Environmental Factors Affecting Transboundary Conservation Strategies for Endangered Salish Sucker in British Columbia and Washington

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Introduction

Effective policies for the conservation of endangered species must be informed by robust scientific study. In cases where endangered fish and wildlife species move across international boundaries, conservation policy requires transboundary cooperation and collaboration among researchers as well as regulatory agencies. The Salish sucker (*Catostomus* sp.) is one such species, an endangered fish found in river systems surrounding and crossing the Canada – U.S. border in southwestern British Columbia and northwestern Washington (McPhail 1987). Despite its limited geographic distribution, the Salish sucker's range encompasses a variety of land uses and differing habitat threats on either side of the border.

The Salish sucker has yet to be scientifically named as a species, but it is considered an evolutionarily significant unit (*sensu* Waples 1995) that is genetically and morphologically distinct from its closest relative, the more common longnose sucker (*Catostomus catostomus*) (McPhail and Taylor 1999). The federal government of Canada has listed the Salish sucker as endangered (Campbell 2001), but it has no federal listing status in the U.S. (Pearson and Healey 2003). At the state level, the Washington Department of Fish and Wildlife (WDFW) lists the Salish sucker as a monitor species, a designation for species that are not considered endangered, threatened or sensitive, but that require monitoring and management to prevent them from becoming endangered, threatened or sensitive (WDFW 2009). These various listings reflect the fact that Salish sucker populations are mostly stable in Washington but are declining rapidly in British Columbia (McPhail 1987, Pearson 1998a).

In comparison with the body of research describing commercial species such as Pacific salmon (*Oncorhynchus* spp.), relatively little is known about the Salish sucker's life history and habitat requirements. This lack of information, along with relatively low levels of public and political awareness, has hampered conservation efforts (Pearson and Healey 2003). Salish sucker populations are likely limited by a combination of stresses related to human land use, including habitat destruction due to dredging and channelization, habitat fragmentation due to dams and culverts, and water quality degradation related to reduced flows and runoff from urbanized and agricultural lands (McPhail 1987, Pearson 2000, Cooke et al. 2005). Of particular concern are the effects of hypoxia (i.e., decreased levels of dissolved oxygen in stream water), which may be caused by a number of factors, including elevated temperatures, low water levels and nutrient inputs from agricultural or urban runoff (Welch et al. 1998). These factors are known to be present in the summer in Salish sucker streams (Pearson 1998b), but few data are available to demonstrate their relative importance or the extent to which hypoxia limits Salish sucker abundance and distribution.

Representatives of both WDFW and the British Columbia Ministry of Environment (MoE) have indicated a need for more data describing environmental factors affecting Salish sucker (M. Hallock and J. Rosenfeld, pers. comm.). In particular, MoE and the federal government of Canada have identified as a management priority the quantification of the relationships between hypoxia, land use practices and Salish sucker distribution (Recovery Team 2009). This information is essential for the development of effective watershed management and land use planning strategies.

In addition to the lack of scientific information, conservation efforts for the Salish sucker have been hampered by challenges related to sharing information and coordinating policies across the international boundary. Although the Salish sucker is not considered threatened in Washington, populations in tributaries of the Nooksack River may be affected by degraded water quality in headwater streams in British Columbia. Little is known about these potential transboundary effects, as few studies have been conducted simultaneously on both sides of the border. Moreover, few mechanisms are in place to enact management strategies in one nation in response to habitat degradation or population decline in the other. Along with a greater understanding of how Salish sucker populations are affected by hypoxia and patterns of land use, greater transboundary collaboration among researchers and policy makers would help bring about more effective conservation policy on both sides of the border.

Objectives

The objectives of this project were to:

1. elucidate the factors limiting Salish sucker abundance and distribution, with particular attention to summer hypoxia;
2. identify transboundary linkages between Washington and British Columbia Salish sucker populations; and
3. characterize and compare Salish sucker population status, habitat quality and potential threats in Washington and British Columbia.

By generating high quality, unbiased scientific data, we anticipate that this project will enhance the effectiveness of watershed management and conservation policies affecting the endangered Salish sucker. By bringing together academic and government researchers from British Columbia and Washington we hope this project will also facilitate transboundary collaboration and cooperation on policy issues and questions related to endangered species management and conservation.

Methods

Study Sites

Data were collected at eight sites within the Bertrand Cr. and Fishtrap Cr. watersheds (Table 1, Fig. 1). Bertrand Cr. and Fishtrap Cr. are tributaries of the Nooksack River, both of which originate in British Columbia and flow southward across the international border to discharge into the Nooksack in Washington. Both watersheds feature low elevations, gentle gradients and a variety

Table 1. Habitat characteristics at study sites.

