.6: Catch per unit effort of Salish suckers (CPUE, mean number of fish per trap) in Pepin Brook. The photograph is from 1999 and the catch data from 1999-2002.



Nooksack Dace Distribution

Nooksack dace are concentrated in the lower reaches, where riffles are abundant (Fig. 6.7). The Salish Creek mitigation project has increased the amount of riffle available in the middle reaches (Patton, 2003).

Assessment

Hypoxia, habitat destruction, sediment deposition and loss of riffle habitat to beaver are all major concerns for Salish sucker and Nooksack dace conservation. Introduced predators and habitat fragmentation are moderate concerns, while lack of water and toxicity are currently minor concerns (see Appendix 1 for details).

Lack of Water	+		Riffle Loss to Beaver	+++
Physical Destruction of Habitat	+++		Increased Predation	++
Hypoxia	+++		Toxicity	+
Sediment Deposition	+++		Habitat Fragmentation	++

Fishtrap Creek

General Description

Fishtrap Creek is a tributary of Washington State's Nooksack River. The Canadian portion of its watershed includes approximately 44 km^2 of land and 12 km of channel (Fig. 6.8). The upper reaches are heavily urbanized and flow through the town of Clearbrook. Numerous storm drains enter the creek and one tributary (East Fishtrap Creek) was converted to a stormwater treatment wetland in 1990. Late summer flows are very low throughout these reaches. The middle reaches flow through an industrial park and beside Abbotsford Airport. They also suffer from low late summer flows and from degraded channel structure (Pearson, 1998). The lower reaches have abundant groundwater inflows and maintain cool temperatures year round (Table 6.4). They are fed by an aquifer in a glacial moraine to the west. Its gravel deposits are well over 30 m thick (Johanson, 1988). Gravel mining is planned for much of the moraine. These reaches flow through an outwash plain that also has thick gravels (Johanson, 1988) and is occupied by berry farms. The entire length of the lower reaches was dredged by the City of Abbotsford in approximately 1990. Detailed reach scale descriptions along with temperature data from a number of sites are given in Pearson (1998).

Figure 6.7: Catch per unit effort of Nooksack dace (CPUE, mean number of fish per trap) in Pepin Brook). The photograph is from 1999 and the catch data from 1999-2002.

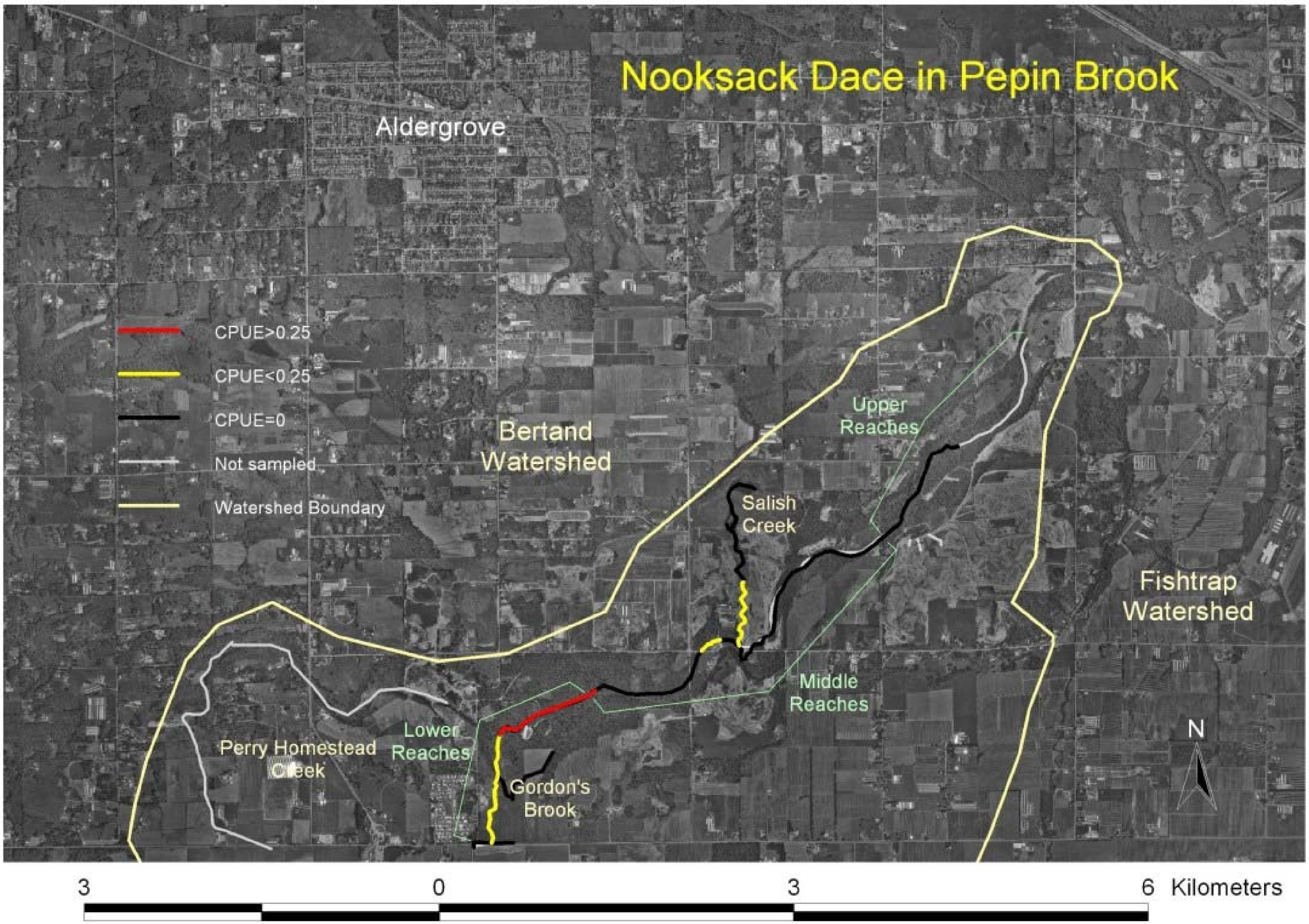
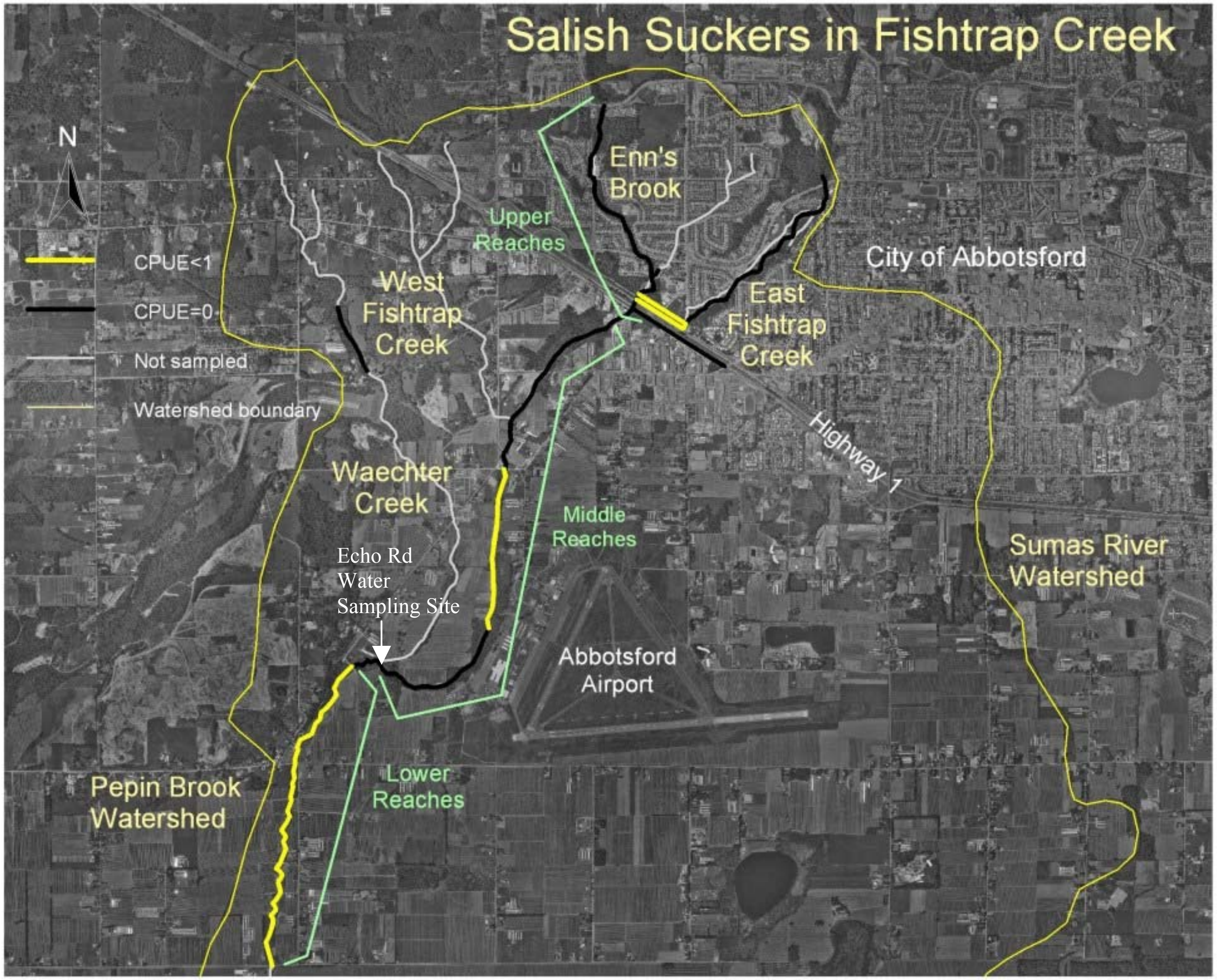


Figure 6.8: Catch per unit effort of Salish suckers (CPUE, mean number of fish per trap) in Fishtrap Creek. The photograph was taken in 1999. Catch data is from 1999-2001. Data from the water-sampling site is given in Appendix 1.



Salish Sucker Distribution

Salish sucker are found at low densities throughout the creek (Fig. 6.8), but were more abundant in parts lower reaches before they were dredged (J.D. McPhail pers. comm.). Despite an abundance of well-vegetated, deep-pool habitat they appear absent from the East Fishtrap Creek stormwater treatment ponds, which contained little oxygen and many brown bullheads when it was sampled (Pearson unpubl.).

Nooksack Dace Distribution

Nooksack dace are also at low densities and were previously abundant in the lower reaches (J.D. McPhail pers. comm.). They may be excluded from the upper reaches (Fig. 6.9).

Assessment

Major concerns include habitat destruction through dredging, and infilling and toxicity from urban sources. Lack of water, hypoxia, increased predation, habitat fragmentation and sedimentation in the headwaters warrant moderate concern. Riffle losses to beaver ponds appear minimal (see Chapter 5).

Lack of Water	++		Riffle Loss to Beaver	+
Physical Destruction of Habitat	+++		Increased Predation	++
Hypoxia	++		Toxicity	++
Sediment Deposition	++		Habitat Fragmentation	++

Upper Salmon River

General Description

The Salmon River lies immediately north of the Nooksack tributaries and enters the Fraser River at Fort Langley. Only the portion of the watershed upstream of 248th street was analyzed. This is a natural dividing point in the stream. Channel gradient increases sharply below it as the river descends through a ravine to the Fraser River floodplain. The upper watershed includes approximately 19 km^2 of land and 8.8 km of channel (Fig. 6.10). Its surface soils are glaciomarine tills with high clay content and very low permeability (Johanson, 1988). Consequently the river receives little groundwater in these upstream reaches during dry periods and is characterized by relatively warm temperatures and extremely variable discharge (Pearson pers. obs.).

Figure 6.9: Catch per unit effort of Nooksack dace (CPUE, mean number of fish per trap) in Fishtrap Creek. The photograph is from 1999 and the catch data from 1999-2001

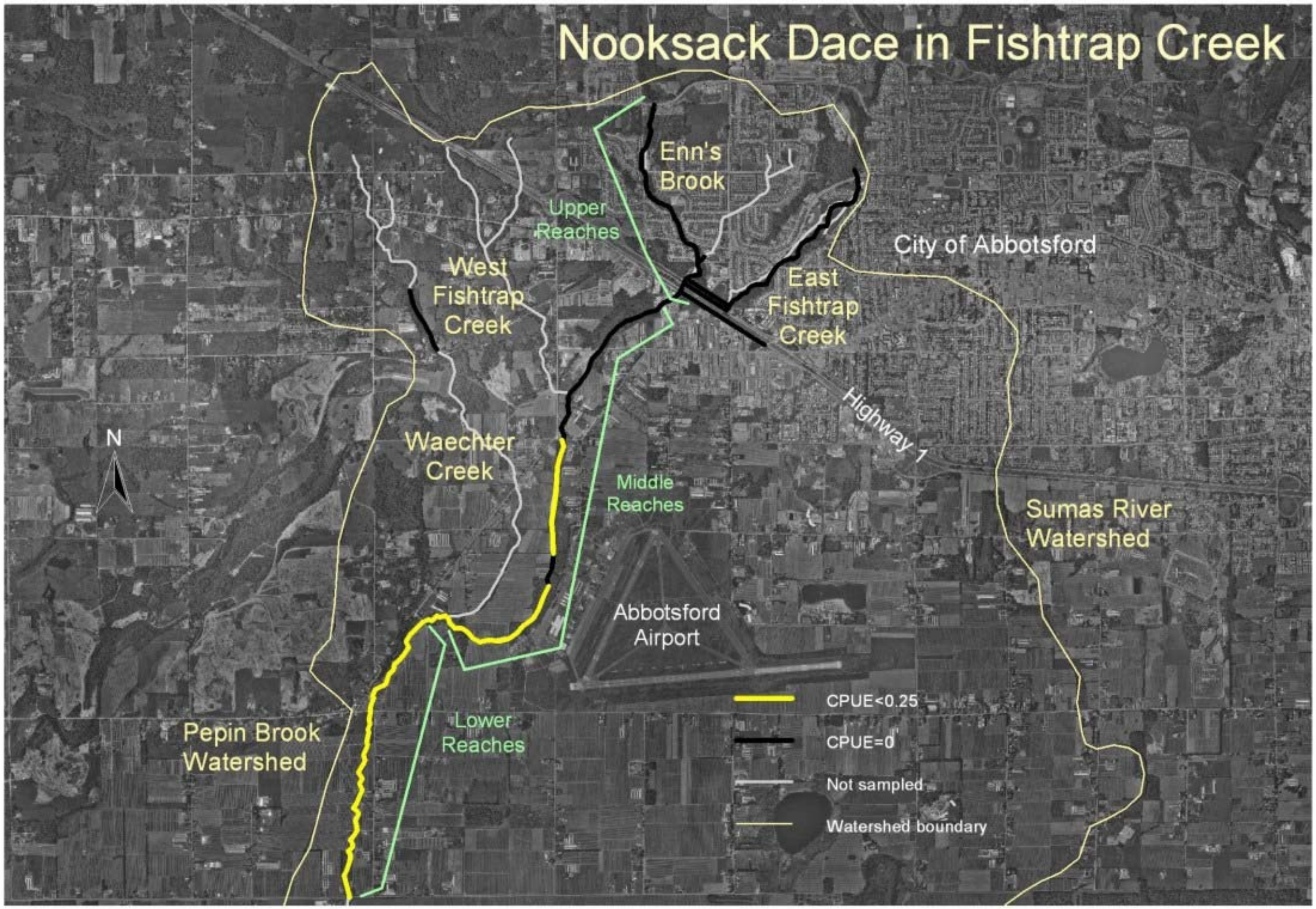
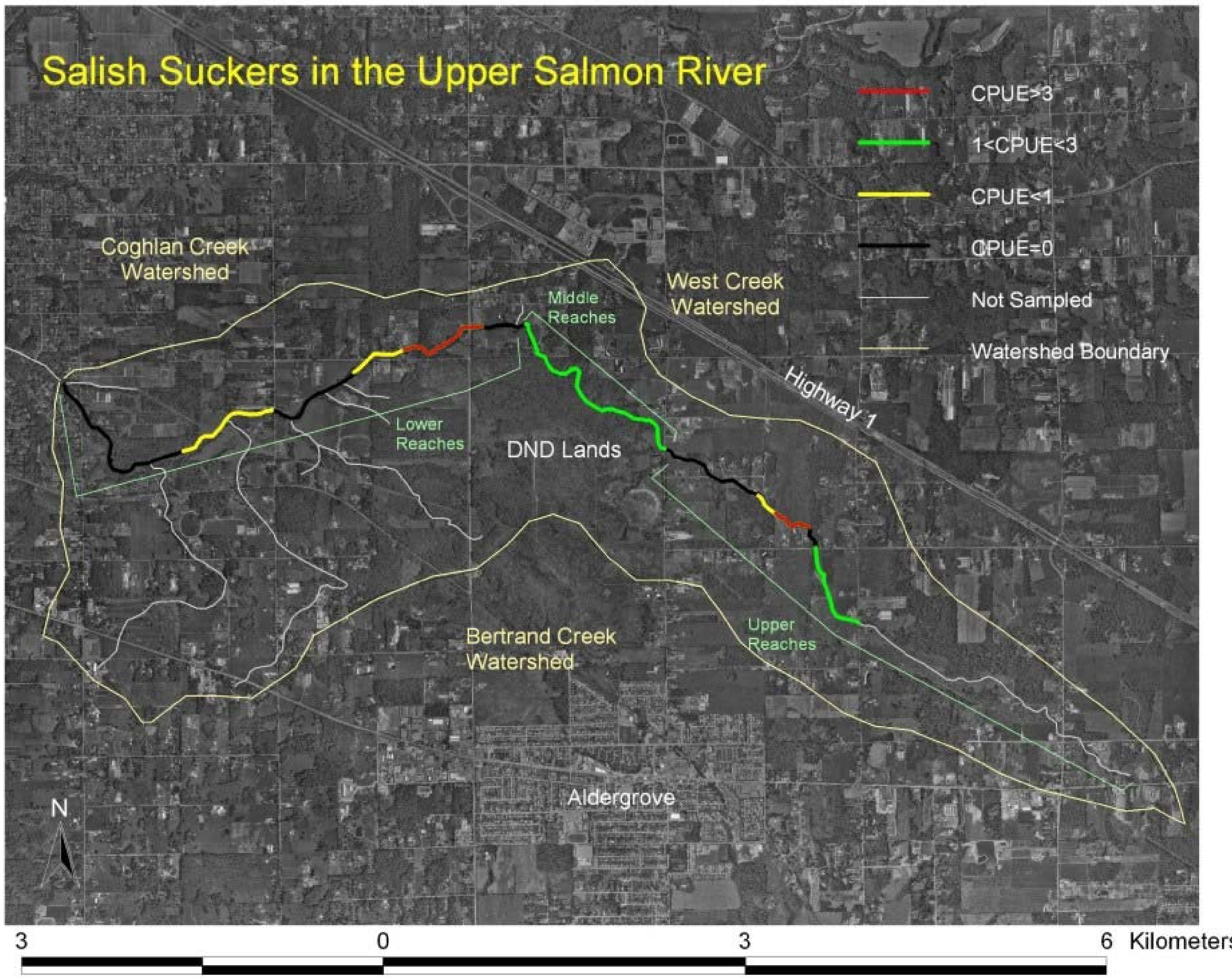


Figure 6.10: Catch per unit effort of Salish suckers (CPUE, mean number of fish per trap) in the Upper Salmon River. The photograph is from 1999 and the catch data from 1999-2002.



The upper reaches flow through agricultural land with patchy riparian forest cover. The middle reaches are on Department of National Defense lands and are well forested. Beaver ponds there maintain water levels when flow ceases in late summer, but are often hypoxic (Pearson unpubl.). Agricultural land and the Greater Vancouver Zoo flank the lower reaches, which contain more riffle and fewer beaver ponds.

Salish Sucker Distribution

Salish suckers are found throughout most of the upper Salmon River, and are at high densities in some reaches (Fig 6.10). Much of their habitat is currently created and maintained by beaver dams. Other refuges from lack of water include a farm pond and the deep pools of an alder swale. Suckers may also inhabit Davidson and Coghlan Creek, two tributaries of the Salmon River that have not been thoroughly surveyed for their presence.

Assessment

Lack of water and hypoxia are the major concerns. Habitat destruction, sediment deposition, habitat fragmentation, and riffle losses to beaver ponds are moderate concerns. Toxicity and introduced predators are minor concerns at present (see Appendix 1 for details).

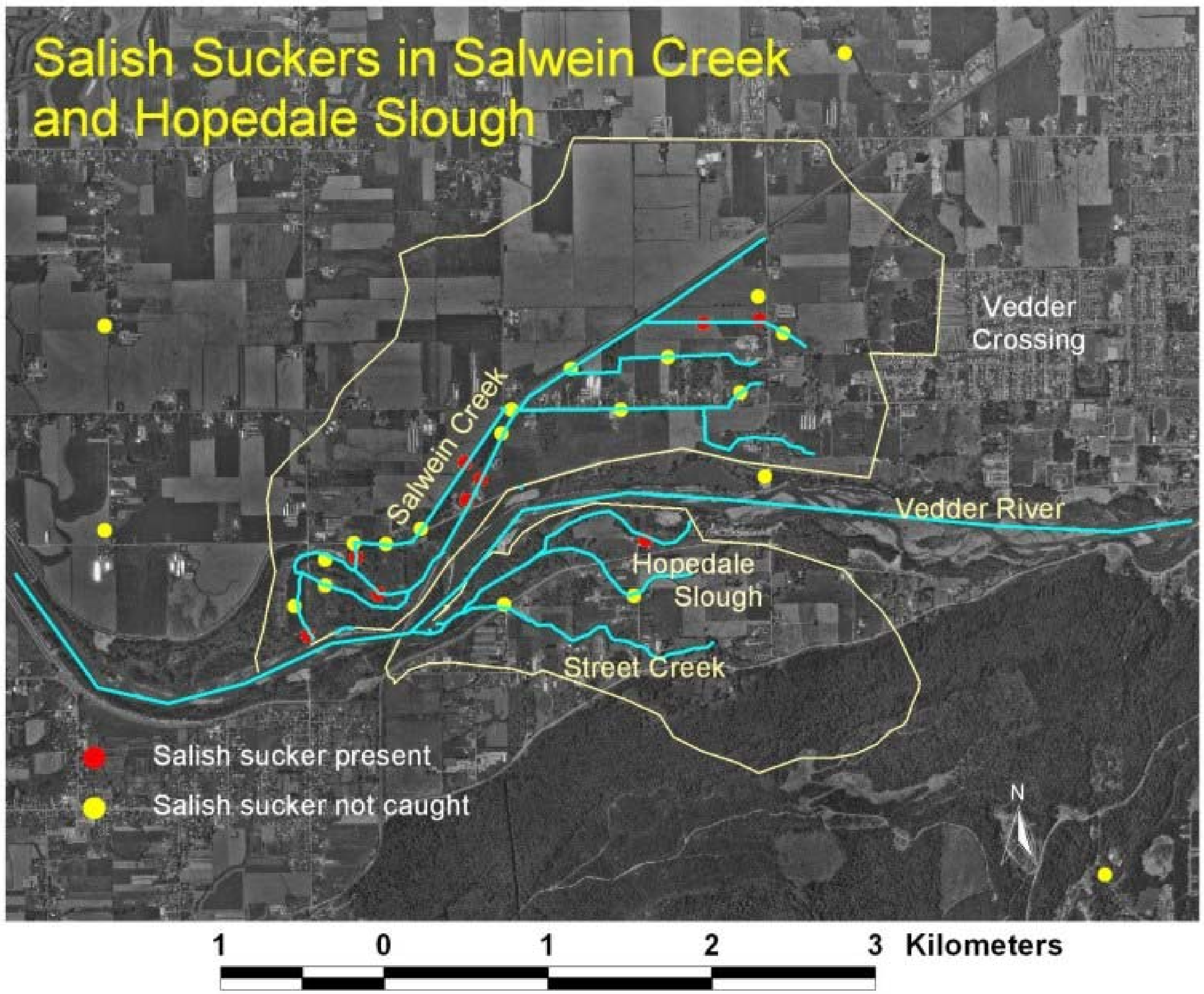
Lack of Water	+++		Riffle Loss to Beaver	++
Physical Destruction of Habitat	++		Increased Predation	+
Hypoxia	+++		Toxicity	+
Sediment Deposition	++		Habitat Fragmentation	++

Salwein Creek and Hopedale Slough

General Description

These systems are considered a unit because of their small size (combined area 10.1 km^2) and close proximity (they enter the Vedder Canal within 1 km). Both are now dyked to protect them from the Vedder in flood, but were probably frequently, if not annually, flooded by Sumas Lake before it was drained in 1920 (see Schaepe, 2001; Woods, 2001). The perennially high water table and gravelly alluvial soils ensure constant supplies of cold groundwater. Despite being largely channelized (Fig. 6.11), they support significant runs of chum, coho and pink salmon (Matt Foy, DFO, pers. comm).

Figure 6.11: Salish sucker distribution in Salwein Creek and Hopedale Slough. All sampling was completed in 1999 – 2002 and the photograph is from 1999.



Land use is primarily agricultural but both watersheds have significant blocks of land in natural vegetation on public lands outside a flood control dyke (Fig. 6.11). A local stewardship group, the Chilliwack-Vedder Watershed Restoration Society (CVWRS) has mapped the habitat, monitored the fish community and completed several habitat enhancement projects in cooperation with DFO.

