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Factors affecting the distribution and abundance of the Salish sucker (*Catostomus* sp.): an endemic and endangered transboundary fish population

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FACTORS AFFECTING THE DISTRIBUTION AND ABUNDANCE
OF THE SALISH SUCKER (CATOSTOMUS SP.): AN ENDEMIC
AND ENDANGERED TRANSBOUNDARY FISH POPULATION

By

Nathaniel S. Lundgren

Accepted in Partial Completion
of the Requirements for the Degree
Master of Science

Kathleen L. Kitto, Dean of the Graduate School

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MASTER'S THESIS

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Nathaniel Lundgren
February 10, 2013

FACTORS AFFECTING THE DISTRIBUTION AND ABUNDANCE
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A Thesis
Presented to
The Faculty of
Western Washington University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

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February, 2013

Abstract

The Salish sucker (*Catostomus sp.*) is a recently described endemic fish species with a patchy distribution and a narrow geographic range in western Washington and southwestern British Columbia. In this study I examined populations within the Nooksack River watershed, attempting to elucidate the environmental factors contributing to observed patterns of distribution and abundance. I hypothesized that hypoxic and hyperthermic conditions during the summer months would restrict Salish sucker distribution. I tested this hypothesis by measuring dissolved oxygen concentrations, temperature, and Salish sucker abundance and movement at eight sites in the Bertrand Creek and Fishtrap Creek sub-basins. The results of this study did not support my original hypothesis; instead it seems more likely that physical habitat characteristics rather than water quality exert greater influence in patterns of abundance and distribution. My findings emphasize the importance of maintaining the quality and connectivity of habitat for Salish sucker conservation.

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Introduction

Biodiversity of native freshwater fishes is declining in North America (Miller et al. 1989, Duncan and Lockwood 2001). The Catostomidae family in particular faces challenges to its conservation and management, as most of the species within the family are classified as “non-game” fish and consequently do not often draw the attention of wildlife management agencies (Cooke et al. 2005). In the Pacific Northwest, economically important fishes such as halibut and salmonids are aggressively managed, while non-game fish are often without management strategies until listed as threatened or endangered by a regulatory agency.

A recently described representative of the *Catostomus* genus of fishes, the Salish sucker (*Catostomus sp.*) is endemic to the Pacific Northwest, descended from an ancestral population of the wide-ranging Longnose sucker (*Catostomus catostomus*) (McPhail and Taylor 1999). During the Pleistocene ice age, glaciers extended south across Puget Sound, allowing the species to evolve in isolation from the Longnose sucker (Pearson and Healey 2003). Currently, the Salish sucker has a limited distribution in several watersheds throughout lowland western Washington and in small streams in southwest British Columbia, just north of the international border (Wydoski and Whitney 2003). The northernmost population of Salish suckers that straddles the border in the Nooksack River watershed is in decline in British Columbia, and has been extirpated from several streams in the area (McPhail 1987, Pearson 1999). In Canada the species is protected under the federal government’s Species At Risk Act (SARA) (DFO 2004). In the United States, the Salish sucker is listed at the state level by the Washington Department of Fish

and Wildlife as a monitor species, a designation that reflects the need for more research and monitoring to prevent a threatened or endangered listing in the future (WDFW 2012).

Habitat loss and degradation is recognized as a primary cause of decline in the Canadian population of Salish suckers (BCMOE 1993, Pearson and Healey 2003), and land use development on both sides of the border presents a challenge to the recovery and protection of the species. For decades much of the natural landscape in this area has been used in dairy production and berry farming. More recently, residential development has altered the landscape and the watersheds as population centers southeast of Vancouver, such as Abbotsford, have expanded. Management and recovery of this trans-national sucker population has been made more complicated by the divergent policy actions of Canada and the United States.

Habitat loss and degradation take many forms in Salish sucker streams and vary with land use. Changes to the physical structure of the streams that may impact Salish suckers are ubiquitous throughout the watershed. Channelization, especially prevalent on agricultural lands where streams have been reduced to roadside ditches, has reduced habitat complexity (McPhail 1987, DFO 2009). Water diversions for agriculture can reduce habitat availability and connectivity between sites. Culverts, dams, and other human made obstacles in the stream may hinder migration throughout the watershed, a major cause of imperilment of freshwater fish in general and catostomids in particular (Allan and Flecker 1993, Cooke et al. 2005).

Habitat can also be degraded due to worsening water quality. Increased nutrient inputs to streams, particularly the limiting nutrients nitrogen and phosphorus, are

pervasive in both urban and agricultural landscapes. In agricultural areas, livestock manure and fertilizers are the biggest components of nonpoint nutrient pollution to streams (Carpenter et al. 1998). The nutrients received by the streams drive the process of eutrophication; excessive aquatic plant growth leads to an increase in the biological oxygen demand, depleting the levels of dissolved oxygen in the stream, often to the detriment of fish species (Dodds and Welch 2000).

The influence of land use and habitat degradation on stream ecosystems and fish populations has been well studied (Karr and Schlosser 1978, Jelks et al. 2008, Utz et al. 2010). Streams having riparian zones with natural vegetation and ecological function are often able to offset some of the deleterious effects that certain land use types have on water quality (Naiman and Décamps 1997), and restoration of these riparian zones has been a strategy for stream recovery for some time (Greenwood et al. 2012). There remains some question as to the effectiveness of this strategy in mitigating land use conversion within the watershed. Central to this question is a continuing debate judging the relative importance of scale in influencing the water quality and biotic integrity (Roth et al. 1996, Lammert and Allan 1999). Specifically, researchers have asked whether large-scale factors (basin-wide land use) are more important than small-scale factors (riparian corridors) in determining stream characteristics. The previously mentioned studies suggest that the evaluation of habitat at multiple scales should be considered in assessing habitat degradation and implementing stream restoration projects.

The complexity of addressing land use and habitat loss to recover the Nooksack watershed Salish sucker population is compounded by the dearth of existing knowledge

regarding the life-history and ecology of the species. Understanding the attributes unique to a particular fish species is important for establishing the most effective conservation and management strategies (Carlson and Muth 1993). Much of what is known about the Salish sucker is the product of research by a small handful of scientists or is inferred through the studies of its closest relative, the longnose sucker (Pearson 1999). Salish suckers prefer pools and lentic backwaters or beaver ponds in low-order tributary streams, but need access to shallow riffles with gravel for spawning (Pearson and Healey 2003). This aspect of their ecology necessitates a certain degree of habitat connectivity, which may decline during certain flow conditions and could be exacerbated by habitat degradation (Pearson 1999).

Dissolved oxygen and temperature tolerances, two factors that are known to limit the distribution of fish (Cech et al. 1990, Smale and Rabeni 1995), are unknown for the Salish sucker. In many aquatic ecosystems, dissolved oxygen and other environmental parameters may be seasonally volatile. For example, the typical lack of rainfall during the Pacific northwest summer may leave a small stream more susceptible to decreases in dissolved oxygen and higher water temperatures. Land use activities that alter physical habitat or increase nutrient inputs to streams may exacerbate seasonal fluctuations of dissolved oxygen and temperature (Wiejters et al. 2009). Stream flow and channel morphology can also influence oxygen concentration. Low-gradient, low-velocity, channelized streams experience less mixing of water and less diffusion of oxygen into the stream (Garvey et al. 2007). Previous research has found that hypoxic conditions are present in some reaches within the Bertrand and Fishtrap Creek watersheds during the

summer when flows normally are at their lowest and water temperature is highest for the year (Pearson 1999).

Flow regime is also important in regulating fish distribution (Horwitz 1978, Bain et al. 1988, Stalnaker et al. 1996). Changes in hydraulic conditions can influence fish distribution by creating physical barriers to movement within a stream, impacting the suitability of certain habitats in a stream, and increasing fluctuations and the extremes in water quality parameters (Magoulick and Kobza 2003). It is not known how Salish sucker populations in the Nooksack watershed are affected by or respond to changing flow levels. Anthropogenic habitat loss, coupled with reduced flows during the summer, may restrict Salish suckers to specific refuge habitats within a stream if certain reaches become inaccessible or if flow mediated conditions make the water quality intolerable.

Whether through the effects of flow, dissolved oxygen, temperature, or a combination of factors, changes to the stream environment restrict fish distributions (Magoulick and Kobza 2003). Dewatering or physical disruption of surface flow can restrict access to habitat, while changes in water quality can render habitats uninhabitable or metabolically suboptimal (Kushlan 1976). The result is that the habitat available to fish decreases as does the ability to move between habitats. In these cases, refuge habitats where tolerable water quality exists may become important to the persistence of a fish population in a stream with frequent disturbance (Lancaster and Belyea 1997). The Salish sucker populations in the Bertrand and Fishtrap watersheds already contend with a stream environment marked by dry summers, resulting in decreased flow and some change in the temperature and dissolved oxygen. Understanding the prevalence and

severity of these habitat limiting factors and their influence on Salish sucker populations is important in determining the appropriate steps in conserving the species.

Objectives and Hypotheses

This study was intended to examine the following questions related to Salish sucker life history.

1. What factors limit Salish sucker abundance and distribution, and how, in particular, is fish abundance and distribution related to hypoxia and hyperthermia during the summer low flow period? I hypothesized that seasonal drought during the summer would create suboptimal temperature and dissolved oxygen conditions for suckers in some study reaches and that other reaches would serve as refuge habitats for fish avoiding these stressful conditions. Accordingly, I hypothesized that sites with lowest levels of dissolved oxygen in summer would have the lowest abundances of Salish sucker.
2. How do Salish suckers move between study sites? Related to the first objective, I wanted to document immigration of Salish suckers into refuge habitats, with particular attention to transboundary migrations of fish between Canada and the United States. I hypothesized that individual fish would outmigrate from summer-hypoxic sites at the onset of summer low flow conditions.
3. What is the Salish sucker population structure in terms of fish total lengths? I intended to compare the size structure of Salish sucker populations between sites and had no hypothesis regarding size and site.

4. What types of land use occur within the two watersheds in this study and what are the implications for Salish sucker conservation? My primary objective was to compare and contrast the land use between the two watersheds, between Canada and the United States, and between study sites. This objective was exploratory in nature with no hypothesis developed.

Methods

Study Sites

Data were collected at eight study sites within the Bertrand Creek and Fishtrap Creek watersheds (Figure 1). Bertrand Creek and Fishtrap Creek are tributaries of the Nooksack River, both of which originate in southwest British Columbia, Canada and flow across the international border to discharge into the Nooksack River in northwestern Washington, USA. Five of the sites are part of the Bertrand Creek sub-basin and the remaining three are within the Fishtrap Creek sub-basin. Of the Bertrand Creek sites, two are located in the United States and three are in Canada. Of the Fishtrap Creek sites, two are in Canada and the remaining site is in the United States. Sites were chosen according to a combination of factors including likelihood of Salish sucker presence, habitat variety, proximity to adjacent sites, and accessibility. To ensure a meaningful study with usable data, some sites known to support suckers were selected *a posteriori* based on previous studies (Mike Pearson, Pearson Ecological, mike@pearsonecolocal.com, pers. comm.) The drainage area of these watersheds is low elevation and the landscape has been extensively altered, much of it converted to agriculture and residential developments. Minimal rainfall during the summer, the absence of a winter snowpack, and water

diversions for agricultural activities all contribute to great fluctuations in stream discharge and temperature from summer to winter (Table 1).

Middle Maberry Pond (Maberry)

This site is part of Bertrand Creek in Washington, south of Loomis Trail Road near Lynden. The creek at this site flows through the Maberry Farm, a commercial raspberry operation. Small dams across the creek create a series of three ponds on the property, the middle pond being chosen as a site in this study. An aerator is present in the pond that may prevent hypoxic summer conditions.