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	0.0
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	0.0
MABERRY	USA	Bertrand	17.3	<1	0.42	47.4

of suburban and agricultural land uses. Of the eight study sites, three were located in Washington (Mayberry, Bertrand, Double Ditch), and five were located in British Columbia (Cave, Howe's, Aldergrove, Gordon's Brook, Salish). Each site consisted of a 200 m stream reach known to support Salish suckers (see Lundgren 2012 for more detailed site descriptions).

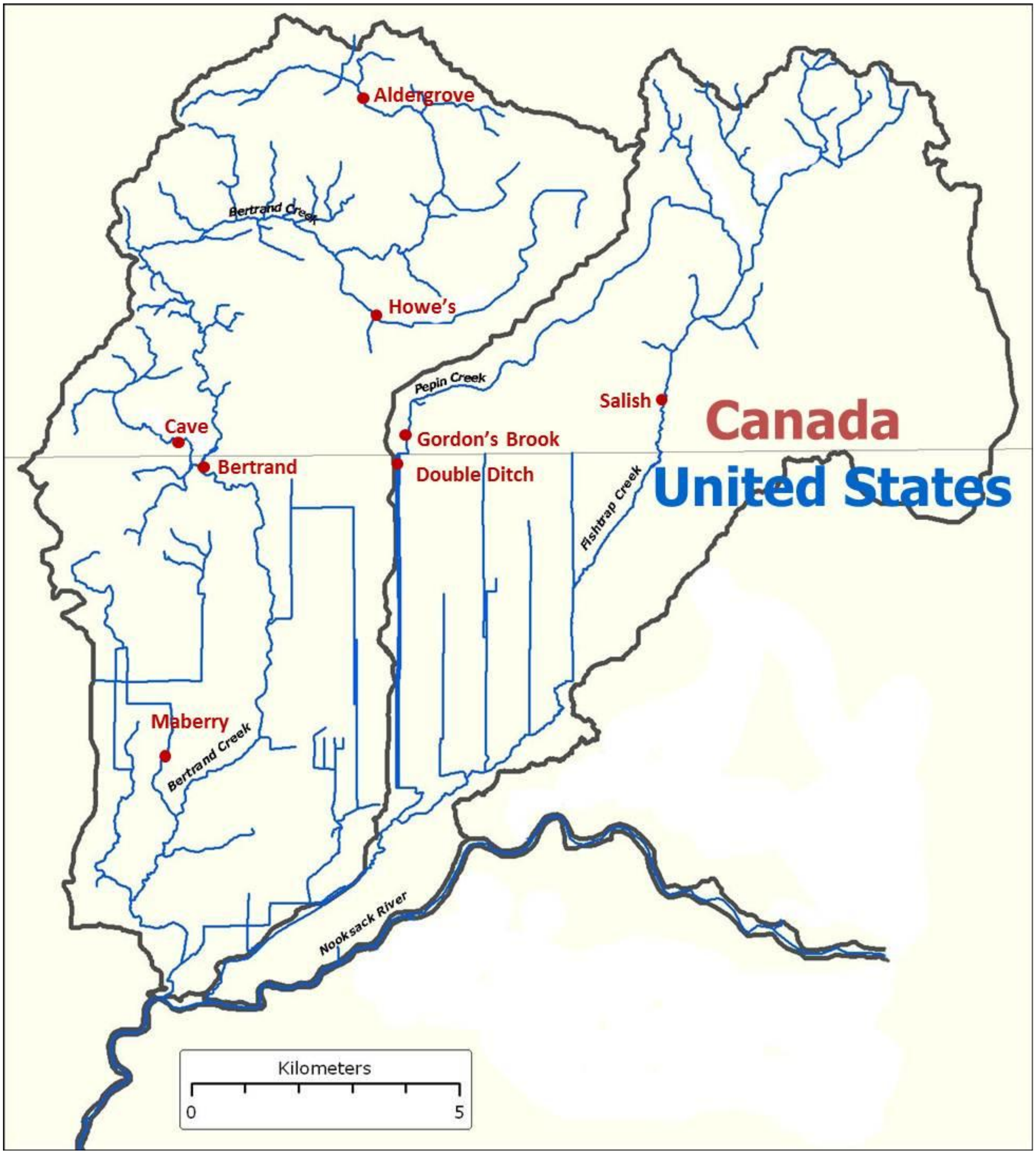

Figure 1. Study sites in the Bertrand Cr. and Fishtrap Cr. watersheds. Black lines indicate watershed boundaries.

Data Collection

To elucidate the factors limiting Salish sucker abundance and distribution, we measured physical habitat characteristics, flow levels, stream temperatures and dissolved oxygen (DO) concentrations, as well as Salish sucker abundance and population structure at each study site. Physical habitat characteristics (i.e., bankfull width, average depth, substrate composition, canopy cover) were characterized once at each site during the summer of 2011, following standard methods (Bain and Stevenson 1999). 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 seasons.