Salish Sucker Distribution

Salish suckers have been found at low densities throughout most of Salwein Creek, but are concentrated outside the dyke. They also occur in a large headwater marsh in Hopedale Slough. (Fig. 6.11). Sumas Lake probably contained large amounts of excellent sucker habitat prior to being drained.

Assessment

The major concern is historical damage done by drainage, dyking and infilling. Sediment deposition, introduced predators, and toxicity from creosote treated logs in a pond's retaining walls are moderate concerns. Hypoxia and riffle losses to beaver ponds are minor concerns at present (see Appendix 1 for details).

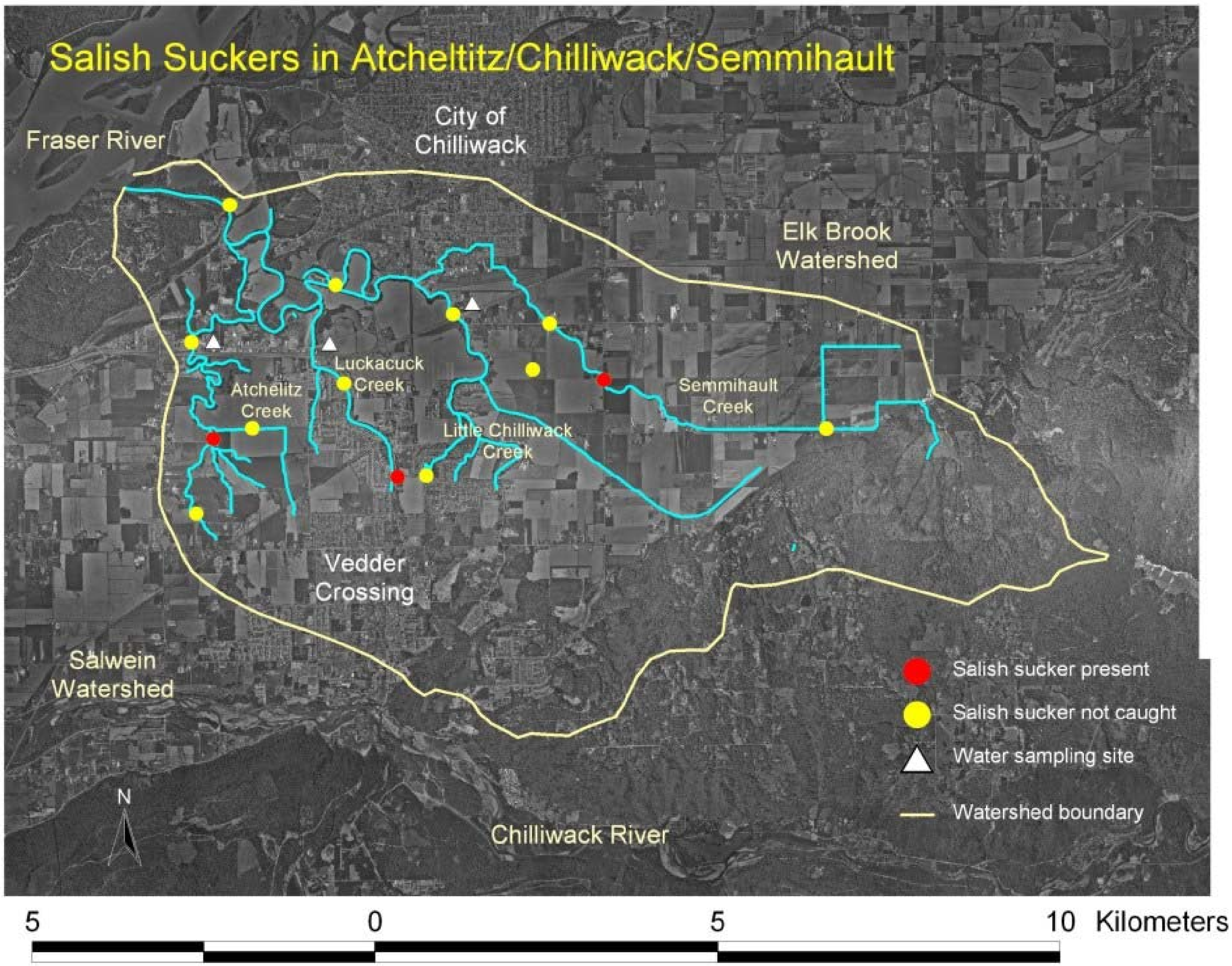
Lack of Water	+		Riffle Loss to Beaver	+
Physical Destruction of Habitat	+++		Increased Predation	++
Hypoxia	+		Toxicity	++
Sediment Deposition	+		Habitat Fragmentation	+++

Atchelitz/Chilliwack/Semmihault

General Description

These creeks flow through the interconnected channels of the former Chilliwack River Delta. The entrance channels to this portion of the delta were blocked by settlers in approximately 1875 to improve drainage (Schaepe, 2001). This left small groundwater fed creeks flowing in the old distrubutary channels. These are fed by an extensive system of agricultural ditches (Fig. 6.12). The watershed covers over 70km^2 of land and contains 55 km of channel. Heavy flows of groundwater maintain flows, temperatures, and dissolved oxygen levels in

Figure 6.12: Salish sucker distribution in the former Chilliwack River Delta. The photograph is from 1999 and the catch data from 1999-2002. Data from water sampling stations is shown in appendix 1.



some branches during late summer, when other areas become sluggish and warm (see Appendix 1). An extensive network of ditches connects to the channels. The watershed is 57% agricultural and 18% urban (Table 6.4). Forest cover is limited to that of the mountainside in the southeast (Fig. 6.12).

Salish Sucker Distribution

Salish suckers have been caught several times in these creeks (Fig. 6.12), but always in very low numbers (J.D. McPhail pers. comm., Pearson unpubl.). Densities may be very low throughout, or high-density reaches may have been missed as little trapping has been done.

Assessment

The major concerns are historical damage done by drainage, habitat fragmentation, dyking and infilling. Hypoxia, sediment deposition, increased predation, lack of water and toxicity are moderate concerns. Riffle loss to beaver ponds is a minor concern at present (see Appendix 1 for details).

Lack of Water	++		Riffle Loss to Beaver	+
Physical Destruction of Habitat	+++		Increased Predation	++
Hypoxia	++		Toxicity	++
Sediment Deposition	++		Habitat Fragmentation	+++

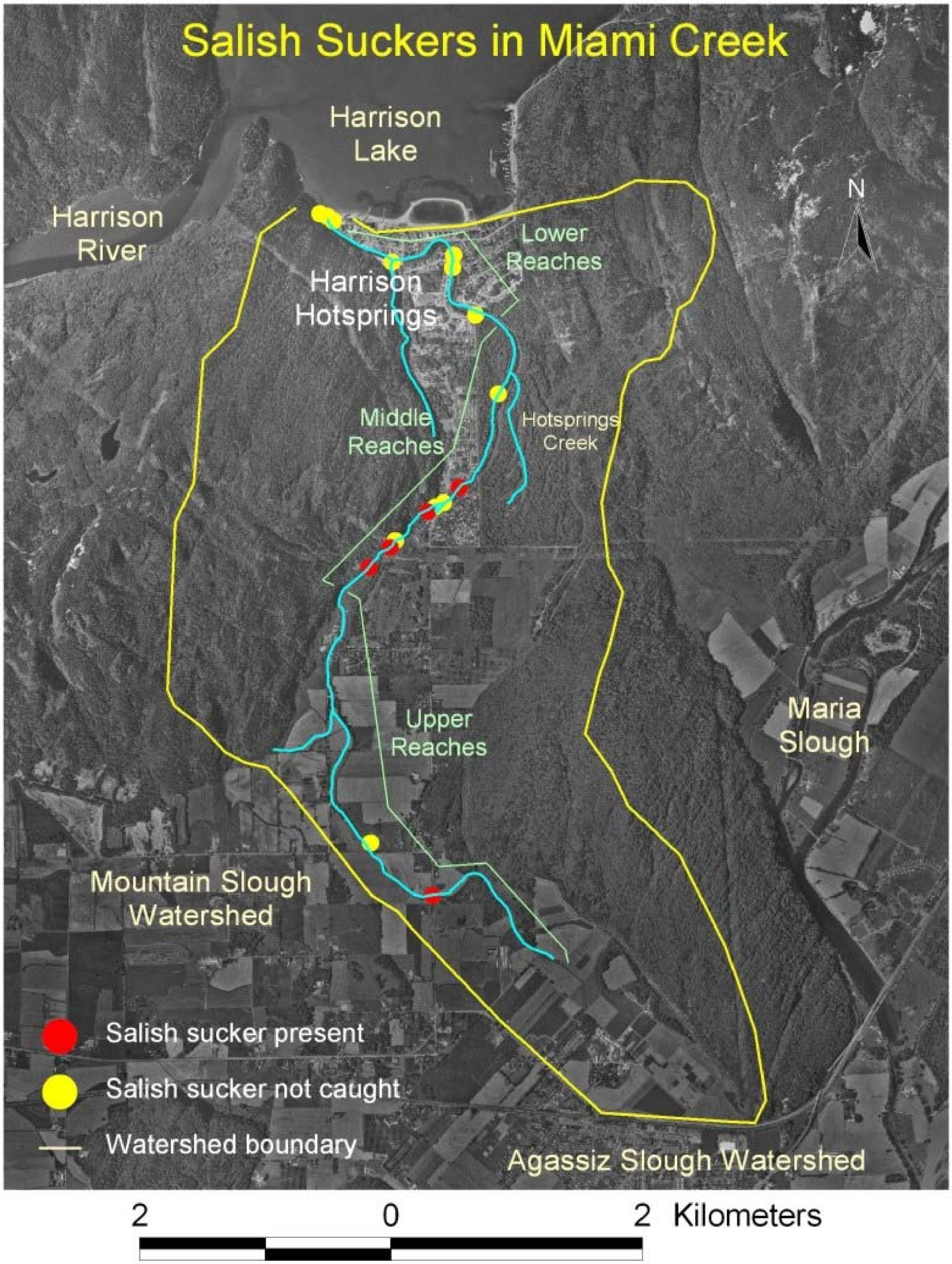
Miami Creek

General Description

Miami Creek flows into the south end of Harrison Lake through the town of Harrison Hotsprings (Fig. 6.13). Its watershed includes 18 km^2 of land and 12 km of channel. Surface soils are alluvial with complex layers of clays, sands and gravels. Water tables and movement vary with levels of Harrison Lake and the Fraser River (Schreier et al., 2003).

The upper reaches pass through farmland from their origin on the property of a federal agricultural research facility. Riparian cover is very sparse. Flows almost cease and hypoxia occurs during late summer. The middle reaches and Hotsprings Creek, a tributary that enters them, flow through mature forest but are hypoxic in late summer in most places (see

Figure 6.13: Salish sucker distribution in Miami Creek. Red dots indicate sites where they were captured. The Photograph is from 1999 and the catch data is from 2001-2003.



Appendix 1). The highest quality water appears to be in reaches where the creek follows the base of the surrounding mountains. The lower reaches are in an urban landscape and have floodgates at their entrance to the lake. Large water level fluctuations and sediment accumulations occur there. Gradient is low throughout the watershed and few riffles occur.

Salish Sucker Distribution

Salish sucker density in the middle reaches were estimated as 94 fish in approximately 250 m of channel, a medium density relative to other reaches in the range (see Chapter 3). They were also captured high in the headwaters (Fig. 6.13) on one occasion, but little trapping has been done in the upper reaches.

Assessment

The major concerns are hypoxia and habitat destruction. Lack of water, sediment deposition, toxicity and habitat fragmentation are of moderate concern. Introduced predators and the loss of riffle to beaver ponds are minor concerns at present.

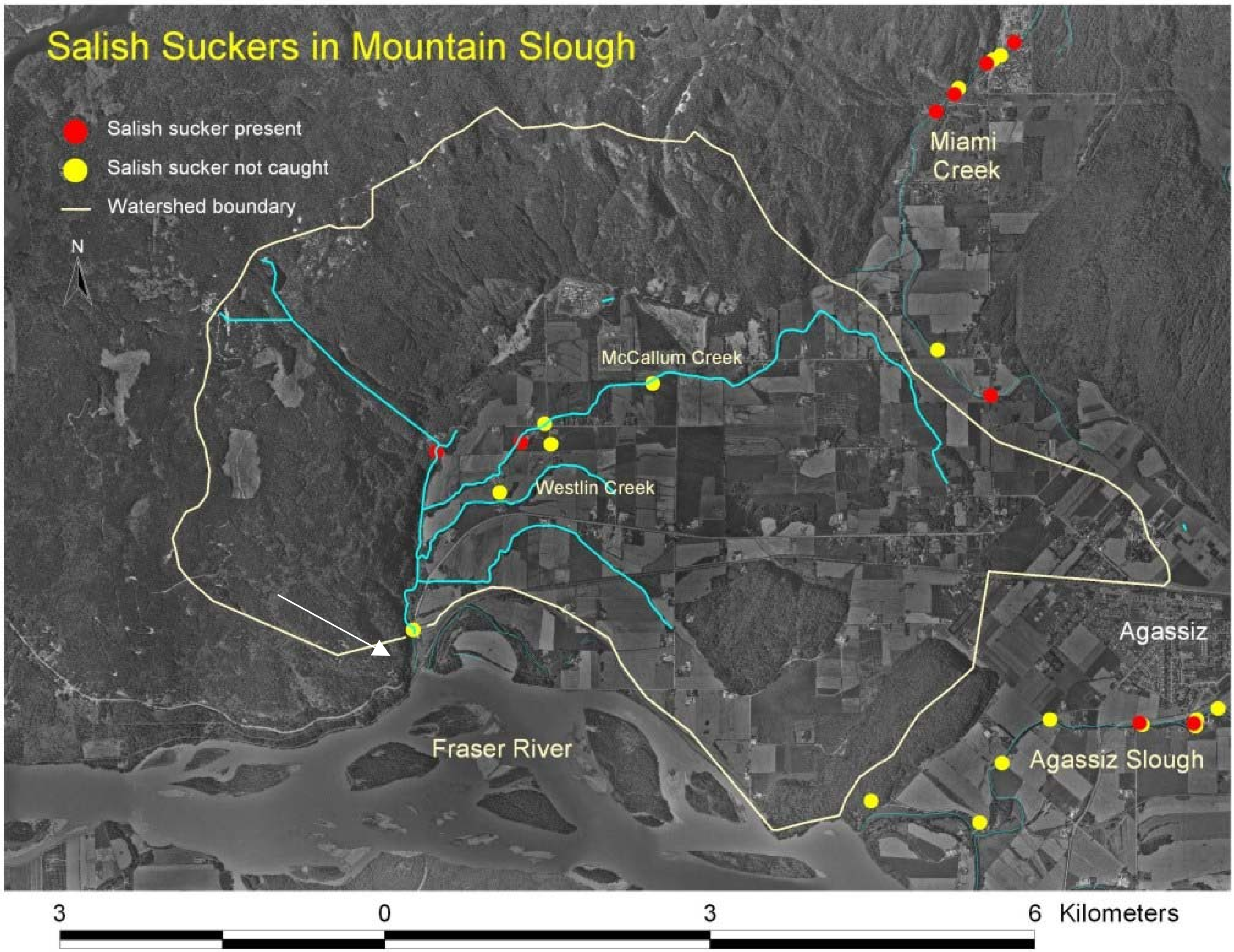
Lack of Water	++		Riffle Loss to Beaver	+
Physical Destruction of Habitat	+++		Increased Predation	+
Hypoxia	+++		Toxicity	++
Sediment Deposition	++		Habitat Fragmentation	++

Mountain Slough

General Description

Mountain Slough is situated west of the town of Agassiz and drains into the Fraser River through the Hammersly pumping station (Fig. 6.14). Its watershed contains 37 km^2 of land and 14.5 km of channel, excluding ditches and is approximately evenly divided between farmland and forested mountain slope (Table 6.4). The farmland is protected from flooding by a system of ditches, dykes, and the pumping station. Soils are a complex mix of gravel, clay and sand deposits. Gravel terraces fringe the valley in places and probably play a role in flood protection and base-flow maintenance. Some of these are currently being mined. Areas adjacent to the mountains have the most favourable oxygen and temperature levels due to

Figure 6.14: Salish sucker distribution in Mountain Slough.. Data from Miami Creek and Agassiz Slough are shown to show proximity. The Photograph is from 1999 and the catch data is from 2000-2003.



their inflows from streams and groundwater. Lack of water is a concern in most other reaches and future agricultural intensification are likely to exacerbate water quality problems.

Salish Sucker Distribution

Salish suckers were first caught in Mountain Slough during the summer of 2003 and a systematic inventory has yet to be completed. It seems likely that their seasonal distribution will mirror that found for coho salmon, with which they usually occur (see Chapter 3). During the winter coho are found throughout Mountain Slough, but in summer are confined to a small number of refugia along the edges of the valley bottom (Pat Slaney, pers. comm.).

Assessment

The major concerns are hypoxia and damage done by drainage, dyking and infilling. Lack of water, sediment deposition, toxicity and habitat fragmentation are moderate concerns. Introduced predators and riffle loss to beaver ponds is a minor concern at present (see Appendix 1 for details).

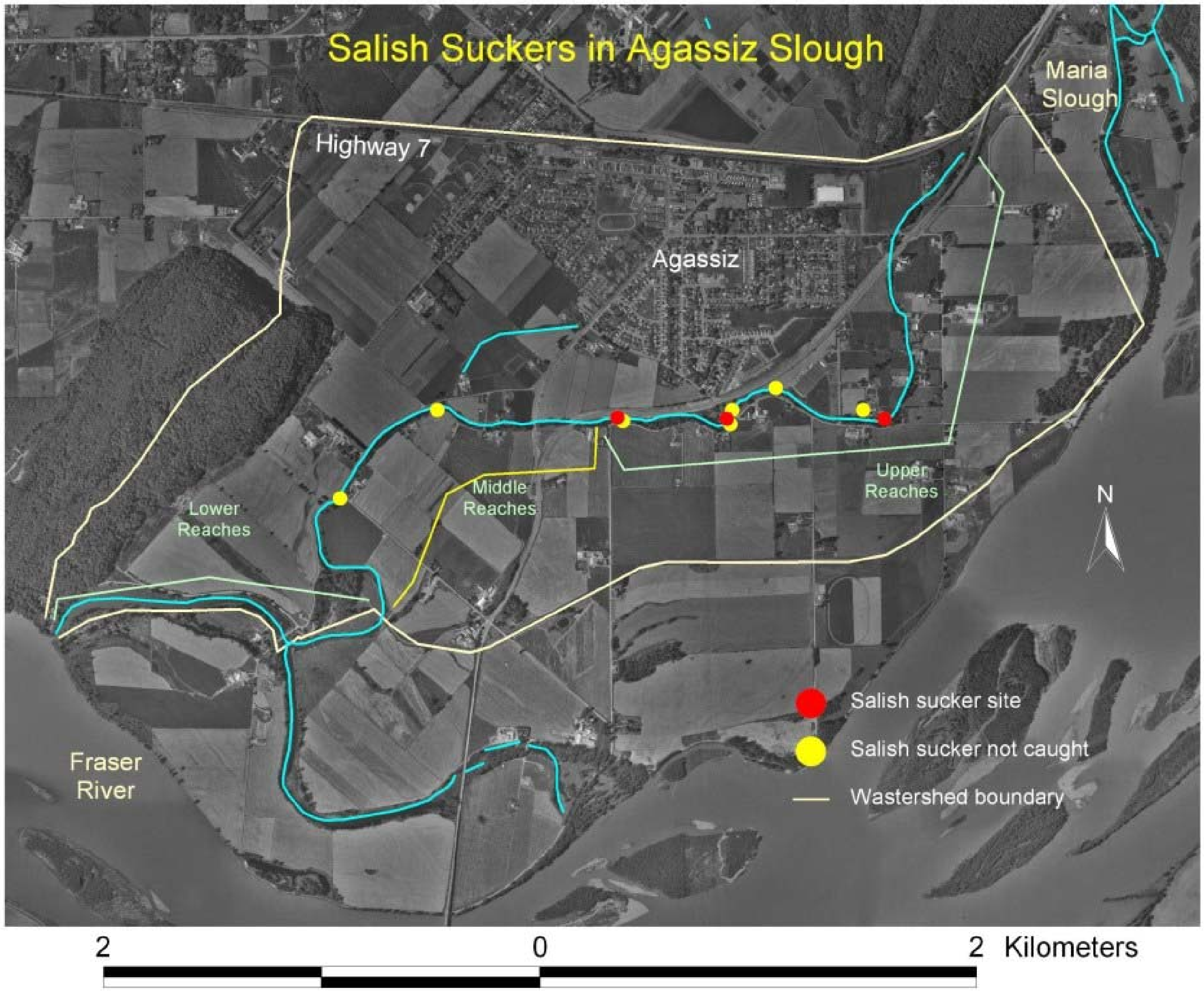
Lack of water	++			Riffle Loss to Beaver	+
Physical Destruction of Habitat	+++			Increased Predation	+
Hypoxia	+++			Toxicity	++
Sediment Deposition	++			Habitat Fragmentation	++

Agassiz Slough

General Description

Historically Agassiz Slough ran between Maria Slough and the Fraser River (Fig. 6.15). The Maria Slough end was blocked off over 40 years ago. A dyke separates the watershed from the Fraser and the slough now drains through it via a doored culvert. The upper reaches of the slough are now isolated and their water levels simply rise and fall with the water table as influenced by the Fraser River (Hans Schreier pers. comm.). The slough currently drains approximately 8 km^2 and contains 6 km of channel. The town of Agassiz occupies 17% of the watershed and its storm sewer system drains into the slough through outlets in the upper reaches. Most of the other land is in agriculture (Table 6.4). Surface soils are a

Figure 6.15: Salish sucker distribution in Agassiz Slough. The watershed is dyked where it faces the Fraser River. The Photograph is from 1999 and the catch data is from 2000-2003.



complex mix of gravel, clay and sand deposits and contain both confined and unconfined aquifers (Schreier et al., 2003). The upper reaches contain areas of groundwater upwelling that maintain water levels and quality during the summer when the rest of the slough is either dry or severely hypoxic. The lower reaches are outside the dyke and are strongly influenced by the Fraser River.

Salish Sucker Distribution

Salish suckers have been caught in three locations, all in the upper reaches (Fig. 6.15), but little sampling has been done.

Assessment

Lack of water, hypoxia, toxicity, habitat fragmentation, and habitat destruction by drainage and infilling are all major concerns. Sediment deposition is a moderate concern. Introduced predators and riffle loss to beaver are minor concerns at present (see Appendix 1 details).

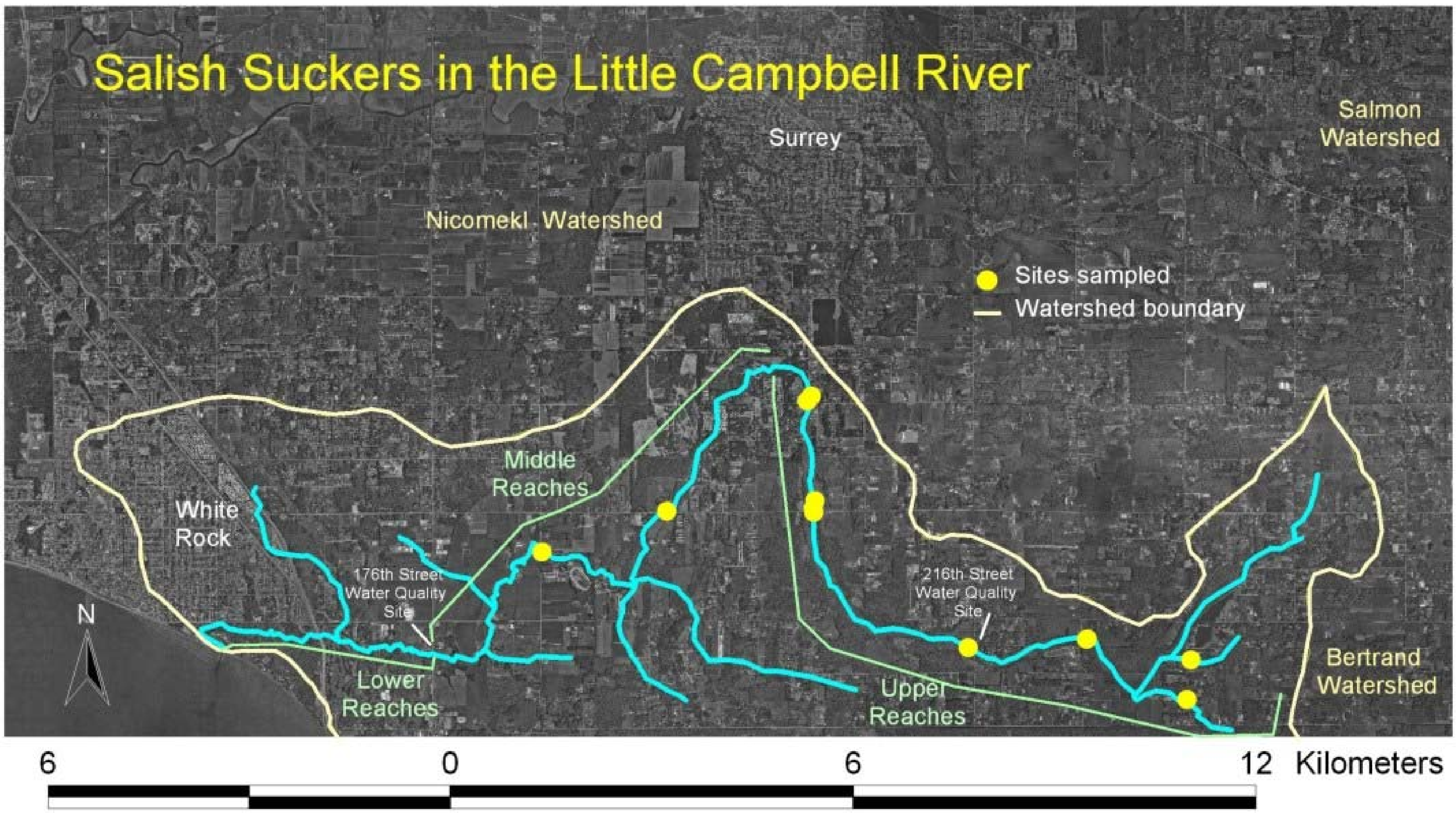
Lack of Water	+++		Riffle Loss to Beaver	+
Physical Destruction of Habitat	+++		Increased Predation	+
Hypoxia	+++		Toxicity	+++
Sediment Deposition	++		Habitat Fragmentation	+++

Little Campbell River

General Description

The Little Campbell River arises immediately to the west of the Bertrand creek watershed and flows westward to enter the Strait of Georgia at White Rock (Fig. 6.16). Its watershed encompasses 73 km^2 of land and approximately 40 km of channel. The lower reaches are under tidal influence and the downstream 1.5 km is estuarine. Land-use around this section is predominantly urban. The middle reaches has a riffle-pool morphology, extensive gravel deposits and flows predominantly through agricultural land. In its upper reaches, where it flows through Campbell Valley Regional Park and agricultural lands, the creek is boggy and sometimes lacks a defined channel (Drever and Brown, 1999).

