[Final]
Utilization of constructed large woody debris structures by cottids and juvenile salmonids in a coastal western stream

By

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Supervisor

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Abstract

Large woody debris (LWD) in streams provides critical habitat for many fishes. This habitat feature is now largely missing in western North American coastal streams compared to historic levels due to human activities relating to land clearing, damming and outright removal. In the South Alouette River near Maple Ridge, British Columbia, thirty triangular LWD structures were placed in this stream in 1997 and 1998 to address this deficiency of natural wood. In order to determine the effectiveness of this wood in creating habitat, this study assessed fish utilization of these structures during the fall and winter of 2005/2006 throughout four defined habitat types: riffle with LWD, riffle without LWD, pool with LWD and pool without LWD. Sculpin (*Cottus* spp.) and juvenile coho (*Oncorhynchus kisutch*) were found to be the primary users of LWD on the South Alouette River. Slow-moving and deeper waters were also commonly found to be associated with these fish captures. In addition, juvenile coho trapped in sites containing LWD were larger and in better condition than those trapped in sites without LWD. Juvenile steelhead (*O. mykiss*) occupied faster moving waters and rarely used LWD in contrast to some of the previously published studies. By defining clear objectives and understanding species' associations with certain habitat types, LWD enhancement projects in the South Alouette River should achieve even greater success in the future.

Acknowledgements

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1.0 Introduction

1.1 The role of large woody debris as fish habitat

Large woody debris (LWD) in streams is integral to shaping channel morphology by creating pools, trapping sediments, and promoting channel migration (Hilderbrand *et al*., 1997). LWD also provides critical habitat for stream-rearing juvenile salmonids, particularly coho (*Oncorhynchus kisutch*) (Cederholm *et al*., 1997; Slaney, 1997; Solazzi *et al*., 2000; Roni and Quinn, 2001) and, perhaps, to a lesser extent steelhead (*O. mykiss*) (Solazzi *et al*., 2000; Roni and Quinn, 2001).

Large woody debris abundance is believed to be depressed compared to historic levels in many rivers in the Pacific Northwest (Collins *et al*., 2002). There are numerous parameters that regulate LWD recruitment, abundance and distribution in coastal streams including climate, topography, forest composition, forest age, stream gradient, and stream flow (Harmon and Chen, 1991). Timber harvesting, stream channelisation, and levee construction have also acted to reduce LWD levels through the reduction of sources and the impediment of further recruitment (Collins *et al*., 2002). Furthermore, in the past, many managers viewed LWD as detrimental and actively removed it from many stream channels (Fausch and Northcote, 1992).

Recent declines in both coho stocks in the Pacific Northwest (Ward, 2000) and steelhead populations in the Greater Georgia Basin (Ward, 2000) have generated increased interest in stream habitat restoration (Slaney, 1997; Roni and Quinn, 2001). Currently, one popular means of enhancement has involved the installation of instream woody debris structures (Giannico, 2000). LWD-structure construction usually involves some sort of cabling and anchoring systems (Slaney and Zaldokas, 1997).

The primary objective in most salmonid habitat restoration projects is to increase egg-to-smolt survival rates in freshwater (Slaney, 2005). LWD structures have the potential to achieve this objective by increasing the amount and complexity of juvenile rearing habitat (Nickelson *et al*., 1992). Winter habitat is a potential limiting factor for juvenile salmonids in the Pacific Northwest (Nickelson *et al*., 1992; Cederholm *et al*., 1997), and as a component of this habitat, LWD plays a role in determining their winter survival.

1.2 Juvenile steelhead and coho habitat associations

1.2.1 Juvenile steelhead

Juvenile steelhead associate with water velocities between 21 and 39 cm/s, and water depths between 10 and 50 cm (Waite and Barnhart, 1992). Steelhead parr consistently associate with specific cover types including cobble/boulder substrates (Slaney and Fachin, 1977; Beechie *et al*., 2005) although Beechie *et al*. (2005) noted that this association may be secondary in nature; that is, steelhead juveniles prefer faster velocities, which in turn are characterized by larger and coarser substrates.

Over-hanging streamside vegetation (Slaney and Fachin, 1977; Beechie *et al*., 2005) and LWD may also be variably used as cover by steelhead (Cederholm *et al*., 1997; Slaney, 2005).

1.2.2 Juvenile coho

Juvenile coho show a strong association with a variety of cover types. They utilize LWD (Roni and Quinn, 2001), overhanging streamside vegetation (Hartman, 1965), cutbanks (Swales *et al*., 1986) and substrates (Ward and Slaney, 1981).

Juvenile coho utilize slow moving pools (Ruggles, 1966; Lister and Genoe, 1970; McMahon, 1983), associating with water depths ranging between 46 and 120 cm (Beecher *et al.*, 2002) and water velocities of less than 20 cm/s (Beechie *et al*., 2005; Bisson *et al*., 1988). Distribution patterns of juvenile coho vary seasonally, utilizing the main stem in the summer (Hartman, 1965; Ruggles, 1966; Lister and Genoe, 1970; McMahon, 1983) and off-channel habitat in the winter (Bramblett *et al*., 2002) although off-channel habitats may be used year-round when there is available water. These off-channel habitats are characterized by slower moving waters, with abundant instream and riparian cover (Bustard and Narver, 1975; Raleigh *et al*., 1984; Swales *et al*., 1986).

1.2.3 Prickly and coastrange sculpin habitat associations

Prickly sculpin (*Cottus asper*) and coastrange sculpin (*C. aleuticus*) are two morphologically similar benthic fishes that often co-exist in coastal streams and rivers from Alaska to southern California (Lee *et al.*, 1980). Sometimes, these species can be separated at the mesohabitat scale in small coastal streams, with prickly sculpin typically occupying pools and coastrange sculpin more often found in riffles (Mason and Machidori, 1976; White and Harvey, 1999).

Prickly sculpin are usually found in areas with water velocities of less than 6 cm/s and are distributed throughout water depths of up to 14 m (White and Harvey, 1999). Coastrange sculpin are usually found in areas with water velocities over 5 cm/s and predominantly utilize stream sections with depths of less than 1 m (White and Harvey, 1999).

1.3 South Alouette River large woody debris project

Natural recruitment of LWD into the South Alouette River has been inhibited by logging and dam construction that began in the late 1800's (Cope, 2005). Logging decreased natural recruitment of LWD by removing large timber from the river's floodplain. In 1925-1926 a dam was built at the outlet of Alouette Lake. The dam reduced and stabilized downstream flow, minimizing high-flow events that function in recruiting wood from riparian areas as well as redistributing wood downstream (Clayton, pers. comm.).

In 1997 and 1998, forty-eight instream LWD structures were constructed in the South Alouette River to remedy the deficiency of natural wood debris. Thirty of these structures were "triangular" in design (Clayton, 1998). The triangular LWD structure is the most commonly-used design in western North America and is routinely applied to other British Columbia streams (Rosenau, pers. comm.). Work on the South Alouette River was conducted by the Alouette River Management Society (ARMS) with funding from the Watershed Restoration Program and the Habitat Conservation Trust Fund (Clayton, 1998).

While considerable time and expense occurred in the development of this habitat, an in-depth and rigorous assessment of the functionality of the LWD structures has yet to be undertaken. Such information is, therefore, of interest to ARMS and the Ministry of Environment, as there are plans for more LWD structures to be placed in the South Alouette next year (Slaney, pers. comm.). The aim of this study is, therefore, to provide information on the fish utilization of the South Alouette River LWD structures, and provide direction for optimal placement of new debris structures.

1.4 Objectives

This study had three objectives. The first was to assess fish utilization of constructed triangular LWD structures in the South Alouette River during fall and winter conditions. The relative abundance of cottids and juvenile salmonids within LWD-treated sites was compared to similar, selected control sites lacking LWD to determine if there were differences in densities and species composition. The second objective was to determine the use of four different habitat types, defined as *riffle with LWD*, *riffle without LWD*, *pool with LWD* and *pool without LWD*. These habitat types were assessed for cottid and juvenile coho usage in the fall, and cottid, juvenile coho and juvenile steelhead usage in the winter. The third objective was to investigate the influence of water velocity and water depth on the distribution of cottids, juvenile coho and juvenile steelhead.