Stream temperatures, DO concentrations and Salish sucker populations were assessed contemporaneously on multiple sampling visits: We visited each site twice during the spring high flow season (i.e., April – early June), 3 – 5 times during the summer low flow season (i.e., August – early September) and then twice again during the fall high flow season (i.e., October – November). For each sampling visit, we measured temperature and DO in the evening (i.e., $\leq$2 hours before sunset) and again in the morning (i.e., $\leq$2 hours after sunrise) of the following day. Both sets of measurements were conducted at approximately middle depth at approximately the mid-point of the 200 m study reach using a hand-held DO meter (YSI Professional Series ProODO™ meter, YSI Inc., Yellow Springs, OH). For a subset of measurements we also collected water samples for DO analysis via Winkler titration (IWS 2001). Winkler analysis data were used for quality assurance and to calibrate the DO meter. For each sampling visit, we used average temperature and DO values (i.e., the mean of evening and morning measurements) as response variables, since these were most indicative of site conditions during the time when fish were collected. Differences between evening and morning measurements were considered indicative of diel fluctuations and the potential influence of eutrophication on hypoxia.

We measured Salish sucker abundance and population structure using baited funnel traps, following design specifications and methods described by Pearson and Healey (2003) and Pearson (2009). Because Salish sucker are primarily nocturnal (Pearson 2009), we deployed the traps in the evening and retrieved them in the morning of each sampling visit. Traps were baited with cat food and deployed on the stream bed at the deepest point of the study reach. Upon retrieving the traps, we recorded the number and species of all fish caught therein. We also recorded the length (total length) of all Salish sucker specimens. Trapped fish were then returned to the stream at the point of capture. Salish sucker abundances for each sampling visit were expressed in terms of catch per unit effort (CPUE), which was calculated as the number of Salish suckers caught per unit trap volume per hour of trap deployment. Population structures were characterized according to size distributions. Fish sampling was suspended on occasions when DO concentrations or temperatures approached lethal thresholds for Salish suckers or salmonid fishes to the extent that trapping or measuring activities were likely to cause undue stress and mortality.

To identify refuge habitats and transboundary linkages between Washington and British Columbia populations, 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 (Cave, Bertrand, Gordon's Brook, Double Ditch, Howe's). At each of these sites we injected one PIT tag into the body cavity of each Salish sucker we captured. We then recorded each tag's unique identification number, along with the date, capture site and length of the tagged fish before releasing the tagged fish at the point of capture. Salish suckers captured during subsequent visits were then scanned with a hand-held reader to detect and record the identification numbers of any tags present. 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. Tagging activities were focused at sites in close proximity to one another but separated by the international boundary (Cave and Bertrand, Gordon's Brook and Double Ditch; Fig. 1), where transboundary migration is most likely. We hypothesized that a deep pool at Cave Cr. would provide summer refuge for fish occurring at other times of the year across the border in the mainstem of Bertrand Cr. Tagging activities at Howe's Cr. were intended to assist mark-recapture population estimates undertaken by our Canadian colleagues at the University of British Columbia and the National Recovery Team for Salish Sucker and Nooksack Dace.

To further characterize and compare habitat quality and potential threats in Washington and British Columbia, we assessed patterns of land use affecting study sites using digitized aerial photographs (ArcGIS™ 10.1 for Desktop, Esri, Inc., Redlands, CA). Through visual estimates we categorized land use within the study watersheds as either (1) forest, (2) agricultural or (3) urban. Forest land included forests and other lands with naturally occurring tall, woody vegetation 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. Urban lands included high-density residential subdivisions, commercial areas and large parking lots, primarily in the areas surrounding the towns of Lynden, Aldergrove and Abbotsford. Using 1:50,000 scale images, we estimated the percent composition of each land use within the American and Canadian portions of each watershed. Using 1:6,000 scale images, we also estimated percent composition of land uses within a 20 ha buffer zone surrounding each study site. Buffer zones extended 1 km upstream from study reaches, including the land within 100 m on either side of the stream.

Data Analysis

Temperature, DO and CPUE data were not normally distributed, necessitating nonparametric analyses. We used Kruskal-Wallis tests followed by pairwise Wilcoxon rank sum tests with Ohms correction factor to evaluate differences among study sites and seasonal differences at each site. We also used Kendall's rank (τ_B) correlation analyses to evaluate relationships between CPUE and site characteristics. To compare Salish sucker size distributions among sites, we used Kolmogorov-Smirnov tests. The Gordon's Brook, Bertrand, and Double Ditch sites were omitted from this analysis due to their small sample sizes. As the Kolmogorov-Smirnov test is applicable to two independent samples, we made 10 pairwise comparisons representing all possible combinations of the five sites included in the analysis. Using this method with a significance level (α) of 0.05, the compounded probability of type I error would be $1 - (1 - 0.05)^{10} = 0.40$. We therefore set α at 0.01 for each pairwise comparison, thereby reducing the overall probability of type I error to 0.096. All statistical analyses were conducted using code developed in version 2.13 of R (R Development Core Team 2012).