Bertrand Creek near Cave Creek confluence (Bertrand)

The second site in the Bertrand Creek watershed is the Bertrand Creek mainstem where Cave Creek enters Bertrand just south of the international border. The riparian zone is heavily wooded while the surrounding area is pastureland and forest. This reach is a mixture of substrate, with boulders, cobble, gravel, sand, and clay all represented. Our specific trap site is just upstream from the mouth of Cave Creek, in a deep pool where the creek makes a sharp bend.

Cave Creek at 248th Street (Cave)

The third site in the Bertrand watershed is located in Cave Creek, a small tributary with intermittent flow during the summers. The study site is located in British Columbia east

of 248th street, in a large pool just upstream from a culvert. This site is near pastureland but retains a vegetated riparian corridor.

Howe's at 16th Street (Howe's)

Howe's Creek is a Bertrand Creek tributary in British Columbia entering Bertrand near the intersection of 16th Street and 264th Street. The study site on this tributary is located near the mouth of Howe's Creek. The creek at this location has been channelized for several hundred meters and lies within a seasonally inundated marshland.

Channelization has reduced the habitat complexity to a single glide in this reach but willows and other deciduous trees grow to the banks and a habitat restoration project has placed some woody debris in the channel.

Bertrand at 33rd Street (Aldergrove)

The fifth and most upstream site in the Bertrand watershed is part of the Bertrand Creek mainstem, in a large, vacant lot near a subdivision in Aldergrove, British Columbia.

Flowing along the forested edge of the lot, Bertrand Creek at this location does retain habitat complexity and canopy cover. The trap location is in a large shaded pool, immediately downstream from a shallow riffle.

East Double Ditch Creek (Double Ditch)

East Double Ditch Creek is a tributary to Fishtrap Creek that has been re-routed to the roadside ditch running alongside Double Ditch Road in Washington. Commercial berry

farms and dairy farms dominate the surrounding landscape. This reach lacks habitat complexity, consisting of a straight channel holding a long glide and no woody debris or canopy cover other than reed canary grass (*Phalaris arundinacea*).

Gordon's Brook (Gordon's Brook)

Situated less than 1 km north of the East Double Ditch site and across the international boundary in British Columbia, the Gordon's Brook study site is a different reach on the same tributary (known as Pepin Creek in Canada rather than Double Ditch). Here the creek meanders through multiple channels in a low-lying area near pastures and farms before forming a single channel at the border. The trap location is on the western-most channel in a shallow pool upstream from a small culvert. Upstream from this location are several large ponds known to support an abundance of Salish suckers in the recent past (Pearson 2004).

Salish Creek (Salish)

Salish Creek is a small Pepin Creek tributary situated on the edge of a gravel pit and aggregates business in British Columbia. The creek is sluggish and marshy, with a narrow riparian corridor of reed canary grass and an overstory of willows. The trap site is located in a deep glide just downstream from where the creek broadens into a pond.

Data Collection

To examine factors that limit Salish sucker abundance and distribution, physical habitat characteristics, dissolved oxygen concentration, stream temperature, and flow were measured at each of the eight sites. The physical habitat of each study site was measured once during the summer of 2011 (Table 2) in accordance with the standardized methods outlined by the American Fisheries Society (Bain and Stevenson 1999). Three transects perpendicular to flow were used to describe the physical habitat characteristics at each site. The middle transect was positioned over the area of the stream where the fish trapping would later take place. The other two transects were located upstream and downstream from the middle, either 25 meters from the middle transect if the trap site and adjacent habitat were homogenous, or at the ends of the specific macrohabitat if the site represented a discrete habitat unit. Cross-sectional profiles measuring bankfull width, wetted width, depth, substrate composition, and canopy cover were created. Water levels were measured continuously from April through November 2011 using a pressure sensor water level logger (HOBO[®] U20 water level logger, Onset Computer Corp., Bourne, MA). Water level data were used to confirm differences between high and low flow periods.

Stream temperatures, dissolved oxygen concentrations, and Salish sucker populations were assessed contemporaneously on multiple sampling visits. After initial study site visitation and selection, each site was visited twice during the period from early April to early June (high flow period) and twice again during October and November (high flow period). A more concentrated sampling effort was made during August and

early September (low flow period), when each site was sampled 3-5 times. I aimed for a balanced data set between each flow period in scheduling the sampling. The temporal separation between the sampling periods was intended to give some distance in order to detect differences in Salish sucker abundance between summer low flow period and the high flow period of spring and fall.

For each sampling visit, I measured temperature and dissolved oxygen concentration in the evening (i.e., ≤ 2 hours before sunset) and again in the morning (i.e., ≤ 2 hours after sunrise) of the following day using a hand-held dissolved oxygen meter (YSI Professional Series ProODO™ meter, YSI Inc., Yellow Springs, OH). Both sets of measurements were conducted at approximately middle depth near the mid-point of the study reach. The unit was calibrated for dissolved oxygen readings before every sampling period with the water saturated air method according to the user manual. For quality assurance we collected water samples during approximately 20% of site visits and performed dissolved oxygen analyses via Winkler titration (IWS 2012). For each sampling visit, I used average temperature and dissolved oxygen values (i.e., the mean of evening and morning measurements) as variables, since these were amenable to statistical analysis and were indicative of site conditions during the time when fish were collected. Differences between evening and morning measurements were considered indicative of diel fluctuations and a potential influence on eutrophication and hypoxia.

To measure Salish sucker abundance, traps were used to capture fish at each site. Custom-made cylindrical, funnel-type fish traps designed by Mike Pearson (Pearson 2009) and smaller store-bought models (a design commonly referred to as minnow traps)

were used in this study. These traps were baited with cat food and left on the stream bottom overnight, near the deepest point of the site. The following morning traps were pulled from the water and the Salish suckers were identified and enumerated. Catch per unit effort (CPUE) was used to describe fish abundance and was calculated as the number of fish captured per trap volume (m^3) per hours spent trapping. Fish sampling was suspended on occasions when dissolved oxygen concentrations or temperatures approached lethal thresholds for Salish suckers or salmonid fishes to the extent that trapping or measuring activities were likely to cause stress-related mortality.

To investigate the possibility of movement of individuals between sites, we marked Salish suckers with passive integrated transponder (PIT) tags (Biomark™ HPT9 9 mm 134.2 kHz, Biomark, Inc., Boise, ID) at five study sites. Fish were first anesthetized with tricaine methanesulfonate (MS-222) and tags were injected into the fish's body cavity. The tags' unique identification numbers were read and recorded along with the date of capture and total length of the fish. During subsequent visits to the sites, all Salish suckers were scanned with a pocket scanner to determine if the fish were recaptured. The recapture at any site of a fish that had been tagged at another site was considered indicative of migration between the two sites. Significant migration to a particular site during the summer low flow season was considered indicative of refuge habitat. Pit-tagging occurred at the Gordon's Brook, Double Ditch, Cave, Bertrand and Howe's sites. Gordon's Brook and Double Ditch, located on Pepin Creek and separated by approximately 800 meters of stream, were chosen because of their proximity to each other and their positions on either side of the international border. The same rationale

was used for Cave and Bertrand Creeks, with the Cave Creek site also having the distinction of containing a large pool in an otherwise ephemeral stream reach. For this reason I believed the Cave Creek site could provide a refuge habitat. Fish at Howe's at 16th Ave. were tagged to expand the effort of the mark-recapture study undertaken by our Canadian colleagues at Pearson Environmental and the University of British Columbia.

To compare Salish sucker population structure between study sites, length-frequency histograms were generated with the total lengths obtained during each round of sampling. Total lengths were measured in the field to the nearest millimeter and fish were immediately released.

To examine the differences in land use among watersheds, nations, and individual sites, I assessed patterns of land use using digitized aerial photographs (ArcGIS™ 10.1 for Desktop, Esri, Inc., Redlands, CA). Three categories were used to describe the landscape: urban, forest, and agriculture. Urban land was restricted mostly to the communities of Lynden, Aldergrove, and Abbotsford and included high density residential subdivisions, business areas in the downtown core, and business parks and large parking lots in the areas outside of the downtown core. Forest land included forests or land with naturally occurring tall, woody shrubs capable of providing shade. Agricultural lands included croplands, dairy farms and associated buildings, pasturelands, vacant fields and large rural residential lots with homes, as well as several gravel pits. Two scales were used to determine land use; a coarse-scale analysis at a 1:50,000 scale for the purpose of examining land use in each watershed and each country, and a fine-scale analysis at a 1:6,000 scale to examine land use in a small buffer zone near each

study site. Buffer zones were 1 - km reaches upstream from the site, including the land within 100 m of each side of the reach.

Data Analysis

To analyze the presence and extent of hypoxia and hyperthermia in Salish sucker habitat, the corresponding trends in abundance, and the existence of refuge habitats, I choose a fine-scale, site level approach as well as two broader analyses. Examining hypoxia, hyperthermia, abundance, and refuge habitats was done within each of the eight sites across the two levels of flow period (high flow and summer low flow). This provided the fine-scale analysis based on the conditions within each individual site.

I also wanted to examine the same questions of hypoxia, hyperthermia, abundance, and refuge on a larger scale. An analysis at the watershed level could provide a broader, ecologically relevant focus. To do this, I pooled the sites together by watershed (three sites for Fishtrap and five for Bertrand). This approach had the added benefit of increasing the power of statistical tests by increasing the sample size. In the fine-scale, site specific analysis, each site had been sampled as few as four times during a flow period “treatment.” With the amalgamation of the site data into watersheds for a coarse-scale analysis, the greater power afforded to statistical tests might offer a better opportunity to detect differences between the flow periods.

The second coarse-scale examination had more geo-political relevance than ecological. To see if there were differences in the conditions of Salish sucker habitat and fish abundance between Canada and the United States, sites were pooled based on nation.

There were three sites in Washington and five sites in British Columbia. I hoped that this analysis, combined with watershed land use, might provide some insight into Salish sucker conservation prospects for each country. As in the watershed level analysis, this nation level approach used combined data and provided a more powerful test than the individual site level tests.

Much of the habitat data was not normally distributed, necessitating a non-parametric approach to the analysis. To investigate changes in dissolved oxygen, temperature, and abundance based on flow period, I used Kruskal-Wallis tests to confirm any significant differences (Zar 1996). I used this approach for all levels of the data; the fine-scale, site specific analysis and the two coarse-scale watershed and nation level analyses. In the site specific analysis, when I compared multiple sites within a single flow period, I followed the Kruskal-Wallis test with a pairwise Wilcoxon test with a holms correction factor (Zar 1996). To investigate factors affecting abundance I used Kendall's tau rank-based correlation analysis to look for relationships between CPUE and several measures of physical habitat (Zar 1996).

I used the Kolmogorov-Smirnov test to determine whether the total length distribution of Salish suckers differed between sites (Gotelli and Ellison 2004). The Bertrand, Gordon's Brook, and Double Ditch sites were omitted from the analysis due to their small sample sizes. As the Kolmogorov-Smirnov test is applicable to two independent samples, I made 10 pair-wise comparisons, representative of all the possible combinations of tests among the five sites included in the analysis. With a standard $\alpha = 0.05$, the compounded probability of a type I error would be $1 - (1 - 0.05)^{10} = 0.40$ under

this method. To reduce the probability of a type I error, I accepted a significance level of $\alpha = 0.01$ for each test between individual sites, reducing the overall probability of a type I error to 0.0956.

Results

Abundance related to hypoxia/hyperthermia and physical habitat

The Kruskal-Wallis tests indicated that there were significant differences in dissolved oxygen among flow periods for three of the eight sites (Table 3, Figure 2). The seasonal differences in temperature were more consistent, with tests revealing that six of the eight sites had higher stream temperatures during low flow period than during high flow (Table 3, Figure 3).

When the data were pooled and dissolved oxygen and temperature were analyzed at the watershed level, more statistically significant differences emerged. Testing for seasonal differences in mean dissolved oxygen concentration and mean temperature revealed that both variables showed significant differences dependent on flow period (Table 3). As expected, stream temperatures were higher and dissolved oxygen lower in the low flow period than during high flow. The temperatures in both watersheds fluctuated more widely around the median during the high flow period than during low flow. The median dissolved oxygen concentrations differed by less than $2 \text{ mg}\cdot\text{L}^{-1}$ between flow regimes in each watershed (Figure 4).