Figure 6.16: Salish sucker sampling locations on the Little Campbell River, 1999-201. All sites were trapped twice. The photograph is from 1999.



Salish Sucker Distribution

Salish suckers were once abundant in the Little Campbell's middle and upper reaches, but they were last recorded in the system in 1976 (McPhail, 1987). The decline in abundance was extremely rapid. Some known spawning riffles were destroyed around the time of the sucker's disappearance (McPhail, 1987), but there still appears to be abundant physically suitable habitat, in the upper reaches. Hypoxia and the high densities of brown bullhead, an introduced predator, are other possible agents of decline.

Assessment

The major concerns are hypoxia and the high densities of introduced predators (brown bullhead). Lack of water, sediment deposition, toxicity, habitat fragmentation, and habitat destruction all warrant moderate concern.

Lack of Water	++		Riffle Loss to Beaver	++
Physical Destruction of Habitat	++		Increased Predation	+++
Hypoxia	+++		Toxicity	++
Sediment Deposition	++		Habitat Fragmentation	++

Summary of Watershed Assessments

At least one threat was rated a major concern in every watershed and in most watersheds two or more hypotheses were of major concern (Table 6.5). Each of the threats was considered a major concern in at least one of the ten watersheds.

Watershed Rankings

Agassiz Slough appears to be most at risk, with five of the eight examined threats considered major concerns. The population of Salish suckers (not yet estimated) is probably also small given the small size of the watershed. Pepin Brook, with four threats of major concern, also appears to be highly threatened. Salwein Creek/Hopedale Slough appears to be the least threatened as many of the indicators are affected positively by its steady supply of cold groundwater. The remaining six watersheds containing extant populations are difficult to rank as all had either one or two threats of major concern. On a relative scale, these should be considered moderately threatened.

Table 6.5: Summary of watershed assessments. Bracketed numbers after each hypothesis refer to their drivers and triggers, which are listed by number in the lower panel. Estimated Salish sucker populations and relative densities of Nooksack dace (see Chapters 3 and 5) are provided for comparison. Assessment details are provided in Appendix 1.

Threat	**Bertrand Creek**	**Pepin Brook**	**Fishtrap Creek**	**Upper Salmon River**	**Salwein/ Hopedale Slough**	**Atchelitz/ Chilliwack/ Semmihault**	**Miami Creek**	**Mountain Slough**	**Agassiz Slough**	**Little Campbell River**
Lack of Water (4,6,7,8,9)	+++	+	++	+++	+	++	++	++	+++	++
Physical Destruction of Habitat (8)	++	+++	+++	++	+++	+++	+++	+++	+++	++
Hypoxia (1,2,3,4,5)	++	+++	++	+++	+	++	+++	+++	+++	+++
Sediment Deposition (2,7,10,11)	+	+++	++	++	+	++	++	++	++	++
Riffle Loss to Beaver Ponds (5)	+	+++	+	++	+	+	+	+	+	++
Increased Predation (12)	++	++	++	+	++	++	+	+	+	+++
Toxicity (7,13,14)	++	+	++	+	++	++	++	++	+++	++
Habitat Fragmentation (15,16)	+++	++	++	++	+++	+++	++	++	+++	++
Salish Sucker Population Estimate (Lower 95% CL)	240 (100)	?	490 (210)	1390 (650)	>1300 (550)	?	850 (350)	?	?	0
Nooksack Dace Density Index	34	4.8	1.8							

+++	major concern	+	minor concern
++	moderate concern	?	insufficient information

Direct Indicators	**Bertrand Creek**	**Pepin Brook**	**Fishtrap Creek**	**Upper Salmon River**	**Salwein/ Hopedale Slough**	**Atchelitz/ Chilliwack/ Semmihault**	**Miami Creek**	**Mountain Slough**	**Agassiz Slough**	**Little Campbell River**
1. Dissolved Oxygen	++	+++	++	+++	+	++	+++	+++	+++	+++
2. Lack of Riparian	++	+	+++	+++	++	++	++	+++	++	+
3, Nutrient Loading	++	+++	++	++	++	++	++	++	++	++
4. Hydrograph	+++	+	++	+++	+	++	++	++	+++	+++
5. Beaver Ponding	+	+++	+	++	+	+	+	+	+	++
6. Impermeable Soils	+++	+	++	+++	+	+	++	+	+	++
7. Impermeable Surfaces	++	+	++	+	+	++	++	+	+++	+
8. Drainage/Dyking/Infilling	++	+++	+++	++	+++	+++	+++	+++	+++	++
9. Water Withdrawal	+++	+	+	++	+	++	++	++	++	+++
10. Riffle Sedimentation	+	+++	++	++	+	++	++	++	++	++
11. Erosion	+	+	++	++	+	++	++	++	++	++
12. Introduced Predators	++	++	++	+	++	++	+	+	+	+++
13. Pesticide/Herbicide Use	++	+	+++	+	+	++	++	++	++	++
14. Toxic Spills	++	+	++	+	++	+	++	+	+	+
15. Population Isolation	+++	++	++	++	+++	+++	++	++	+++	++
16. Internal Fragmentation	++	++	++	++	++	++	++	++	+++	++

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Population estimates of Salish sucker seem inversely related to the number of threats of major and moderate concern (Table 6.5). The Pepin Brook population was estimated at 2,860 individuals in 2000 (95% LCL= 1990), making it the largest known population. It apparently crashed in 2002, coincident with the onset of severe hypoxia in the most densely populated reaches. The current population is unknown, but believed to be much reduced (Chapter 3). Approximately 70% of Canada's Nooksack dace appear to inhabit Bertrand Creek (Chapter 5). This is likely because of the large amount of high quality riffle it contains relative to Pepin Brook and Fishtrap Creek.

Although useful for considering broad patterns, simply ranking population risk by the number of threats considered a major concern can be misleading, as a major escalation of a single threat could cause a population crash (as apparently occurred in Pepin Brook) or even extirpate a population. Given the low number of fish in each population and the fact that habitats are changing rapidly as a result of human population growth, urban expansion, and agricultural intensification, all populations should probably be considered at significant risk of extirpation.

Major Range-Wide Threats

Hypoxia and direct habitat destruction via physical destruction of habitat were identified as major concerns in more than half of the watersheds and, with lack of water (see below), rank as the most serious threats range wide. Hypoxia is particularly worrisome in that it appears to be widespread, degrades areas of otherwise suitable habitat, can kill large number of fish quickly, has numerous contributing factors, can easily go undetected, and is likely occurring with increasing frequency. One of its main drivers, nutrient loading, is known to be increasing rapidly with agricultural intensification and urban expansion. For example, in Abbotsford manure application to agricultural lands is adding approximately 3 times the amount of nitrate that plants can take up (Lavkulvich et al. 1999) The excess enters groundwater and surface waters.

Direct habitat destruction appears to have been major cause of decline in both species historically. Large portions of all creeks examined have been channelized, in-filled, or repeatedly dredged. The Chilliwack area has been most affected, with the draining of Sumas Lake and the closing off of distributary channels in the former Chilliwack River delta (Chapter 3). Damage continues to occur through municipal ditch cleaning activities and unauthorized works on private land.

Lack of water is a major concern in three watersheds, but is most troubling in Bertrand Creek where it affects the largest of only three Nooksack dace populations in Canada. It is also a potentially exacerbating factor for several other threats including hypoxia, toxicity and introduced predators (by concentrating individuals in specific areas). Dry sections of channel will also contribute to habitat fragmentation. Creeks with naturally low base flow due to watershed geology are especially vulnerable to further wetland drainage, increases in impermeable surfaces and/or water withdrawal. Some watersheds appear to be oversubscribed for licensed water withdrawals, but real rates of abstraction probably differ greatly from those estimated (see FRP, Table 6), as unlicensed withdrawals occur on all creeks, and some existing licenses are unused (Pearson pers. obs.).

Minor and Moderate Range-Wide Threats

Riffle loss to beaver ponds is a minor issue in all but two watersheds and a major issue in only one (Pepin Brook, see below). Sediment deposition is also only a major issue in Pepin Brook at present, because of a chronic, large-scale release of fine sediment from a gravel mine. Such events, although rare, are a risk in all watersheds where mining occurs close to streams and their tributary ditches. Bank erosion in reaches lacking adequate riparian vegetation is a moderate problem in most study streams.

Poorly Understood Threats

The degree of risk posed by three threats, increased predation, habitat fragmentation and toxicity, is poorly understood at present. Bullfrogs, brown bullheads and/or largemouth bass are present in every watershed inhabited by Salish sucker and Nooksack dace and all are implicated in declines and extinctions of endemic fishes elsewhere (Cannings and Ptolemy, 1998; Miller et al., 1989). However, the date of introduction of long these species to the study streams is unknown, as are their current densities and how habitat variables, particularly temperature, alter their effectiveness as predators. Pumpkinseed (*Lepomis gibbosus*), black crappie (*Pomoxis nigromaculatus* Lesueur), and smallmouth bass (*Micropterus dolmieui* Lacepede) are also established in some systems.

Toxic contamination is poorly documented in most Salish sucker/Nooksack dace streams, but is likely present to some degree in all. Agassiz Slough is known to contain sediments contaminated by urban storm drainage (Schreier et al., 2003). Portions of three other streams (Bertrand Creek, Fishtrap Creek, and Atchelitz/Chilliwack/Semmihault) also receive storm water from adjacent urban areas and are highly likely to be contaminated as all other urban streams that in the Fraser Valley that have been studied are (FREMP, 1996; Hall et al., 1991). Pesticides and herbicides have been detected in both surface water and groundwater in the study area (Hall et al., 1991; Schreier et al., 2003). Data is lacking on threshold concentrations for acute and sublethal effects to Salish sucker and Nooksack dace and, with the exception of Agassiz Slough sediments, on levels of contamination in the watersheds.

Habitat fragmentation is clearly widespread at the regional and watershed scales. The drainage of Sumas Lake, the diversion of the Chilliwack River away from its delta, and the complete isolation of the upper reaches of Agassiz Slough are the starkest examples. More than a century of wetland drainage, dyking and infilling on lesser scales, however, has undoubtedly reduced opportunities for fish movement between and within watersheds across the range. The long term impacts on Salish sucker and Nooksack dace populations can only be speculated upon at present.

Special Cases: Pepin Brook and The Little Campbell River

Pepin Brook is a particularly important watershed because it contained the largest known population of Salish sucker until recently, and is inhabited by one of only three Canadian populations of Nooksack dace. Two threats, riffle loss to beaver ponds and large-scale sediment deposition, are considered major concerns only in it among the study streams. In 1999, beaver had impounded 47% of Pepin Brook's mainstem. By 2001 a further 690 m was flooded, eliminating 10% of the 938 m of riffle recorded in the 1999 survey (Chapter 5). Although further expansion is likely to be limited by a lack of suitable dam sites and flooding conflicts with human use, riffle losses and impacts on the Nooksack dace population needs to be monitored. Massive quantities of fine sediments have been discharged from a gravel pit into the headwaters of Pepin Brook for approximately ten years. Deposits more than 100 cm deep have largely destroyed fish habitat for at least 500 m and habitat is likely damaged considerably downstream of this (Pearson pers. obs.). Impacts on Salish sucker and Nooksack dace populations are uncertain but likely significant.

The Little Campbell River is the only watershed in which Salish sucker extirpation has been documented and the prospect of reintroducing a population to it requires consideration in recovery planning. The results of this threats assessment are not encouraging. The middle reaches, which contained the bulk of the historical Salish sucker population (J.D. McPhail, UBC, pers. comm.) and where physical habitat appears best (Pearson pers. obs.), are chronically hypoxic and inhabited by high densities of an introduced predator, the brown bullhead.

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Chapter 7

Legislative and Policy Tools For Conservation and Recovery of Salish Sucker and Nooksack Dace

INTRODUCTION

Conservation initiatives in a densely settled landscape such as the Fraser Valley are complicated by a high degree of private land ownership, multiple and overlapping regulatory jurisdictions and intense, competing pressures for various types of land development. The success of a species recovery plan requires consideration of these factors if it is to be effective.

In this chapter I briefly review and assess existing federal, provincial and municipal jurisdiction, legislation and policy with potential utility in conservation and restoration of Salish sucker and Nooksack dace habitats. I use the factors identified as drivers or triggers of the eight threats described in Chapter 6 (see Fig. 6.2) as a framework to highlight weaknesses and gaps in policy and legislation. In light of those findings I then assess the tractability of each of the eight threats within the current regulatory context.

JURISDICTION

Overview

Laws passed by any level of government in Canada must conform to the *Constitution Act, 1867*[2]*,* which establishes the jurisdictions of provincial and federal governments. Laws that are passed outside a government's area of jurisdiction (Table 7.1) or are found to interfere with the civil liberties set out in the *Charter of Rights and Freedoms* to an extent greater than necessary to protect the public good will be struck down by the courts (Estrin and Swaigen, 1993). Municipal government regulatory powers are not set out in the Constitution, but rather are delegated to local governments by the province that created them. Consequently the jurisdictional scope that municipalities can apply to their by-laws may be expanded or contracted at provincial discretion (Anonymous, 1997).

As this division of powers occurred more than a century ago, it reflects the social and political priorities of that time. Issues of 'environment' in the modern sense did not exist, and were not categorically assigned to a jurisdiction. Consequently, responsibilities overlap or are

[2] The original Canadian constitution, the *British North America Act* was renamed the *Constitution Act, 1867* in 1981. The *Charter of Rights and Freedoms was also* added at this time.

Table 7.1: Areas of provincial and federal jurisdiction in Canada (adapted from Estrin and Swaigen 1993)

Provincial Jurisdiction	Federal Jurisdiction
• Control of natural resources • Management and sale of provincial lands and their resources • Establishment and control of municipal institutions • Power over property and civil rights within the province • All matters of a purely local or private nature in the province	• Criminal law • Taxation and spending in any way that does not interfere with provincial jurisdiction • Regulation of international and inter-provincial trade and commerce • Regulation of works or undertakings that are inter-provincial or international in nature • Seacoast and inland fisheries • General power to make laws for 'peace order and good government in Canada' (interpreted to justify intrusion on provincial jurisdiction when a problem has achieved a national dimension)

unclear in many instances. Protection of species at risk is such a case. When jurisdictions overlap, junior government standards must meet those of senior governments (if in existence), but are free to exceed them (Estrin and Swaigen, 1993). The Federal Government can legislate in areas of provincial jurisdiction when a problem has a 'national dimension', (although they are generally reluctant to do so) and may encourage particular policy directions by spending federal tax dollars on research or by developing model laws and by-laws for provincial or municipal adoption. Federally regulated industries and federal lands such as military bases, Indian reserves, national parks and airports are always exempt from provincial law (Estrin and Swaigen, 1993).

Assessment

Salish sucker and Nooksack dace are under federal jurisdiction as 'aquatic species' listed under the *Species at Risk Act* (*SARA*, see below). Responsibility for most of their habitat, however, is shared between the provincial and federal governments. The province owns the water and beds of most streams on non-federal lands and has clear authority over land use including riparian zones, but the federal government has claimed jurisdiction over fish habitat as defined under the *Fisheries Act*[3] (see below) and over habitat designated as 'critical' for aquatic species listed under *SARA*. The federal government has exclusive jurisdiction over habitat on the two federal properties where Salish sucker are known to occur (on the Salmon River and Salwein Creek). Both are owned by the Department of National Defense (Pearson, 1998).

CONVENTIONS AND ACCORDS

Overview

Canada signed the *Convention on Biological Diversity* at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992 and ratified it later that year. In 1994 a Federal-Provincial-Territorial Biodiversity Working Group was established to

[3] 'Fish habitat' means spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes (R.S.C. 1985, c. F-14).

develop a *Canadian Biodiversity Strategy*. It was released in 1995 and contains five broad goals, which address biodiversity conservation, education, and the need for research, incentives, supporting legislation and international cooperation (BCO, 1995). One of the first initiatives to follow was the *National Accord for the Protection of Species At Risk* (Environment Canada, 1996), an agreement between Federal and Provincial/Territorial Ministers, which sets out principles and actions to be taken by each jurisdiction. The *Accord* explicitly recognizes the need for coordinated policies, the need for support of stewardship activities, and that lack of scientific certainty is not a valid reason for delaying conservation action (the Precautionary Principle). It established the Canadian Endangered Species Conservation Council (CESCC)[4], and commits all governments to establishing complementary legislation and programs that 'provide for effective protection of species at risk throughout Canada'. These are to include habitat protection, consideration in environmental assessment processes, regular monitoring and reporting, effective enforcement, and public education (Environment Canada, 1996).

Assessment

The National Accord sets out the criteria for protection of species at risk that provincial and federal legislation is to meet. With the passage of *SARA* (see below) the federal government appears to have met these criteria. The province of British Columbia, however, has not passed species at risk legislation. Instead it argues that listing provisions under its *Wildlife Act* (see below) and Forest Practices Code meet its obligations. The argument is very tenuous given that only four species have been listed under the *Wildlife Act* legislation since it was passed in 1980.

FEDERAL LEGISLATION

Species at Risk Act (SARA)

Overview

The Canadian *Species at Risk Act* (S.C. 2002, c.29) received Royal Assent on December 12, 2002 following several unsuccessful attempts dating from 1995 (see Scudder, 1999 for

[4] The CESCC consists of the federal Ministers of Environment, Fisheries and Oceans and Canadian Heritage and provincial and territorial ministers responsible for conservation and management of wildlife.

review). The Act is intended to prevent indigenous species, subspecies, and distinct populations from being extirpated or becoming extinct, to provide for the recovery of endangered or threatened species, and to prevent other species from becoming at risk (s.6). It sets out the process of listing species, includes prohibitions on activities that harm listed species and their habitats, provides for compensation of landowners for hardships caused by habitat protection measures and establishes a web-based public registry for documents such as recovery strategies, government responses to species status assessments and public comments. All *SARA* related actions are to be consistent with aboriginal treaty rights and to respect authority of other federal ministers and provincial governments. *SARA* also requires that the 'best available knowledge' be used in recovery planning and that lack of scientific certainty not be used as a reason to delay appropriate recovery actions.

The Listing Process

SARA uses a two-stage listing process. In the first stage, it reaffirms the role of the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) [5] in assessing the status of species based solely on biological criteria. The committee consists of individuals appointed by the Minister of Environment on the basis of their expertise in scientific, community or traditional aboriginal knowledge. They, in turn, establish specialized sub-committees to assist in the preparation and review of status reports. These reports along with an assessment of risk category (extinct, extirpated, endangered, threatened, special concern) are forwarded to the federal Minister of Environment, the CESCC, and are posted on the public registry (s. 14-18, 24-25).

In the second stage the Minister of Environment posts a report on the public registry within 90 days, outlining how he or she intends to respond to the assessment. Within nine months, the federal Cabinet must add the species to the legal (SARA) list, reject it, or refer the matter back to COSEWIC for further consideration. In the latter two cases, reasons must be posted on the public registry. Failure to meet the deadline automatically results in the species being

[5] COSEWIC was originally established to assess the status of species at risk following the Conference of Federal-Provincial-Territorial Wildlife Directors in 1976.

added to the legal list (s. 25, 27). Status assessments are reviewed by COSEWIC every 10 years or more frequently when the status is believed to have changed significantly (s. 24).

Prohibitions

SARA contains a number of prohibitions regarding species legally listed as extirpated endangered or threatened. These apply to all such species on federal lands and on all lands for aquatic species (as defined in the *Fisheries Act*[6]) and migratory birds (as defined in the *Migratory Birds Convention Act*, *1994*). Specifically it is forbidden to kill, harm, harass or capture individuals, to possess, collect, buy sell or trade individuals or parts of individuals, or to damage or destroy an individuals residence (s. 32-33). In addition, the destruction of any part of habitat designated as critical in a species' recovery strategy or action plan (see below) is forbidden (s. 58). Permits for activities that violate these prohibitions may be issued under SARA for scientific research, activities that will benefit the species, or activities that have only an incidental effect on the species, providing that the species' survival or recovery are not jeopardized (s. 73).

Recovery Planning

SARA requires the preparation of recovery strategies and action plans for extirpated, endangered and threatened species (s. 37, 47). Preparation of these documents is delegated by the Minister of Environment to National Recovery Teams under the purview of RENEW (Recovery of Nationally Endangered Wildlife Program), which was established under the *National Accord for the Protection of Species at Risk* (see Treaties and Accords above).

The strategy must determine if recovery is technically and biologically feasible. If recovery is feasible, it must address threats to the species survival, identify strategies to address the threats, identify critical habitat (to the extent feasible), set population and distribution objectives, identify research needs, and set timelines for action plan preparation (s. 40-41). The action plans must identify critical habitat, and/or gaps in information necessary to define it. If information gaps do exist a schedule of studies to fill them must be included. For identified critical habitat, the strategy must propose or describe measures to protect portions

[6] 'Fish' includes (a) parts of fish…and, (c) the eggs, sperm, spawn, larvae, spat and juvenile stages of fish…

of it that remain unprotected. In addition measures taken to implement other elements of the strategy must be described and appropriate methods to monitor recovery, and evaluate socio-economic costs and benefits of plan implementation must be included (s. 49). Critical habitat is to be protected within 180 days of its identification in a strategy or plan posted on the public registry (s. 57-58). All strategies and must be prepared in cooperation and consultation with affected parties including provincial governments, First Nations, landowners and other affected individuals (s. 39, 48).

Assessment

The Nooksack dace is currently on the legal endangered[7] list. The status of the Salish sucker was under review by COSEWIC when *SARA* was passed. Its status was confirmed as endangered, but its addition to the legal list awaits the conclusion of public consultation (currently underway) and a decision by Cabinet. If added to the list, the Salish sucker, like the Nooksack dace, will fall under federal jurisdiction across its entire range as an aquatic species. The prohibitions under sections 32 and 33 of *SARA* (killing, harming, harassing, possessing, selling etc.) are of minimal importance to Salish sucker and Nooksack dace as neither species is of any commercial or recreational value. They could be applied to cases in which water quality degradation from addition of toxins or other substances caused harm or death. These cases would be covered under the Fisheries Act, however, (see below) which has a lesser burden of proof. The prohibition on destruction of a 'residence' as defined under the act is difficult to apply to these species (except perhaps to spawning areas). A joint recovery strategy and action plan covering both Nooksack dace and Salish sucker is currently in preparation by the National Recovery Team and will include designation of critical habitats (Jordan Rosenfeld, Fisheries Research Section, Province of British Columbia, pers. comm.). Assuming Cabinet approves the strategy and action plans, the requirements for protection of critical habitat will be the most powerful provisions under *SARA*. In addition, federal financial support for stewardship activities and landowner compensation under the *Act* promises to play an important role in implementing the recovery plans.

[7] A species threatened with imminent extirpation or extinction (*Species at Risk Act*, S.C.2002, c.29, s. 2).

Fisheries Act

Overview

The federal *Fisheries Act* (R.S.C. 1985, c. F-14) was first enacted in 1868 and is enforced by the federal Department of Fisheries and Oceans (DFO) in cooperation with relevant provincial ministries. It was amended in 1976 to include prohibition of the harmful alteration, disruption, or destruction of fish habitat (HADD), unless authorized by DFO (s. 35-36). In 1986, DFO adopted a habitat management policy to support the physical habitat provisions of the *Fisheries Act* (DFO, 1986). It states that DFO's long-term objective is 'the achievement of an overall net gain in the productive capacity of fish habitats.' Achievement of this objective is to be attained through the restoration of damaged fish habitat, the creation of new fish habitat, and compensation for loss of habitat productive capacity (no net loss) in development projects (DFO, 1998).

The no net loss principle is applied when DFO issues an authorization for a HADD resulting from development activities. As a condition of authorization, the proponent is required to balance unavoidable losses in the productive capacity of fish habitat through compensation projects that restore, create or enhance habitat. DFO follows a hierarchy of preferences in selecting compensation sites. Creation or enhancement of habitat similar to that affected by the HADD and of benefit to the same population is preferred, but projects in other watersheds and/or benefiting other species may be selected at the discretion of managers (DFO, 1998; DFO, 1986).