2.0 Study area

2.1 Area description

The study area is located in the mid-upper reach of the South Alouette River downstream of the BC Hydro dam near the city of Maple Ridge in British Columbia, Canada (Figure 1). The Alouette watershed has a gross drainage area of 234 km^2 and lies within the Coastal Western Hemlock Biogeoclimatic Zone. The South Alouette River originates upstream of Alouette Lake. Alouette Lake is a hydro-electric reservoir operated by the British Columbia Hydro and Power Authority. Discharges from Alouette Lake are either diverted into Stave Lake through a hydro-electric generation station, or downstream into the South Alouette River over or through the dam. Prior to dam construction in 1925, the mean annual discharge (MAD) of this river was 22.7 m^3/s. From the time the dam was completed until 1971, there was no flow released from the dam, except seepage, with only the water from tributaries reaching the confluence with the North Alouette River. In 1971, a minimum MAD of 0.057 m^3/s from the dam, or 0.57 m^3/s at the 232nd St. Bridge was required. In 1996, following a water use agreement with BC Hydro, MAD from the dam increased to 2.6 m^3/s (Clayton, pers. comm.).

Figure 1. Map of study area in relation to Vancouver, BC [Adapted from MapQuest.ca].

The Alouette watershed is dominated by second growth hemlock and western red cedar, which naturally regenerated following logging in the early 1900's. The South Alouette River is characterized by stable water flows, an artifact of a hydro-electric dam located at the outlet of Alouette Lake (Figure 2).

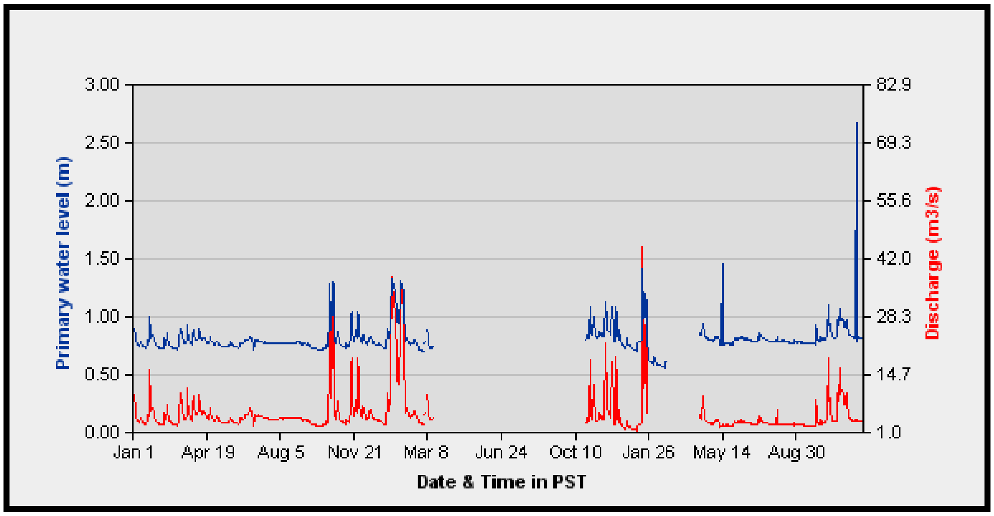

Figure 2. Water levels and discharges of the South Alouette River near Haney. (Station 08MH005), British Columbia. *Note: Survey station is located downstream of the study area and is influenced by tributaries [figure adapted from Environment Canada, 2006].

The study area is confined to one reach, 7 km upstream of Allco Park and roughly 3 km downstream of the hydro-electric dam (Figure 3). No significant tributaries are present above or within the study area; therefore, stream flow is mostly determined by the water released from the dam.

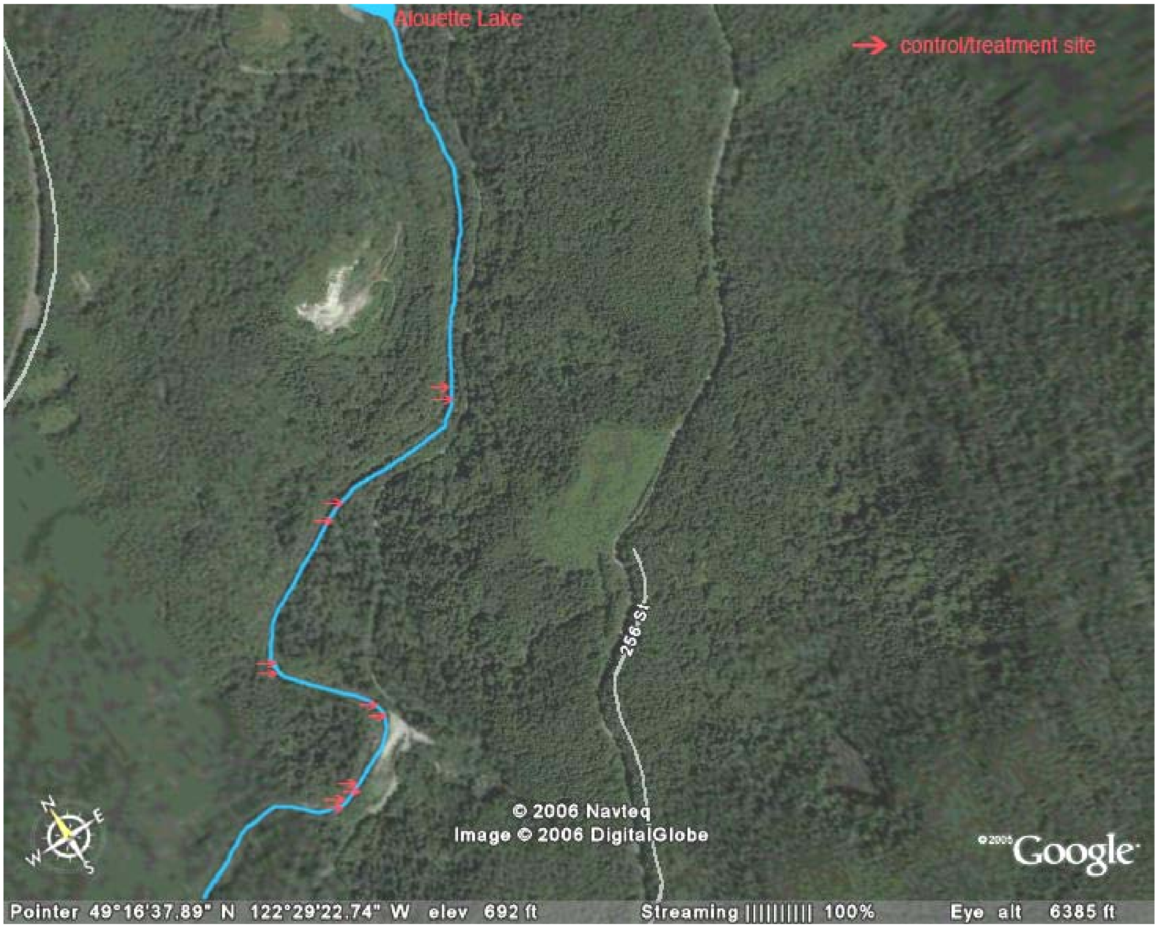

Figure 3. Map of study reach on the South Alouette River, near Maple Ridge, BC [Figure adapted from Google Earth, 2006]. Arrows indicate control or treatment site locations.

2.2 Reach description

The upper canopy of the riparian zone is dominated by western red cedar and western hemlock with a small component of Sitka spruce. The most prevalent deciduous tree species is red alder, although there is a small number of bigleaf maple. The understory is lush with sword fern, lady fern, salmonberry, willow and vine maple.

The approximate pool to riffle ratio along the reach is 2:1 (Clayton, pers. comm.). The average riffle gradient is 2-3% and the average pool depth is approximately 1.3 m (Clayton, pers. comm.).

3.0 Methods

3.1 Site selection and trap placement

Constructed triangular LWD structures (from here on referred to as LWD structures or LWD-treated sites) and control sites were assessed for fish utilization (Figure 4). Control sites, which lacked LWD, were matched with treatment sites using physical criteria including mean water velocity, water depth, and trapping area.

Figure 4. Triangular constructed LWD structure, used as a LWD-treated site, in the South Alouette River, near Maple Ridge, BC.

A total of 84 traps were placed within six constructed LWD structures and six control sites during the fall sampling session. Seven traps were placed systematically in each constructed LWD structure and in each control site (Figure 5). All traps were placed at least 1.5 m apart for consistent site coverage and never further than 1 m from the structure perimeter. Within each structure, distances around the trap perimeter were measured and used to define the size of the trapping area in the corresponding control site. Controls sites were always located upstream of treatment sites.