The second coarse-scale analysis of the data at the nation level showed that this grouping into nations also yielded differences in dissolved oxygen concentration and

temperature based on flow period (Table 3, Figure 4); both variables varied seasonally in Canada and the United States, with the predictable increase in temperature and decrease in dissolved oxygen observed during the low flow period.

Salish suckers were captured at all sites at least once during the sampling season. There were no significant differences in seasonal Salish sucker abundance within the individual sites (Table 3). Changes in Salish sucker abundance at the watershed level and nation level based on flow period were also not significant. Median CPUE for both watersheds was at or near zero for low and high flows (Figure 5). The CPUE ranged widely for most sites, usually with wider variation above the median than below.

Of the physical habitat variables measured, correlation analysis revealed that the strongest correlation for CPUE was with average site depth (Kendall's $\tau = 0.924$, $p = 0.002$) (Table 4). The trend shows that in this study Salish suckers tended to be more abundant in the deeper sites (Figure 6).

Immigration to Refuge Habitats

A total of 40 Salish suckers were PIT tagged at five sites (Table 5). Only fish at the Cave Creek site were recaptured, with eight marked individuals eventually being recaptured during subsequent visits. One of these fish was recaptured twice. At the Howe's Creek site, many Salish suckers were previously PIT tagged by our Canadian colleagues during an unrelated study and we captured two of these previously marked individuals. There was no movement of individual fish among sites documented in my study; all recaptured fish were trapped in the study site where they were originally marked. Most of the

recaptured fish were tagged and recaptured during the summer low flow period (i.e., August through mid-September), but one was recaptured on October 18 (i.e., after the onset of the fall high flow season).

Salish sucker population structure

Fish at Cave Creek were notably smaller than those captured at all other sites, with a median total length of 89 mm and no fish exceeding 127 mm (Table 7). The Kolmogorov-Smirnov tests confirmed that Cave Creek was unique relative to the other sites in terms of the size of individuals in its Salish sucker population (Table 8). The distribution of total lengths across the Cave Creek population was similar in shape to the other sites (Figure 7), but the size range distinguished Cave Creek from the other sites.

The largest fish captured during the study were from the Maberry site, with several individuals exceeding 200 mm. Maberry shows considerable overlap with the other sites in fish lengths below about 150 mm; above this level larger fish were represented more frequently in Maberry than the other sites (Figure 7). These exceptionally large fish were outliers; nine fish were greater than 1.5 times the interquartile range (Figure 8). Two sites actually had greater median lengths than Maberry despite the large specimens. The Kolmogorov-Smirnov test did not distinguish the Maberry fish population from other sites based on total length; this is probably attributable to the overlap in size-class distribution with the smaller fish.

With the exception of Cave Creek, total lengths could not separate the fish populations in this study by site. In their length frequency histograms, most sites with

sufficient data suggest a normal distribution of fish across size classes (Figure 9). The Maberry site is more ambiguous, with a considerable size gap between a normally distributed population of fish with a mode close to 120 mm, and fish larger than 180 mm. With the presence of similarly large individuals, Gordon's Brook, Bertrand Creek, and Double Ditch are sites that could exhibit this same pattern, but low sample size precluded the analysis.

Land use patterns

The majority of the land within the Bertrand and Fishtrap Creek watersheds is agricultural land and rural residential properties outside the cities (Table 6). This designation accounts for 77% of the land area in the Bertrand Creek watershed and 75% of the Fishtrap Creek watershed. Forests and urban areas comprise a smaller percentage of the land area of these watersheds, with Fishtrap Creek possessing almost three times the amount of urban land area at 16%, compared with 6% for Bertrand Creek. Forests accounted for 9% of the watershed area in Fishtrap Creek and 17% of the watershed in Bertrand. In both watersheds, the Canadian portions had a greater percentage of the total land area designated urban than did the portions in the United States; yet Canada also had a greater percentage of forests than the United States.

Analysis of land use within individual sites showed dissimilar land use relative to their parent watersheds as a whole. There was no urban land within the specified 100-meter buffers at any of the study sites (Table 6). For most of the individual sites, forested land was represented at much higher proportions relative to their parent watersheds.

Total land use was split between forests and agricultural, with four sites having majority agricultural land use and four sites having majority forest land. Percentages varied widely between sites, with the Double Ditch buffer being 100% agricultural and the Bertrand Creek site buffer consisting of 82% forest.

Discussion

Hypoxia, hyperthermia, and changes in abundance

Changes in temperature and dissolved oxygen between flow season in the coarse-scale analysis of watersheds and nations were readily apparent in this study. These trends were also seen in some of the individual sites in the fine-scale analysis, but low sample size made it likely that this phenomenon, if it was present, would be undetectable with statistical tests in the remaining sites. Where changes in dissolved oxygen and temperature were observed, the overall direction of these changes was expected, with higher stream temperatures and lower dissolved oxygen concentrations present during the low flow conditions of summer.

There were no concurrent patterns in abundance as measured by CPUE related to flow period during the time frame that this study was undertaken. This was true of the fine-scale within-site analyses, as well as the two coarse-scale analyses. The correlation analysis also yielded no significant correlations between CPUE and dissolved oxygen or temperature. In another study of Salish suckers, researchers similarly noted that there were no significant differences in CPUE rates from May through October at their study site (Pearson and Healey 2003).

There are several reasons why Salish sucker abundance may remain unchanged despite the observed seasonal fluctuations in dissolved oxygen and temperature, or if changes in abundance are actually occurring, why they may not have been detected in this study. Despite dissolved oxygen concentrations that were lower and temperatures that were higher in the watersheds during the summer low flow conditions, these levels may be well within the range of tolerable environmental conditions for the Salish sucker. Many of the members of the Catostomidae family in North America are generally considered intolerant of pollution and habitat degradation, but there are many species in the family, some of which are quite tolerant of poor water quality (Grabarkiewicz and Davis 2008). Exact, laboratory defined dissolved oxygen limits for the species are unavailable, but it has been suggested in previous literature that Salish suckers are fairly tolerant of mild hypoxia, with dissolved oxygen concentrations of $4 \text{ mg}\cdot\text{L}^{-1}$ and above being suitable and levels of $2\text{-}4 \text{ mg}\cdot\text{L}^{-1}$ inducing sub-lethal effects (DFO 2009). One study estimated that concentrations below $3 \text{ mg}\cdot\text{L}^{-1}$ would be considered lethal (Pearson 2004). Research on the closely related Longnose sucker has shown that dissolved oxygen levels of $5\text{-}6 \text{ mg}\cdot\text{L}^{-1}$ are tolerable for the species (Edwards 1983). There were only three sites in my study with mean dissolved oxygen concentrations that dropped below $5 \text{ mg}\cdot\text{L}^{-1}$. These include the Aldergrove, Howe's at 16th, and Salish Creek sites. Salish suckers were captured at these sites on sampling dates during the summer when morning dissolved oxygen concentrations between 4 and $5 \text{ mg}\cdot\text{L}^{-1}$ were observed. The presence of these fish during times of low dissolved oxygen, coupled with the unchanged CPUE throughout the sampling season, suggests that for Salish suckers moderate hypoxia is not

immediately harmful to individuals in the juvenile and adult life stages that were the subject of this study.

The higher temperatures observed during the low flow conditions of summer did not appear to limit Salish sucker abundance. Stream temperatures exceeded 20°C at some of the sites during the summer afternoons. During two periods of sampling at the Salish Creek site, temperatures were above 20°C during the afternoons and did not fall below 18°C the following mornings when the traps were retrieved. Salish suckers were captured during these two times. Temperature limits for the Salish sucker are unknown, but Longnose suckers prefer temperatures of 10-15°C (Edwards 1983). In a previous study of Salish suckers, CPUE was highest during trapping periods when water temperatures were between 12 and 15°C (Pearson and Healey 2003). If this threshold indicates optimal temperature conditions, then some of the higher temperatures in my study were sub-optimal but not immediately threatening to Salish sucker health and did not result in migration from the sites.

My study failed to elucidate any evidence of migrations of Salish suckers between sites or identify sites where favorable conditions provided refuge during summer low flow period. This study suggests that temperature and dissolved oxygen conditions that were non-lethal but sub-optimal existed during the summer, but that these conditions did not induce any large-scale movement in the fish. With a tolerance for high existing temperatures and low dissolved oxygen conditions, the Salish suckers at these sites may not need extensive refuge habitat that requires movement between reaches to access.

A finer analysis of the individual study sites could reveal exploitable heterogeneity in the Salish sucker's environment during the summer low flow period and give insight into how Salish suckers contend with hyperthermic and hypoxic conditions. Scale is important in assessing habitat and environmental variability and the opportunities or limitations imposed on a species by that habitat (Levin 1992, Diez and Pulliam 2007). Within a single stream reach there may be small-scale differences in the environment that offer refuge from disturbance (Lancaster and Belyea 1997). In my study, two dissolved oxygen and temperature measurements at one fixed location were representative of the entire site for that trapping period. For some of the sites, notably the same sites where Salish suckers were most abundant, the stream reaches were deep and wide, the flow velocities low, and the dissolved oxygen and temperature levels were presumably much more heterogeneous and dynamic than at stream riffles. My sampling methods were too limited to gain a complete of the environmental heterogeneity that may be present in these sites.

The exploitation of environmental heterogeneity within a confined habitat can allow fish to persist in marginal conditions. For some species living in harsh environments, utilizing small-scale refuges is important to survival (Torgersen et al. 1999). In a hypoxic environment with thermal stratification, fish can move to cooler waters in order to reduce respiration (Rankin and Jensen 1993). In intermittent stream pools, some fish are able to survive exposures to hypoxic conditions at night as long as there is a return to higher dissolved oxygen concentrations during the day (Labbe and Fausch 2000). The deep pools preferred by Salish suckers can resemble lentic habitats in

their heterogeneous distribution of oxygen and temperature, especially during periods of intermittent flow when there is little mixing of water. These habitats present a dynamic environment for fish that often face choices between mutually exclusive tolerable dissolved oxygen and temperature levels that vary considerably through time and space (Matthews and Berg 1997, Elliot 2000).

For Salish suckers, other aspects of their physical habitat may be more important than optimal dissolved oxygen and temperature levels in habitat selection. While my study did not show any patterns in abundance from flow period to flow period, suckers tended to favor deeper habitat. A previous study reaffirms this pattern, and noted that the preference for deep pools, beaver ponds, and near stagnant stretches of stream grows stronger as the fish reach larger sizes (Pearson 2004). Research on the topic of habitat selection in stream fishes suggests that larger fish face less predation risk from birds and mammals in deeper pools (Harvey and Stewart 1991). Refuge habitat can lessen the exposure to a variety of hazards, both biotic and abiotic, and the threats posed by these hazards may change as the individual grows or as the environment fluctuates (Schlosser 1985, Magoulick and Kobza 2003). Seeking refuge from predation rather than hypoxia may be a more important survival strategy for suckers during the summer flow period when water levels are lower.

Physical barriers in the stream may play a role in the inability of fish to move across habitats. Previous telemetry studies show that adult Salish suckers have home ranges of a similar size to other stream fish species and are capable of moving across several hundred linear meters of stream channel if physical barriers to dispersal are not an

impediment (Pearson and Healey 2003). Beaver dams were an obstacle in the same study, and suckers did not readily cross them. At the Cave Creek site, a riffle above the large pool where the trapping site was located was nearly dry for most of the summer, preventing dispersal upstream during this time. The property owners also indicated that a large beaver dam was present downstream from the site, making it likely that this population of Salish suckers was somewhat restricted in its movement. The recapture of one individual during October sampling that was previously captured at the site during the summer suggests that there may be limited movement of fish at Cave Creek.