Results and Discussion

Contrary to expectations, summer hypoxia appeared not to be an important factor affecting Salish sucker abundance. Although stream temperatures were significantly warmer during the summer low flow season at almost all sites (Fig. 2a), only three sites demonstrated significant summertime decreases in DO (Fig. 2b), and no sites exhibited significant summertime decreases in CPUE (Fig. 2c). Moreover, the sites with the highest summer DO concentrations were those with the lowest all-season CPUE values (Fig. 3). It should be recognized that, although summer DO varied significantly among sites (Fig. 3b), all sites maintained concentrations >3 mg/L, which is assumed to be the threshold for acute mortality, depending on such factors as water temperature, duration of exposure and fish size (Pearson 2004). It is therefore possible that Salish sucker distribution is limited to sites which maintain a threshold level of DO, but that variations above that threshold do not affect local abundance. Among the site characteristics we measured, only average depth was significantly correlated with Salish sucker CPUE (Table 2). These findings suggest that Salish sucker prefer deeper waters, and that physical habitat characteristics might have a greater influence on local variations in Salish sucker abundance than do water quality parameters.

Analyses of population structures suggested that the Salish sucker population at Cave Cr. was distinct from those at other sites. Pairwise Kolmogorov-Smirnov tests indicated significant differences in size distribution between Cave Cr. and every other site, but no significant differences between any other site pairs (Table 3; Fig. 4). The fact that the Cave Cr. population is comprised exclusively of fish smaller than 130 mm in total length suggests that this site is used primarily as rearing habitat for juveniles.

Mark-recapture analyses did not demonstrate any migration between sites. Of the 40 Salish suckers we tagged, eight were recaptured, all of which were both tagged and recaptured at Cave Cr. One of these was recaptured twice. At Howe's Cr. we captured one additional Salish sucker that had been tagged at the same location by our Canadian colleagues, and another that could not be identified because it had no tag, but which we judged to have been previously tagged due to a characteristic scar at the typical point of PIT tag insertion. Most of the recaptured fish were tagged and recaptured during the summer low flow season (i.e., August through mid-September), but one was recaptured on October 18th (i.e., after the onset of the fall high flow season). The fact that at least some summer residents do not migrate from Cave Cr. in fall, combined with our observation that CPUE at Cave Cr. was not significantly greater during the low flow season relative to the high flow season (Fig. 2c), suggests that Cave Cr. is not necessarily used as a summer refuge habitat.

Analyses of aerial photographs indicated comparable patterns of land use in both watersheds and on both sides of the international border. Agriculture was the dominant land use, accounting for 77% of the Bertrand Cr. watershed and 75% of the Fishtrap Cr. watershed. In both watersheds, the American portion featured more agriculture and less forest than did the Canadian portion, but these differences were subtle (Table 4; Fig. 5). Finer scale analyses indicated that the 20 ha buffer zones surrounding each site tended to feature more forested land and less urbanized land relative to the entire watershed (Tables 4 and 5). Buffer zone land use varied considerably among sites, with no clear patterns related to watershed or country. There was no clear relationship between percent forest cover and CPUE, as evidenced by the fact that the site with the highest percentage of forested land in its buffer zone (Bertrand, 82%) had the lowest CPUE (Figs. 2 and 3). There was a positive correlation between percent forest cover and DO concentration ($\tau_{B7(2)} = 0.228$, $p = 0.01$), and between percent forest cover and average site depth ($\tau_{B7(2)} = 0.199$, $p = 0.03$).