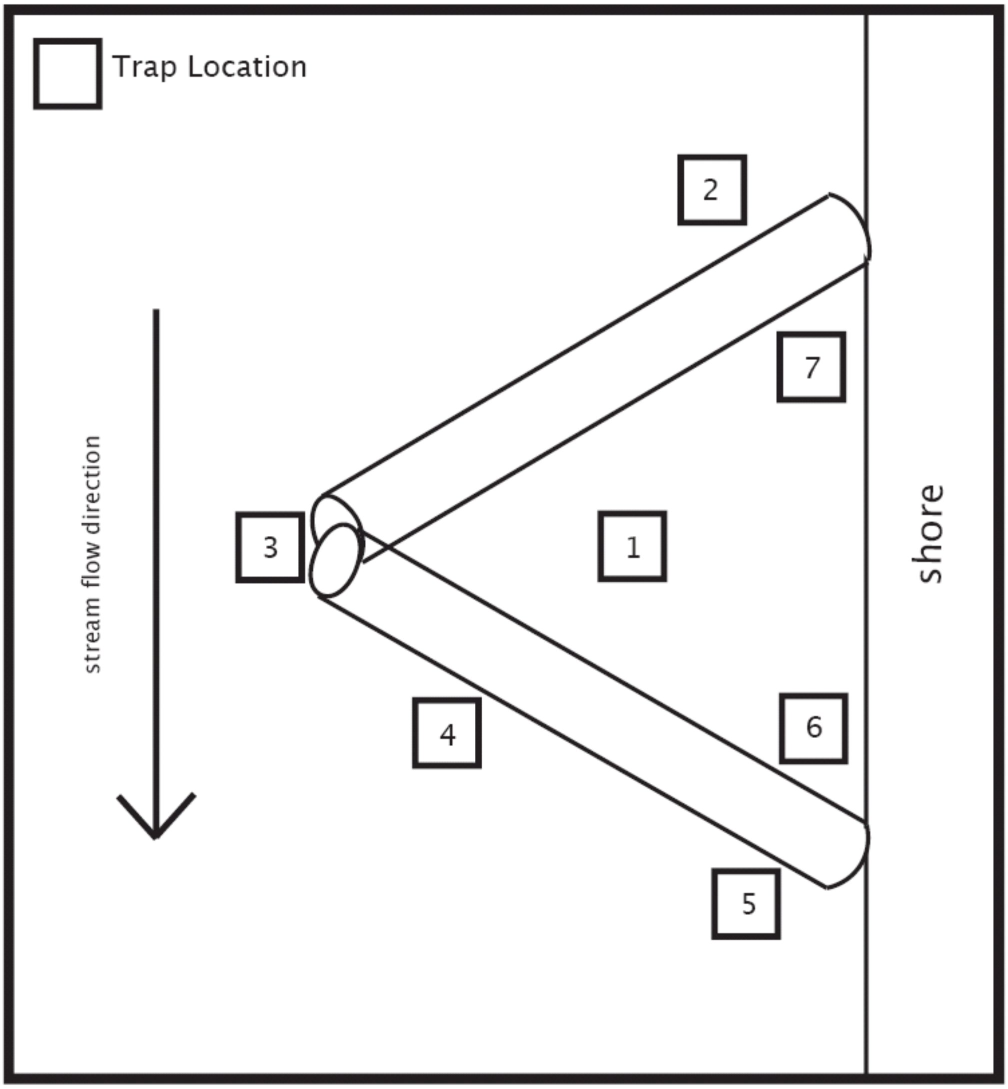

Figure 5. Trapping configuration in treatment and control sites in the South Alouette River, near Maple Ridge, BC. Note: control sites were defined as sites lacking LWD; trap locations within these sites follow a similar arrangement however, logs were not present.

In the winter, 112 traps were placed within four habitat types, defined as *riffle with LWD, riffle without LWD, pool with LWD* and *pool without LWD,* with intent to trap juvenile steelhead. Winter sampling primarily consisted of individual traps set in pools and riffles with and without LWD influence however, also included clusters of traps (Figure 5) set in four constructed LWD structures (previously sampled in the fall). Individual traps targeted mean water velocities of 21 to 39 cm/s, and water depths of 10 to 50 cm. Sites with theses characteristics were defined by Waite and Barnhart (1992) as areas of high juvenile steelhead use.

Fish were sampled using Gee traps (Figure 6), which are also known as minnow traps. Traps were baited with golf-ball-sized pieces of salmon roe, each approximately 35 g. Roe was encased in nylon stocking, to inhibit consumption by fish. Gee traps were placed in the stream and collected the following day to accommodate crepuscular feeding. Gee trapping occurred during fall 2005 (October and early November), and winter 2005/2006 (late November and January). Water temperature was the criterion used to differentiate between the two sampling periods.

Figure 6. Gee trap used for trapping fishes in the South Alouette River, near Maple Ridge, BC.

3.2 Site characterization and fish measurements

Mean water velocity (0.6 of the depth), trap water velocity, substrate type, trap location complexity and water depth were recorded while setting traps. Water velocities were measured using the Marsh-McBirney Flo-Mate 2000™. Substrate category was determined using a modified Wentworth Scale (Wentworth, 1922) that included organic, sand, cobble and boulder categories only. Air and water temperature were measured and recorded for each trapping session.

Captured fish were removed from traps and placed in a bucket. All fish were identified to the lowest taxonomic level. Length, markings (previous clips), and applied markings (dorsal or ventral caudal clip given) were recorded for each salmonid. Selected individuals (some coho and most steelhead) were weighed and scale samples were taken for ageing. Unusual occurrences and accidental deaths were noted. Fish were released where captured. To avoid recaptures during processing, releases occurred only after all the traps in the site had been processed. See Appendix I for Fish Collection Data Card.

3.3 Scale sampling

Scales were removed with a scalpel and transferred to a scale collection envelope for ageing. Envelopes were labeled with identification codes, weight, length, date, collector, project and location.

3.4 Fin clipping (salmonids only)

In order to assess if baited traps were attracting juvenile salmonids from one trapping site to another, caudal fins were clipped. A caudal clip on the dorsal lobe was given to fish in treatment sites, and a ventral caudal clip was given to fish in control sites.

3.5 Data analysis

Pools and riffles were defined using the relationship of mean water column velocity/water depth. We classified riffles as having a water velocity to depth ratio of greater than or equal to 0.2 and pools as less than 0.2 (Figure 7). Jowett (1993) and Dolling (1968) showed that a velocity/depth ratio was the best single discriminator of habitat types. Dividing ratios for habitat assessments change from river to river as gradient changes, therefore the value used to segregate habitats will not be the same across all rivers. This is also a simple index and not a strict division of habitats, used to increase repeatability and predictability (Jowell, 1993).

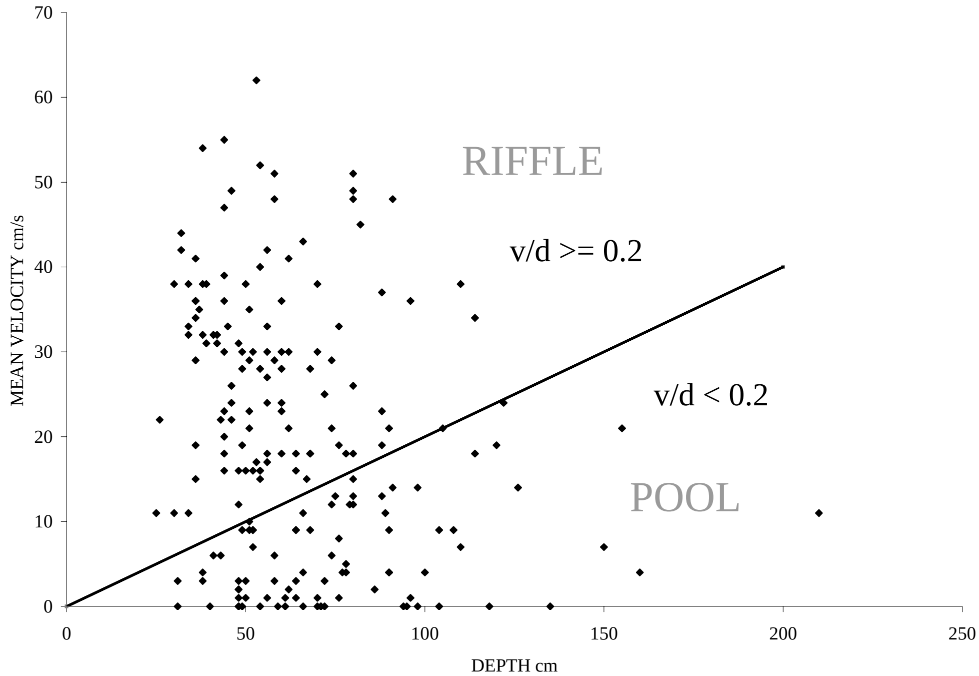

Figure 7. Classification of pool and riffle habitats by a mean water column velocity/depth ratio in the South Alouette River, near Maple Ridge, BC. Line denotes separation between pool and riffle habitat and is defined by the equation y=0.2x; n=196 traps.