Finally, it is also likely that low statistical power would make it difficult to confidently test for differences in abundance across flow season in the fine-scale analyses within study sites. Each site was sampled up to five times during the low flow period and up to five times during the high flow period. Unless the effect size is large, the power of a Kruskal-Wallis is probably low due to small sample size and the probability of committing a type II error is high.

Population structure and fish movement

The Maberry pond and Cave Creek sites stand out among all sites in their length frequency distributions. Maberry pond appeared to contain fish of multiple age classes, some of which were very large individuals, and Cave Creek harbored juvenile fish exclusively. At Maberry pond, the majority of fish I captured were centered on a mode of 120-130 mm total length. At this size, most Salish suckers are in their second year of life and are just beginning to reach sexual maturity (Pearson and Healey 2003). Fish in

the 160-189 mm range were absent from the site, while fish greater than 190 mm comprised approximately 20% of the Maberry site population. The presence of these larger, sexually mature fish during the spring and summer spawning period is noteworthy, as there appears to be no suitable spawning substrate in the Maberry pond. These may be individuals that have been washed downstream and are unable to cross back over the dams on either side of the pond to reach suitable spawning grounds. This site also contains an aerator, which may attract Salish suckers from nearby habitats, although the relative absence of suckers during the low flow period when hypoxia is more pronounced compared with the high flow period suggests that Salish suckers are not seeking refuge in this site during the summer.

Conversely, the Cave Creek site is noteworthy because of the absence of large, sexually mature fish. The largest individual was 127 mm long and most fish were much smaller; the mode was the size class of 80 to 89 mm fish, accounting for about 35% of the population. In their study of Salish sucker life-history, Pearson and Healey noted that 50% of the males were mature by 125 mm and 50% of females were mature by 135 mm (Pearson and Healey 2003). Applying the above criteria to the Cave Creek population, it is possible that there were no sexually mature fish at this site. This is an interesting finding because Cave Creek was the second deepest study site at 132 cm, and Salish sucker adults are more strongly associated with deep pool habitats than are juveniles (Pearson 2004). This pattern of deep pool preference by larger stream-dwelling fish is well documented (Harvey and Stewart 1991). That there were only juveniles captured at

this site throughout the field sampling season would seem to indicate that this habitat is inaccessible or otherwise untenable for adult Salish sucker when the sampling took place.

For many lotic fish species, beaver ponds are an important habitat, acting as a population source from which individuals disperse during favorable conditions (Schlosser 1998). Ponds can provide ideal rearing habitat for juvenile fishes, in part by increasing productivity and invertebrate abundance (leading to increased fish growth rates) and providing refuge from high flows (Kemp et al. 2012). The presence of these ponds in Cave Creek and the large numbers of juveniles found at the study site in this creek may indicate that this area is an important nursery habitat for Salish suckers. The proximity of this Canadian site to the United States and the lower reaches of Bertrand Creek suggest that international cooperation is important in establishing conservation measures if fish are crossing the border when dispersing from source habitats.

Beaver ponds can also act as barriers to dispersal during certain times of the year, with limited movement across dams by stream fishes followed by periods of migration (Schlosser 1995). The land owner at the Cave Creek site indicated that there were beaver ponds downstream from the trapping site. This may explain the pattern of abundant juvenile fish and the absence of adults in the Cave Creek site. It seems likely that at some time period, this site must have been accessible to adults who spawned at the site or in the riffle just upstream. The adults then moved downstream and their offspring were left behind to rear at the site. These juvenile fish may be trapped at this site until high flows during the winter can breach the dams or rewater the seasonally dry portion of the creek upstream. Trapping efforts focused on recapturing previously tagged juvenile fish

and elucidating their migration patterns might be most successful if timed during the winter or early spring to coincide with the highest flows.

In their strong preference for deep pools and lentic habitats such as beaver ponds that are patchily distributed throughout the watershed, Salish sucker populations are likely to be naturally isolated to some extent. For two of the sites in this study, suckers were present only once during the field sampling while the areas just upstream from these two sites included deep pools and ponds where Salish suckers were prolific. Two suckers were captured in East Double Ditch Creek and one sucker was caught in the Bertrand Creek site. Upstream from each of these sites were two areas of high sucker density; the ponds above the Gordon's Brook site (upstream from Double Ditch Creek), and the Cave Creek site (upstream from the Bertrand site). High concentrations of fish near stream reaches where fish are mostly absent is a documented phenomenon in fisheries biology; the linear nature of streams limits the scope of dispersal throughout the watershed and particular life history traits necessitate the use of specific habitat that may only occur in patches (Dunham and Rieman 1999, Koizumi 2011). These conditions can segregate stream fish into sub-populations, something that may be occurring with Salish suckers in the Bertrand and Fishtrap Creek watersheds.

For stream fish populations exhibiting this type of patchy distribution, dispersal and habitat connectivity are important to the persistence of the species (Schlosser 1991, Koizumi 2011, Poos and Jackson 2012). Where habitat fragmentation has occurred or where barriers to dispersal exist, movement of individuals between sub-populations is curtailed which may leave stream fish vulnerable to extinction (Dunham and Rieman

1999). Channelized sections of streams, devoid of the pools where suckers typically reside as well as riffles containing gravel for spawning, present such barriers to Salish suckers. The watershed map clearly shows the legacy of channelization in the Fishtrap Creek watershed in the United States, which has affected several tributaries (Figure 1). The tributaries flowing south from Canada are constrained in roadside ditches for several kilometers upon entering the United States, and the natural channel morphology is not regained until these tributaries enter the Fishtrap Creek mainstem.

East Double Ditch Creek, with its straightened channel relegated to a roadside drainage ditch for over 5 km, is one such tributary afflicted by channelization and loss of habitat. The distance from the Gordon's Brook ponds and other areas in Canada to the lower reaches of Fishtrap Creek in the United States where the natural sinuosity of the stream returns and pools are once again present, may be too great a distance to connect the locally abundant sucker populations in the Fishtrap Creek headwaters to the lower reaches. State biologists have noted the absence of Salish sucker in much of the southern portion of the Fishtrap Creek watershed (Robert Vadas, WDFW, robert.vadas@dfw.wa.gov, pers. comm.). The barrier that these homogeneous glides create for potential dispersers may hinder Salish sucker persistence in the lower Fishtrap Creek watershed.

Land use patterns

Although the area is seeing rapid residential development, the Fishtrap and Bertrand Creek watersheds are still dominated by agricultural land (Figure 10). Land use patterns

are generally similar on either side of the border. Agricultural land remains prevalent, urban land is a smaller percentage but is growing, and forested land remains in pockets throughout the watersheds, especially in parks and riparian buffers adjacent to agricultural land. These patterns of land use within the study watersheds have important implications for riparian habitat integrity and for Salish sucker conservation.

Agricultural land does not provide the same ecological utility as a natural, forested landscape, but it does not alter the natural ecosystem processes to the same extent as urban land. The deleterious effects of agricultural land use on stream health are generally less severe and easier to mitigate for than for urban land use (Wasson et al. 2010, Violin et al. 2011, Herringshaw et al. 2011). Even in watersheds where agriculture is extensive, changes in the fish communities and indices of biotic integrity may be slight, especially where riparian buffers exist (Stauffer et al. 2000, Greenwood et al. 2012). In one study, changes to the fish communities within streams were apparent only after at least 50% of the watershed had been converted to agriculture (Wang et al. 1997). Contrasting this with the impact of urban land on streams, some studies have shown that deleterious effects to stream health due to urban land use are manifested at a far lower threshold than agriculture (Stepenuck et al. 2002, Wang and Kanehl 2003). Urban land and the accompanying impervious surfaces are expected to grow in the Bertrand and Fishtrap Creek watersheds, though they are not currently near the levels of percent agricultural land use. An emphasis on strategic growth may help mitigate the impacts of future land use conversion.

The scale and location of disturbance and land use, rather than a simple measure of overall land use percentage of a watershed, is an important consideration in assessing the potential for riparian habitat degradation (Roth et al. 1996, Stauffer et al. 2000). Some of the evidence suggests that in watersheds dominated by agriculture, the near-stream land use is more important than basin-wide land use in determining the fish species assemblage, due to the influence of the riparian corridor on in-stream habitat (Karr and Schlosser 1978, Meador and Goldstein 2003, Teels et al. 2006). A naturally vegetated riparian corridor can help trap sediment runoff from the adjacent land, contribute to channel sinuosity and roughness, and reduce scouring of the stream channel; these functions help to maintain habitat diversity and the diversity of fish assemblages in turn (Karr and Schlosser 1978). At every site except for Double Ditch, the percent of forest land in the riparian zone was higher than that of the watershed as a whole. This pattern is present in much of the Bertrand and Fishtrap Creek watersheds; even in cases where the waterways flow through agricultural fields, there remains forested riparian corridors in many reaches where more natural stream processes can occur. This provides some hope in addressing habitat preservation for Salish sucker conservation.

In both watersheds, on either side of the border, stream restoration efforts including riparian plantings and large woody debris installments have taken place on some of these agricultural lands. The Nooksack Salmon Enhancement Association, the Bertrand Creek Enhancement Society, and the USDA Conservation Reserve Enhancement Program all have undertaken stream enhancement projects with the goal of restoring riparian ecosystem integrity and improving fish habit. Even though the

quantifiable results of such activities are under some debate -- how much of a return to a more natural stream ecosystem can be expected with a given effort? -- the utility of restoration projects in improving fish habitat on agricultural lands is well supported and such measures should continue in the future as part of a Salish sucker recovery strategy.

Conclusions

Contrary to expectations, Salish sucker abundance did not change between summer low flow period and the spring/fall high flow period. This was despite the fact that lower dissolved oxygen concentrations and higher temperatures were present during the summer. This phenomenon was less apparent in the site level analysis but more conspicuous with the pooled data of the two coarse-scale analyses examining temperature and dissolved oxygen at the levels of watershed and country. Of all the physical habitat characteristics measured in this study, average site depth was the factor most strongly correlated with Salish sucker abundance.

Hyperthermia and hypoxia at levels that would be lethal to Salish suckers during the adult and juvenile stages did not appear to be persistent or widespread throughout the sites I visited. Salish suckers were still present at the sites with the lowest dissolved oxygen concentrations and highest temperature readings during summer low flow period when water quality should have been most stressful.

With the importance of habitat considered, conservation efforts to recover the Salish sucker should focus on maintaining habitat diversity. Though a relatively small percentage of the two watersheds remain undeveloped, there is some promise in the

utility of riparian buffers for the maintenance of physical habitat, as well as water quality, in watersheds where agriculture and rural land use is extensive. In contrast to the paved landscapes in an urban environment, an agricultural landscape is more easily manipulated back into a natural state conducive to maintaining habitat diversity and complexity, through restoration efforts such as revegetation and the installment of large woody debris.

Conservation actions that support habitat integrity and connectivity at the larger scale are important in preserving the Salish sucker. With its preference for large pool habitats that are patchily distributed throughout the landscape and an obligatory habitat shift to riffles during the spawning season, a strategy that minimizes habitat fragmentation and dispersal barriers is important in developing Salish sucker conservation measures.

A greater understanding of Salish sucker life history and ecology will prove helpful in developing successful conservation plans for the species. Examining patterns of dispersal from possible source habitats such as Cave Creek, investigating the movements of Salish suckers throughout the watersheds and the extent to which habitat degradation creates barriers to dispersal, and the identification of source habitats in the watersheds should all be considered as future research objectives.

Appendix

Table 1. Average monthly discharge and temperature, representing the four-year average from 2007 to 2010. Data provided by USGS gauging stations, located at Front Street in Lynden (Fishtrap Creek) and the international border (Bertrand Creek). Fishtrap Creek temperature data not available for January.

	Discharge (feet ³ /second)		Temperature (°C)	
	January	July	January	July
Bertrand Creek	109	1.7	3.9	17.2
Fishtrap Creek	185	15	--	15.9

Table 2. Physical habitat characteristics of each site.