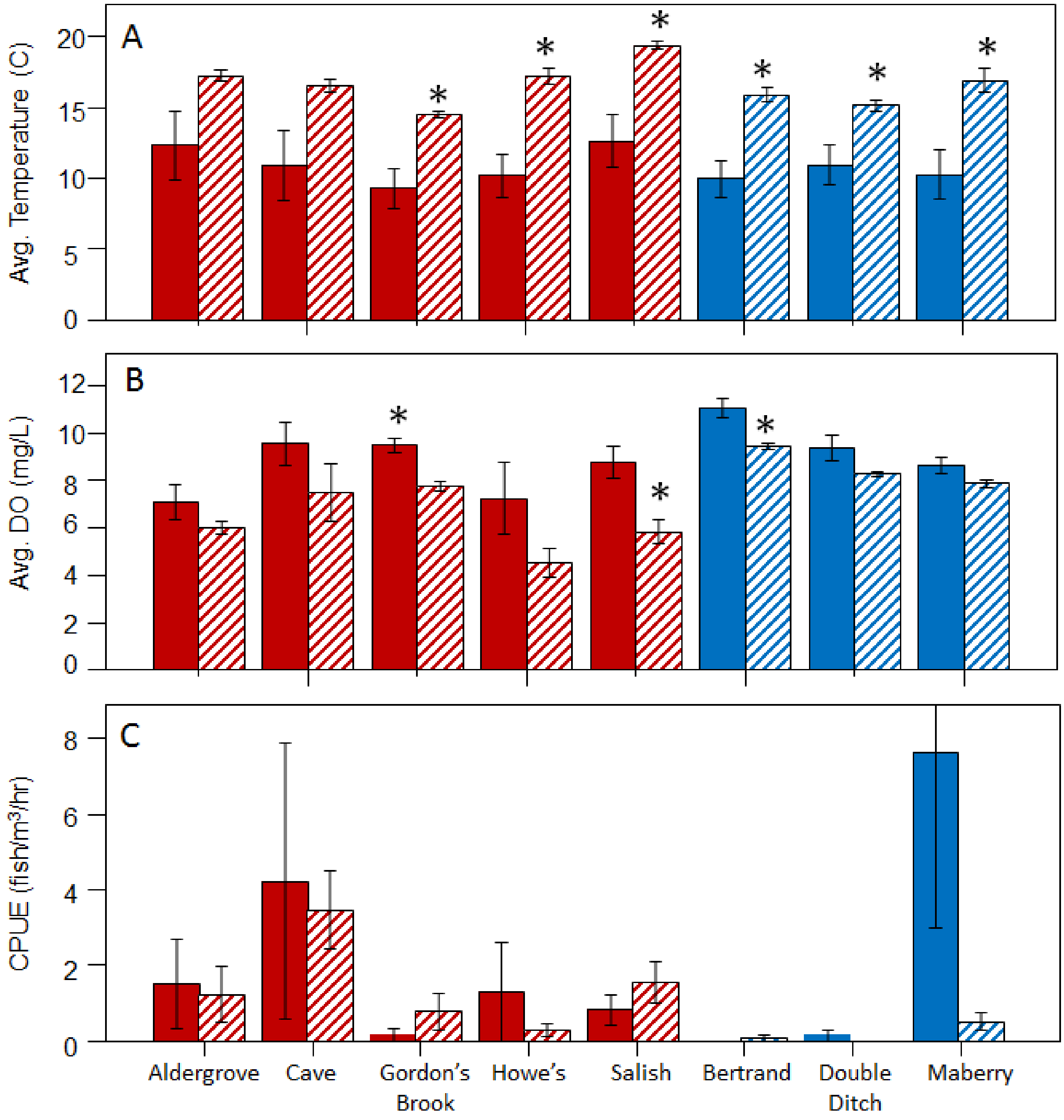

Figure 2. Stream temperature (A), dissolved oxygen (B) and Salish sucker catch per unit effort (C) at study sites (mean +/- 1 SE). Solid bars indicate high flow season, and striped bars indicate low flow season. Red bars indicate British Columbia sites and blue bars indicate Washington sites. Asterisks indicate significant differences ($p < 0.05$) between high and low flow seasons, as determined by Kruskal-Wallis tests.