Using two parameters (pool/riffle and presence/absence of LWD) four habitat types were defined: *riffle with LWD*, *riffle without LWD*, *pool with LWD* and *pool without LWD*. Distribution of cottids and juvenile coho was compared between the four habitat types during the fall. Distribution among the four habitat types was re-examined in the winter for cottids, juvenile coho and juvenile steelhead.

Data from fall trapping sessions, which consisted of trap clusters (see section 3.1 for trapping configuration) placed in treatment and control sites, was reanalyzed. In this later analysis, traps were assumed independent of one another and reassigned to one of the four habitat types.

To allow for comparison between habitat types, fish catch-per-unit-effort (CPUE) was calculated. In this study, CPUE was the average number of fish captured per trap, per trap-night.

To establish statistical trends for cottid and juvenile coho distributions, three habitat types were aggregated and are subsequently referred to as “all other” habitat type. These aggregated habitats are *riffle with LWD*, *riffle without LWD* and *pool without LWD*. A weighted-mean CPUE was calculated for the aggregated habitat and compared with CPUE for *pool with LWD* habitat.

To establish a statistical trend for juvenile steelhead distribution, two habitat types were aggregated and are subsequently referred to as “*pool and riffle with LWD*” habitat type. A weighted-mean CPUE was calculated for the aggregated habitat and compared with CPUE for *riffle without LWD* habitat.

Fulton’s Condition Factor was calculated for juvenile coho and is represented by:

$$\text{Condition} = (100 * \text{Weight}) / \text{Length}^3$$

where: Weight = grams

Length = centimetres

Fulton’s Condition Factor assumes that heavier fish of a given length are in better condition, and assumes isometric growth. This condition factor measures individual fish, as opposed to other factors that measure the condition of subpopulations (Jones *et al*., 1999).

Microsoft Excel (2003) was used to calculate descriptive statistics and create graphs.

4.0 Results

4.1 Site characteristics

Water temperatures at the study sites ranged from a high of 12.5˚C to a low of 4.5˚C during the study period. Fall trapping took place between October 14th and November 6th with water temperatures decreasing from 12.5˚C to 11˚C. Winter trapping took place between November 11th and January 22nd with water temperature decreasing from 8.5˚C to 4.5˚C (Figure 8).

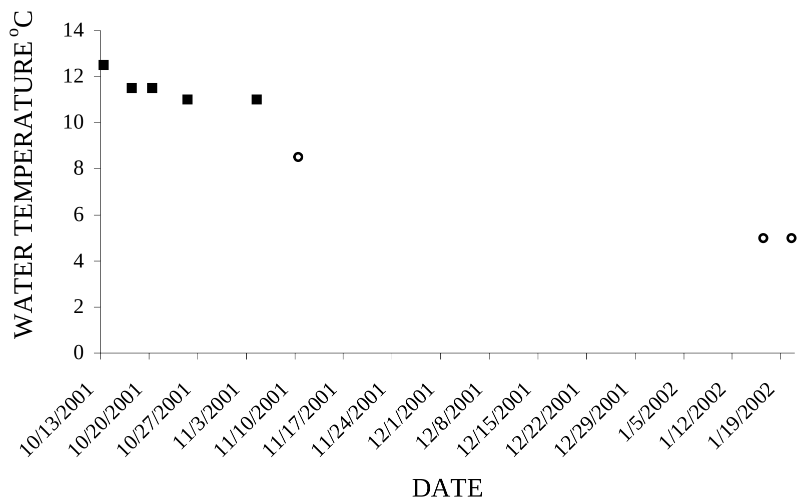

Figure 8. Water temperatures at the study site, in the South Alouette River, near Maple Ridge, BC, from October 2005 to January 2006. Black squares denote fall sampling, while white circles denote winter sampling.

Mean water-column velocity, depth and trapping area varied between LWD-treated and control sites; however, pairings were the best matches available within the study reach (Table 1).

Comparison of habitat types with and without LWD showed similar mean depths and velocities within pools and within riffles separately (Table 2). Combining these two parameters into a ratio (mean water column velocity/depth) further exhibited the similarity within pool habitat types (*pool with LWD* and *pool without LWD*) and distinguished them from riffles habitats (*riffle with LWD* and *riffle without LWD*) (Figure 9). Due to similarities within pool and riffle habitats, differences seen in fish abundance between these habitat types can be attributed to the presence or absence of LWD.

Table 1. Depth, velocity and area attributes of Gee traps set in LWD-treated sites and control sites in the South Alouette River, near Maple Ridge, BC. Each statistic comprised a sample of n=7 and the points of measurement within each site were determined systematically.

Site Pairings	**Mean Water Depth** (cm)	**Mean Water Column Velocity** (cm/s)	**Velocity/Depth Ratio** (cm/s/cm)	**Trapping Area** (m^2)
Site 1				
Treatment	82	17.4	0.21	38.2
standard deviation	17.5	16.8	0.21	
Control	52	23.9	0.46	54.5
standard deviation	8.1	10.9	0.18	
Site 2				
Treatment	59	16.4	0.28	51.2
standard deviation	15.6	9.4	0.14	
Control	42	31.0	0.74	47.8
standard deviation	6.3	16.0	0.28	
Site 3				
Treatment	70	7.1	0.10	29.1
standard deviation	27.5	6.7	0.07	
Control	69	7.3	0.10	30.0
standard deviation	30.5	8.8	0.09	
Site 4				
Treatment	53	5.1	0.10	45.1
standard deviation	21.5	5.1	0.15	
Control	79	7.7	0.10	50.8
standard deviation	21.5	8.06	0.10	
Site 5				
Treatment	97	6.6	0.07	58.6
standard deviation	48.3	4.5	0.07	
Control	76	2.1	0.03	77.3
standard deviation	17.0	3.3	0.04	
Site 6				
Treatment	110	2.4	0.02	44.0
standard deviation	53.9	4.4	0.04	
Control	80	6.7	0.08	60.0
standard deviation	41.1	9.2	0.06	
Average				
Treatment	78.7	9.2	0.13	44.4
Control	66.4	13.1	0.25	53.4

Table 2. Depth and velocity attributes for Gee traps set in four defined habitat types in the South Alouette River, near Maple Ridge, BC. Points of measurement were determined systematically.

Habitat Type	**Water Depth** (cm)	**Mean Water Column Velocity** (cm/s)	**Velocity/Depth Ratio** (cm/s/cm)
Pool with LWD			
Mean	79.6	5.9	0.08
95 % Confidence	9.3	1.3	0.02
Sample Size	55	55	55
Pool without LWD			
Mean	74.0	5.6	0.07
95 % Confidence	10.4	2.6	0.03
Sample Size	29	29	29
Riffle with LWD			
Mean	62.3	27.0	0.46
95 % Confidence	6.5	3.4	0.07
Sample Size	43	43	43
Riffle without LWD			
Mean	51.5	31.3	0.66
95 % Confidence	3.6	2.7	0.07
Sample Size	69	69	69

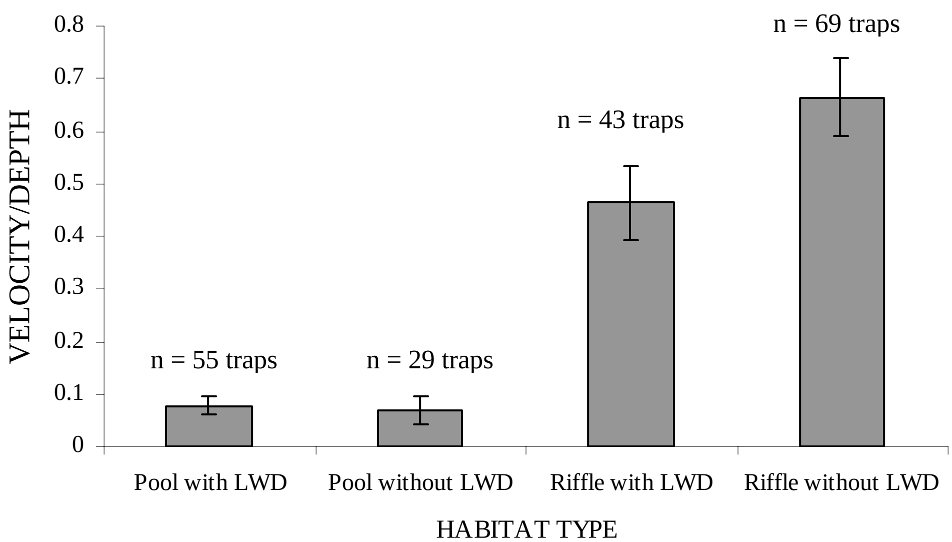

Figure 9. Mean value of mean water column velocity/water depth ratio for Gee traps set in four defined habitat types in the South Alouette River, near Maple Ridge, BC. Black bars denote 95% confidence intervals.