Assessment

Although the *Act's* usefulness is limited by its reactive nature (it reacts to incidents rather than preventing damage from occurring) and lack of enforcement due to resource limitations and political concerns, its severe penalties act as a significant deterrent (Nowlan, 1996). Retrospective assessments of habitat policy effectiveness have shown that no net loss has not been achieved (Kistritz 1996, Cudmore-Vokey et al. 2000, Minns and Moore 2003). The *Act* does afford legal protection to all Salish sucker and Nooksack dace habitat (rather than just designated critical habitat) through its HADD prohibitions. Although historically, compensation projects from HADD authorizations have virtually always been intended to benefit game species, DFO has considerable scope under the *Act* to use them to create or restore Salish sucker and Nooksack dace habitat.

Canada Wildlife Act

Overview

The *Canada Wildlife Act* (R.S.C., 1985, c. W-9) is primarily intended to allow Environment Canada to acquire lands for wildlife research, conservation, and interpretation. The National Wildlife Areas, Migratory Bird Sanctuaries and Marine Wildlife Areas established under this legislation protect habitat for a variety of species at risk, but are chronically under funded and in many cases badly degraded (Canadian Nature Federation, 2002). The Act also allows the government, 'in cooperation with one or more provincial governments having an interest therein, to take such measures as the Minister deems necessary for the protection of any species of wildlife in danger of extinction' (s. 8).

Assessment

Both the land acquisition provisions and the broader powers under section 8 of this *Act* appear redundant given the powers afforded DFO for aquatic species under the *Species at Risk Act* (see above).

Canadian Environmental Assessment Act (CEAA)

Overview

Under the *Canadian Environmental Assessment Act* (S.C. 1992, c. 37) all federal agencies including departments, agencies and crown corporations are required to assess the environmental impacts of their own proposed projects and all those for which they provide funding, permits or licenses (s.5). These assessments must include a meaningful public consultation component (s. 22). It is administered by the Canadian Environmental Assessment Agency, an independent body that reports directly to the Minister of Environment and maintains a public registry of all assessments. The definition of 'environmental effect' under the *CEAA* was amended with the passage of *SARA* to include ‘any change…to a listed wildlife species, its critical habitat or the residences of individuals of that species, as those terms are defined in subsection 2(1) of the *Species at Risk Act’* (S.C.2002, c.29, s. 137). Thus, all federal environmental assessments must explicitly consider effects on legally listed species.

Assessment

A wide variety of development projects may affect Salish sucker and Nooksack dace habitat. Most will trigger environmental assessments by virtue of receiving federal funding or requiring federal permits (e.g. HADD authorizations under the *Fisheries Act*). The assessments must consider impacts on the fish and any habitat features identified a residence or as critical habitat under the *Species at Risk Act*.

Wild Animal and Plant Protection and Regulation of International and Interprovincial Trade Act.

Overview

Transport and trade of wildlife across international or interprovincial borders is forbidden without permits under this Act (R.S.C. 1992, c. 52. s. 6-9).

Assessment

Although attempts to transport Salish sucker or Nooksack dace across borders are unlikely, the transport of introduced species that may impact them does occur. A number of piscivorous species (e.g. bullfrog, brown bullhead, and largemouth bass) are present within streams inhabited by Salish sucker and Nooksack dace (Pearson, 2000). All were present in the Fraser Valley prior to the Act’s passage in 1992 and are native to eastern Canada (Corkran and Thoms, 1996; McPhail and Carveth, 1994). Although future introductions of additional species are highly probable, enforcement of the Act’s prohibitions is unlikely due to difficulties in attributing responsibility.

Pesticide Products Control Act

Overview

Although primarily concerned with registration of pesticides for use in Canada, the act does prohibit the possession, handling, storage, transport, use, or disposal of pesticides in ways that endanger the environment (S.C. 2002, c. 28, s.6). Maximum penalties for conviction are high ($500,000 and/or 3 years in prison for conviction on indictment).

Assessment

Pesticides are used heavily in the Fraser Valley, particularly on row crop agricultural lands and likely impact Salish sucker and Nooksack dace at least occasionally (see Chapter 6). Pesticide containers have been dumped in Fishtrap Creek in the past (Don McPhail, UBC, pers. comm.). Enforcement of the Act will be difficult given the large areas, ubiquity of use, and limited monitoring resources involved.

PROVINCIAL LEGISLATION

Wildlife Act

Overview

The *Wildlife Act* (RSBC 1996, c. 488) prohibits killing, hunting, trapping, taking, wounding, possessing, trafficking, or transporting of all wildlife without a permit (s. 26, 33, 37). It also permits the Minister of Water, Land, and Air Protection to designate a species as endangered or threatened and to set aside lands as critical habitat for such species (s.5-6). With passage of the *Fish Protection Act* (see below) the *Wildlife Act* was amended to cover fish, which were formerly excluded from the definition of wildlife. The British Columbia Conservation Data Centre compiles provincial Red (endangered) and Blue (threatened) lists (Harcombe, 1994; Harper et al., 1994) for potential legal designation under the *Act* and for use in setting conservation priorities for inventory and recovery efforts.

Assessment

Nooksack dace and Salish sucker are protected from capture, transport and direct harm under the *Wildlife Act*, but these impacts do not threaten either species and are covered under the federal *Species at Risk Act*. The prohibitions on transporting wildlife apply to introductions of potentially harmful non-native species to watersheds inhabited by Nooksack dace and Salish sucker, but attributing responsibility for such acts is rarely possible. Salish sucker and Nooksack dace are candidates for legal designation as endangered under the *Wildlife Act* as both appear on the provincial Red List (Cannings and Ptolemy, 1998). To date this has not been done. In fact, since the Act was passed in 1980 only four of the 137 species now on the Red List have been legally listed (B.C. Reg. 253/2000, App. 2, s. 8-9.), and the critical habitat protection provision has been used only once (for the Vancouver Island marmot, *Marmota vancouverensis;* s. 5(1) en. B.C. Reg. 183/91). As currently applied, the provincial *Wildlife Act* offers no meaningful protection to either species.

Fish Protection Act

Overview

The major provisions under the *Fish Protection Act* (S.B.C. 1997, c. 21) with potential to affect Salish sucker and Nooksack dace conservation are the Streamside Protection Policy Directives, the Sensitive Stream Designations, and the maintenance of in-stream flows. Each of these is summarized below.

Streamside Protection Policy Directive (SPPD)

The SPPD (B.C. Reg. 10/2001; O.C. 34/2001) was brought into effect in January 2001 under section 12 of the *Act*, but is currently under review and is expected to be weakened (E. Stoddard, BC MWLAP, pers. comm). It currently requires that municipal by-laws set minimum standards for width of streamside protection areas (SPAs) on lands proposed for new residential, commercial, and industrial development by 2006. The widths range from 5 m for significantly disturbed sites with little remnant riparian vegetation and that lack fish, to 30 m for areas largely intact areas around fish bearing streams. All areas lacking permanent structures, including paved lands are considered to have potential for revegetation. Passive recreation facilities are permitted in SPAs only if there is sufficient room to accommodate them and protect the habitat. Roads and utilities may cross them, but must be located to minimize damage. SPAs are not to be used as road or utility corridors.

Sensitive Streams Designation

A special category of 'Sensitive Streams' is created under the *Act* for protection of fish populations at risk due to critically low water flows or habitat degradation (s.6). Criteria for designation have yet to be released, although 15 candidates were selected by the province in 1998. They were chosen based on immediate need for protection of their salmon populations and the 'minimal impact designation is likely to have on water users' (Erin Stoddard, BC

MWLAP pers. comm.). Designations are made by Cabinet and are completely discretionary. Preparation of Recovery Plans (s. 7) for designated streams is also discretionary and only intended for those 'unable to rehabilitate naturally' (2 of the initial 15, for example). Plans must include public and stakeholder involvement, and seem relatively comprehensive in scope, but require Cabinet approval for implementation. None have been completed to date. Applicants for water withdrawal licenses in Sensitive streams must show that no viable alternative sources exist, that harm will not be caused to fish or their habitat, that stream flow will be augmented when necessary, and that the proposal is consistent with any Recovery Plan.

Minimum In-Stream Flows

The *Fish Protection Act* amended British Columbia's *Water Act* (see below) with the stated intention of safeguarding in-stream flow levels for fish. Decision makers 'may' consider the needs of fish and fish habitat in relation to applications for water withdrawal licenses but no consultation is required with fish and wildlife managers (s. 5). It allows, but fails to require, monitoring and reporting of impacts and permits the Minister temporarily to reduce withdrawals by permit holders in drought conditions (s. 9). The Act also allows non-government organizations (NGOs) to acquire licenses for conservation purposes but unlike other license categories, those for conservation need Cabinet approval, are subject to cancellation without compensation, and will only be given to groups with a 'community based interest' that have undertaken fish habitat improvements (WCEL, 1997).

Assessment

The Streamside Protection Policy Directive will benefit Salish sucker and Nooksack dace, as urban and industrial development will continue to occur in most of the watersheds they inhabit. The major weakness of the SPPD is its inapplicability to lands in the Agricultural Land Reserve and to mining operations. These categories constitute the majority of lands adjacent to Salish sucker/Nooksack dace streams. If, as expected, the regulation is weakened following the current review, it is uncertain how much protection it will provide even on lands to which it does apply. Designation of Salish sucker and Nooksack dace streams as 'Sensitive' under the act could provide badly needed protection for those that suffer from low flows due to excessive water withdrawals (see Chapter 6). None of the 15 streams proposed for designation contain populations of these two species, however, and no progress on finalizing designations, or selecting additional candidates has been made for several years. At present, no provincial staff are even working on the issue (Erin Stoddard, BC MWLAP, pers. comm.). The minimum in-stream flows provisions also have potential to benefit Salish sucker and Nooksack dace streams. The high degree of discretion associated with their application likely precludes widespread use, but they may prove a useful tool in implementing recovery plans developed under the federal *Species at Risk Act*.

Water Act

Overview

The *Water Act* (RSBC 1996 c. 483) regulates surface water withdrawals and 'works in or about a stream'. Withdrawal of surface water for purposes other than domestic needs, mineral prospecting or fire fighting requires a license, which determines the volume removable (on a daily or annual basis) and is given a priority (relative to other licenses for the watershed) based on the date of application (s. 15). Licenses can be issued for conservation purposes (s. 1; see Fish Protection Act above) to maintain in-stream flows for fish. Licenses are attached to land title, mining rights, or the undertaking of the licensee (e.g. cattle watering on crown range lands). When land or a mine is sold, water rights pass to the new owner (s. 16). The license may be revoked if the owner does not make beneficial use of water for three successive years, fails to pay license fees, or does not follow terms or conditions of the license (s. 23), although revocation for reasons other than a failure to pay are extremely rare (Narinder Singh, Land and Water BC, pers. comm.). Provincial water managers may also declare a stream fully subscribed, precluding issuance of further licenses or to add conditions to licenses to ensure maintenance of minimum instream flows.

A water license is also required for projects that involve making changes in and about a stream (s. 9). These include bridge and culvert installations, drainage works, dams, and habitat restoration/enhancement projects. Typically projects that trigger this section of the *Water Act* will also trigger federal review under the federal *Fisheries Act*, and if a HADD is deemed to occur, the *Canadian Environmental Assessment Act* (see above). The province considers applications that meet *Fisheries Act* permit requirements to meet *Water Act* requirements (Narinder Singh, Land and Water BC, pers. comm.).

Assessment

Water withdrawal occurs in all streams inhabited by Nooksack dace and Salish sucker, although a large proportion of withdrawals appear to lack licenses and some existing licenses appear to be unused (Pearson pers. obs.). Several streams, particularly Bertrand Creek, suffer from critically low summer flows, but the lack of any monitoring of actual amounts withdrawn precludes an assessment of the impact of licensed or unlicensed withdrawals. Among Salish sucker and Nooksack dace streams only the Salmon River is listed as fully subscribed due to lack of water (Land and Water BC database, http://lwbc.bc.ca/06search/rrr/restrictions.pdf, accessed May 21, 2004). A number of others, particulary Bertrand Creek should be added. Revocation of unused licenses and/or application for licenses for conservation use may also prove useful tools in developing and implementing the Recovery Action Plans for these watersheds under *SARA*.

Waste Management Act

Overview

The Waste Management Act (RSBC 1996, c. 482) is the most widely used law for protecting water quality in British Columbia (Nowlan, 1996; Devereaux Jennings et al., 1999). It contains regulations for a wide variety of activities that could influence stream water quality, including the disposal of used lubricating oil, petroleum storage facilities, asphalt plant regulations, and motor vehicle emissions. Here I will limit the scope of discussion to regulation of agricultural waste, the pollutant source most likely to influence water quality in streams inhabited by Salish sucker and Nooksack dace by virtue of its ubiquitous distribution in the Fraser Valley (Lavkulich et al., 1999).

Solid agricultural waste may be applied to land as a fertilizer or soil conditioner if it does not cause pollution of a watercourse or groundwater (s.13). The province issues weather dependent advisories on when application is permitted. Typically it is forbidden between mid November and mid February (Dawn Ross, BC MWLAP, pers. comm.). Manure may be stored either in a containment facility or on a field. Containment facilities must be located at least 15 m from a watercourse unless constructed before 1992 (B.C. Reg. 131/92, O.C. 557/92 s. 7). Field storage is permitted for up to nine months provided waste cannot escape and cause pollution. Within the Fraser Valley, field storage piles must be covered during the rainy season (October 1 to April 1; B.C. Reg. 131/92, O.C. 557/92 s. 8-9). Discharge of any agricultural waste to a watercourse or groundwater is forbidden (s. 11).

The Act is to be replaced by the *Environmental Management Act*, Bill 57. The new legislation is expected to eliminate waste discharge permits for all but 'high risk' industries, although these remain undefined (WCEL 2003). It does promote the development of 'area based plans' to reduce pollution originating from many sources or non-point sources.

Assessment

Nutrient loading from agricultural waste is one of the greatest concerns identified in the threats analysis (see Chapter 6). The major shortcoming of *Waste Management Act's* regulations is the lack of control over the quantity of waste added per unit area of land. The provisions preventing applications that cause pollution to a watercourse or groundwater are extremely difficult to enforce, as attributing the source to a specific farm is usually impossible (Dawn Ross, BC MWLAP pers. comm.). The impacts of Bill-57 on agricultural nutrient loading are difficult to assess given that the relevant regulations have yet to be developed. Its proposed area based plans may provide an effective way of dealing with agricultural nutrient loading, although they are not obligatory and important details of their implementation await development of regulations under the act (WCEL 2003). There is also very little monitoring of agricultural waste management due to resource limitations (Dawn Ross, BC MWLAP pers. comm.).

Pesticide Control Act

Overview

This Act (RSBC 1996, c. 360) controls pesticide storage, transport, disposal and licensing of applicators. Its regulations (B.C. Reg. 319/81, O.C. 1728/81) contain no provisions regarding the frequency or amounts applied and exempt users on private agricultural and residential lands from its licensing and permit requirements. They do prohibit the application of pesticides directly to natural waterbodies or waters connected to them (s. 10).

Assessment

The controls on storage, disposal and spraying over natural waterways provide some protection for fish habitat, although offences affecting Salish sucker and Nooksack dace habitat would more likely be prosecuted under the federal *Fisheries Act*. The lack of control over quantity and frequency of application, however, is likely to allow pesticides to enter waterways by indirect routes.

The Land Title Act

Overview

In 1994 the *Land Title Act* (RSBC 1996, c. 250) was amended to allow the Minister of Environment, Lands and Parks to designate anyone eligible to hold conservation covenants, written agreements between a landowner and an organization in which the owner commits to protect the land in specific ways (Hillyer, 1996). This allowed conservation organizations and stewardship groups to hold covenants with landowners for the first time in British Columbia. Previously only government organizations could.

When conservation covenants are voluntarily entered into (as opposed to being a condition of subdivision approval) tax breaks may be a significant incentive. Provincial assessments of property tax for lands outside agricultural or forestry zonings are based on fair market values and must consider changes in value stemming from conservation covenants. Generally this will be a decrease in value due to restrictions on use and development of the covenant protected area.

Assessment

Conservation covenants have great potential for long-term protection of Salish sucker and Nooksack dace habitat, as virtually all of it is found on private lands. Two problems must be overcome though. First, lack of tracking, monitoring and enforcement has hampered the effectiveness of many covenants. A study in Surrey (Inglis et al. 1995) found that 75% of 185 riparian zone covenants had been broken. Second the existing tax breaks offer little incentive to landowners within the Agricultural Land Reserve, as their property tax rates are already very low (Penn, 1996).

MUNICIPAL BY-LAWS AND POLICY

Municipal governments are creations of the province having no separate constitutionally based powers (see jurisdiction, above). The *Local Government Act* (RSBC 1996, c. 323) provides the legal framework for their existence and delegates specific powers to them. Under the newly enacted *Community Charter* (Bill 14 – 2003) the relationship between the municipal governments and the province is further clarified. It formally recognizes municipalities as an order of government under provincial jurisdiction (s. 1).

These Acts and many other provincial statutes contain enabling provisions, which allow local governments to pass by-laws. They often prescribe how this may be done, but rarely require that it happen. Consequently the strength of each jurisdiction's environmental regulation and enforcement depends almost entirely on the political culture of its councilors and staff. Not surprisingly variations in both commitment and approach amongst municipalities is enormous (Curran, 1999).

Many municipal decision makers are reluctant to embrace environmental protection fully, viewing it as outside their proper jurisdiction or as 'downloading' of responsibilities by senior governments (Nowlan, 1997). These concerns have been addressed in the provinces new Community Charter, which authorizes municipal councils to regulate, prohibit or impose requirements in relation to 'protection of the natural environment' (s.8), prohibits downloading of responsibilities without provision of resources necessary for their exercise, and requires provincial consultation on matters of municipal interest (s. 2).

The municipal constituency is also a key factor in determining its political culture. Affluence, mobility, cultural mix, employment levels, and land ownership, of residents and industry are important determinants of local support for environmental initiatives. Environmental regulation may also provoke special interest groups, which are frequently more politically powerful at the local level (Press et al., 1996).

In the following sections I outline some of the major legislative and policy tools available to municipalities wishing to protect aquatic species at risk. I then review the by-laws in place in the four municipalities that encompass the Canadian range of Salish sucker and Nooksack dace (Township of Langley, City of Abbotsford, City of Chilliwack, and District of Kent; Fig. 7.1).

Types of Municipal Regulation

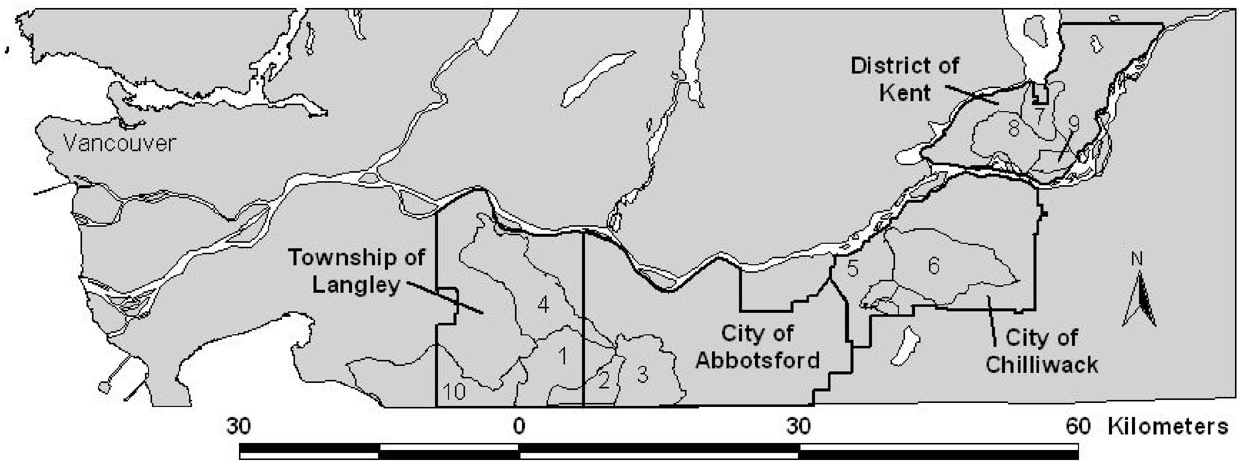
Official Community Plans

The Official Community Plan (OCP) sets out the broad goals, objectives and policies of development in a municipality. Although typically general in nature, they are quite important as all by-laws enacted and works undertaken must be consistent with them (Anonymous, 1997). Policies concerning environmentally sensitive areas (ESAs), parks and open spaces, greenway systems, stormwater management and erosion control may be included. Development permit areas (DPAs), in which development must conform to area-specific requirements may also be designated for environmental purposes (see below; Anonymous 1997). The scope for innovation is very large. Curran (1999) details some of British Columbia's more progressive OCP designs and by-law structures. OCP features of potential benefit to Salish sucker and Nooksack dace would include goals and objectives addressing protection of fish and wildlife, species at risk, water resources, and growth management, the designation of watercourses and riparian zones as ESAs and/or DPAs and policies concerning environmental protection. On its own, an OCP has little regulatory value.To be truly effective, an environmentally progressive OCP must be backed by enforceable by-laws and policies and by the commitment of staff and council to both its spirit and its intent.

Zoning By-Laws

Local governments use zoning to control the type and form of development in different areas (zones) of the municipality. Zoning can be a very powerful and effective tool for protecting sensitive habitats, but is unwieldy for small areas (Kotyk, 1996). Commonly used provisions

Figure 7.1: Location of Municipalities in relation to watersheds inhabited by Salish sucker and Nooksack dace.



1. Bertrand Creek
2. Pepin Brook
3. Fishtrap Creek
4. Salmon River
5. Salwein Creek/Hopedale Slough
6. Atchelitz/Chilliwack/Semmihault Creeks
7. Miami Creek
8. Mountain Slough
9. Agassiz Slough
10. Little Campbell River (believed extirpated)

in zoning by-laws include requirements that development be set back from ESAs or streams, the prohibition of polluting land uses near sensitive areas, and incentives for protection of ESAs (Anonymous, 1997). A common example of an incentive is the application of density bonuses, in which developers are permitted to build more housing units than the zoning would normally permit in exchange for something of public benefit - such as transferring ownership (dedication) of a wetland or stream corridor to the municipality, or undertaking habitat restoration work (Anonymous, 1993). Others useful provisions include the prohibition of subdivision below a minimum size without dedication of ESAs to the municipality, and the requirement of larger set backs for developments with more impermeable area (Anonymous, 1997). Again, there is substantial scope for innovation (Curran, 1999). Comprehensive Development Zones may be used for complex zoning of larger, mixed-use sites allowing customized land use planning. For example they may include residential, commercial, park land and ESA areas (Anonymous, 1993).

There are three major pitfalls in the use of zoning for habitat protection. The first applies to all municipal by-laws. When privately owned land is 'sterilized' (effectively rendered unusable for any purpose but a public one) by by-laws, the owner must be compensated (Anonymous, 1997). Uses may be severely curtailed, so long as one or more private ones remain possible (Nowlan, 1999). Secondly, incentives like density bonuses only work when the economic climate supports them. If a developer can make more money using the original zoning, that is what will happen. Third, zoning by-laws are cumbersome to enforce as the only legal remedies are court injunctions or prosecution under the *Provincial Offenses Act* (Anonymous, 1997).

Blanket By-laws

Blanket by-laws apply throughout a municipality. Various local governments have enacted *Tree Removal By Laws, Watercourse Protection By-Laws*, *Landscaping By-Laws* and/or *Soil Removal and Deposit By-laws* to help protect habitat from development impacts. They may be drafted separately or be combined into an *Environmental Protection By-Law,* and can be very effective in protecting stream and riparian habitat (Anonymous 1997; Kotyk 1996).

Typical provisions include prohibitions on tree cutting in ESAs without permits, requirements for replacement planting as a condition of permits, fencing restrictions on livestock, and controls on the timing and methods of soil removal and deposit to minimize erosion and sedimentation (Anonymous 1997). They may also include requirements for preparations of Environmental Impact Statements by accredited consultants as conditions of permit (Kotyk 1996; Curran 1999). Advantages of blanket by-laws over the exclusive use of Zoning and DPAs include their application across the entire municipality and their ease of application, as staff may grant or revoke permits or issue tickets without involving Council (Anonymous, 1997).

Development Permits

Development permits may be used to protect habitat in two ways. If effective blanket by-laws are in effect, DPAs can be used to vary setbacks and other restrictions in areas that are non-conforming. This may be useful in avoiding land sterilization under the blanket by-laws. DPAs may also constitute the primary control over the development form and process around streams and other ESAs if effective blanket by-laws are not in place (Anonymous, 1997) and could include all of the same elements. The major advantage of DPAs is that they are clearly defined in the OCP and have an associated public process. The disadvantages are that projects outside the designated areas are exempt and that the lengthy process of Council approval is required (Kotyk 1996).

Integrated Plans

Comprehensive plans dealing with stormwater management, neighbourhood development, or entire watersheds may be prepared under the OCP and are powerful tools for protecting habitat and wildlife (Anonymous 1993). Their chief advantage is in the holistic approach used, although their usefulness will depend largely on their terms of reference and the spirit in which they are carried out. For example a basin wide stormwater plan could be used to allow development while ensuring preservation of a stream's hydrograph features. The plans also benefit local government and developers by reducing the need for time consuming referrals of plans to provincial and federal agencies - which are always required for works in and around watercourses. The plan is approved as a unit, so the need for subsequent referrals is greatly reduced (Kotyk 1996).