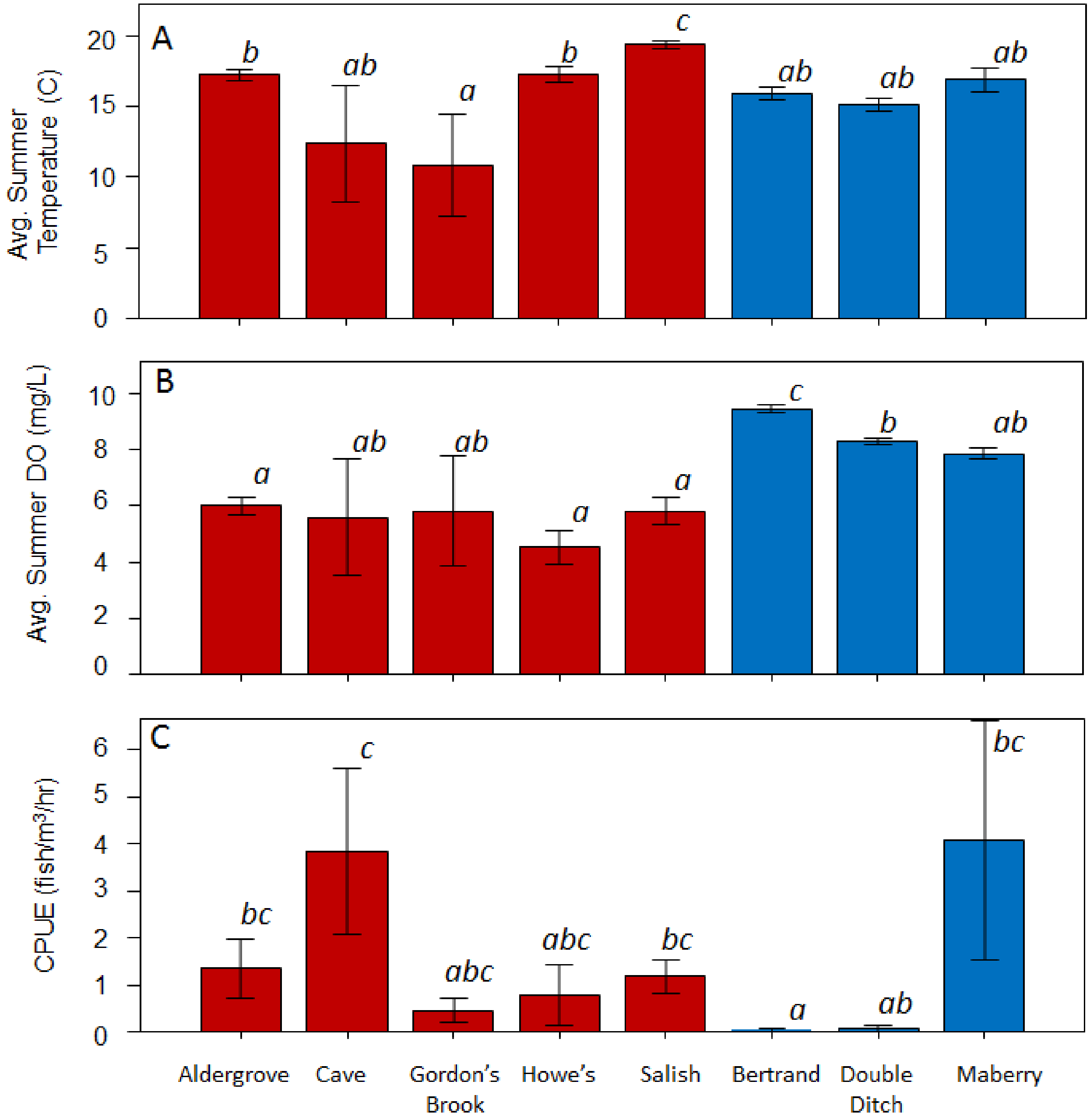

Figure 3. Summer temperature (A), summer dissolved oxygen (B) and all-season Salish sucker catch per unit effort (C) at study sites (mean +/- 1 SE). Red bars indicate British Columbia sites and blue bars indicate Washington sites. Lower case superscript letters indicate homogenous subsets ($p < 0.05$), as determined by pairwise Wilcoxon rank sum tests.