4.2 Juvenile coho

Catch-per-unit-effort (CPUE) of juvenile coho in *pools with LWD* was 3.1 times greater in the fall and 5.5 times greater in winter than in *pools without LWD.* In addition, CPUE during the fall and winter was 16.7 and 5.9 times greater, respectively, in *riffles with LWD* than in *riffles without LWD* (Figure 10) although both riffle catches of coho were substantially less than pools with LWD. *Riffle with LWD* catch rates were similar to catch rates of *pools without LWD* in the fall, but the winter catch rates in *pools without LWD* dropped over fall while the *riffle with LWD* catch rates did not drop. Catches in winter in *pools with or without LWD* dropped from the fall period to winter. Catch-rates of coho in *riffles without LWD* were universally poor regardless of season. Juvenile coho utilized *pools with LWD* more than all other habitat types combined (Fall: t-test $p = 0.0097$, $df = 82$; Winter: t-test $p < 0.001$, $df = 110$) (Figure 11).

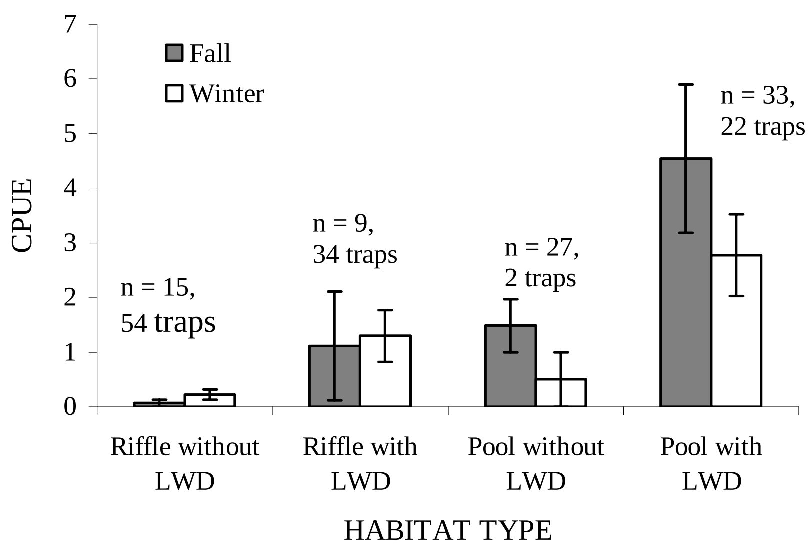

Figure 10. Juvenile coho CPUE by habitat type in the fall and winter in the South Alouette River, near Maple Ridge, BC. Error bars represent 1 Standard Error.

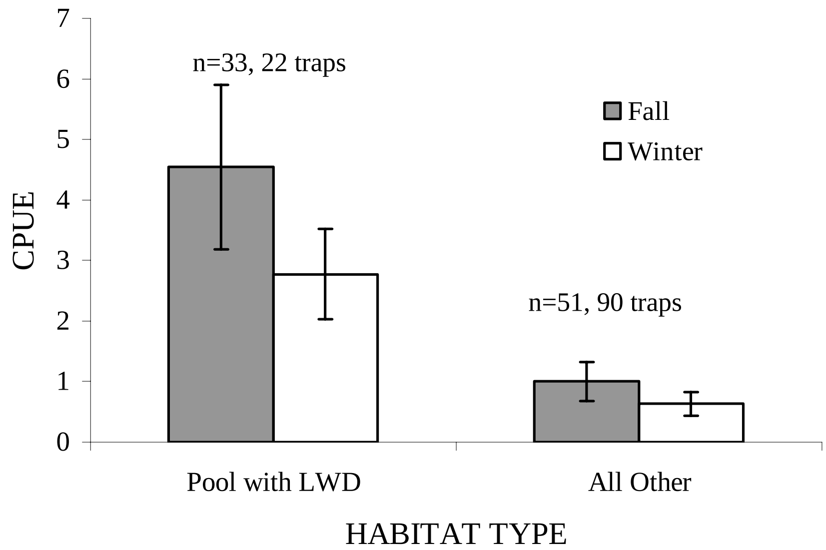

Figure 11. Juvenile coho CPUE in pools with LWD compared to all other habitat types (aggregated) for the fall and winter in the South Alouette River, near Maple Ridge, BC. Error bars represent 1 Standard Error.

During fall, larger coho were captured in LWD-treated sites while smaller coho were found in controls sites without LWD (t-test $p < 0.001$, df = 200); the mean fork lengths of these fish were 81 mm and 71 mm, respectively (Figure 12). In addition, coho trapped in treatment sites were in better condition (based on the Fulton's Condition Factor) than coho trapped in control sites (t-test $p < 0.001$, df = 40) (Figure 13). Due to sampling design changes, lengths and weights were not recorded in winter.

In trapping locations lacking LWD, juvenile coho that were longer (fork length) were also found to be in faster water velocities (mean water column velocity) than shorter coho (Figure 14).

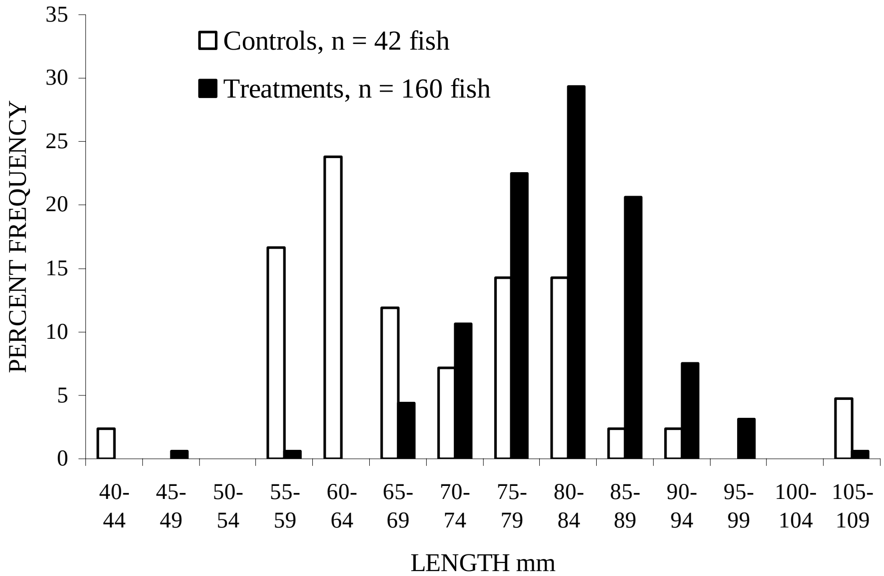

Figure 12. Length–frequency comparison of juvenile coho captured in LWD-treated sites compared to control sites, during the fall in the South Alouette River, near Maple Ridge, BC.

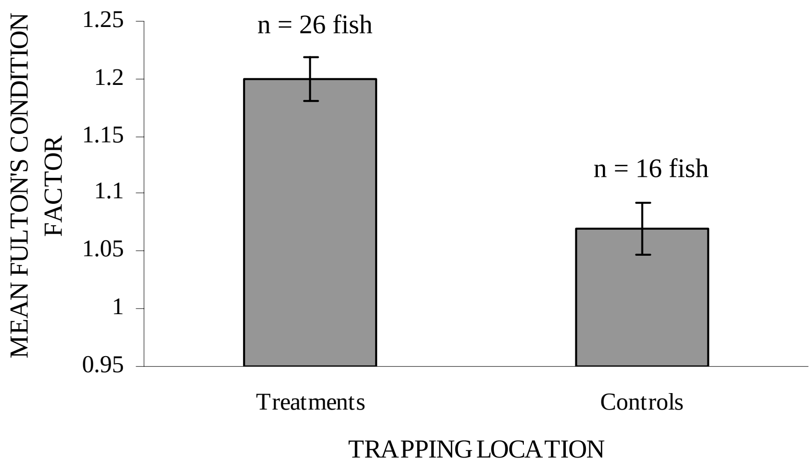

Figure 13. Mean Fulton's Condition Factor for juvenile coho captured in LWD-treated sites compared to control sites, during the fall in the South Alouette River, near Maple Ridge, BC. Error Bars represent 1 Standard Error.