Site	Country	Watershed	mean bankfull width (m)	mean gradient (%)	mean depth (m)	canopy cover (%)
Aldergrove	Canada	Bertrand	5.3	<1	0.29	61.4
Cave	Canada	Bertrand	8.5	<1	0.53	22.3
Gordon's Brook	Canada	Fishtrap	6.5	<1	0.32	0
Howe's	Canada	Bertrand	3.2	<1	0.14	55.6
Salish	Canada	Fishtrap	4.8	<1	0.44	9.4
Bertrand	USA	Bertrand	9.1	2	0.30	32.6
Double Ditch	USA	Fishtrap	2.7	<1	0.22	0
Maberry	USA	Bertrand	17.3	<1	0.42	47.4

Table 3. Kruskal-Wallis test results, testing for within watershed and within site differences between flow periods.

	Dissolved oxygen (mg·L ⁻¹)		Temperature (°C)		CPUE	
	H statistic	p- value	H statistic	p- value	H statistic	p- value
Bertrand watershed	5.27	0.022	19.85	<0.001	0.23	0.628
Fishtrap watershed	9.95	0.002	13.28	<0.001	0.51	0.476
United States	4.77	0.029	18.02	<0.001	0	1
Canada	12.73	<0.001	18.12	<0.001	1.74	0.188
Maberry	2.08	0.149	4.50	0.034	0.09	0.767
Bertrand	6.00	0.014	6.00	0.014	0.80	0.371
Cave	1.13	0.289	1.13	0.289	0.76	0.384
Howe's	1.33	0.248	5.33	0.021	0.11	0.741
Aldergrove	0.24	0.624	1.50	0.221	0.06	0.803
Double Ditch	2.46	0.117	5.77	0.016	1.00	0.317
Gordon's Brook	4.50	0.034	4.50	0.034	1.16	0.282
Salish	5.33	0.021	5.33	0.021	1.03	0.309

Table 4. Correlation analysis between median Salish sucker CPUE (fish/m³/hr) for each site (n=8) and various habitat characteristics.

Habitat characteristic	Correlation coefficient (Kendall's τ)	p-value
mean depth (cm)	0.92	0.002
mean summer DO (mg·L ⁻¹)	-0.27	0.373
mean summer temperature (°C)	0.19	0.524
canopy cover (%)	0	< 1
riparian vegetation coverage (%)	0.11	0.702

Table 5. Number of Salish suckers PIT tagged and the number recaptured, organized by site.

site	PIT tagged	
	fish	recaptures
Cave*	33	8
Howe's**	1	2
Gordon's Brook	3	0
Double Ditch	2	0
Bertrand	1	0

* There were 9 incidences of recapture but only 8 individuals involved; 1 sucker was recaptured twice.

**An unknown number of suckers had been tagged during another project at this site. Our study marked 1 individual and recaptured 2 individuals from the other project.

Table 6. Land use percentages for watersheds, watershed portions within each country, and site specific buffer zones for the area of influence of each study site.

	Land use percentage		
	Urban	Forest	Agriculture/Other
Bertrand	6	17	77
Bertrand United States	3	14	83
Bertrand Canada	8	20	72
Fishtrap	16	9	75
Fishtrap United States	12	4	84
Fishtrap Canada	18	13	69
Maberry	0	67	33
Bertrand	0	82	18
Cave	0	65	35
Howe's	0	23	77
Aldergrove	0	37	63
Double Ditch	0	0	100
Gordon's Brook	0	61	39
Salish	0	17	83

Table 7. Salish sucker total length statistics in millimeters. Values were rounded to the nearest millimeter. The Gordon's Brook, Bertrand, and Double Ditch sites were omitted due to small sample sizes.

site	median	IQ range	maximum	minimum
Maberry	130	124-154	261	96
Cave	89	84-100	127	60
Howe's	123	114-138	177	61
Aldergrove	125	116-142	183	106
Gordon's Brook	192	164-213	226	135
Salish	147	134-158	174	91

Table 8. Results from the Kolmogorov-Smirnov tests examining similarity in population structure between sites. Asterisks represent significant differences in populations based on total lengths.

site comparisons	D	
	statistic	p-value
Maberry/Cave*	0.871	<0.001
Maberry/Howe's	0.313	0.328
Maberry/Aldergrove	0.303	0.071
Maberry/Salish	0.308	0.090
Cave/Howe's*	0.682	<0.001
Cave/Aldergrove*	0.833	<0.001
Cave/Salish*	0.868	<0.001
Howe's/Aldergrove	0.181	0.958
Howe's/Salish	0.510	0.042
Aldergrove/Salish	0.412	0.026

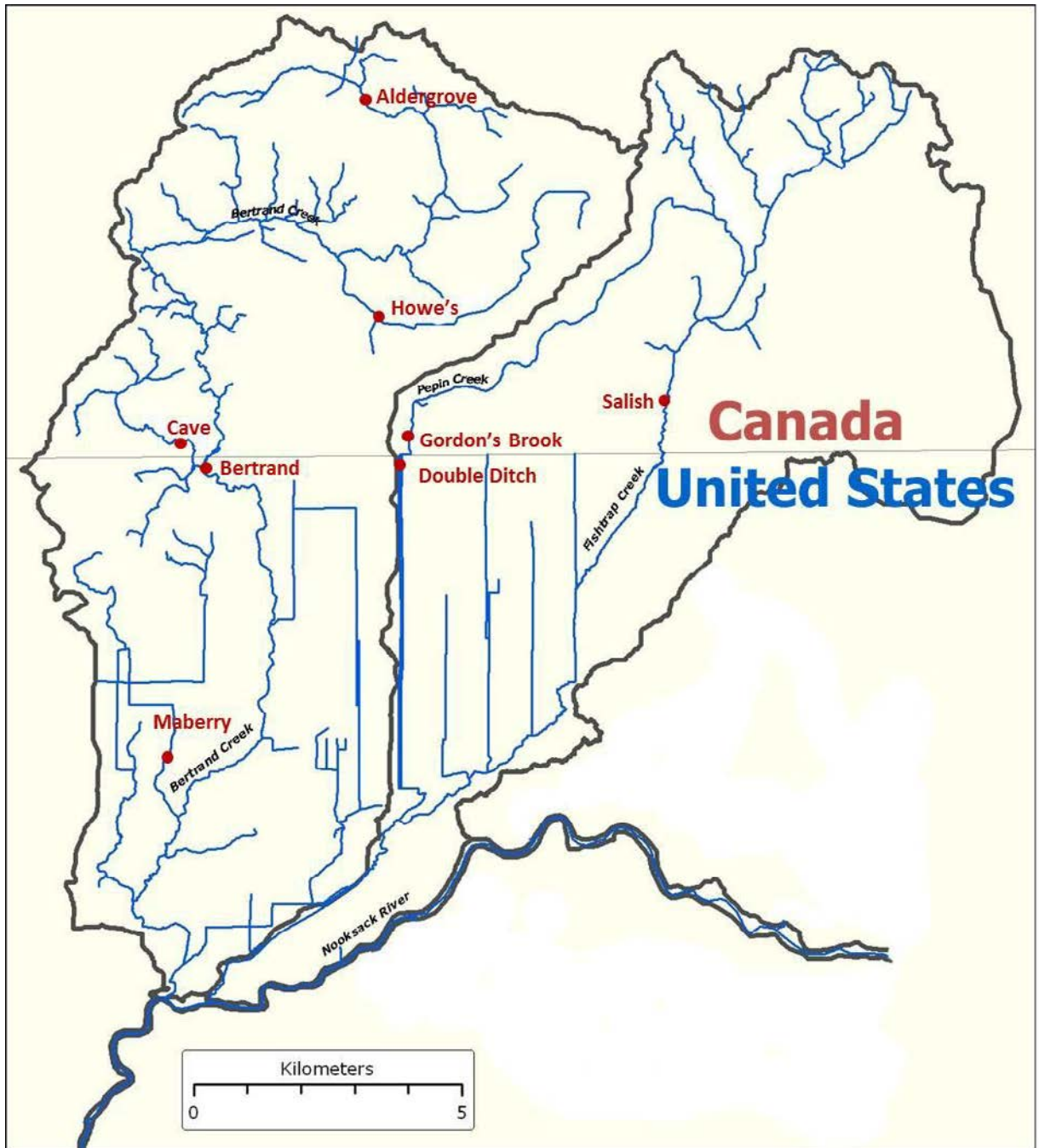


Figure 1. Map showing the Fishtrap Creek and Bertrand Creek watersheds with the locations and names of the study sites.

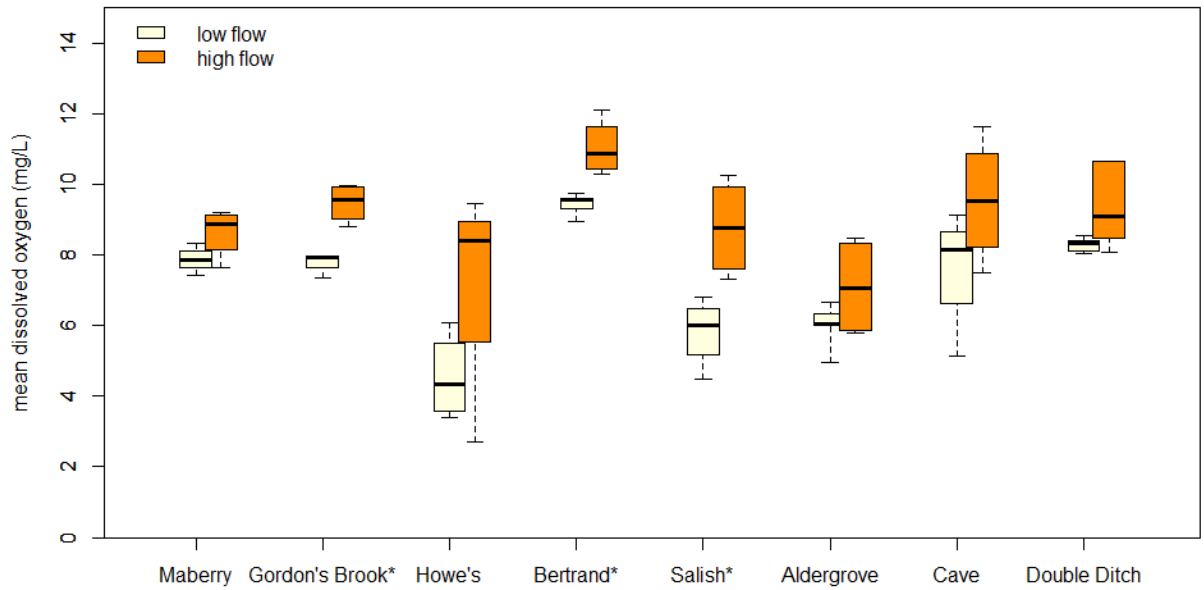


Figure 2. Boxplots of site dissolved oxygen across flow period. Sites with significant differences are marked with an asterisk ($p < 0.05$).