Subdivision and Subdivision Servicing

The subdivision process is a critical step in ensuring that habitat is protected in development. It defines the development pattern; lot sizes, what lands will be protected, where roads and infrastructure will be located, and what design standards will be used for such key features as creek crossings and stormwater facilities. It is also the point at which conservation covenants may be attached to deeds under the *Land Title Act* (see below). The *Local Government Act* (RSBC 1996, c 323) requires that landowners dedicate 5% of their lands or pay cash-in-lieu to local governments at the time of subdivision. This is commonly used to secure parkland and/or ESAs including riparian zones (Anonymous 1993, 1997). Although an effective protection measure, riparian dedications meet some resistance from planners and the public, as agency staff are generally reluctant to allow public access close to watercourses, which effectively denies parkland area to local residents (P. Andzans, City of Abbotsford pers. comm.). Local governments may also require the dedication of lands for paths and walkways as 'highways' (Anonymous 1997). Engineering and construction standards included in the by-law may be used to require environmentally sensitive design and construction practices e.g. for infiltration of roof drain water, erosion control, vegetation protection, and habitat restoration (Anonymous 1997).

Limitations on Municipal Land Use Control

A major constraint on local government control over land use in the Fraser Valley is imposed by provincial legislation related to agriculture. The majority of land area in Abbotsford, Langley and Chilliwack is within the province's Agricultural Land Reserve (ALR). Under the *Farm Practices Protection (Right to Farm) Act* (RSBC 1996, c. 131 s. 2) a municipality is prohibited from passing by-laws that restrict 'normal farm practices' on ALR lands. The *Agricultural Land Commission Act* (RSBC 2002, c. 36 s. 26) allows municipalities to approve subdivision or non-farm uses on ALR lands only when the power is delegated to them by the Agricultural Land Commission. In combination these statutes severely limit the scope of municipal power to enact environmental (or any other) legislation on ALR lands.

The 'normal farm practices' are guidelines and lack the force of law. The final arbitrator in determining whether a particular practice is protected by the *Right to Farm Act* is the Farm Practices Board established by the Act (s. 9). The guidelines contain some environmentally important provisions concerning such issues as manure spreading, handling and storage of pesticides and herbicides, and stormwater management, but lack any riparian protection, or livestock exclusion provisions.

For Nooksack dace and Salish sucker the ALR is a mixed blessing. It has benefited stream health to the extent that it has curtailed urban development, but it largely prevents municipalities from protecting watercourses from damaging activities through by-law enactment.

Review of Existing Municipal Regulation and Policy

The Township of Langley

The Township contains most of the Bertrand Creek, and Salmon River watershed in addition to the upstream half of the Little Campbell River and the downstream half of the Pepin Brook watersheds (Fig. 7.1). With the exception of its western fringe and the town of Aldergrove, the township is entirely within the Agricultural Land Reserve. A moratorium on gravel mining is in place.

Official Community Plan

The current OCP was passed in 1979. One of its five overall goals is environmental: the 'Preservation of good quality air, water and land environments'. The plan identifies areas of the township for urban, commercial, industrial and agricultural development and articulates objectives and policies for each, none of which are environmental in character. Detailed neighbourhood plans are to be prepared for each of the designated urban growth areas. The Natural Areas section of the plan (s. 4.10) includes the objective 'to encourage the enhancement of the aquatic environment of the Salmon River, Nicomekl River, Campbell River and creeks throughout the municipality'. A supporting policy prohibits development in designated natural areas, but these are limited to the beds of creeks and rivers and a narrow buffer strip along the Fraser River. Another states that storm drainage management in designated urban development areas will ‘prevent flooding and inhibit the introduction of pollutants and hydrocarbons into streams’ and ‘function to recharge groundwater supplies, where possible’. Environmental concerns do figure prominently in the township’s mission and value statements, which were much more recently developed. ‘We wish to protect the quality of our environment’ is second of four community value statements and its corporate mission statement includes commitments to preserving ‘a lifestyle that is environmentally, socially, culturally and economically balanced’ and to ‘management of growth in an environmentally and fiscally responsible manner’ (Township of Langley, 2003). No ESAs are identified in the OCP, although an inventory completed in 1993 (Cook et al. 1993) is used informally by staff (Marina Stejpovic, Township of Langley, pers. comm.).

By-Laws

The Zoning Bylaw defines building setbacks for streams based on provincial flood control requirements, which provide some protection for riparian areas. On all Salish sucker/Nooksack dace streams these are 15 m from the channel (annual flood line), but the provincial Ministry of Agriculture, Food, and Fisheries is currently proposing to reduce this to 4.5 metres (Marina Stepjovic, Township of Langley, pers. comm.). The township has attempted to use density bonuses to increase parkland and stream setbacks several times in developing areas, but developers have not been interested so far (Marina Stepjovic, Township of Langley, pers. comm.). Several relevant by-laws are currently in development. These include groundwater and drinking water protection bylaws and one prohibiting erosion and sediment discharges into municipally maintained ditches (Marina Stepjovic, Township of Langley, pers. comm.).

Programs and Plans

Watercourse Classification: A complete inventory of watercourses, including ditches has been completed and is posted on the web. It categorizes streams in terms of fish presence or potential for presence and is used by staff and concerned landowners to identify potential areas of impact on fish resources. The maps were developed by an NGO, the Langley Environmental Partners Society, which works in close cooperation with the township (Marina Stjepovic, Township of Langley, pers. comm.).

Water Resources Management Plan: In 1998 the Township began developing a comprehensive plan for protection of its ground and surface waters. Inventories, public consultation and public education efforts (including door-to-door landowner contact in selected areas) have been included in efforts to date. Setback requirements and watershed based integrated stormwater management plans (see below) are also in development (Marina Stepjovic, Township of Langley, pers. comm.).

Integrated Stormwater Management Plans: The Township, though its involvement with the Greater Vancouver Regional District's (GVRD) *Liquid Waste Management Plan,* has committed to developing integrated stormwater management plans (ISMP) for each of its watersheds. Each ISMP will include inventories and consideration of riparian areas and fish values. Bertrand Creek, which contains Salish sucker and Nooksack dace and is impacted by urban stormwater within the town of Aldergrove, is to be addressed in 2005 (Marina Stepjovic, Township of Langley, pers. comm.).

Public Education: The township website (www.tol.bc.ca) includes extensive information on environmental issues and township programs related to them. The Engineering Department organized a volunteer based, door-to-door education program on groundwater protection in the Salmon River watershed during the summers of 2002 and 2003 (Marina Stjepovic, Township of Langley, pers. comm.).

Support of Community Stewardship Groups: The Township provides core funding, space and utilities to the Langley Environmental Partners Society (LEPS), an independent non-governmental organization that conducts a variety of environmental education and outreach programs and undertakes riparian and in-stream habitat enhancement projects. The township also provides a small annual budget to six watershed based community groups, two of which focus on Salish sucker/Nooksack dace streams (Lonnie Prouse, LEPS, pers. comm.).

Assessment

Although its aging OCP contains little environmental language and few supporting provisions, the Township has implemented a variety of progressive policies and programs likely to benefit Salish sucker and Nooksack dace populations. Of particular importance is the comprehensive watercourse classification system, support of the stewardship community, and development of ISMPs. A number of additional plans and by-laws with potential to further improve the situation are in development.

The City of Abbotsford

All of Fishtrap Creek and the upper half of Pepin Brook flow through this municipality (Fig. 7.1). With the exception of urbanized headwaters of Fishtrap Creek their watersheds are completely within the Agricultural Land Reserve. Extensive gravel mining is underway in the Pepin Brook catchment. Seventeen percent of its area was being actively mined in 1999 (see Chapter 3), and the area has expanded since. Lower Fishtrap Creek is also slated for extensive gravel mining (Peter Andzans, City of Abbotsford, pers. comm).

Official Community Plan

The *City of Abbotsford Official Community Plan* (OCP; B/L 439-97) contains its *Vision Statement* and its *Corporate Strategic Pl*an. The former includes the statement 'Abbotsford will be an economically, socially, and environmentally healthy city...' and the latter states that the City will 'Promote the conservation and enhancement of the natural environment' in its objectives section. The OCP itself has seven guiding principles of which the last is 'a recognition of the City's natural features and the need to protect those resources'. Section 11 of the plan deals with the 'Natural Environment'. Its first goal is 'to promote the conservation and enhancement of the natural environment, and to preserve the bio-diversity of the local area'. It goes on to describe a number of development policies that include environmental impact assessments for all proposed 'high impact uses', formulation of development controls to protect environmentally sensitive areas, avoidance of floodplain development, and encouraging retention and replanting of native vegetation, protection of fish bearing streams by measures including 'adequate setbacks' and 'storm detention facilities'. Other statements in this section relate to minimizing storm drain impacts on fish bearing streams, developing a comprehensive biophysical inventory, and identifying degraded streams to determine what restoration measures are required. The OCP identifies a Natural Environment and Hazardous Conditions DPA. Development is not to be permitted in 'the area necessary to protect the fishery resource' and biophysical inventories are required for parcels larger than 2 ha. It encompasses the steep hills slope areas, outside the ALR, none of which are adjacent to Salish sucker or Nooksack dace streams.

Charter of Sustainability

In 2003 the City passed a *Charter of Sustainability*, which is intended to serve as a high level policy document with which all municipal initiatives must be consistent. (http://www.city.abbotsford.bc.ca/environmental/Dec_Charter.pdf, accessed February 3, 2004). It rests on the five principles of responsible growth, pollution prevention and resource conservation, shared responsibility, fairness/equity, and cooperation. It contains few specifics, and emphasizes voluntary measures and public education, while placing considerable emphasis on maintaining economic growth and minimizing social impacts.

By-Laws

The *Tree Protection By-Law* (1995, Consolidated No. 55-95) prohibits tree cutting without a permit. Permits are not issued for tree removal within 5 m of a watercourse (measured from top of bank) on slopes exceeding 35 percent. *The Private Swimming Pool Regulation By-Law (*1997, Consolidated 375-97*)* requires that pools drain to the sanitary sewer system rather than the storm sewer system or (if no sanitary connection is available) to a rock pit at least 30 m from any watercourse. *The Industrial Waste Bylaw* (1999, Consolidated 844-99) prohibits discharge of a wide variety of hazardous substances to storm and sanitary sewers. *The Farm Bylaw* (1998, Consolidated 698-98) requires storm water management plans and regular testing of effluent for mushroom composting facilities. Buildings setbacks must be at least 15 m from watercourses. Other on-farm composting operations must observe the same setback.

Programs

The major initiative of the Environmental Services department is the Abbotsford Environmental Pledge Program, in which citizens or businesses sign a pledge to follow environmentally sound practices. The section on streams and fish includes pledges to leave riparian vegetation intact, to refrain from dumping refuse or walking in the stream, and to leave fallen trees and stumps in the channel. It has received limited participation from business and virtually none from private citizens (Clare Beaton, City of Abbotsford, pers. comm.). The groundwater protection initiatives consist of the installation of informational roadside signs. The City has classified watercourses based on fish presence, although the supporting data is very incomplete (Clare Beaton, City of Abbotsford, pers. comm.). They also follow a policy of planting the south sides of ditches on right of ways and private land where owners agree (Clare Beaton, City of Abbotsford, pers. comm.).

Assessment

The City of Abbotsford's OCP contains numerous statements of intent regarding programs and policies that would benefit Salish sucker and Nooksack dace. Their approach to environmental management emphasizes public education and voluntary measures, but is poorly supported by data gathering activities such as stream and wetland mapping. The environmental stewardship program undertaken by the City to date appears to have been ineffective.

The City of Chilliwack

The City of Chilliwack includes the entire watersheds of Salwein Creek and the old Chilliwack River Delta (Atchelitz/Chilliwack/Semmihault; Fig. 7.1). Agricultural land occupies over half of the municipality, with forested hill slopes and the urban areas of Chilliwack proper, Sardis, and Vedder Crossing constituting the remainder. Drainage is a critical issue in the District as most of the inhabited and farmed lands are less than 20 m above sea level and at high flood risk from the Fraser and Vedder Rivers.

Official Community Plan

The Chilliwack OCP purports to adopt an ecosystem approach that integrates environmental concerns with those of the economy and community. Among its principles are the promotion of 'a healthy, sustainable community', to 'advocate environmental stewardship through individual and neighbourhood responsibility', and to 'value … agricultural, natural, cultural and heritage resources in … decision making'. Its long vision statement ends with a summary sentence: 'Ultimately, our vision is one of complete communities and sustainable development, combined with a pragmatic approach to growth and development.' It goes on to outline the goals and policies for environmental and natural resource issues including stewardship, environmentally sensitive areas, riparian and wetland protection, greenways, tree protection and waste management among others (s. 4.3). These contain numerous statements of intent to promote activities that would benefit Salish sucker populations including:

- To develop and coordinate community education and support programs to encourage environmental stewardship.
- To undertake environmental protection, enhancement, and remediation of creeks, riparian habitats….and other sensitive environmental features.
- To promote environmentally sensitive design
- To identify ESAs in the City for incorporation into land use planning
- To promote biodiversity…through protection of riparian corridors and linkages of natural areas
- To protect riparian habitat and associated natural features along water courses
- To identify and protect significant wetlands from rural and urban development
- To promote alternative forms of agricultural waste management

Infrastructure policies (s. 4.4.9) with direct applicability to fish habitat include:

- To reduce per-capita water demand (through possible metering/pricing changes, public education, and leak detection)
- To…minimize effects (of stormwater) on aquatic environments.
- To restore aquatic habitat damaged by stormwater facilities

The City proposes to develop Comprehensive Development Plans where possible and to use density bonuses to achieve other desired outcomes including environmental protection above regulatory standards (s. 5.2). The OCP also establishes a number of Development Permit Areas for environmental reasons, but none contain provisions for stream or habitat protection. Implementation of the plan is to be monitored by a committee that will report to Council every two years (s. 4.5).

By-Laws

A *Watercourse Protection Bylaw* (B/L 168, consolidated 1983) prohibits filling or fouling watercourses (making specific mention of livestock), but its applicability to streams and ditches containing fish are redundant with the provincial *Waste Management Act* and the federal *Fisheries Act* (see above). No other by-laws with direct applicability to riparian or fish habitat has been adopted.

Programs

Watercourse Inventory: Over 50% of the 600 km of watercourses within the City's jurisdiction have been mapped in detail and assessed for fish presence. These include all waters known to contain Salish sucker (Jim Vickerson, City of Chilliwack, pers. comm.).

Alternative Ditch Cleaning Methods: The City initiated an experimental 'gentle maintenance' program for ditch cleaning in Salwein Creek in 2003 and plans to expand the program slightly in 2004. Vegetation is cut back or removed by hand in spring and fall. A minimum of 1 square metre of vegetation in each 10 metres of channel is left as cover. On City land and where private landowners are agreeable, the south or west sides of watercourses are also planted with native vegetation to provide shade and reduce in-stream vegetation growth. Early results indicate that the cost is comparable to machine cleaning, and that flood prevention may be improved as more frequent cleaning is possible (Neal Calver, City of Chilliwack, pers. comm.).

Assessment:

The OCP contains an impressive number of progressive environmental goals and objectives that would, if implemented, benefit Salish sucker populations. Very few have actually been acted upon, however, and there are no plans for implementing some of the most important ones - e.g. the ESA study, stream remediation projects, or water conservation projects (Jim Vickerson, City of Chilliwack, pers. comm.). There is also likely to be conflict between achieving some of the environmental goals and other OCP aims related to population growth and business development. Already, the City has applied to the province to open a new well to supply increased demand for water. By their own estimates it would reduce base flow in Atchelitz, Luckacuck, Little Chilliwack Creeks by more than 10% from current levels (Janet Demarcke, City of Chilliwack, pers. comm.). On the positive side, mapping of fish habitat and presence is well underway in the Municipality.

The District of Kent

The District includes all of Agassiz Slough and Mountain Slough, and the portion of Miami Creek known to contain Salish sucker (Fig. 7.1). Drainage is a critical issue in the District as most of the inhabited and farmed lands are less than 20 m above sea level and at high flood risk from the Fraser River. An extensive network of ditches, dykes and floodgates protect the land, but are considered in urgent need of upgrading (Ted Westlin, District of Kent, pers. comm.).

Official Community Plan

The OCP (1994 updated 2001) lists ‘growth management’ as the first of its nine guiding principles. Part of the rationale for its inclusion is ‘to preserve the natural environment’, although none of the objectives or policies under it (S.B.1) relate to environmental concerns. The second guiding principle: to ‘protect the environment and properly manage land and water resources’ has only one objective that could be related to aquatic habitat, the ‘protection of environmentally sensitive areas’. Section B.2.3.3 deals with fish bearing streams and streamside setbacks. It recommends a ‘protective leavestrip remain naturally vegetated …adjacent to fish bearing watercourses’. Widths are to be determined on a site-specific basis, but developers are encouraged to use the Land Development Guidelines

(Chilibeck et al., 1992). One policy (2.8), however, directs Council to 'seek to ensure that drainage ditches are not considered part of streamside setback regulations proposed by the Province' (see *Fish Protection Act*, see above). Development of a district-wide drainage management plan for all agricultural lands is to be considered (policy 7-36() and is, in fact, underway (see below). The existence of ESAs in Kent is recognized in the OCP (s. B.2.3.4) and a policy (2-11) directing that an inventory be developed is included.

A 16.4 ha parcel adjacent to the section of Agassiz Slough known to contain Salish suckers is designated as Residential Reserve and could accommodate up to 150 homes, although it is currently in the ALR (s. B.4.3.5). An application to remove it from ALR would be considered following development of a Neighbourhood Plan which must include consideration of (among other things) 'environmentally sensitive areas, conservation of areas of natural, (or) scientific…. Significance', and must include a storm water drainage analysis..(that ensures) maintenance of the natural character of watercourses in the area' (policy 4-36).

By-Laws and Policies

The District has passed no environmentally oriented by-laws (Keith Paisley, District of Kent, pers. comm.).

Programs

Watercourse Inventory: The District has completed studies of fish use, water quality, and drainage mapping of the Miami Creek and Mountain Slough systems, but no inventory work has been done on Agassiz Slough (Keith Paisley, District of Kent, pers. comm.).

Assessment

The District of Kent lacks by-laws and contains little in its OCP that could be applied to Salish sucker conservation or recovery. There is a growing realization among staff and councilors, however, that fish habitat work, including Salish sucker recovery efforts may complement their need for drainage improvements and alleviation of sediment contamination in Agassiz Slough (Keith Paisley, District of Kent, pers. comm.).

Summary

The four municipalities vary widely in the amount and types of environmental policies, programs and legislation in place (see Table 7.2 for summary). The Township of Langley currently has the most programs underway, while the District of Kent has the least. Although the OCPs of Chilliwack, and Abbotsford, contain many goals, objectives and intentions that sound beneficial to fish conservation, very few actual programs have resulted.

TRACTABILITY ANALYSIS

In this section I assess the 'tractability' of the eight threats identified in Chapter 6. Tractability is defined as the ability of existing legislation, policy and programs to address a threat by preventing its occurrence, mitigating its impact or reversing its effects. I start by assessing the ability of existing federal, provincial and municipal legislation, policy and programs to address each of the factors identified as drivers or triggers of the eight threats using a three level subjective scale (major concern, moderate concern, minor concern; Table 7.2). The ratings for all drivers/triggers associated with a threat are then combined in an assessment of its tractability.

Ability to Address Drivers and Triggers

Lack of Riparian Vegetation

Existing riparian vegetation is relatively well protected on lands slated for urban development through the *Fish Protection Act*, the municipal development permitting process and (in Abbotsford) a tree protection bylaw. Within the Agricultural Land Reserve, however, it receives very little protection as none of these mechanisms has jurisdiction. Unfortunately the majority of Salish sucker and Nooksack dace habitat falls within the ALR. Replanting native vegetation in denuded riparian zones is among the easiest, most cost-effective methods of improving habitat. Abundant volunteer labour is available, stewardship groups to organize it are established, and granting programs to purchase plants exist. The major impediment to progress is, again, the lack of requirement for riparian buffer strips on agricultural lands. This is firmly within provincial jurisdiction and would be most easily addressed by modifying the

Table 7.2: Summary of Municipal environmental initiatives with potential to benefit Salish sucker and Nooksack dace.

	Township of Langley	City of Abbotsford	City of Chilliwack	District of Kent
Official Community Plan	Contains few environmentally oriented statements, policies or programs. 'Neighbourhood Plans' to be developed for each designated urban growth area.	Contains numerous environmentally oriented statements and proposed policies or programs.	Contains numerous environmentally oriented statements and proposed policies or programs.	Contains very few environmentally oriented statements and proposed policies or programs.
Watercourse Inventory with Fish Use Data	Complete coverage and excellent detail	Patchy coverage Poor detail in most watersheds.	Approximately 50% complete. All streams known to contain Salish sucker are complete.	Miami Creek and Mountain Slough complete. Agassiz Slough not covered.
ESAs	Identified but used for information only.	Not Identified	Not identified.	Not identified.
Environmentally Based DPAs	None identified.	Steep slopes and hazard lands only, none in Salish sucker/Nooksack dace watersheds.	Steep slopes and hazard lands only, none that include known Salish sucker habitat.	Steep slopes and hazard lands only, none that include known Salish sucker habitat.
Environmental By-laws (details in text)	Erosion and Sediment Control (in development)	Tree Protection Swimming Pool Industrial Waste Farm	Watercourse Protection.	None
Public Education Programs	Extensive coverage of stream/watershed issues on web site. Door to door landowner contact program in Salmon River watershed.	Business and personal environmental pledge program. Very limited effectiveness.	River cleanups on Chilliwack River organized twice annually.	None.
Other Initiatives	Major support for stewardship organizations (>$100,000 per year)	In-kind support for Abbotsford Land Trust.	Experimental gentle ditch maintenance program in Salwein Creek	None.
	Water Resources Management Plan (in progress) will lead to groundwater protection bylaw, drinking water protection bylaw, stream setbacks, and integrated stormwater management plans.	New Charter of Sustainability to guide all programs and upcoming rewrite of OCP.		

Table 7.3: A summary of the utility of federal, provincial and municipal legislation in addressing factors that may drive or trigger impacts on Salish sucker and Nooksack dace (see Chapter 6). Lighter shading indicates increased utility. Overall rating is indicated in the left hand column.

Driver/Trigger	Federal	Provincial	Municipal
Lack of Riparian Vegetation	*Fisheries Act*: Could apply compensation projects required under habitat policy to revegetate key areas. Unless HADD occurs on property needing riparian, must have landowner consent.	*Fish Protection Act:* Streamside protection policy requires retention of significant riparian buffers during development, but regulations will likely be weakened. No lands.	*Vari* *e* for developing lands uirements unde A desig over ALR lands
Nutrient Loading	*Fisheries Ac:* Prohibition of deleterious substance addition to fish habitat. Good for point sources, but sources that predominate.	*Waste management Act:* Restrictions on storage facilities and manure appli applied are largel	*Poor Jurisdiction*: Largely prevented from regulating by provincial *Right to Farm*
Beaver Activity	*SARA:* Applicable if defined critical habitat is affected.	through permitting for works in or about a stream. *Wildlife Act*: Regulates trapping and relocation, by pe	*No ju*
Impermeable Surfaces	*No jurisdiction*	*No specific legislation.* Could develop model by-laws for municipalities.	*Development Permits*: Have ability to limit through controls on development form, but very few precedents.
Habitat	*Fisheries Act:* Prohibits damage or destruction of fish habitat. Compensation for permitted HADDs could be applied to restoration. *SARA* prohibitions on damaging residences and defined critical habitat.	*Water Act:* Requires permits for works in and about a stream (does not apply to dug ditches).	*Responsible for drainage*, can adopt progressive ditch cleaning practices and increase habitat values during routine work (e.g. gravel addition, pool creation).
	Fisheries Act: Severe cases could be regulated as HADDs, but difficult to apply to cumulative effects. *SARA* provisions protecting residences and designated critical habitat may be applicable.	*Water Act*: Controls water withdrawals but unlicensed pu licenses are very common. *Fish Protection Act* allows licenses to be overridden during drought, water to be reserved for fish needs, and recovery plans for sensitive streams, but powers	*No d* *risdiction*. Can promote water conservation through variety of policies and by-laws (e.g. metering domestic use, development permits, public education, watering restrictions)

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		unlikely to be applied in near future.	
Riffle sedimentation	*Fisheries Act:* Prohibition of addition of deleterious substance to fish habitat	*Waste Management Act:* Prohibitions on the addition of waste into the environment.	and monitoring of construction methods.
	Fisheries Act: Prohibition of addition of deleterious substance to fish habitat.	*Waste Management Act*: Prohibitions on the addition of waste into the environment.	*Development Permit Process*: Control and monitoring of construction methods.
Introduced Predators	*Regulation of International and Interprovincial Trade Act:* Prohibitions on transporting wildlife. Extremely difficult to attribute responsibility.	*Wildlife Act:* Prohibition of transporting wildlife without a permit. Extremely difficult to attribute responsibility.	*No jurisdiction.*
Pesticide/Herbicide Use	Prohibits storage, transport, and use of pesticides in ways that endanger the environment. *Fisheries Act* prohibition of addition of deleterious substances to fish habitat.	storage, transport, disposal and applicator amounts applied. No permits necessary for private residential or agricultural lands. *Waste Management Act*: Contains provisions for hazardous waste disposal.	*Can ban all cosmetic pesticide* use on residential properties *(Spraytech v.* by the provincial *Right to Farm Act from* addressing ALR lands.
	Fisheries Act prohibition of addition of deleterious substances to fish habitat. *SARA* prohibitions for direct harm, and	*Waste Management Act:* Prohibitions on the addition of waste into the environment	*Plans:* Can minimize risk by locating transportation corridors and industrial areas away from streams through zoning bylaws and transportation plans.
Isolation of Population/Subpopulation	projects for HADDs to restore key habitats. Usually dependent on landowner cooperation.	*Fish Protection Act*: Streamside protection policy directives maintain riparian corridors in developing lands. No existing legislation applies to agricultural lands.	riparian continuous riparian corridors during development. No jurisdiction on ALR lands or lands already developed.
Fragmentation Within Watershed	projects for HADDs to restore key habitats. Usually dependent on landowner cooperation.	*Fish Protection Act*: Streamside riparian corridors in developing lands. No existing legislation applies to agricultural lands.	*Development Permits*: Protection of riparian continuous riparian corridors during development. No jurisdiction on ALR lands or lands already developed.