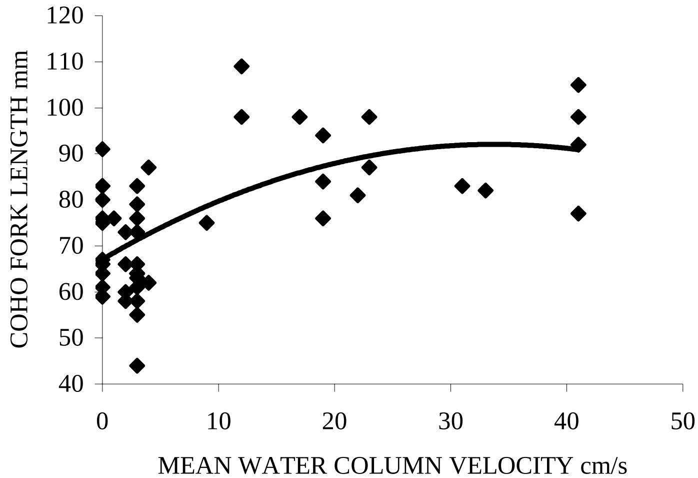

Figure 14. Juvenile coho fork length to mean water column velocity in trapping locations lacking LWD in the fall and winter in the South Alouette River, near Maple Ridge, BC. n = 54 fish.

4.3 Cottids

Within-season sculpins generally preferred pools over riffles, and habitats with LWD over those without; the exception to this pattern was for pools in the fall where there was no difference between these habitats with or without woody debris (Figure 15). Catches of cottids in the winter were generally lower than in the fall regardless of habitat type, although these differences were not always significant (Figure 15). The weighted mean-CPUE's for sculpins during fall and winter was 3.4 and 3.7 times greater, respectively, in pools than in riffles (Figure 16).

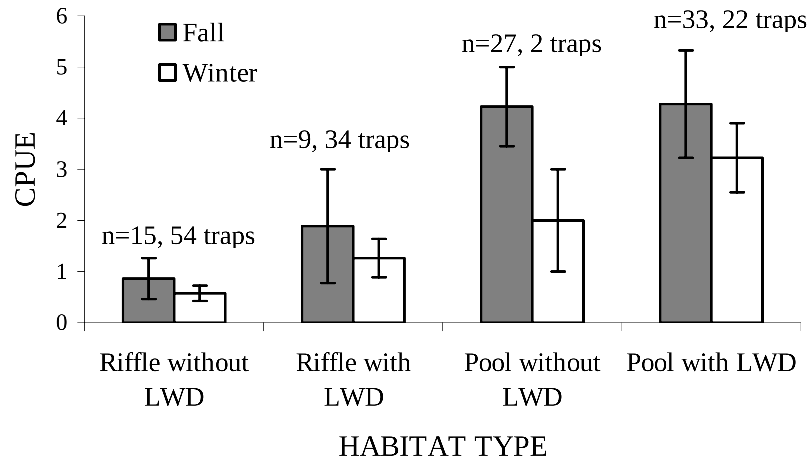

Figure 15. Sculpin spp. CPUE by habitat type in the fall and winter in the South Alouette River, near Maple Ridge, BC. Error bars represent 1 Standard Error.

Fall trapping showed no significant difference between CPUE in *pools with LWD* versus all other habitat types combined (t-test, p = 0.7002, df = 82). However during the winter, data indicates that sculpin species do have a strong affinity for *pools with LWD* (t-test, p = <0.001, df =110) (Figure 16).

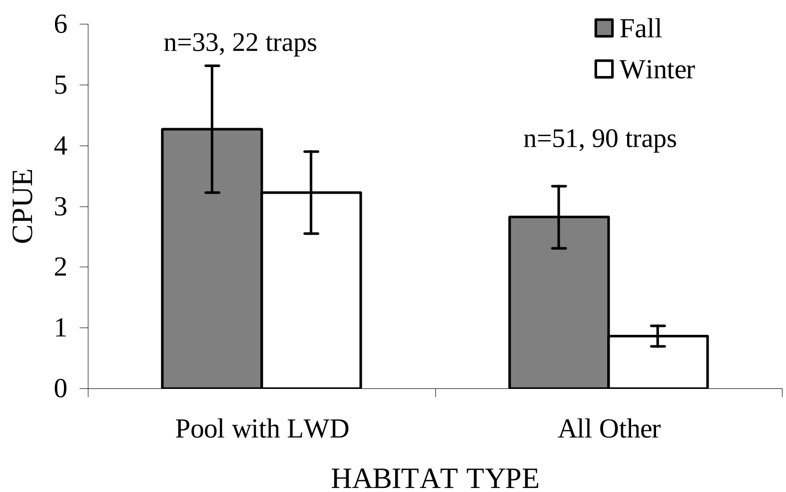

Figure 16. A comparison of sculpin CPUE for pools with LWD versus all other habitats (aggregated) in the fall and winter in the South Alouette River, near Maple Ridge, BC. Error bars represent 1 Standard Error.

4.4 Juvenile steelhead

During the winter the CPUE of juvenile steelhead in *riffles without LWD* was 7.3 times greater than in *pools with LWD* and 2.5 times greater than in *riffles with LWD* (Figure 17). *Pools without LWD* habitat were excluded due to small sample size. Also, habitat type analysis for juvenile steelhead was not conducted for the fall as riffles were not sampled during this period. During the winter, juvenile steelhead utilized *riffles without LWD* more than *pool and riffle with LWD* habitat types combined (t-test, p = 0.0129, df = 108) (Figure 18).

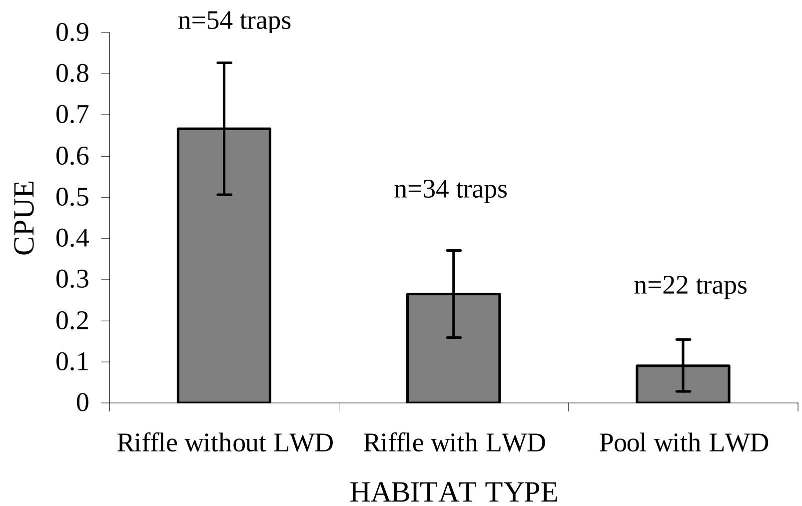

Figure 17. Juvenile steelhead CPUE by habitat type in the winter, in the South Alouette River, in Maple Ridge, BC. Pools without LWD habitat was excluded due to small sample size. Also, habitat type analysis for juvenile steelhead was not conducted for the fall due to small sample size. Error bars represent 1 Standard Error.