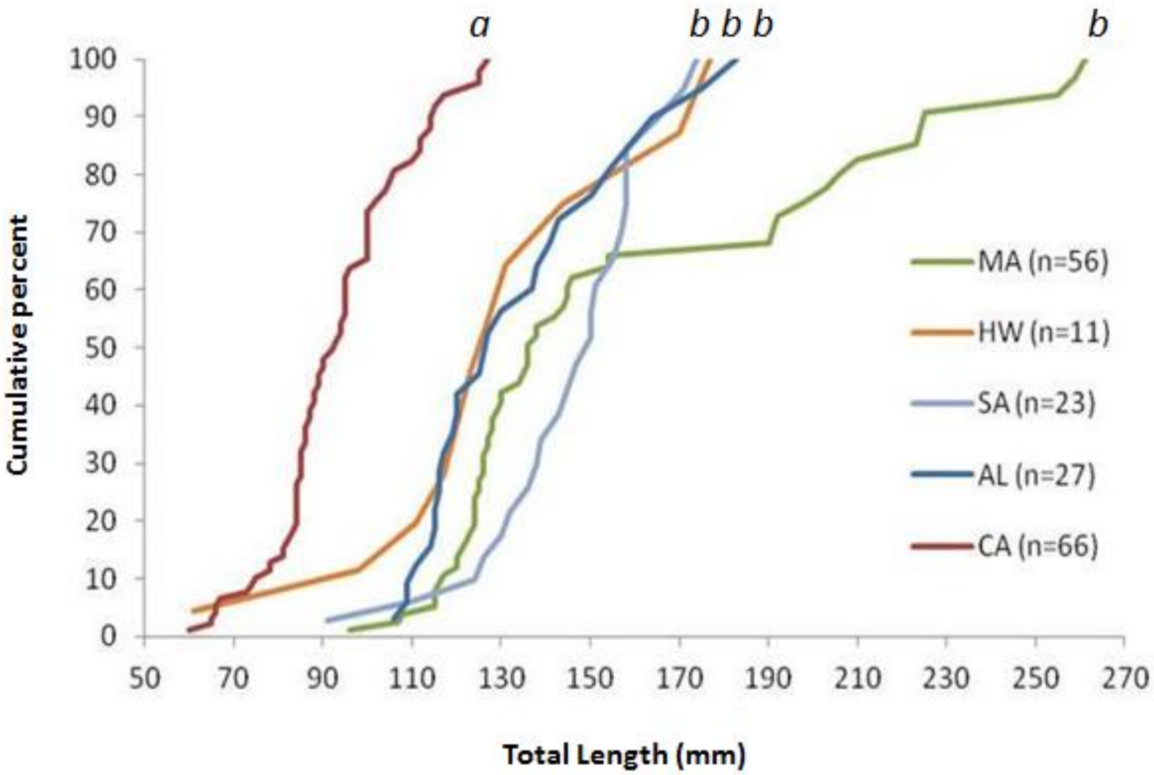

Figure 4. Cumulative percentages of Salish sucker specimens by length at Maberry (MA), Howe's (HW), Salish (SA), Aldergrove (AL) and Cave (CA). Lower case superscript letters indicate homogenous subsets ($p < 0.01$), as determined by pairwise Kolmogorov-Smirnov tests.

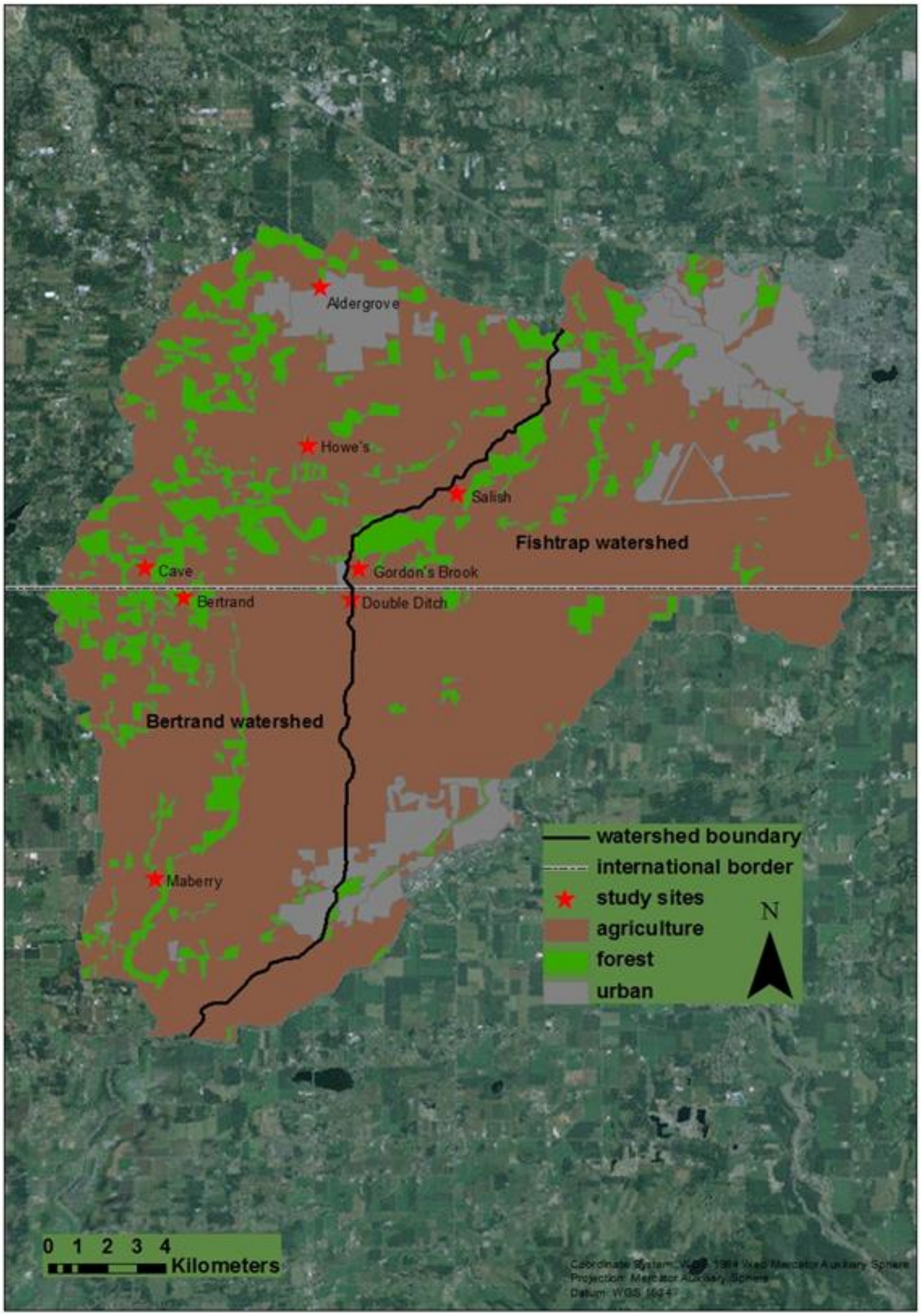

Figure 5. Land use at study sites.

Table 2. Kendall's rank correlation coefficients (τ_B) for site characteristics potentially affecting Salish sucker catch per unit effort (CPUE) at study sites. Asterisks indicate significant correlations between variables.