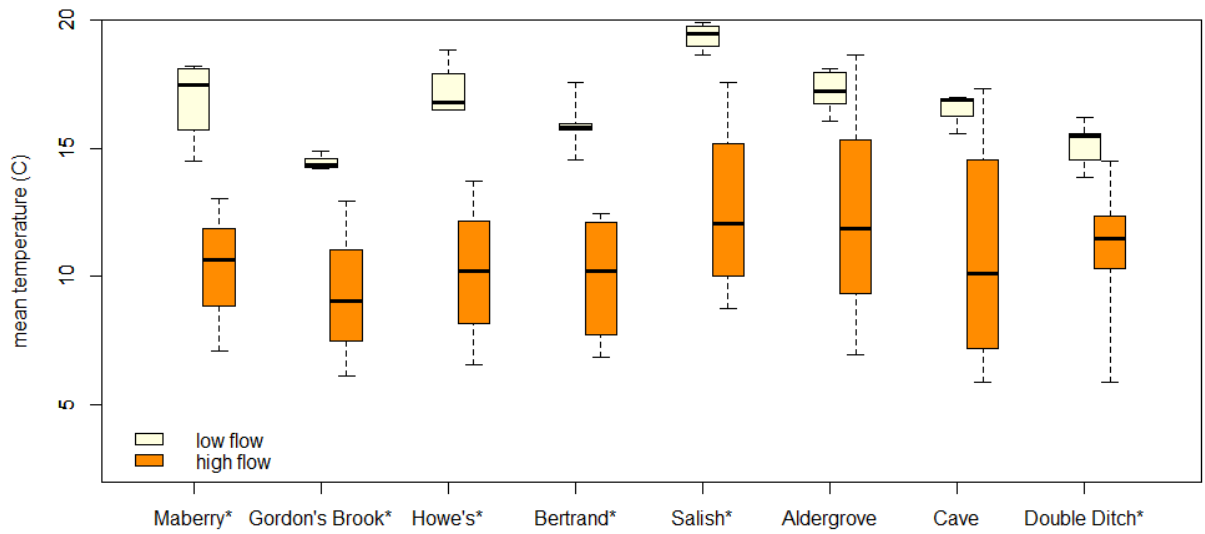


Figure 3. Boxplots of site temperature across flow period. Sites with significant differences are marked with an asterisk ($p < 0.05$).

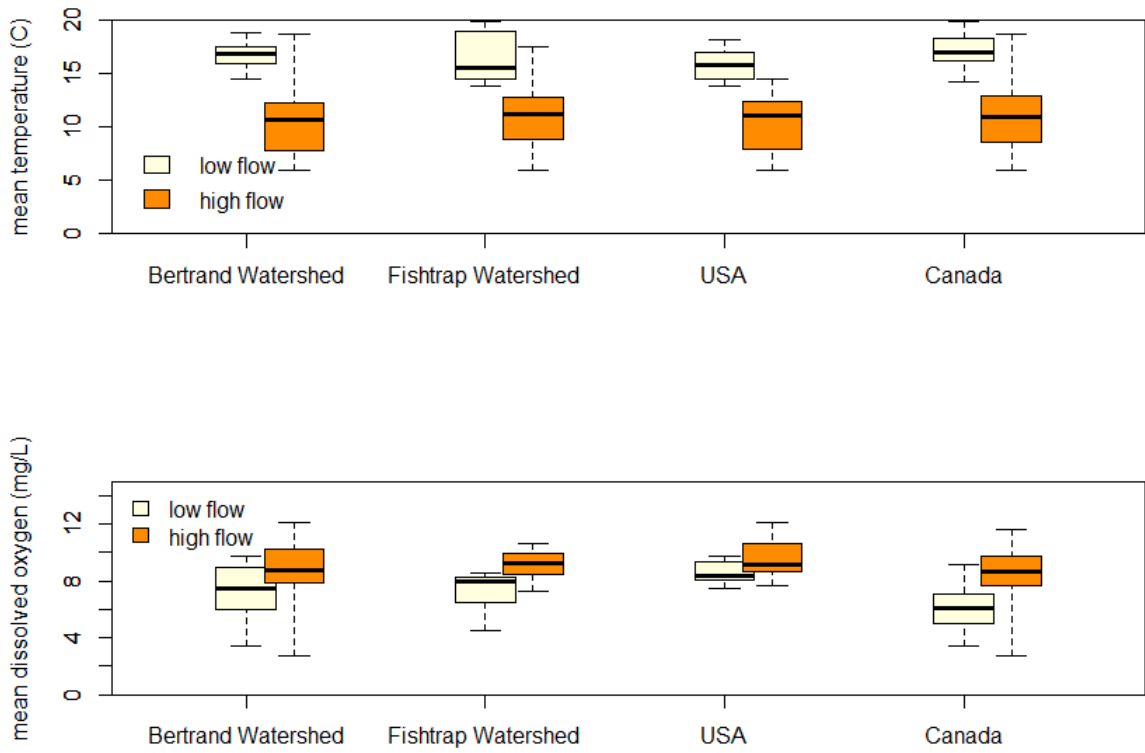


Figure 4. Boxplots of temperature and dissolved oxygen across flow period in each watershed and each country.

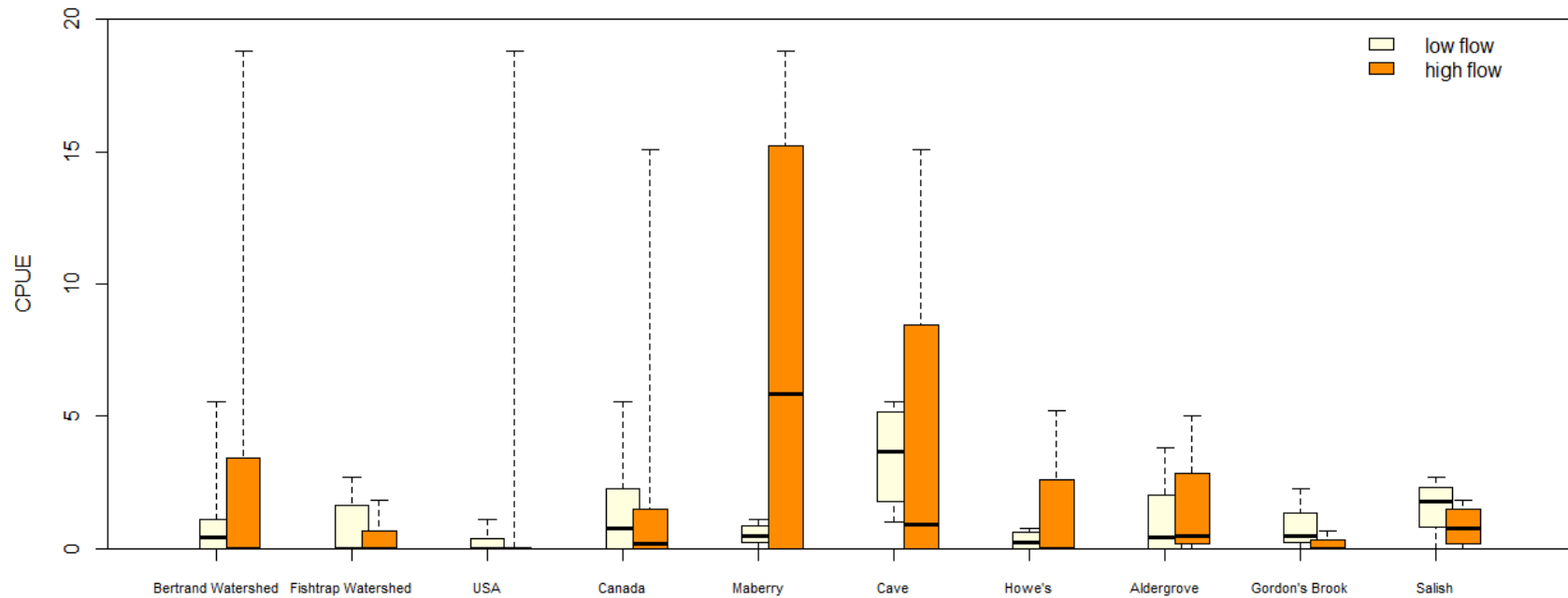


Figure 5. Boxplots for catch per unit effort (CPUE) across flow period in each watershed, country, and site. Double Ditch and Bertrand were omitted due to small sample size. None of the figures represent significant differences between flow levels as determined by the Kruskal-Wallis tests ($p < 0.05$).

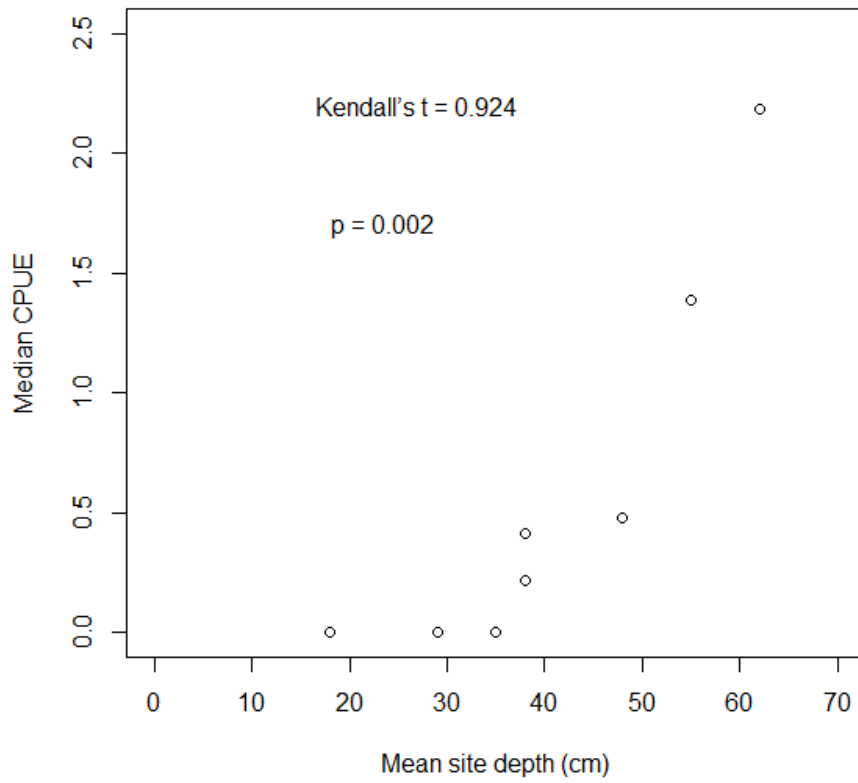


Figure 6. Scatterplot showing the correlation between depth and CPUE.

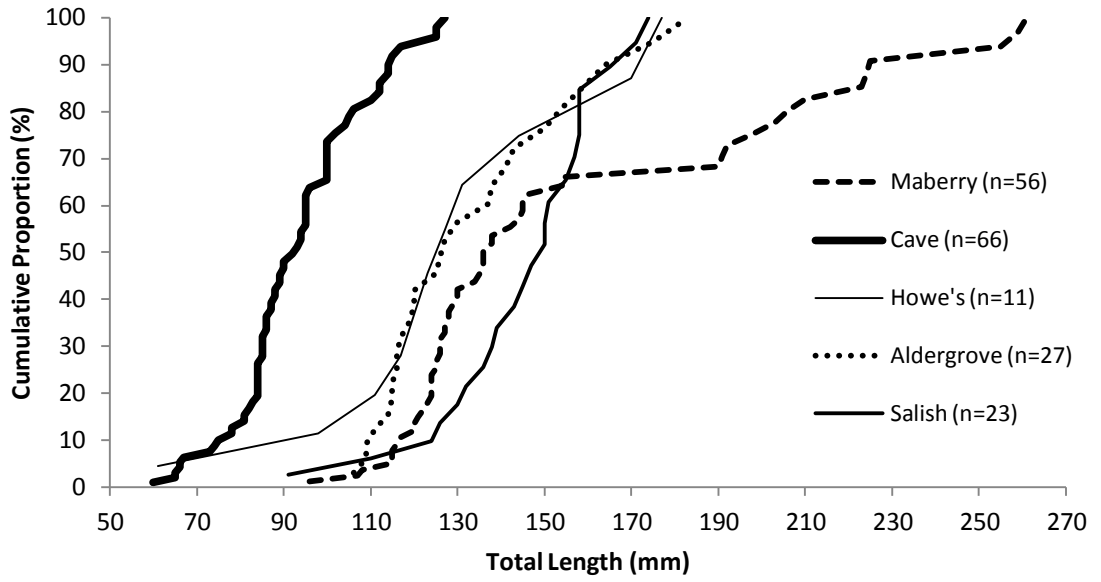


Figure 7. Cumulative proportion of Salish sucker total lengths by site. The Gordon's Brook, Bertrand, and Double Ditch sites were omitted due to small sample sizes.