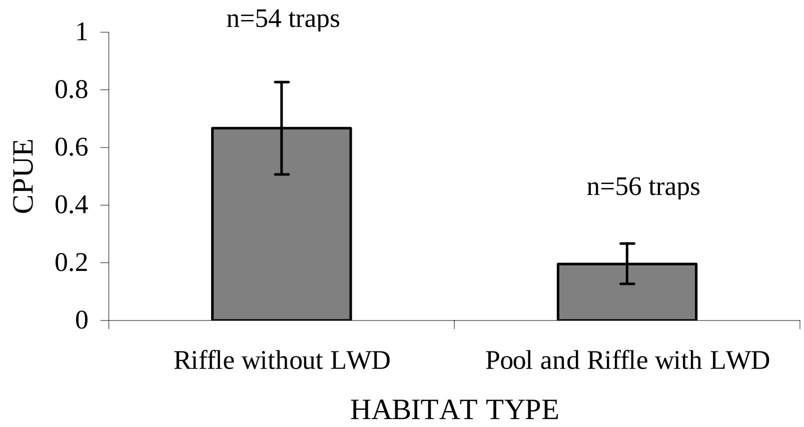

Figure 18. Juvenile steelhead CPUE by habitat type in the winter, in the South Alouette River, in Maple Ridge, BC. Pools without LWD habitat was excluded due to small sample size. Also, habitat type analysis for juvenile steelhead was not conducted for the fall due to small sample size. Error bars represent 1 Standard Error.

4.5 Winter among-species comparison of habitat utilization

During winter, juvenile steelhead utilize *riffle without LWD* habitat more than any other species. Under these conditions for juvenile steelhead the average CPUE was 1.2 times greater than sculpin and 3 times greater than juvenile coho. Sculpin and juvenile coho appear to use *riffle with LWD* more extensively than juvenile steelhead. This propensity becomes even more evident when *pool with LWD* habitat is examined. In this habitat, CPUE for sculpin is 1.2 times greater than juvenile coho and 35.5 times greater than juvenile steelhead (Figure 19).

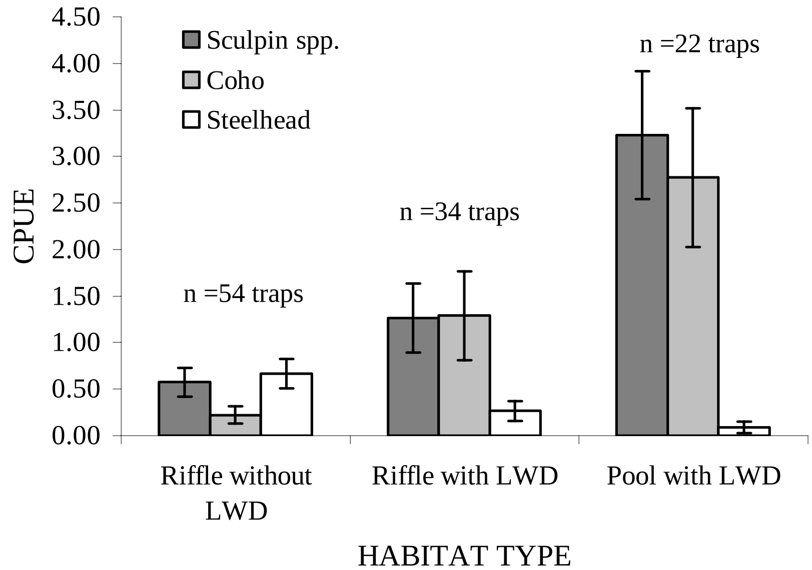

Figure 19. Fish species utilization of habitat types for the winter, in the South Alouette River, near Maple Ridge, BC. Error bars represent 1 Standard Error.

5.0 Discussion

Sculpin and Juvenile Coho Utilization of LWD

This study found that sculpin and juvenile coho were the primary species that utilized LWD on the South Alouette River.

Coho clearly favored *pools with LWD* more than *pools without LWD*. In riffle habitat, juvenile coho were almost never trapped unless LWD was present. Overall, coho utilized *pools with LWD* more than any other habitat type. These findings agree with past research that shows juvenile coho have a strong association for pools with instream cover such as LWD (Ward and Slaney 1981; Swales *et al.*, 1986; Roni and Quinn, 2001; Beecher *et al.*, 2002).

Sculpin also used LWD, although distribution of sculpin species was more strongly influenced by the presence of pools than by the presence or absence of LWD. Similar to coho, sculpin used *riffle without LWD* habitat the least. Sculpin in this study were not identified to the species level and therefore the data on distribution becomes problematic. If only prickly sculpin were present in the study reach, then the sculpins' apparent affinity for pools could be verified. However, if coastrange sculpin also inhabit the study reach then few conclusions can be drawn from the data as these two species are believed to have very different habitat associations (Mason and Machidori, 1976; Lee et al., 1980).

Characteristics of Juvenile Coho

Body length and especially condition are two important factors that determine fish survivorship, performance and reproductive success (Neff and Cargnelli, 2004). Ricker (1975) defines condition as the amount of available energy that an individual can allocate to various life functions including reproduction, foraging, and over-wintering survival. Therefore, individual fish condition is important to the overall success of populations in a given aquatic system.

On the South Alouette River, juvenile coho trapped in habitat treated with LWD were longer and in better condition than those trapped in untreated habitat types. While many studies have shown larger numbers of coho in LWD, few have found that LWD enhancement has resulted in larger fish within treated sites. This is likely due to the inverse relationship of fish size to population density (Fraser, 1969). In a system where fish populations are held at carrying capacity, as fish numbers increase, overall fish size decreases.

There are two explanations for why juvenile coho density and size were greater in habitat with LWD than in habitat without wood on the South Alouette River. First, it is recognized that complex cover, such as LWD, creates habitat that is energetically less costly for fish because of the better foraging opportunities and protection from predation it affords (Cederholm *et al*., 1997). Therefore, juvenile coho within LWD habitat are able to allocate more energy to growth and than those outside of LWD. The second explanation involves intra-specific competition for limited LWD habitat. It is possible that coho in better condition are displacing smaller coho from LWD and creating the stratification by size evident in the data (Mason and Chapman, 1964). While more research is required to determine whether there is one main cause for the differences in condition and length of juvenile coho between treated and untreated sites, it is likely that both explanations hold some amount of truth; that is, juvenile coho compete for access to LWD because it provides habitat that increases their chances of survival.

Juvenile Steelhead on the South Alouette River

This study found that juvenile steelhead primarily utilized riffles on the South Alouette River and clearly favored this habitat type over pools. This finding is in agreement with other research that shows juvenile steelhead have a strong affinity for faster water velocities (Waite and Barnhart, 1992).

Trapping on the South Alouette River also showed that juvenile steelhead rarely used habitat treated with LWD. Although some research has shown similar results to this study, other data suggests a strong correlation between juvenile steelhead and LWD cover (Cederholm *et al*., 1997; Slaney, 2005).

When juvenile steelhead use LWD cover, the literature shows it is predominantly during the winter months or during high flow events (Slaney, pers. comm). During winter, research has shown that these fish are prone to use LWD when water temperatures reach 3˚C or lower (Slaney, pers. comm.). Lower availability of food and the high energy costs required to maintain position in fast moving riffles, especially during high flow events, also makes LWD important habitat for juvenile steelhead during the winter.

On the South Alouette River in the winter, the presence of the Alouette Lake dam 5 km upstream of the study reach buffered water temperatures. This monomictic lake resevoir maintained steady temperatures of approximately 4-5 ˚C during the winter and, due to the lack of tributaries, provided the vast majority of inputs to the study site (Cope 2005, Wilson, pers. comm). While water temperatures on the South Alouette have dropped to lows of 3˚C in some years, these events only lasted for a few days. Therefore, high winter water temperatures on the stream provide one explanation for the low use of LWD by juvenile steelhead.

The presence of the upstream dam and absence of tributaries also buffered water flows on the South Alouette River. The lack of high flow events on the stream caused juvenile steelhead to use LWD habitat less than if there were regular high flow occurrences. In sum, the water temperature and flow conditions under which juvenile steelhead would regularly use LWD during the winter are not present on the South Alouette River.

Management Implications

Understanding how LWD will affect a stream's morphology is important when choosing structure locations. Within the center of the LWD structure, where wood concentration is highest, water velocities are reduced. Conversely, velocity is increased around the upstream perimeter, which causes scouring in the lee of the structure (Cederholm et al., 1997). On the South Alouette River, LWD has created a number of pools and sometimes slowed water velocity within the structures to 0 cm/s. LWD's ability to change the physical aquatic habitat likely impacted species distribution within the study reach.

With sculpin and juvenile coho favoring slow-moving water and pool habitats, it is no surprise that these species were trapped in the highest abundances within LWD structures in the South Alouette River. On the other hand, juvenile steelhead have a strong affinity for shallow fast moving waters, characteristics not promoted by LWD placement. In this way, LWD has an indirect affect on fish species composition in a given area. By changing physical attributes of the stream, LWD placement may inadvertently create preferred habitat for some species while excluding others. On the South Alouette River, steelhead were trapped in very low numbers in LWD habitat, not because of an aversion to complex cover, but probably due to the modifications wood had on velocity and depth. If this is true, juvenile steelhead utilization of LWD can be encouraged by extending the structure into the thalweg or altering structure design in other ways to promote faster velocities. This would provide steelhead with cover in velocities that they prefer.