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definitions of 'normal farm practices' in regulations under the *Right to Farm Act* and by subjecting ALR lands to the Streamside Protection Policy Directives under the *Fish Protection Act*. Unfortunately, the provincial Ministry of Agriculture, Food and Fisheries and the Agricultural Land Commission are adamantly opposed to these moves (Erin Stoddard, BC Ministry of Water, Land and Air Protection, pers. comm.). Riparian vegetation declared critical habitat in an approved Recovery Strategy under *SARA* would be protected on all lands.

Nutrient Loading

Existing federal and provincial legislation can deal with identifiable point sources of nutrients, although a chronic shortage of resources does hamper enforcement. Non-point sources, particularly of agricultural origin, are a much larger problem. The province has clearest jurisdiction and regulations for manure storage and timing of application. The major gap is a complete lack of control over quantities of manure and fertilizer spread on farmland. Until the amount of nutrients added to land is linked to the quantity that crops can take up, the problem is likely to worsen (Hans Schreier, UBC, pers. comm.).

Beaver Activity

Beaver ponds appear to represent a habitat tradeoff between Salish sucker and Nooksack dace habitats (see Chapter 6). Riffles constitute critical habitat for Nooksack dace and are destroyed by ponding, yet the ponds provide excellent habitat for Salish sucker. Consequently their removal needs to be considered carefully on a case-by-case basis. When removal of animals or dams is advisable, there are no legislative impediments to taking action. Appropriate permits are obtainable from the province.

Impermeable Surfaces

Although the importance of minimizing impermeable surfaces in urban areas to reducing flooding and maintaining base flows is well understood (Hollis, 1975; Lavkulich et al., 1999), to date most efforts have focused on flood control though storm water detention, which alleviates floods but does little to maintain low flows unless the water is infiltrated to the aquifer. Municipal governments have jurisdiction (through the province) over urban development form within their boundaries but none of the municipalities covered here have policies for limiting impermeable surfaces in new developments. The major control over expansion of impermeable area in the Fraser Valley is, in effect, exercised by the provincial prohibition on urban development on ALR lands.

Drainage/Dyking/Infilling

Direct habitat destruction through these activities is now closely regulated, particularly by the federal government under the *Fisheries Act* and its associated habitat policy. Unapproved dredging and infilling is still relatively common, particularly on agricultural land (pers. obs.), but the problem is a lack of resources for enforcement rather than lack of regulations. There is considerable scope and some progress for restoration of historical damage to habitats through the activities of stewardship groups and habitat compensation projects approved under DFO's Habitat Policy (see *Fisheries Act* above)

Water Withdrawal

Withdrawal of surface water is regulated by the province through a largely dysfunctional licensing system. Most actual withdrawal from streams inhabited by Salish sucker and Nooksack dace appears to be from unlicensed pumps and some existing water licenses are unused (pers. obs.). Absolutely no monitoring occurs beyond ensuring that fees are paid on existing licenses and streams are not assessed for the quantity of water that may be safely removed. Licenses are issued unless objections are received from DFO (Narinder Singh, Land and Water BC, pers. comm.). Provisions in the *Fish Protection Act* to preserve in-stream flows have not been used and are unlikely to be in the foreseeable future due to staff shortages (Erin Stoddard, Ministry of Water, Land and Air Protection, pers. comm.). In short, all of the provisions necessary to address problems are in place, but lack of monitoring, enforcement and tracking renders them ineffective.

Riffle Sedimentation

Direct discharges of sediment to watercourses containing fish are strictly prohibited by both the federal *Fisheries Act* and the provincial *Waste Management Act*. Such events do occur regularly, but lack of enforcement resources prevent detection of many and prosecution of all but the most damaging occurrences in which the odds of securing a conviction are perceived to be very high (Alan Johnston, Fisheries and Oceans Canada, pers. comm.).

Erosion

Excessive bank erosion is common in Fraser Valley streams, particularly in areas lacking adequate riparian vegetation (pers. obs.), but cannot be addressed under existing legislation on private land unless directly caused by human activity. The best remedy for the problem is through restoration of riparian vegetation (see above).

Introduced Species

Both the federal and provincial governments have enacted legislation that effectively prohibits introductions of non-native species. Enforcement, however, is extremely difficult given the low chances of attributing blame. Public education on the risks to native fish stocks, particularly the salmonids prized by the sports fishing community, are likely to be most effective preventative measures. Eradication of introduced species, once established, is generally not possible.

Pesticide/Herbicide Use

Both the federal and provincial governments have enacted legislation to control pesticide use. The federal act applies universally and prohibits uses that endanger the environment. The provincial legislation exempts private agricultural and residential lands from many of its provisions, but does prohibit spraying in natural water bodies. Again, the legislation is present, but enforcement is relatively weak due to lack of resources. A Supreme Court of Canada decision in 2001 (*Spraytech v. Town of Hudson*) established that municipalities have the right to control or ban cosmetic use of pesticides, but none of the four local governments examined in this study is currently contemplating such a move.

Toxic Spills

Toxic spills are rare, low risk events but their potentially devastating consequences make them a concern. I have not reviewed in detail legislation designed to reduce the threat of toxic spills. Hazardous materials storage, disposal and transport practices, road design, and the location of transportation corridors all have influence, and are all regulated by one or more levels of government. Enforcement of these regulations is also likely to be stricter than for any other of the drivers and triggers examined because of the strong human health interests involved.

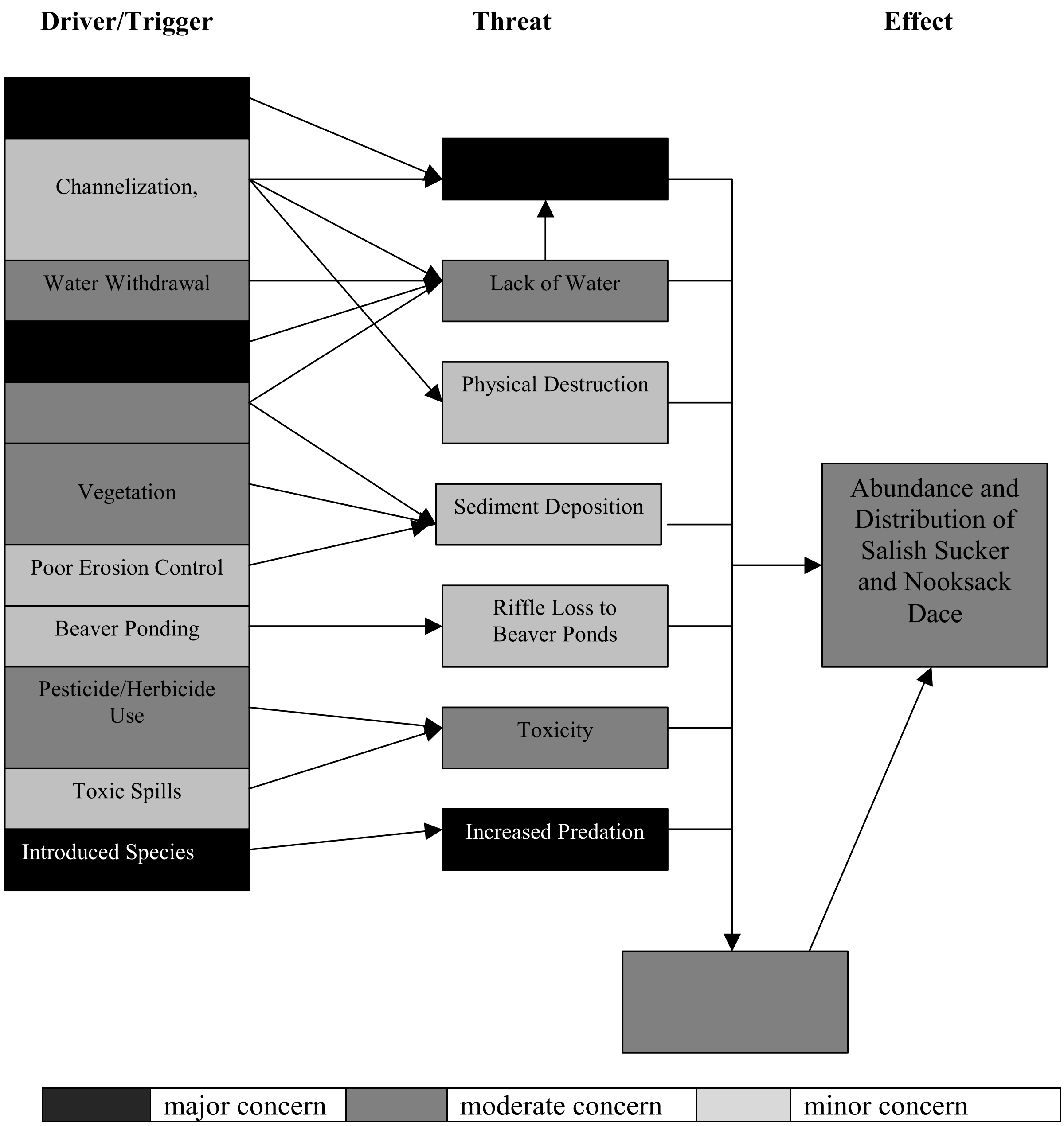
Isolation of Population/Subpopulation and Fragmentation Within Watersheds

The major challenge in addressing these issues is the large spatial scale on which they occur. Many of the provisions in existing legislation can be applied to restoring or improving connectivity within and between watersheds (e.g. habitat compensation projects), but to be effective they need to be applied within the context of watershed and regional scale plans. To date, these plans have not been developed, although the Township of Langley's Integrated Stormwater Management Plans may provide one such framework. Similarly DFO, in partnership with the City of Chilliwack, has commissioned a watershed scale restoration plan for Salwein Creek (Matt Foy, Fisheries and Oceans Canada, pers. comm.).

Tractability of Threats

Combining ratings of the drivers and triggers resulted in the identification of two threats of major concern with respect to tractability, hypoxia and increased predation (Fig 7.2). In the case of hypoxia the result stems from the inability to limit agricultural nutrient loading to lands under existing legislation and policy. In contrast the introduction of predators is clearly contrary to both federal and provincial legislation. The problem stems from the near impossibility of enforcing it effectively or of addressing the problem once it has occurred. Toxicity, stream lack of water and habitat fragmentation appear moderately difficult to address. In the case of toxicity, lack of source control over quantities of pesticides/herbicides and urban runoff contamination complicate prevention. Lack of water problems are difficult to address under the dysfunctional provincial water licensing system and due to the natural susceptibility of some watersheds due to surface soil characteristics. The difficulty in addressing habitat fragmentation is due to the large spatial scales on which it occurs and the dependence on the cooperation of owners of linking habitats. The other threats can be easily addressed through existing legislation and policy, although in some cases (e.g. illegal drainage works) better enforcement would improve matters further.

Figure 7.2: Tractability of threats to Salish sucker and Nooksack dace based on an analysis of the ability of existing legislation, policy and programs to address the factors driving and triggering threats.



CONCLUSIONS

Federal Government

The federal government has enacted a powerful array of legislation with application to protecting aquatic species at risk. Together the *Fisheries Act*, the *Species at Risk Act (SARA),* and the *Canadian Environmental Assessment Act*, could be used to restore long-term viability to all Salish sucker and Nooksack dace populations. Whether or not they are is largely a matter of political will. The history of habitat protection through enforcement of *Fisheries Act* provisions over the past 25 years has been patchy at best. Its compensation requirements and enforcement of prohibitions have both been criticized (Kistritz 1996, Cudmore-Vokey et al. 2000, Minns and Moore 2003).

At present it is difficult to say what the impacts of *SARA* will be. The first prohibitions are just coming into effect, no recovery strategies or action plans have been approved under the *Act,* and details of important policies around landowner compensation and exemption permits have yet to be made public. A Recovery Team has been formed and is working on development of strategies and plans and the federal government is devoting resources to stewardship initiatives for both species. It does seem likely, however, that enforcement of *SARA* prohibitions, including those protecting critical habitat, will suffer from the same resource starvation that hampers the effectiveness of the *Fisheries Act*.

Provincial Government

The Province also has a fairly powerful set of legislative tools enabling them to protect Salish sucker and Nooksack dace, but has frequently failed to develop effective policies under them. The one major gap in legislation is the lack of control over quantities of nutrients added to agricultural lands. Major gaps in policy include the omission of Salish sucker and Nooksack dace (and virtually all other species at risk) from the legal list under the *Wildlife Act*, the exclusion of lands in the Agricultural Land Reserve from the Streamside Protection Policy Directives of the *Fish Protection Act*, and the failure to designate Salish sucker and Nooksack dace streams as Sensitive under the *Fish Protection Act* (which among other things could be used to protect in-stream flows). Another grave concern is the dysfunctional nature of the provinces water licensing system. A complete inventory of licensed and unlicenced water use and assessment of each stream's ability to support further water withdrawals is necessary at minimum. Enforcement of existing legislative prohibitions is also very weak due to lack of enforcement resources.

Municipal Governments

The four municipalities included in this study varied widely in the level of protection they afford fish habitat, although all had significant gaps. The Township of Langley, has very little in terms of policy, but has a number of very progressive inventory and public education programs established. The Cities of Abbotsford and Chilliwack have much more environmental policies and language in their Official Community Plans, but acted on very few of their policies. The District of Kent lacks any significant environmental provisions in its by-laws and plans and has taken little action. Inventories of fish habitat, the most basic information necessary to avoid impacts on fish habitat, is complete in Langley, well underway in Chilliwack and Kent, but almost non-existent in Abbotsford. None of the municipalities have Environmentally Sensitive Areas designate in its Official Community Plan. Drainage maintenance (ditch cleaning) is perhaps the most direct impact that municipalitities have on fish habitat. Chilliwack's pilot project of hand maintenance (as opposed to machine cleaning) appears to be very promising development. Hopefully it will be emulated in the other jurisdictions.

RECOMMENDATIONS

Federal Actions

- Increase resources applied to enforcement of the *Fisheries Act* and *SARA*
- Utilize compensation projects required in authorizations under section 32 of the *Fisheries Act* to enhance or restore Salish sucker and Nooksack dace habitats.
- Increase resources devoted to stewardship initiatives to aquatic species at risk
- Devote resources to public education on the potential impacts of introduced species.

Provincial Actions

- List Salish sucker and Nooksack dace as endangered species under the *Wildlife Act*

- Designate all Salish sucker and Nooksack dace streams as 'Sensitive' under the *Fish Protection Act*
- Ensure that future water licence applications are refused by applying water license restrictions under the *Water Act* to Bertrand Creek, Agassiz Slough, and Miami Creek.
- Revamp the water licensing system to ensure protection of adequate instream flows.
- Enact legislation that limits the amount of nutrient addition to agricultural lands to that which plants can absorb.
- Revise the *Fish Protection Act's* Streamside Protection Policy Directives to include lands within the Agricultural Land Reserve
- Develop a model by-law for local governments that restricts impermeable area in new developments.
- Devote resources to public education on the potential impacts of introduced species.

Municipal Actions

Township of Langley

- Update Official Community Plan to include environmental goals and objectives and delineations of Environmentally Sensitive Areas
- Adopt a gentle (hand) maintenance program for ditches if the City of Chilliwack's pilot program is successful
- Develop and adopt by-laws for tree protection and watercourse protection

City of Abbotsford

- Complete inventory of fish bearing watercourses
- Adopt a gentle (hand) maintenance program for ditches if the City of Chilliwack's pilot program is successful
- Develop a comprehensive water resources management plan
- Increase partnerships and financial support for local stream stewardship organizations.
- Develop and implement public education programs on environmental stewardship.

City of Chilliwack

- Complete inventory of fish bearing watercourses

- Increase partnerships and financial support for local stream stewardship organizations.
- Develop a comprehensive water resources management plan
- Develop and implement public education programs on environmental stewardship.

District of Kent

- Update Official Community Plan to include environmental goals and objectives and delineations of Environmentally Sensitive Areas
- Complete inventory of fish bearing watercourses
- Develop a comprehensive water resources management plan
- Adopt a gentle (hand) maintenance program for ditches if the City of Chilliwack's pilot program is successful
- Increase partnerships and financial support for local stream stewardship organizations.
- Develop and implement public education programs on environmental stewardship.

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Chapter 8

Conclusions: Prospects For Recovery

INTRODUCTION

The prospects for recovery of a species at risk depend upon its vulnerability to the threats facing it, their ubiquity across its range and on how readily those threats can be overcome or addressed (how tractable they are). In the preceding chapters all of these factors have been assessed for Salish sucker and Nooksack dace. I studied their life history and habitat requirements and used the information to assess their vulnerability to eight hypothesized threats. The presence and severity of each threat in all of their native watersheds within Canada was then evaluated. Finally I critically reviewed the legislative and policy options available and evaluated the tractability of each threat in the current regulatory and policy context. In this final chapter I summarize the major findings and use them to assess the potential for recovery of both species.

PROSPECTS FOR RECOVERY

Salish Sucker

Salish sucker populations appear to be most vulnerable to habitat loss through drainage, dyking and infilling activities, acute hypoxia in critical habitats during late summer, and introduced predators (Chapter 6). Two of these threats, hypoxia and physical destruction of habitat, occur very commonly within the range (Table 8.1). Hypoxia is also very difficult to address in the current regulatory and policy context suggesting that it is the single largest threat facing the species.

Physical destruction of habitat, although a serious widespread threat, is relatively easy to address through existing legislation, habitat restoration and/or public acquisition of critical habitat. Restored sites should be located near reaches with moderate to high densities of Salish sucker (Chapter 3) and in areas where connections between existing populations or subpopulations will be enhanced (Chapter 6). The available data suggest that Salish suckers will colonize and thrive in restored habitats (Patton, 2003, Pearson unpubl.).

Introduced predators are considered a major threat because of their ubiquity across the Canadian range, the likelihood of their sharing habitat with Salish suckers, and their documented impacts on other species (Chapter 6). The threat of future introductions is also

Table 8.1: An overview assessment of threats to Salish sucker and Nooksack dace. Vulnerability and prevalence assessments are derived from Tables 6.3 and 6.5 respectively. Tractability assessments are from figure 7.2.

Salish Sucker	Vulnerability	Severity	Tractability
Hypoxia	+++	+++	+++
Lack of water	+	++	++
Physical Destruction of Habitat	+++	+++	+
Riffle Loss to Beaver Ponds	+	+	+
Sediment Deposition	++	++	+
Introduced Predators	++	++	+++
Toxicity	++	++	++
Habitat Fragmentation	++	++	+

Nooksack Dace	Vulnerability	Severity	Tractability
Hypoxia	+	++	+++
Lack of Water	+++	+++	++
Physical Destruction of Habitat	+++	+++	+
Riffle Loss to Beaver Ponds	+++	++	+
Sediment Deposition	+++	++	+
Introduced Predators	++	++	+++
Toxicity	++	++	++
Habitat Fragmentation	++	++	+

+++	major concern	++	moderate concern	+	minor concern

very difficult to address through legislation and policy because of the difficulty in attributing responsibility (Chapter 7). Research on the impacts of introduced predators on Salish sucker populations and an aggressive public education program aimed in particular at recreational fishers are likely to be the most effective tactics in addressing with the problem.

Habitat fragmentation is currently considered a moderate threat to Salish sucker, but is also poorly understood (Chapter 6). Detailed research on its impacts is likely to be expensive and perhaps inconclusive. The best strategy is likely to assume that it is important, try to minimize future fragmentation and to attempt to improve connectivity through strategic placement of restoration projects. Sediment deposition and toxicity (in the form of contaminated sediments) appear to be major threats in particular watersheds, but do not threaten the species on a range-wide scale. Both are reasonably tractable when problematic using existing legislation and policy (Chapter 7).

Nooksack Dace

Nooksack dace are considered most vulnerable to lack of water, habitat loss to drainage activities, sediment deposition and riffle loss to beaver ponds (Table 8.1). Of these threats, lack of water and habitat loss are most prevalent within their range and lack of water is the less tractable. The difficulty in addressing lack of water is a product of the impossibility of addressing one its most important drivers, surface soil composition of the watershed, and of a dysfunctional provincial water licensing system (Chapter 7). Given that lack of water is a major concern in the reaches of Bertrand Creek containing an estimated 70% of the Canadian population, it ranks as the most pressing threat to the species.

Introduced predators are widespread in the range and very difficult to address (see comments above), but seem less likely to impact Nooksack dace than Salish sucker at present because of less potential for habitat overlap with those species currently established (Chapter 7). The impacts of habitat fragmentation on Nooksack dace are not well understood and a similar strategy to that recommended for Salish sucker (see above) seems prudent.

Riffle loss to beaver ponds is a major concern in Pepin Brook, but not in Bertrand Creek or Fishtrap Creek, and is relatively easy to remedy if monitoring shows that impacts are unacceptable. Hypoxia, sediment deposition and toxicity are significant threats in some sections of at least one watershed, but do not threaten the species throughout its range.

Conclusion

Both Salish sucker and Nooksack dace face a number of pressing threats, some of which will be difficult to fully address with the tools currently available. Many of threats, however, can be well addressed with the available regulatory and policy tools, given a modest amount of political will and public education and support. Those threats that are difficult to address through regulation are probably best approached through education and stewardship projects spearheaded by local groups. The recovery planning process mandated by the new federal *Species at Risk Act* provides a framework and some political impetus for this to occur and provides some optimism that populations of both species will survive into the long term.

LITERATURE CITED

Patton, T. M. 2003. Evaluation of the Salish creek mitigation project. M. Sc. Thesis, Resource Management and Environmental Studies, University of British Columbia, Vancouver.

Appendix 1

Assessment Tables and Provincial Water Quality Data Used in Watershed Assessments

Table A1-1: Bertrand Creek assessment.

Impact Hypothesis	Drivers/Triggers and Indicators
Hypoxia Hypothesis (Moderate concern)	*Dissolved Oxygen*: Mid and late summer dissolved DO in the middle reaches were below $5 mg \cdot l^{-1}$ in some years. Those in the lower reaches always exceeded this (Fig. A1-1; Moderate concern) *Lack of riparian vegetation*: Although much of the stream is moderately shaded by a narrow strip of riparian vegetation, large portions of the middle reaches, where Salish sucker appear to be concentrated lack it completely (Fig. 6.1; Moderate concern) *Nutrient loading*: Fecal coliform levels regularly exceed levels recommended for aquatic life but nitrate and ammonia are levels are within provincial and federal guidelines in the upper and lower reaches (Fig. A1-1). Approximately 66 percent of the watershed is in agriculture. (Moderate concern) *Hydrograph*: see below (Major concern) *Beaver activity*: see below (Minor concern)
Lack of Water Hypothesis (Major concern)	*Hydrograph*: Discharge is extremely variable (Table 6.4). Channel altering floods and extremely low flows occur annually. Surface flows cease in most of the watershed during dry summers. *Soils*: Impermeable glaciomarine clays are overlain by thin gravel in 75% of the watershed. A tributary, Howe's Creek, drains the remaining portion. It is perched on the edge of a moraine and loses water through the gravel to neighbouring Pepin Brook (Johanson, 1988). (Major concern) *Impermeable surfaces*: Approximately 10% of the watershed is urbanized (Moderate concern) *Physical Destruction of Habitat*: see below (Moderate concern) *Water withdrawal*: Irrigation accounts for 97% of permitted annual removals ($307,000 m^3$). The four-month FRP of $0.029\ m^3 \cdot s^{-1}$ is equivalent to mean summer flow and nearly double the 5-year minimum daily flow (Table 6.4). Unpermitted pumping is common. (Major concern)
Drainage/Dyking/ Infilling Hypothesis (Moderate concern)	*Physical Destruction of Habitat*: The watershed is 9% urban and 66% agricultural. Major impacts were historically common. Some continue on smaller tributaries and ditches. A 2 km long marsh that contained 'suckers' at the headwaters of Cave Creek was drained in the 1960s (Pearson, 1998a). (Moderate concern)
Sedimentation Hypothesis (Minor concern)	*Riffle condition*: Most riffle substrate in Bertrand Creek is loose gravel. Fines are flushed from the system during high winter flows. (Minor concern) *Erosion*: Localized areas of erosion and bank failure are common in

	areas lacking riparian vegetation and contribute unknown quantities of sediment to the channel (Pearson, 1998a). Most of the erosion occurs during high flow events and little material is deposited on the substrate. (Minor concern) *Impermeable surfaces*: The watershed is approximately 9% urban. Some sediment deposition from storm drains occurs in upper reaches during long lapses between major storms. (Moderate concern)
Riffle Loss to Beaver Pond Hypothesis (Minor concern)	*Beaver activity*: Beaver are present, and influence the middle and upper reaches. Impact is limited as dams are washed out regularly in winter floods or are removed by landowners. The availability of deciduous trees in the riparian zone is limited (Minor concern)
Introduced Predator Hypothesis (Moderate concern)	*Introduced Predators*: Brown bullhead, pumpkinseed and bullfrog populations are established in reaches containing Salish sucker (Pearson, 1998b). (Moderate concern)
Toxicity Hypothesis (Moderate concern)	*Impermeable surfaces*: The watershed is 9% urban. Storm sewer systems from the town of Aldergrove drain directly into the upper reaches. (Moderate concern) *Pesticide/herbicide use*: The watershed is 66% agricultural, but relatively little row cropping occurs near the creek. (Moderate Concern) *Toxic spills*: At least ten bridges or culverts in the town of Aldergrove, including the Fraser Highway, cross Bertrand Creek. The main route between Highway 1 and the Aldergrove Border Crossing also crosses it (Fig. A1-1). (Moderate concern)
Habitat Fragmentation Hypothesis (Major concern)	*Isolation*: It is possible, but unlikely, that there are significant populations of either species in the Washington State portion of the creek, as there is little suitable habitat (McPhail, 1997). Headwater connections to the Upper Salmon occur occasionally at high water, but have not been assessed for ease of passage. Periodic links to the Little Campbell though Cave Creek also occur during winter. (Major concern) *Internal fragmentation*: Low flows, beaver dams, and seasonal hypoxia all likely fragment the reaches containing Salish suckers to greater or lesser extents. (Moderate concern)

Figure A1-1: Seasonal water quality measurements in Bertrand Creek at 8th Avenue (lower reaches) and at 272nd Street (middle reaches). The complete available record (1971-2002) is shown. Black dots indicate data more recent than 1998. Horizontal dashed lines indicate federal water quality guidelines for the protection of freshwater aquatic life. Sampling locations are shown on figure 6.4. Data are from the Land and Water BC database (http://wlapwww.gov.bc.ca/sry/p2/eq/wat_qual_data/index.html) and were not collected in all years.