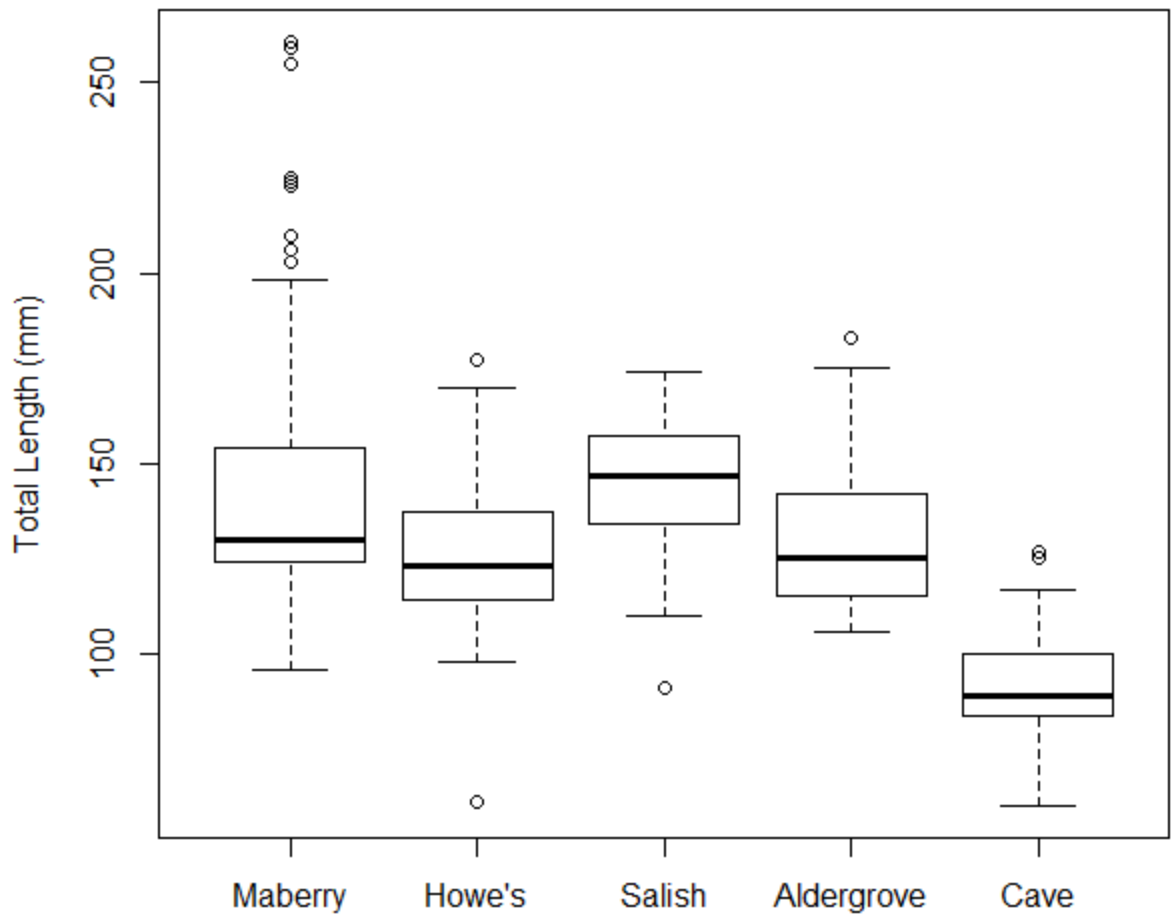


Figure 8. Boxplots of Salish sucker total length statistics for each site. The Gordon's Brook, Bertrand, and Double Ditch sites were omitted due to small sample sizes.

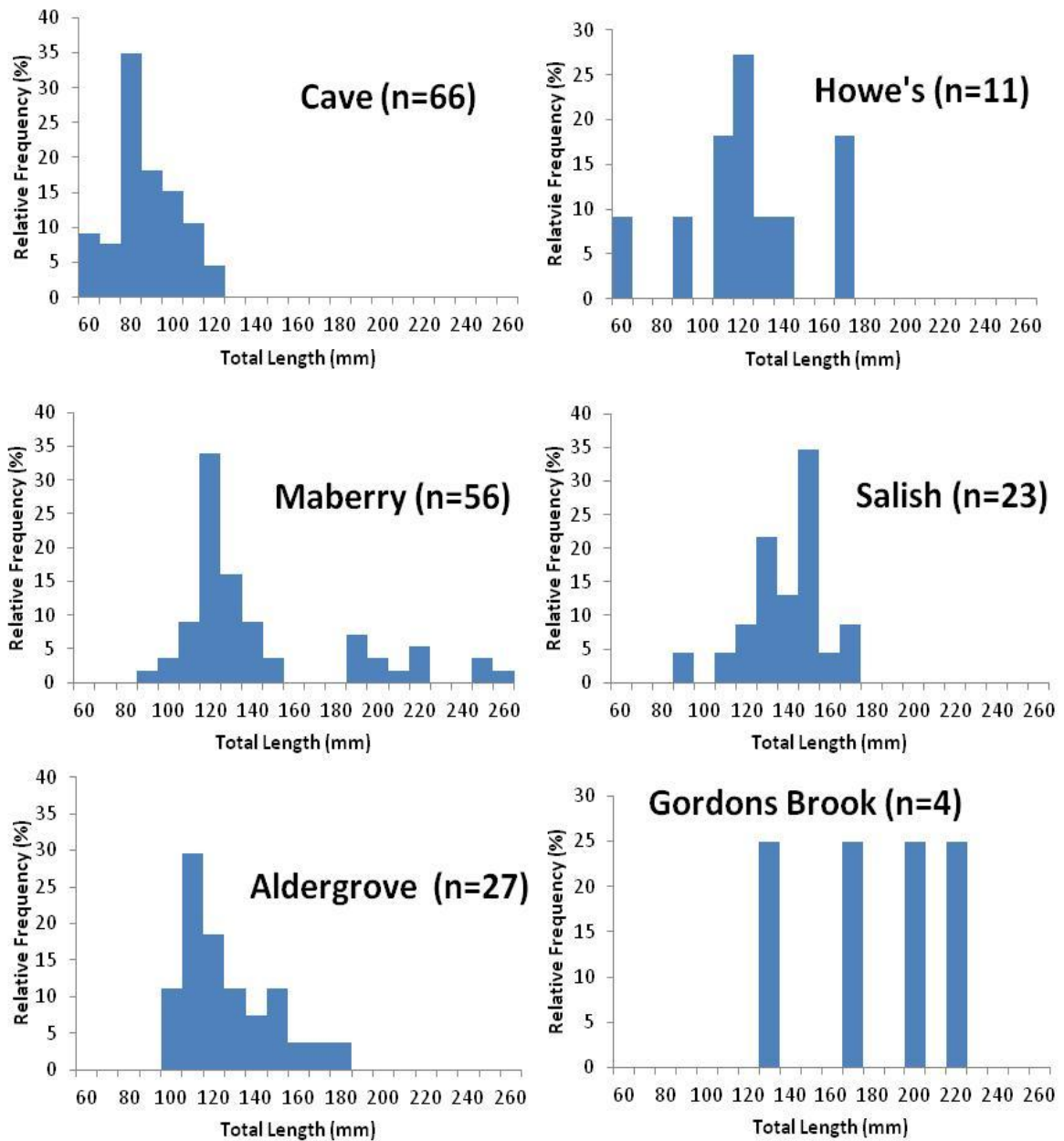


Figure 9. Length frequency histograms of Salish sucker total lengths, expressed in 10 mm intervals. The Bertrand and Double Ditch sites were omitted due to small sample size.

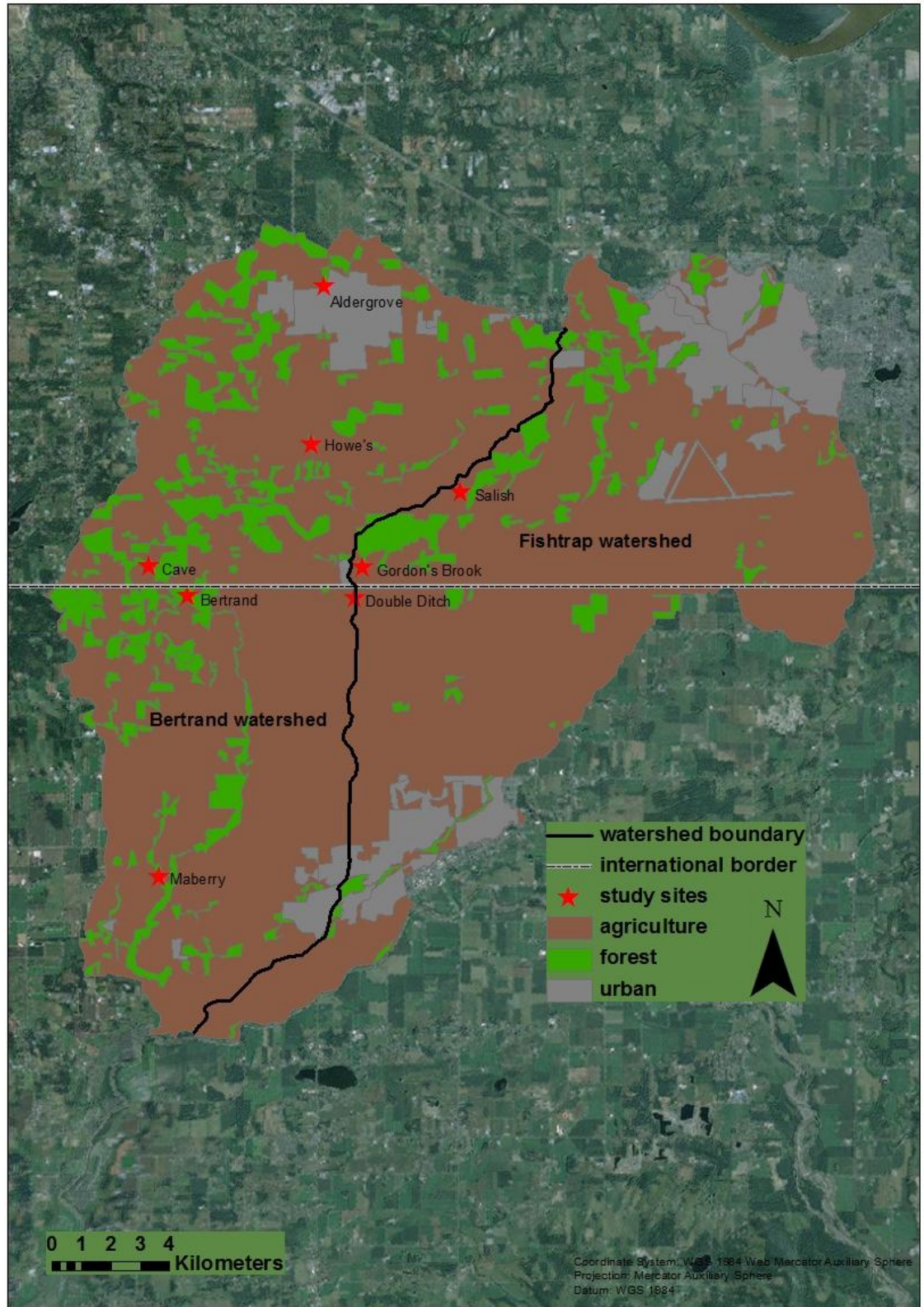


Figure 10. Land use map of the Bertrand and Fishtrap Creek watersheds.