	Median CPUE (fish/m^3/hr)	Mean temp. (C)	Mean summer temp. (C)	Mean DO (mg/L)	Mean summer DO (mg/L)	Mean canopy cover (%)	Mean depth (cm)
Median CPUE (fish/m^3/hr)							
τ_B		.416	.265	-.265	-.340	.077	.718
p (2-tailed)		.161	.373	.373	.252	.798	.016*
n		8	8	8	8	8	8
Mean temperature (C)							
τ_B	.416		.786	-.571	-.643	.400	.071
p (2-tailed)	.161		.006**	.048*	.026*	.170	.805
n	8		8	8	8	8	8
Mean summer temperature (C)							
τ_B	.265	.786		-.643	-.571	.473	.000
p (2-tailed)	.373	.006**		.026*	.048*	.105	1.000
n	8	8		8	8	8	8
Mean DO (mg/L)							
τ_B	-.265	571	-.643		.786	-.473	.071
p (2-tailed)	.373	.048*	.026*		.006**	.105	.805
n	8	8	8		8	8	8
Mean summer DO (mg/L)							
τ_B	-.340	-.643	-.571	.786		-.255	000
p (2-tailed)	.252	.026*	.048*	.006**		.383	1.000
n	8	8	8	8		8	8
Mean canopy cover (%)							
τ_B	.077	.400	.473	-.473	-.255		-.182
p (2-tailed)	.798	.170	.105	.105	.383		.533
n	8	8	8	8	8		8
Mean depth (cm)							
τ_B	.718	.071	.000	.071	.000	-.182	
p (2-tailed)	.016*	.805	1.000	.805	1.000	.533	
n	8	8	8	8	8	8	

** Significant correlation at $\alpha = 0.01$

* Significant correlation at $\alpha = 0.05$

Table 3. Pairwise comparisons of Salish sucker size distributions at study sites. Asterisks indicate significant differences ($\alpha = 0.01$), as determined by Kolmogorov-Smirnov ($D_{1(2)}$) tests.

Sites	Test Statistic ($D_{1(2)}$)	*P*
Cave vs. Maberry*	0.871	<0.001
Cave vs. Howe's*	0.682	<0.001
Cave vs. Aldergrove*	0.833	<0.001
Cave vs. Salish*	0.868	<0.001
Maberry vs. Howe's	0.313	0.328
Maberry vs. Aldergrove	0.303	0.071
Maberry vs. Salish	0.308	0.090
Howe's vs. Aldergrove	0.181	0.958
Howe's vs. Salish	0.510	0.042
Aldergrove vs. Salish	0.412	0.026

Table 4. Percent composition, by area, of land uses within the Bertrand Cr. and Fishtrap Cr. Watersheds.

	Agriculture	Urban	Forest
Bertrand Total	77	6	17
Bertrand Washington	83	3	14
Bertrand British Columbia	72	8	20
Fishtrap Total	75	16	9
Fishtrap Washington	84	12	4
Fishtrap British Columbia	69	18	13

Table 5. Percent composition, by area, of land uses within 20 ha buffer zones surrounding study sites. Buffer zones extend 1 km upstream from and 100 m on either side of study reaches.

	Agriculture	Urban	Forest
Bertrand Washington sites			
Bertrand	18	0	82
Maberry	33	0	67
Bertrand British Columbia sites			
Aldergrove	63	0	37
Cave	35	0	65
Howe’s	77	0	23
Fishtrap Washington sites			
Double Ditch	100	0	0
Fishtrap British Columbia sites			
Gordon’s Brook	39	0	61
Salish	83	0	17

Conclusions

The findings of this study suggest that, contrary to prior expectations, summer hypoxia appears not to be the most important factor controlling abundance and distribution of Salish sucker. Our findings suggest that physical habitat, particularly deep pools, might be more important. It should also be recognized that, although the Salish sucker is listed as endangered in Canada but not in the United States (Campbell 2001, Pearson and Healy 2003), the population is actually more abundant in British Columbia than it is in Washington.

Our findings do not demonstrate any significant differences between Washington and British Columbia sites with respect to land use or habitat quality, nor do they demonstrate any widespread transboundary migration of Salish suckers to or from summer refuge habitats. Nonetheless, it is possible that transboundary migrations might be important with respect to ontogeny (i.e., changes in individual fish associated with growth and development), as evidenced by the prevalence of juvenile rearing habitat at Cave Cr. in British Columbia, less than 1 km above a Washington site known to support adults. A greater mark-recapture sampling effort, particularly in spring, might be necessary to fully characterize ontogenetic migration patterns.

From the perspective of Salish sucker conservation, the most valuable result of this study might be the development of partnerships linking researchers and representatives of government agencies on both sides of the international boundary. This project demonstrates the relative ease with which data and other information may be shared, while establishing a network of researchers to help facilitate future collaboration.

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