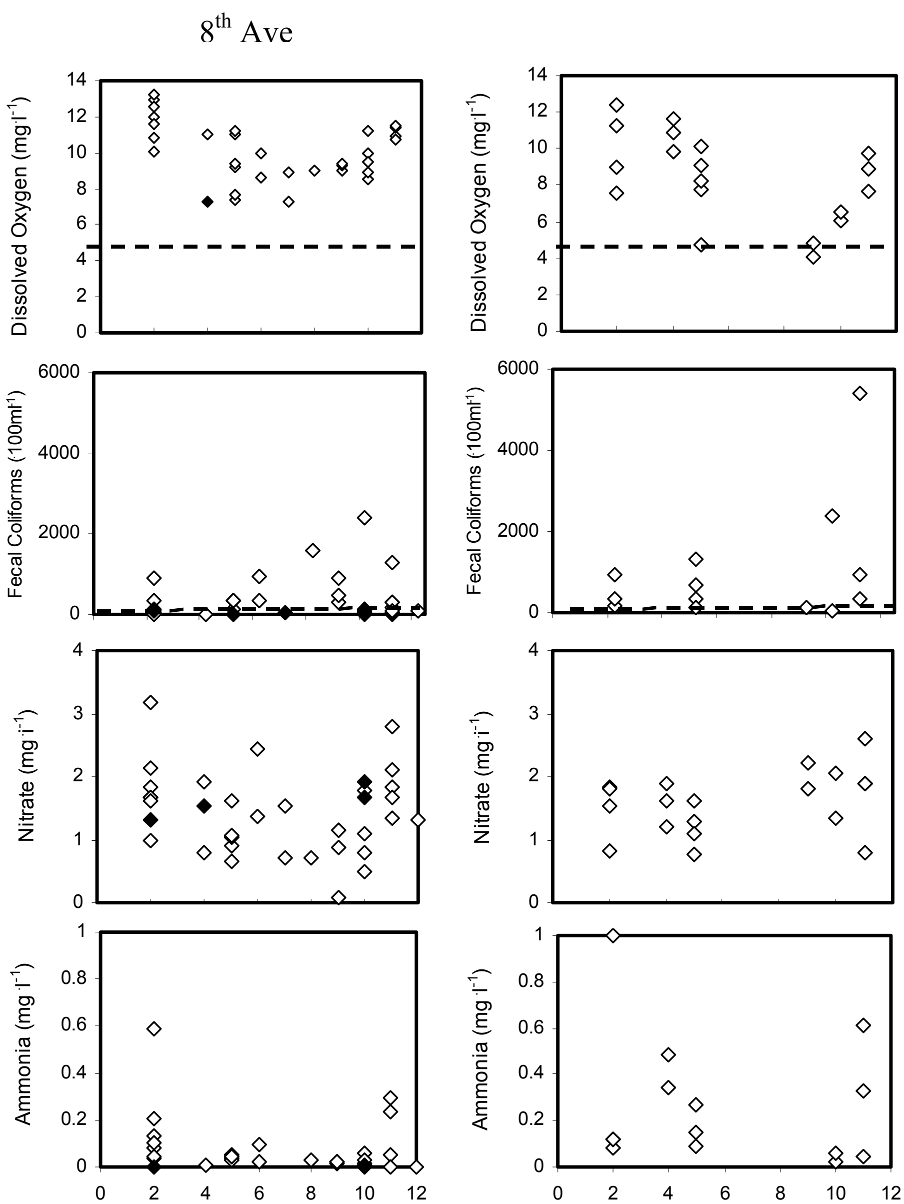


Table A1-2: Pepin Brook Assessment.

Impact Hypothesis	Drivers/Triggers and Indicators
Hypoxia Hypothesis (Major concern)	*Dissolved Oxygen*: Severe late summer hypoxia affected at least half of the creek's length during the summer of 2003. A marsh was that had previously supported over 1000 Salish sucker was virtually anoxic and devoid of fish between June and September (Krista Payette, MWLAP and Pearson unpubl. data). (Major concern) *Lack of riparian vegetation*: Most the creek is flanked by a wide belt of mature riparian forest. In the lower reaches, which flow through Aldergrove Lake Regional Park, this is secure, but substantial losses to gravel mining are occurring in the middle and upper reaches. (Minor concern) *Nutrient loading*: Nutrient sampling at four locations in the watershed was completed in summer and fall of 2003 and will soon be available (Krista Payette, MWLAP pers. comm.). Approximately 55% of the watershed is in agriculture. (Major concern) *Hydrograph*: see below (Minor concern) *Beaver activity*: see below (Major concern)
Lack of Water Hypothesis (Moderate concern)	*Hydrograph*: Strong base flows are maintained by groundwater throughout the watershed (Table 6.4s). (Minor concern) *Soils*: The watershed occupies a glacial moraine (Johanson, 1988). Its deep gravel deposits have been mined heavily for 20 years and will continue for some time to come. Seventeen percent of the watershed was being actively mined in 1999. The long-term impacts of extraction on base flow are unknown but may be significant. (Minor concern) *Impermeable surfaces*: The watershed is 1.5% urban. (Minor concern) *Physical Destruction of Habitat*: see below. (Major concern) *Water withdrawal*: Approximately 75% of the 657,000 m^3/year permitted is licensed for gravel processing. The four-month FRP of 0.030 $m^3 \cdot s^{-1}$ is less than 10% of base flow and one third of the 5-year minimum daily flow (Table 6.5). (Minor concern)
Drainage/Dyking/ Infilling Hypothesis (Major concern)	*Physical Destruction of Habitat*: Major impacts were historically common and continue. More than 200 m of wetland in the upper reaches were in-filled without a permit to improve cattle pasture (1997-2001). A headwater marsh on a tributary, Perry Homestead Creek, has been damaged by ongoing excavation since 2000. (Major concern)

Sedimentation Hypothesis (Major concern)	*Riffle Condition*: A direct sediment discharge from a gravel pit in the upper reaches deposited more than 100 cm of sediment in the channel for a distance of more than 500 m (as of 1999). This material has obliterated the area's fish habitat. Complaints from neighbours and biologists have prompted two investigations since 1990, but no charges have been laid. The mine has since expanded. In contrast, direct discharge of sediment from a tributary flowing through the gravel mine of Columbia Bitulithic Ltd was stopped in 1999 when the company constructed the Salish Creek mitigation project in cooperation with graduate students and a local streamkeepers group. It has since been colonized by both species (Patton, 2003 and unpubl.).(Major concern) *Erosion*: Bank erosion is minimal as most riparian zones are in excellent condition. (Minor concern) *Impermeable surfaces*: The watershed is 1.5% urban. (Minor concern)
Riffle Loss to Beaver Pond Hypothesis (Major concern)	*Beaver activity*: Beaver moved into the upper reaches in the late 1960s and have expanded rapidly in recent years (Pearson, 1998a). In 2001 their dams impounded 58% of channel length; up from 47% in 1999. There scope for further expansion is probably limited by conflict with human activities and a lack of suitable sites.
Introduced Predator Hypothesis (Moderate concern)	*Introduced predators*: Largemouth bass, brown bullhead and bullfrogs are all established in the system (Pearson, 1998b, and unpubl.). (Moderate concern)
Toxicity Hypothesis (Minor concern)	*Impermeable surfaces*: The watershed is only 1.5% urban. (Minor concern) *Pesticide/herbicide use*: The watershed is 56 % agricultural, but little row cropping occurs near the creek. (Minor concern) *Toxic spills*: There are very few road crossings and most carry only local traffic. Huntington Road (8th Avenue) is heavily used by gravel trucks. The main route between Highway 1 and the Aldergrove Border Crossing crosses Perry Homestead Creek. An upgrading of the 16th Ave crossing to improve access to Abbotsford Airport has been discussed. (Minor concern)
Habitat Fragmentation Hypothesis (Moderate concern)	*Isolation*: The Washington State portion of the creek is confined to roadside ditches until it enters Fishtrap Creek a few km south of the border. Fish may occasionally move between these systems. (Moderate concern) *Internal fragmentation*: Seasonal hypoxia and beaver dams fragment habitat for parts of the year. (Moderate concern)

Table A1-3 Fishtrap Creek Assessment.

Impact Hypothesis	*Drivers Triggers and Indicators*
Hypoxia Hypothesis (Moderate concern)	*Dissolved Oxygen:* Sever hypoxia (<3 $mg \cdot l^{-1}$) occurs in some headwater reaches in late summer (Pearson unpubl.), but the middle and lower reaches appear well oxygenated (Fig. A1-2). (Minor concern) *Lack of riparian vegetation:* Most of the stream lacks adequate cover. (Major concern) *Nutrient loading:* Dissolved nitrate and ammonia concentrations are within provincial and federal guidelines, but fecal coliform counts frequently exceed those recommended for aquatic life (Fig. A1-2). Over 70% of the watershed is agricultural, much of it in commercial berry farms. (Moderate concern) *Hydrograph:* see below (Moderate concern) *Beaver activity:* see below (Minor concern)
Lack of Water Hypothesis (Moderate concern)	*Hydrograph:* Moderate base flows continue to be maintained by groundwater in the lower reaches (Table 6.5), but the discharge is critically low in the headwaters during dry periods. (Moderate concern) *Soils:* Thick gravel deposits underlie most of the watershed, but the surface soils of the north-east quarter are low-permeability glacio-marine tills (Johanson, 1988). Large-scale gravel extraction is beginning on the western edge of the watershed. Its long-term impacts on base flow are unknown.(Moderate concern) *Impermeable surfaces:* Approximately 18 percent of the watershed is urbanized, primarily in the headwater reaches (Fig. 6.6). (Moderate concern) *Physical Destruction of Habitat:* see below (Major concern) *Water withdrawal:* Approximately 99% of the 293,000 m^3/year permitted for withdrawal is licensed for irrigation. The four-month FRP of 0.034 $m^3 \cdot s^{-1}$ is approximately one tenth of mean summer discharge (Table 6.5). (Minor concern).
Drainage/Dyking/ Infilling Hypothesis (Major concern)	*Physical Destruction of Habitat:* Major impacts were historically common and some continue to occur on smaller tributaries and ditches. The Municipality of Abbotsford dredged the entire length of the lower reaches in 1990-1991 to control flooding on adjacent lands. (Major concern)
Sedimentation Hypothesis (Moderate concern)	*Riffle condition:* Some riffles, especially in the middle reaches are compacted with sediment (Pearson, 1998a). (Moderate concern)

	Erosion: Localized areas of erosion and bank failure are common in areas lacking adequate riparian vegetation. They contribute unknown quantities of sediment to the channel. Gravel mining is expanding in the western portion of the watershed, increasing the risk of major erosion events. (Moderate concern) *Impermeable surfaces:* The watershed is approximately 18% urban. Sediment deposition from storm drains occurs in headwater riffles during long lapses between major storms. (Moderate concern)
Riffle Loss to Beaver Pond Hypothesis (Minor concern)	*Beaver activity:* Beaver are present, and have impounded portions of the middle reaches. Their impact is limited as dams are washed out regularly in winter floods and the riparian zone contains little deciduous tree cover (see Chapter 5).
Introduced Predator Hypothesis (Moderate concern)	*Introduced Predators:* Brown bullhead, pumpkinseed, black crappie, largemouth bass and bullfrog are all established in the system (Pearson unpubl, FISS database). (Moderate concern)
Toxicity Hypothesis (Major concern)	*Impermeable surfaces:* The watershed is 18% urban. Stormwater from the Town of Clearbrook drain into two headwater tributaries (Enn's Brook and East Fishtrap Creek). The latter was converted to a 1.5 km long stormwater treatment wetland around 1990. (Moderate concern) *Pesticide/herbicide use:* The watershed is 70% agricultural, most of which is row cropping of berries. (Moderate concern) *Toxic spills*: The creek is crossed by at least 10 public bridges and culverts, by Highway 1 and by the Fraser Highway. Abbotsford International Airport is located on beside the middle reaches. An industrial park occupies land south of Highway 1. (Moderate concern)
Habitat Fragmentation Hypothesis (Moderate concern)	*Isolation*: Pepin Brook enters Fishtrap Creek in Lynden, several km south of the Washington border. Migration between the populations is possible, but habitat in the American portion of the creeks is degraded (McPhail, 1997). (Moderate concern) *Internal fragmentation*: Low flows, seasonal hypoxia, hanging culverts and/or beaver dams fragment habitat for at least parts of the year.(Moderate concern)

Figure A1-2: Seasonal water quality measurements in Fishtrap Creek at Echo Road. Horizontal dashed lines indicate federal water quality guidelines for the protection of freshwater aquatic life. Nitrate and ammonia levels were within guidelines in all samples. Sampling location is shown on figure 6.8. The complete available record (1971-1979) is shown. Data and were not collected in all year and are from the Land and Water BC database (http://wlapwww.gov.bc.ca/sry/p2/eq/wat_qual_data).

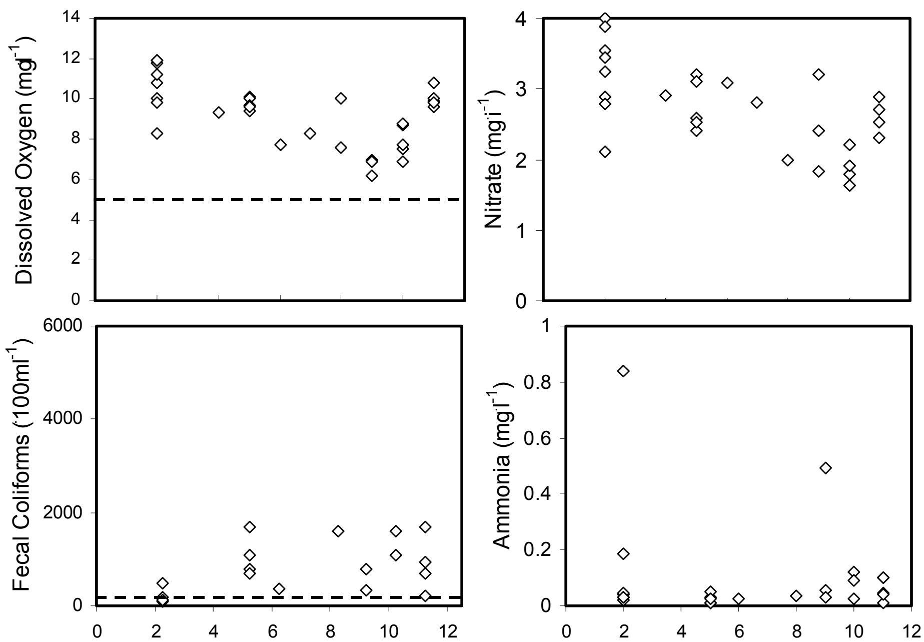


Table A1-4: Upper Salmon River Assessment.

Impact Hypothesis	*Drivers Triggers and Indicators*
Hypoxia Hypothesis (Major concern)	*Dissolved Oxygen:* Severe hypoxia (<3mg·l^{-1}) was recorded in the middle reaches during August and September of 2001. Several suckers asphyxiated in traps there during this period (Pearson unpubl.).(Major concern) *Lack of riparian vegetation:* Riparian vegetation is patchy. Some reaches flow through forest and others lack woody vegetation altogether. (Major concern) *Nutrient loading:* Approximately 60% of the watershed is in agriculture. (Moderate concern) *Hydrograph:* see below. (Major concern) *Beaver activity*: see below (Minor concern)
Lack of Water Hypothesis (Major concern)	*Hydrograph:* No flow records are available, but surface flows cease in the middle and upper reaches during late summer. (Major concern) *Soils:* Thin gravel deposits overlie impermeable glaciomarine clays (Johanson, 1988). (Major concern) *Impermeable surfaces:* This portion of the watershed is not urbanized. (Minor concern) *Physical Destruction of Habitat:* see below. (Moderate concern) *Water withdrawal:* An uncertain amount is pumped, but any significant volumes are likely to have impacts given the very low late summer flows. (Moderate concern)
Drainage/Dyking/ Infilling Hypothesis (Moderate concern)	*Physical Destruction of Habitat:* Major impacts were historically common. Some continue on smaller tributaries and ditches. (Moderate concern)
Sedimentation Hypothesis (Moderate concern)	*Riffle sedimentation:* Riffles in the upper and middle reaches are compacted.with sediment. Those in the lower reaches are less so (Moderate concern) *Erosion:* Localized areas of erosion and bank failure occur in areas lacking adequate riparian vegetation. They contribute unknown quantities of sediment to the channel.(Moderate concern) *Impermeable surfaces:* The watershed contains no urban land. (Minor concern)
Riffle Loss to Beaver Pond Hypothesis (Moderate concern)	*Beaver activity*: Beaver are present, and their ponds most of the standing water in the middle reaches in late summer (Minor concern)

Introduced Predator Hypothesis (Minor concern)	*Introduced Predators:* Bullfrogs, but no introduced fish were caught despite intensive trapping in 2000 and 2001 (Pearson unpubl.). (Minor concern)
Toxicity Hypothesis (Minor concern)	*Impermeable surfaces:* see above (Minor concern) *Pesticide/herbicide use:* The watershed is 59% agricultural, little of which is row cropping. (Minor concern) *Toxic spills*: There are few road crossings and most carry only local traffic. The main route between Highway 1 and the Aldergrove Border Crossing (264th Avenue) crosses the middle reaches. (Minor concern)
Habitat Fragmentation Hypothesis (Moderate concern)	*Isolation*: The presence of other subpopulations in major tributaries of the Salmon River (i.e. Davidson and Coghlan Creeks) is possible, but unconfirmed. Lone fish are occasionally caught downstream of the ravine (Matt Foy, DFO pers. comm., Pearson unpubl.), but it's gradient probably limits immigration. A high water connections with a tributary of Bertrand Creek occurs on the national defense lands (Fig. 6.8), but it has not been assessed for barriers. (Moderate concern) *Internal fragmentation:* Low flow, seasonal hypoxia, and beaver dams fragment habitat for parts of the year. (Moderate concern)

Table A1-5: Salwein and Hopedale Slough Assessment.

Impact Hypothesis	*Drivers, Triggers and Indicators*
Hypoxia Hypothesis (Minor concern)	*Dissolved Oxygen:* Dissolved oxygen is likely near saturation in most areas due to cold temperatures and steady groundwater fed flows, although some headwater reaches should be checked. (Minor concern) *Lack of riparian vegetation:* Both creeks are forested along parts of their length, large sections, particularly in Salwein Creek lack native riparian vegetation altogether (Fig. 6.9). (Moderate concern) *Nutrient loading:* No water quality data is available. Over 90% of the Salwein and 55% of the Hopedale Slough watersheds are in agriculture.(Moderate concern) Hydrograph: see below. (Minor concern) *Beaver activity:* (see below) (Minor concern)
Lack of Water Hypothesis (Minor concern)	*Hydrograph:* No discharge records are available but flows are adequate in all seasons in most areas. Surface flow ceases in Street Creek during dry summers. (Minor concern) *Impermeable surfaces:* The watersheds contain no urban lands. (Minor concern) *Physical Destruction of Habitat:* see below. (Major concern) *Water withdrawal:* No licenses are listed for Salwein Creek on the Land and Water BC database. Street Creek has a single domestic water license listed (1,650 $m^3 \cdot yr^{-1}$). (Minor concern) *Soils:* Complex fluvial soils underlie both watersheds. Both permeability and water tables are very high. (Minor concern)
Drainage/Dyking/ Infilling Hypothesis (Major concern)	*Physical Destruction of Habitat:* The majority of the length of these creeks is channelized and Salwein Creek is largely confined to roadside ditches (Fig. 6.9). The creeks are former tributaries to Sumas Lake, which was shallow, marshy, varied in size from 32 to over 100 km^2 depending on the level of the Fraser River. It was drained completely in 1920 (Woods, 2001). Until 2002 the City of Chilliwack dredged portions of both Creeks for flood control on a four-year rotation. In Salwein Creek, they have started an experimental hand-cleaning program with promising early results. In this 'gentle maintenance' approach, crews remove most vegetation, but leave some cover for fish. Early indications are that this will significantly reduce the frequency with which dredging is required (P Heidy, City of Chilliwack pers. comm). (Major concern)

Sedimentation Hypothesis (Minor concern)	*Riffle condition:* Sediment accumulates during low flow periods but is removed from most riffle areas by high flows and salmon spawning (John Kupp, Chilliwack, pers. comm). (Minor concern*)* *Erosion:* Localized areas of erosion and bank failure occur where adequate riparian vegetation is lacking. (Minor concern) *Impermeable surfaces:* see above (Minor concern)
Riffle Loss to Beaver Pond Hypothesis (Minor concern)	*Beaver activity:* Beaver have impounded a significant, but unmeasured amount of habitat (John Kupp, Chilliwack, pers. comm.). (Minor concern)
Introduced Predator Hypothesis (Moderate concern)	*Introduced Predators:* Brown bullheads are established in a large pond in the lower reaches of Salwein Creek. Peak summer water temperatures the rest of the creek, however, are low (<15C) which may reduce impacts of warm-water predators like bullheads. (Moderate concern)
Toxicity Hypothesis (Moderate concern)	*Impermeable surfaces*: see above. *Pesticide/herbicide use:* The Salwein watershed is over 90% agricultural. The Hopedale Slough watershed is 57% agricultural. (Moderate concern) *Toxic spills*: The roads of these watersheds carry only local traffic and Hopedale Slough is crossed in only two places. Salwein Creek runs in ditches, parallel to road and railroad, for most of its length, increasing the risk of spills. Salwein Creek flows through a former military base just before entering the Vedder. A large pond on the property was used for bridge building exercises and its banks are reinforced with creosote-treated logs. (Moderate concern)
Habitat Fragmentation Hypothesis (Major concern)	*Isolation*: Salwein Creek and Hopedale Slough enter the Vedder River within 1 km of one another. Salish sucker movement between them may occur, but its frequency is unknown. Connections between these creeks and those of the Atchelitz/Chilliwack/Semmihault drainages were severed when the Chilliwack delta was drained ca. 1875 (Woods, 2001). (Major concern) *Internal fragmentation:* Beaver dams fragment habitat within each Creek for parts of the year. (Moderate concern)

Table A1-6: Atchelitz/Chilliwack/Semmihault Assessment.