Literature Cited

- Allan, J.D., and A.S. Flecker. 1993. Biodiversity conservation in running waters. *BioScience* 43: 32-43.
- Bain, M.B., J.T. Finn, and H.E. Booke. 1988. Streamflow regulation and fish community structure. *Ecology* 69: 382-392.
- Bain, M.B. and N.J. Stevenson, eds. 1999. *Aquatic Habitat Assessment: Common Methods*. American Fisheries Society, Bethesda, Maryland.
- British Columbia Ministry of Environment, Lands and Parks (BCMOE). 1993. Salish sucker. Available online at <http://www.env.gov.bc.ca/wld/documents/salishsucker.pdf> (accessed 20 October 2010).
- Carlson, C.A. and R.T. Muth. 1993. Endangered species management. In: Kohler, C.C., and W.A. Hubert, eds. *Inland fisheries management in North America*. American Fisheries Society, Bethesda, Maryland. pp. 355-381.
- Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications* 8: 559-568.
- Chech, J.J. Jr., S.J. Mitchell, D.T. Castleberry, and M. McEnroe. 1990. Distribution of California stream fishes: influences of environmental temperature and hypoxia. *Environmental Biology of Fishes* 29: 95-105.
- Cooke, S.J., C.M. Bunt, S.J. Hamilton, C.A. Jennings, M.P. Pearson, M.S. Cooperman, and D.F. Markle. 2005. Threats, conservation strategies, and prognosis for suckers (Catostomidae) in North America: insights from regional case studies of a diverse family of non-game fishes. *Biological Conservation* 121: 317-331.
- Department of Fisheries and Oceans Canada (DFO). 2009. Recovery potential assessment for the Salish sucker (*Catostomus* sp.) in Canada. Canadian Science Advisory Report. 2008/046.
- Department of Fisheries and Oceans Canada (DFO). 2004. Aquatic species at risk: Salish sucker. Available online at <http://www.dfo-mpo.gc.ca/species-especes/species-especes/salishsucker-meuniersalish-eng.htm> (Accessed 15 February 2012).
- Diez, J.M. and H.R. Pulliam. 2007. Hierarchical analysis of species distributions and abundance across environmental gradients. *Ecology* 88: 3144-3152.

- Dodds, W.K. and E.B. Welch. 2000. Establishing nutrient criteria in streams. *Journal of the North American Benthological Society* 19: 186-196.
- Duncan, J.R. and J.L. Lockwood. 2001. Extinction in a field of bullets: a search for causes in the decline of the world's freshwater fishes. *Biological Conservation* 102: 97-105.
- Dunham, J.B. and B.E. Rieman. 1999. Metapopulation structure of bull trout: influences of physical, biotic, and geometrical landscape characteristics. *Ecological Applications* 9: 642-655.
- Edwards, E.A. 1983. Habitat suitability index models: longnose sucker. U.S. Department of the Interior, Fish and Wildlife Service. FW/OBS-82/10.35. 21 pp.
- Elliott, J.M. 2000. Pools as refugia for brown trout during two summer droughts: trout responses to thermal and oxygen stress. *Journal of Fish Biology* 56: 938-948.
- Garvey, J. E., M. R. Whiles, and D. Streicher. 2007. A hierarchical model for oxygen dynamics in streams. *Canadian Journal of Fisheries and Aquatic Sciences* 64: 1816-1827.
- Gotelli N.J. and A.M. Ellison. 2004. *A primer of ecological statistics*. Sunderland, MA: Sinauer Associates, Inc.
- Grabarkiewicz, J. and W. Davis. 2008. *An introduction to freshwater fishes as biological indicators*. U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC. EPA-260-R-08-016.
- Greenwood, M.J., J.S. Harding, D.K. Niyogi, and A.R. McIntosh. 2012. Improving the effectiveness of riparian management for aquatic invertebrates in a degraded agricultural landscape: stream size and land-use legacies. *Journal of Applied Ecology* 49: 213-222.
- Harvey, B.C. and A.J. Stewart. 1991. Fish size and habitat depth relationships in headwater streams. *Oecologia* 87: 336-342.
- Herringshaw, C.J., T.W. Stewart, J.R. Thompson, and P.F. Anderson. 2011. Land use, stream habitat and benthic invertebrate assemblages in a highly altered Iowa watershed. *American Midland Naturalist* 165: 274-293.
- Horwitz, R.J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. *Ecological Monographs* 48: 307-321.
- Institute for Watershed Studies (IWS). 2012. *Quality assurance manual and standard*

operating procedures. Bellingham, Washington.

- Jelks, H.L., S.J. Walsh, N.M. Burkhead, S. Contreras-Balderas, E. Diaz-Pardo, D.A. Hendrickson, J. Lyons, N.E. Mandrak, F. McCormick, J.S. Nelson, S.P. Platania, B.A. Porter, C.B. Renaud, J.J. Schmitter-Soto, E.B. Taylor, and M.L. Warren. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. *Fisheries* 33: 372-407.
- Karr, J.R. and I.J. Schlosser. 1978. Water resources and the land-water interface. *Science* 201: 229-234.
- Kemp, P.S., T.A. Worthington, T.E. Langford, A.R.J. Tree, and M.J. Gaywood. 2012. Qualitative and quantitative effects of reintroduced beavers on stream fish. *Fish and Fisheries* 13: 158-181.
- Kushlan, J.A. 1976. Environmental stability and fish community diversity. *Ecology* 57: 821-825.
- Koizumi, I. 2011. Integration of ecology, demography and genetics to reveal population structure and persistence: a mini review and case study of stream-dwelling Dolly Varden. *Ecology of Freshwater Fish* 20: 352-363.
- Labbe, T.R. and K.D. Fausch. 2000. Dynamics of intermittent stream habitat regulate persistence of a threatened fish at multiple scales. *Ecological Applications* 10: 1774-1791.
- Lammert, M. and J.D. Allan. 1999. Assessing biotic integrity of streams: effects of scale in measuring the influence of land use/cover and habitat structure on fish and macroinvertebrates. *Environmental Management* 23: 257-270.
- Lancaster J. and L.R. Belyea. 1997. Nested hierarchies and scale-dependence of mechanisms of flow refugium use. *Journal of the North American Benthological Society* 16: 221-238.
- Levin, S.A. 1992. The problem and pattern of scale in ecology: the Robert H. MacArthur award lecture. *Ecology* 73: 1943-1967.
- Magoulick, D.D. and R.M. Kobza. 2003. The role of refugia for fishes during drought: a review and synthesis. *Freshwater Biology* 48: 1186-1198.
- Matthews, K.R. and N.H. Berg. 1997. Rainbow trout responses to water temperature and dissolved oxygen stress in two southern California stream pools. *Journal of Fish Biology* 50: 50-67.

- McPhail, J.D. 1987. Status of the Salish sucker, *Catostomus* sp., in Canada. Canadian Field Naturalist 101: 231-236.
- McPhail, J.D. and E.B. Taylor. 1999. Morphological and genetic variation in northwestern longnose suckers, *Catostomus catostomus*: the Salish sucker problem. Copeia 1999: 884-893.
- Meador, M.R. and R.M. Goldstein. 2003. Assessing water quality at large geographic scales: relations among land use, water physicochemistry, riparian condition, and fish community structure. Environmental Management 31: 504-517.
- Miller, R.R., J.D. Williams, and J.E. Williams. 1989. Extinctions of North American fishes during the past century. Fisheries 14: 22-38.
- Naiman, R.J. and H. Décamps. 1997. The ecology of interfaces: riparian zones. Annual Review of Ecology and Systematics 28: 621-658.
- Pearson, M.P. 1999. The biology and management of the Salish sucker and Nooksack dace. In: Biology and management of species and habitats at risk, Kamloops, British Columbia. pp. 619-624.
- Pearson, M.P. 2004. The ecology, status, and recovery prospects of Nooksack dace (*Rhinichthys cataractae* ssp.) and Salish sucker (*Catostomus* sp.) in Canada. Doctoral Thesis, University of British Columbia, 239 pp.
- Pearson, M.P. 2009. Guidelines for the collection of Salish sucker (*Catostomus* sp.). Unpublished manual. 10 pp.
- Pearson, M.P. and M.C. Healey. 2003. Life-history characteristics of the endangered Salish sucker (*Catostomus* sp.) and their implications for management. Copeia 2003: 759-768.
- Poos, M.S. and D.A. Jackson. 2012. Impact of species-specific dispersal and regional stochasticity on estimates of population viability in stream metapopulations. Landscape Ecology 27: 405-416.
- Rankin, J.C. and Jensen, F.B., eds. 1993. Fish Ecophysiology. Chapman and Hall, London, UK. 421 pp.
- Roth, N.E., Allan J.D., and Erickson, D.L. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. Landscape Ecology 11: 141-156.
- Schlosser, I.J. 1985. Flow regime, juvenile abundance, and the assemblage structure of stream fishes. Ecology 66: 1484-1490.

- Schlosser, I.J. 1991. Stream fish ecology: a landscape perspective. *Bioscience* 41: 704-712.
- Schlosser, I.J. 1995. Dispersal, boundary processes, and trophic-level interactions in streams adjacent to beaver ponds. *Ecology* 76: 908-925.
- Schlosser, I.J. 1998. Fish recruitment, dispersal, and trophic interactions in a heterogeneous lotic environment. *Oecologia* 113: 260-268.
- Smale, M.A. and C.F. Rabeni. 1995. Influences of hypoxia and hyperthermia on fish species composition in headwater streams. *Transactions of the American Fisheries Society* 124: 711-725.
- Stalnaker, C.B., K.D. Bovee, and T.J. Waddle. 1996. Importance of the temporal aspects of habitat hydraulics to fish population studies. *Regulated Rivers: Research and Management* 12: 145-153.
- Stauffer, J.C., R.M. Goldstein, and R.M. Newman. 2000. Relationship of wooded riparian zones and runoff potential to fish community composition in agricultural streams. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 307-316.
- Stepenuck, K.F., R.L. Crunkilton, and L.Z. Wang. 2002. Impacts of urban landuse on macroinvertebrate communities in southeastern Wisconsin streams. *Journal of the American Water Resources Association* 38(4): 1044-1051.
- Teels, B.M., C.A. Rewa, and J. Myers. 2006. Aquatic condition response to riparian buffer establishment. *Wildlife Society Bulletin* 34: 927-935.
- Torgersen, C.E., D.M. Price, H.W. Li, and B.A. McIntosh. 1999. Multiscale thermal refugia and stream habitat associations of Chinook salmon in northeastern Oregon. *Ecological Applications* 9: 301-319.
- Utz, R.M., R.H. Hilderbrand, and R.L. Raesly. 2010. Regional differences in patterns of fish species loss with changing land use. *Biological Conservation* 143: 688-699.
- Violin, C.R., P. Cada, E.B. Sudduth, B.A. Hassett, D.L. Penrose, and E.S. Bernhardt. 2011. Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems. *Ecological Applications* 21: 1932-1949.
- Wang, L., J. Lyons, P. Kanehl, and R. Gatti. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. *Fisheries* 22: 6-12.

- Wang, L.H. and P. Kanehl. 2003. Influences of watershed urbanization and instream habitat on macroinvertebrates in cold water streams. *Journal of the American Water Resources Association* 39: 1181-1196.
- Washington Department of Fish and Wildlife (WDFW). 2012. Washington species of concern lists. Available online at <http://wdfw.wa.gov/conservation/endangered/list/Fish/> (Accessed 15 February 2012).
- Wasson, J., B. Villeneuve, A. Iital, J. Murray-Bligh, M. Dobiasova, S. Bacikova, H. Timm, H. Pella, N. Mengin, and A. Chandesris. 2010. Large-scale relationships between basin and riparian land cover and the ecological status of European rivers. *Freshwater Biology* 55: 1465-1482.
- Weijters, M.J., J.H. Janse, R. Alkemade, and J.T.A. Verhoeven. 2009. Quantifying the effect of catchment land use and water nutrient concentrations on freshwater river and stream biodiversity. *Aquatic Conservation: Marine and Freshwater Ecosystems* 19: 104-112.
- Wydoski, R.S. and R.R. Whitney. 2003. *Inland Fishes of Washington*. American Fisheries Society, Bethesda, Maryland.
- Zar, J.H. 1996. *Biostatistical analysis*. 3rd ed. Upper Saddle River, New Jersey: Prentice Hall.