Impact Hypothesis	*Drivers Triggers and Indicators*
Hypoxia Hypothesis (Moderate concern)	*Dissolved Oxygen:* Hypoxia is documented in some areas but strong base flow and cold water temperatures prevent it in others (Fig. A1-3; Pete Heidy, City of Chilliwack pers. comm.).(Moderate concern) *Lack of riparian vegetation:* Most of the watershed is devoid of woody riparian vegetation. (Major concern) *Nutrient loading:* Ammonia and nitrate levels are within provincial and federal guidelines for the protection of aquatic life, but fecal coliform counts regularly exceed limits at all sampling sites (Fig. A1-3). The watershed is approximately 58% agricultural. (Moderate concern) *Hydrograph:* see below (Moderate concern) *Beaver activity*: see below (Minor concern*)*
Lack of Water Hypothesis (Major concern)	*Hydrograph*: Groundwater maintains high base flow through some of the system (e.g. Luckacuck Creek, east branch of Atchelitz Creek), but low flows occur in other areas. The headwaters of Little Chilliwack Creek and Semmihault Creeks are fed by runoff and groundwater from a forested mountainside. (Moderate concern) *Soils:* Complex fluvial soils underlie the watersheds. Both permeability and water tables are very high in most areas. (Minor concern) *Impermeable surfaces:* Approximately 18% of the watershed is urbanized. (Moderate concern) *Physical Destruction of Habitat:* see below (Major concern) *Water withdrawal:* Licenses: (Major concern) Atchelitz: 113,500 $m^3 \cdot y^{-1}$, 100% irrigation; 4 month FRP 0.010 $m^3 \cdot s^{-1}$, baseflow unknown. Little Chilliwack: 530,500 $m^3 \cdot y^{-1}$, 99% irrigation; 4 month FRP 0.051 $m^3 \cdot s^{-1}$; baseflow unknown
Drainage/Dyking/ Infilling (Major concern)	*Physical Destruction of Habitat:* These streams flow through channels of former distributaries of a large delta at the mouth of the Chilliwack River. Their connection to the river was severed in 1875 by settlers eager to improve drainage of agricultural land (Woods, 2001). Large sections have been channelized and/or are dredged for flood control. A ditch diverts water out of lower Semmihault Creek during low flows, drying approximately 3 km of habitat. (Major concern)
Sedimentation	*Riffle sedimentation:* Riffle condition has not been assessed. In lower

Hypothesis (Moderate concern)	Atchelitz Creek large quantities of sediment have accumulated. (Moderate concern) *Erosion:* Localized areas of erosion and bank failure occur where riparian vegetation is lacking. They deliver unknown quantities of sediment to the channel. (Moderate concern) *Impermeable surfaces:* The watershed is approximately 18% urban. With impermeable areas concentrated around the headwaters of Chilliwack Creek and Luckacuck Creek (Fig. A1-3).
Riffle Loss to Beaver Pond Hypothesis (Minor concern)	*Beaver activity:* Beaver are present but ponding activity is limited by conflict with human activities. (Minor concern)
Introduced Predator Hypothesis (Moderate concern)	*Introduced Predators:* Carp and black crappie have been recorded (FISS database http://srmapps.gov.bc.ca/apps/fidq/), but inventory work has been limited. (Moderate concern)
Toxicity Hypothesis (Moderate concern)	*Impermeable surfaces:* The watershed is 18% urban. Stormwater from the City of Chilliwack drains into two tributaries (Moderate concern) *Pesticide/herbicide use:* The watershed is 58% agricultural.(Moderate concern) *Toxic spills*: Within the City of Chilliwack the creek is crossed by at least 10 bridges and culverts and by Highway 1. (Moderate concern)
Habitat Fragmentation Hypothesis (Moderate concern)	*Isolation*: Connections between these creeks and those of the Atchelitz/Chilliwack/Semmihault drainages were severed when the Chilliwack delta was drained (see Woods, 2001). (Moderate concern) *Internal fragmentation:* Low flows and beaver dams probably fragment habitat for parts of the year, but this has not been assessed. (Moderate concern)

Figure A1-3: Seasonal water quality measurements in Luckacuck, Chilliwack and Atchelitz Creeks at Old Yale Road. Black dots indicate data more recent than 1998. Dashed lines indicate federal or provincial water quality guidelines. All values for nitrate and ammonia are within guidelines. Sampling sites are shown on Fig 6.12. The complete available record (1971-2002) is shown. Data was not collected in all years and is from the Land and Water BC database.

(http://wlapwww.gov.bc.ca/sry/p2/eq/wat_qual_data/index.html).

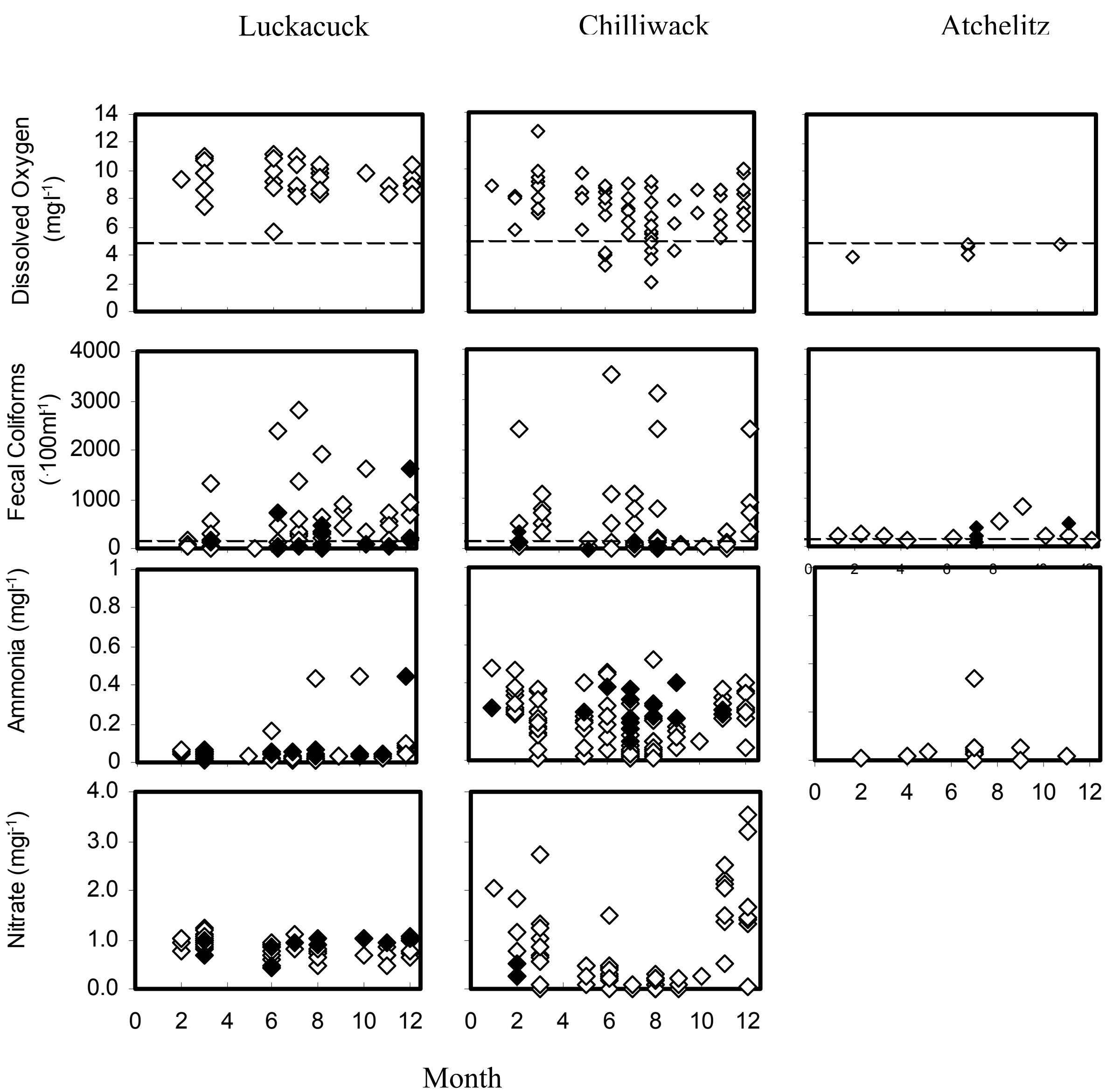


Table A1-7: Miami Creek Assessment.

Impact Hypothesis	*Drivers Triggers and Indicators*
Hypoxia Hypothesis (Major concern)	*Dissolved Oxygen:* Dissolved oxygen is critically low at many sites during late summer (Schreier et al., 2003, Pearson unpubl.). Groundwater maintains cool oxygenated water in areas where the channel is close to the surrounding mountains (B. Chillibek, Northwest Hydraulics pers.com). (Major concern) *Lack of riparian vegetation:* The upper and lower reaches lack adequate riparian vegetation, but the middle reaches flow through mature forest (Fig. 6.11). (Moderate concern) *Nutrient loading:* The watershed is approximately 22% agricultural and 8% urban. (Moderate concern) *Hydrograph:* see below (Moderate concern) *Beaver activity:* see below (Minor concern)
Lack of Water Hypothesis (Moderate concern)	*Hydrograph:* Water levels vary by over 1.5 m converting large, ponded areas to mud flats in the lower reaches during late summer. Surface flow is low or absent in the upper reaches, but extensive pools, particularly in the middle reaches maintain habitat volume year-round. (Moderate concern) *Soils:* The surface geology is complex with interwoven seams of gravel, sand and clay laid down by a glacial spillway and later rivers. It contains both confined and unconfined aquifers (Hans Schreier, UBC, pers comm.). (Moderate concern) *Impermeable surfaces:* Approximately 8% of the watershed is urbanized, but this is concentrated in the lower reaches. (Moderate concern) *Physical Destruction of Habitat:* see below (Major concern) *Water withdrawal:* No licenses listed on the Land and Water BC database.
Drainage/Dyking/ Infilling Hypothesis (Major concern)	*Physical Destruction of Habitat:* Most of the stream length has been dredged at some time and extensive wetland drainage has occurred. The District of Kent currently cleans ditches that connect to the upper reaches for flood control. A dyke with floodgates was installed across the creek's mouth at Harrison Lake in the 1940s to prevent back-flooding. (Major concern)
Sedimentation Hypothesis (Moderate concern)	*Riffle sedimentation:* Riffle sediments have not been assesses, but some impacts seem likely given the lack of riparian cover in the upstream reaches. (Moderate concern) *Erosion:* Localized areas of erosion and bank failure occur in areas where riparian vegetation is inadequate. They contribute

	unknown quantities of sediment to the channel. (Moderate concern) *Impermeable surfaces:* see above. (Moderate concern)
Beaver Activity (Minor concern)	*Beaver activity:* Beaver are active but ponding is limited by conflict with human activities to the middle reaches. (Minor concern)
Introduced Predator Hypothesis (Minor concern)	*Introduced Predators:* None are known at present (FISS database). (Minor concern)
Toxicity Hypothesis (Moderate concern)	*Impermeable surfaces:* see above (Moderate concern)
	Pesticide/herbicide use: The watershed is 22% agricultural. A golf course flanks a section of the middle reaches.(Moderate concern) *Toxic spills*: Within Harrison Hotsprings, Miami Creek is crossed by at least 9 bridges or culverts two of which are on the main route into the town of Harrison Hotsprings. (Moderate concern)
Habitat Fragmentation Hypothesis (Moderate concern)	*Isolation*: Suckers likely move between the headwaters Miami Creek and Mountain Slough at high water, through a short section of ditch, as they have been found in the area (Fig. 6.12). (Moderate concern)
	Internal fragmentation: Low flows, acute hypoxia, and beaver dams fragment habitat for parts of the year. (Moderate concern)

Table A1-8: Mountain Slough Assessment.

Impact Hypothesis	*Drivers Triggers and Indicators*
Hypoxia Hypothesis (Major concern)	*Dissolved Oxygen:* Severe late summer hypoxia occurs across the watershed with the exception of localized areas along the base of the mountain (Pearson unpubl. Barry Chilibeck, Northwest Hydraulics pers. comm., Schreier et al., 2003).(Major concern) *Lack of riparian vegetation:* Riparian vegetation is almost completely lacking in over 80% of the watershed. The lower reaches are flanked to the west by a forested mountainside. (Major concern) *Nutrient loading:* Nitrate and ammonia are within guidelines for the protection of aquatic life, but are increasing (Schreier et al., 2003). The watershed is approximately 46% agricultural and 1% urban. (Moderate concern) Hydrograph: see below (Major concern) *Beaver activity:* see below (Minor concern)
Lack of Water Hypothesis (Moderate concern)	*Hydrograph:* Reaches along the base of the mountains are well supplied with cold groundwater at least locally, but some reaches further out in the valley lack water or flow during extended dry periods (Ted Westlin, District of Kent, pers. comm.). (Major concern) *Soils:* The surface geology is complex, with interwoven seams of gravel, sand and clay. It contains both confined and unconfined aquifers (Hans Schreier, UBC, pers. comm.). (Minor concern) *Impermeable surfaces:* The watershed contains no urban lands. (Minor concern) *Physical Destruction of Habitat:* see below (Major concern) *Water withdrawal:* No licenses are listed in the Land and Water BC database.
Drainage/Dyking/ Infilling Hypothesis (Major concern)	*Physical Destruction of Habitat:* Most of the stream length has been dredged at some point. The District of Kent cleans the channel and connecting ditches over much of the watershed for flood control. The Hammersly pumping station and a large dyke system prevent back-flooding from the Fraser River.
Sedimentation Hypothesis (Moderate concern)	*Riffle sedimentation:* Riffles have not been assessed for compaction, but some impacts are likely are likely given the extent of agricultural land and lack of riparian vegetation. (Moderate concern)

	Erosion: Areas of erosion and bank failure occur in areas that lack adequate riparian vegetation. They contribute unknown quantities of sediment to the channel (Moderate concern) *Impermeable surfaces:* see above (Minor concern)
Riffle Loss to Beaver Pond Hypothesis (Minor concern)	*Beaver activity*: Beaver are present but ponding activity is limited by conflict with human activities. (Minor concern)
Introduced Predator Hypothesis (Minor concern)	*Introduced Predators:* None are known at present (FISS database). (Minor concern)
Toxicity Hypothesis (Moderate concern)	*Impermeable surfaces:* see above (Minor concern) *Pesticide/herbicide use:* The watershed is 46% agricultural. Cranberry farms drain directly into McCallum Creek and elevated levels of Atrazine, a herbicide used on cornfields, has been documented two tributaries (Schreier et al., 2003). (Moderate concern) *Toxic spills*: There are few road crossings and most carry local traffic. The one major crossing (Hwy 7) is located at the mouth of the slough. (Minor concern)
Habitat Fragmentation Hypothesis (Moderate concern)	*Isolation*: Suckers likely move between the headwaters Mountain Slough and Miami Creek at high water, through a short section of ditch, as they have been found in the area. (Moderate concern) *Internal fragmentation:* Low flows, hypoxia, and beaver dams fragment habitat for parts of the year. (Moderate concern)

Table A1-9: Agassiz Slough Assessment.

Impact Hypothesis	*Drivers Triggers and Indicators*
Hypoxia Hypothesis (Major concern)	*Dissolved Oxygen*: Severe late summer hypoxia (<3mg/l) is documented across the watershed with the exception of localized areas of groundwater upwelling (Schreier et al., 2003, Pearson unpubl.). (Major concern) *Lack of riparian vegetation:* Mature trees shade some sections, but much of the slough lacks adequate riparian shading. (Moderate concern) *Nutrient loading:* Ammonia and nitrate levels are within guidelines for the protection of aquatic life but are increasing in the area (Schreier et al., 2003). The watershed is approximately 76% agricultural and 17% urban. (Moderate concern) *Late summer drying:* see hydrograph below (Major concern) *Beaver activity:* see below (Minor concern)
Lack of Water Hypothesis (Major concern)	*Hydrograph:* Water levels vary by more than 1.5 m in many sections. A large but unknown portion of the channel dries completely in late summer. (Major concern) *Soils:* The surface geology is complex with interwoven seams of gravel, sand and clay. It contains both confined and unconfined aquifers (Hans Schreier, UBC, pers. comm.). An unconfined aquifer appears to supply the upper reaches of the slough, maintaining water levels and quality there. (Minor concern) *Impermeable surfaces:* Approximately 17% of the watershed is urban. (Major concern) *Physical Destruction of Habitat:* see below (Major concern) *Water withdrawal:* Single irrigation license for 24,500$m^3 \cdot yr^{-1}$. Four month FRP is negligible at 0.002$m^3 \cdot s^{-1}$ (Moderate concern)
Drainage/Dyking/ Infilling Hypothesis (Major concern)	*Physical Destruction of Habitat:* Most of the stream length has been dredged at some point. The District of Kent cleans some connecting ditches for flood control. The sloughs connection to Maria Slough was severed approximately 40 years ago and it enters the Fraser through a flapped culvert in a dyke.
Sedimentation Hypothesis (Moderate concern)	*Riffle condition:* The slough has no riffles. Some areas of the slough have accumulated large quantities of sediment, but others only a thin layer over a hard gravel bottom. (Minor concern) *Erosion:* Localized areas of erosion and bank failure probably occur but this has not been surveyed. (Moderate concern) *Impermeable* surfaces: see below (Major concern)

Riffle Loss to Beaver Pond Hypothesis (Minor concern)	*Beaver activity:* Beaver are present but ponding activity is limited in many areas by lack of water and flow. (Minor concern)
Introduced Predator Hypothesis (Moderate concern)	*Introduced Predators:* None have been documented but little inventory work has been done. (Minor concern)
Toxicity Hypothesis (Major concern)	*Impermeable surfaces:* The watershed is 17% urban. Storm sewer discharges have elevated copper and zinc concentrations in the slough's sediments to levels exceeding those recommended for aquatic life (Schreier et al., 2003) (Major concern) *Pesticide/herbicide use:* The watershed is 76% agricultural. Elevated levels of atrazine, a herbicide used on cornfields, occur in the water (Schreier et al., 2003). (Moderate concern) *Toxic spills:* The main road from the Agassiz-Rosedale bridge over the Fraser River crosses the slough twice. The few other crossings carry only local traffic. (Minor concern)
Habitat Fragmentation Hypothesis (Major concern)	*Isolation:* The population is isolated within a portion of the slough without surface connection to neighbouring waterbodies. The presently occupied habitat was connected to Maria Slough until an underpass was built on the Loughheed highway in the 1960s. It may have also connected at high water with the Miami Creek headwaters, but construction of the highway would have severed this as well. (Major concern) *Internal fragmentation:* A tributary is isolated completely by infilling (Fig. A1-15). Hypoxia and lack of water additionally fragment habitat for portions of the year. (Major concern)

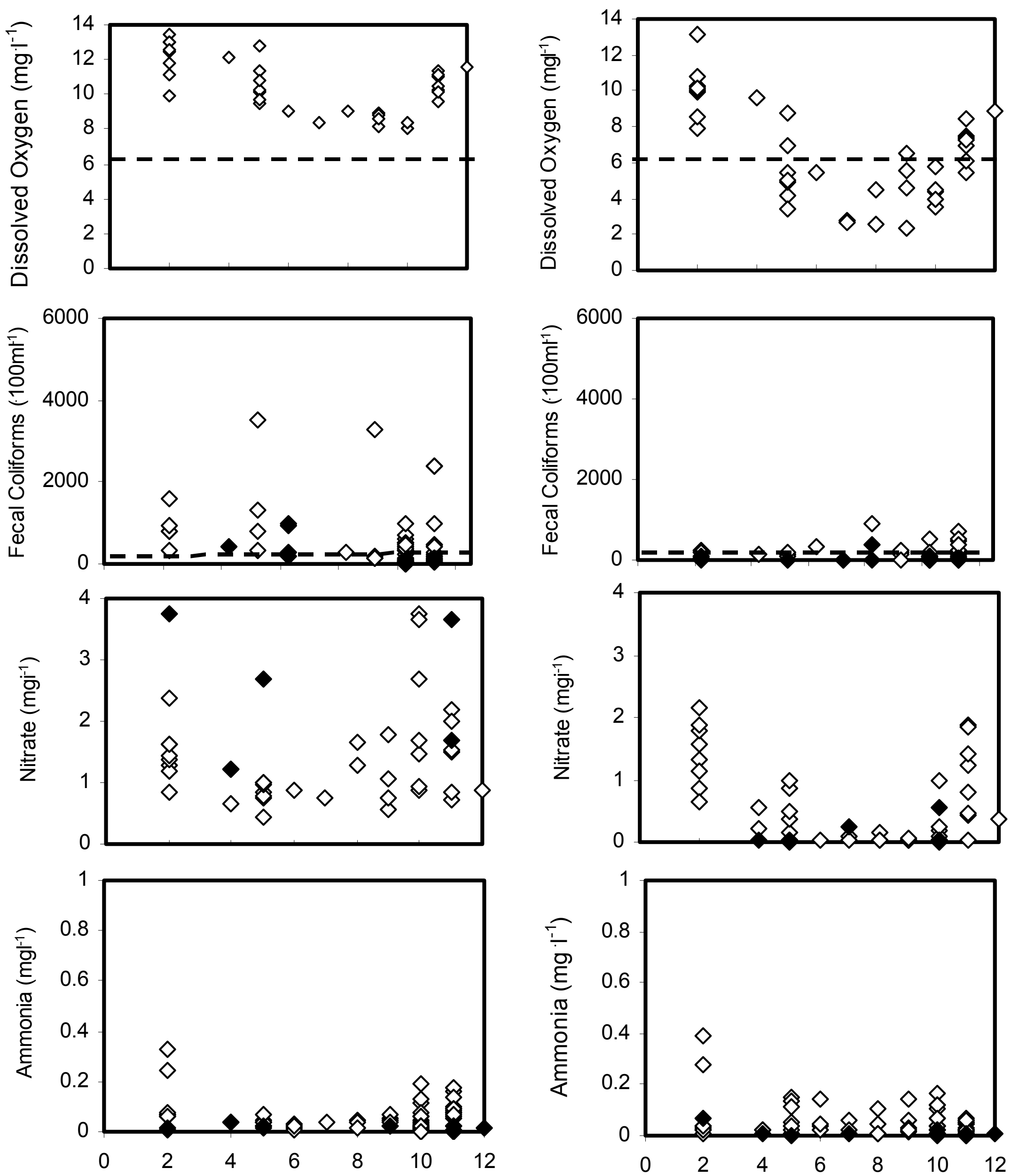
Table A1-10: Little Campbell River Assessment.

Impact Hypothesis	*Drivers Triggers and Indicators*
Hypoxia Hypothesis (Major concern)	*Dissolved Oxygen:* Provincial monitoring records show chronic hypoxia in late summer at 216th Street in the upper reaches Levels always exceeded guidelines at 176th Street in, at the downstream end of the middle reaches (Fig. A1-4). (Major concern)
	Lack of riparian vegetation: The upper reaches, flow primarily through forested riparian zones. In the middle and lower reaches, however, a number of reaches lack adequate vegetation. (Minor concern)
	Nutrient loading: Nitrate and ammonia levels are below provincial and federal guidelines for freshwater aquatic life, however, fecal coliforms counts regularly exceed them (Fig. A1-4). Approximately 56% of the watershed is in agriculture. (Moderate concern)
	Hydrograph: see below (Major concern)
	Beaver activity: see below (Moderate concern)
Lack of Water Hypothesis (Moderate concern)	*Hydrograph:* Several sections of stream run dry every summer (Drever and Brown, 1999). Water levels are maintained through much of the upper reaches beaver dams. (Major concern)
	Soils: Headwater areas have impermeable glaciomarine clays as surface soils. Permeability and groundwater flows are higher in the middle reaches. (Moderate concern)
	Impermeable surfaces: Over 13% of the watershed is urbanized but its impact is confined to the lowermost reaches. (Minor concern)
	Physical Destruction of Habitat: see below (Moderate concern)
	Water withdrawal: The Little Campbell has 36 listed water licenses (excluding a hatchery that returns its water to the river) permitting a total of 702,800 $m^3 \cdot y^{-1}$. Approximately 90% of this volume is for irrigation. The four-month FRP of.063 $m^3 \cdot s^{-1}$ is almost one third of mean summer flow and exceeds the 5-year daily minimum (Table 6.5). The river was declared, 'fully subscribed' in 1959 and the issuance of further water permits was discontinued. This restriction was removed in 1969 and since then further water licenses have been issued (Drever and Brown, 1999). (Major concern)
Physical Destruction of Habitat Hypothesis (Moderate concern)	*Physical Destruction of Habitat:* Historically common and probably still significant on tributaries and ditches. The Township dredged approximately 1200 m of channel around 216th Street in 1993 and 1997 in response to flooding complaints from owners of homes built in the floodplain (Drever and Brown, 1999).
Sedimentation	*Riffle condition:* Riffles have not been assessed for compaction,. In five

Hypothesis (Moderate concern)	of 8 fall sampling periods between 1988 and 1992 turbidity increases between the 216th Street and 176th street stations (Fig. A1-16) failed to meet provincial water quality objectives (Drever and Brown, 1999). (Moderate concern) *Erosion:* Localized areas of erosion and bank failure probably occur but this has not been surveyed. (Moderate concern) *Impermeable surfaces*: see above (Minor concern)
Riffle Loss to Beaver Pond Hypothesis (Moderate concern)	*Beaver activity:* Beaver damming is extensive in the middle and upper reaches especially in Campbell Valley Regional Park. (Moderate concern)
Introduced Predator Hypothesis (Major concern)	*Introduced Predators:* Brown bullheads are present in high densities in the middle reaches. Bullfrogs and pumpkinseed are also established (Pearson unpubl.). (Major concern)
Toxicity Hypothesis (Moderate concern)	*Impermeable surfaces:* see above (minor concern) *Pesticide/herbicide use:* The watershed is 56% agricultural, and is bordered by two golf courses. (Moderate concern) *Toxic spills:* A portion of White Rock' storm sewer system drains into the lowermost reaches, but there is little habitat downstream of it. Highways 99 and 10 also cross the lower reaches. There are few crossings of the middle and upper reaches. (Minor concern)
Habitat Fragmentation Hypothesis (Moderate concern)	*Isolation:* The little headwaters of the Little Campbell connect to those of Cave Creek, a tributary of Bertrand Creek. A stewardship project restored fish access around an agricultural dam between Bertrand and upper Cave Creek in 2000. Access is still very tenuous, however, as Cave Creek runs dry for several months each summer. (Moderate concern) *Internal fragmentation:* Low flows, beaver dams and hypoxia all cause seasonal fragmentation. (Moderate concern)

Figure A1-4: Seasonal water quality measurements in the Little Campbell River at 176th Street (lower reaches) and at 216th Street (middle reaches). Sampling sites are shown on Fig. 6.16. The complete available record (1971-2002) is shown. Black dots indicate data more recent than 1998. Data was not collected in all years and was obtained from Land and Water BC (http://wlapwww.gov.bc.ca/sry/p2/eq/wat_qual_data/index.html).

76th Street **216th Street**



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