Beyond providing cover and foraging habitat for specific species of fish, LWD also plays an important ecological role in watersheds. LWD traps and retains fish carcasses and leaf litter (Cederholm *et al.*, 1997). As these materials decompose, they release nutrients back into the environment and are then available to be sequestered by other living organisms such as algae, aquatic plants, insects and fishes. By storing organic materials and nutrients, LWD is essential in maintaining stream productivity (Minshall, 1984).

When undertaking an enhancement of fish habitat, it is imperative to have clear and measurable objectives. Understanding species preferences for certain habitat types becomes crucial, especially when multiple species with different habitat requirements are present in a stream. Moreover, all types of restoration projects need to be evaluated on a stream to stream basis. Extrapolating results from studies on other rivers is dangerous practice. It is relatively inexpensive to conduct assessments and the benefits resulting from them will often outweigh the costs, making restoration projects more effective.

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Appendices

Appendix I – Data Entry

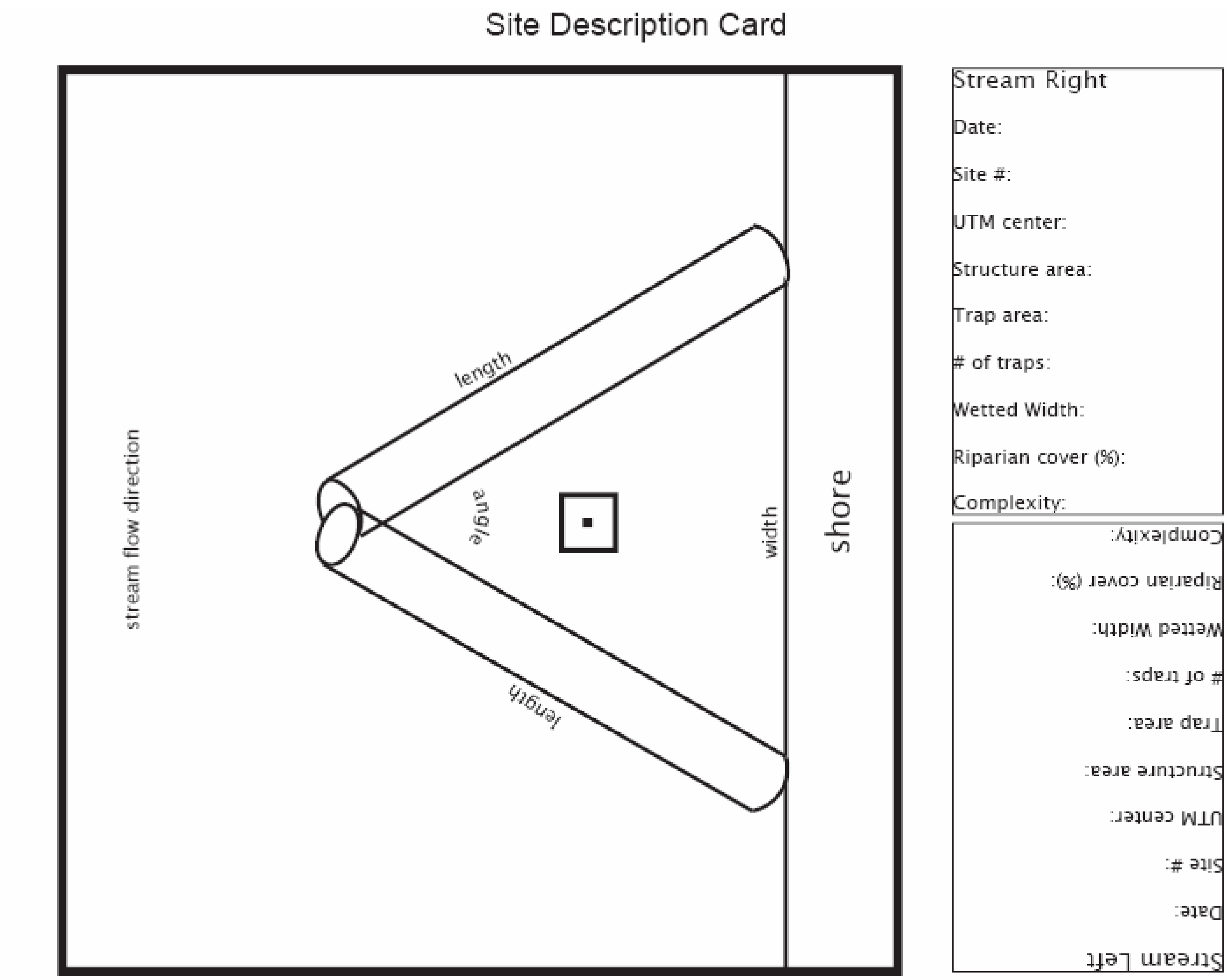

Figure 20. Site description card used for describing site characteristics on the South Alouette River, near Maple Ridge, BC.

Date:

Crew:

Weather:

Air Temp (^oC):

Site #:

UTM:

Site Description:

Flow (m/s):

Bait:

Trap #:

Sampling Method:

Substrate:

Mean Water Velocity (cm/s):

Water Depth (cm):

Soak Time In:

Trap Velocity (cm/s):

Water Temperature (^oC):

Soak Time Out:

Species	Lifestage	Marks Applied	Markings	Fork Length (mm)	Weight (g)	Scale ID	Comments

Figure 21. Fish collection card used for describing fish sampled in the South Alouette River, near Maple Ridge, BC.

Appendix II – Data

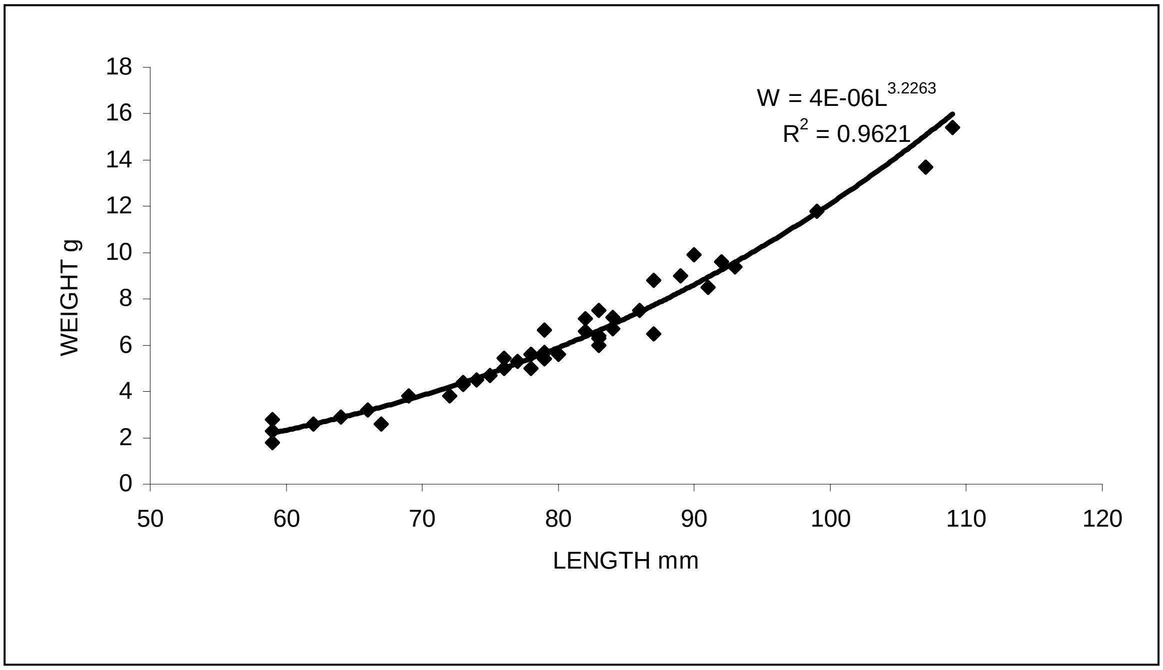

Figure 22. Weight-to-length relationship of juvenile coho trapped during the fall in the South Alouette River, near Maple Ridge, BC.

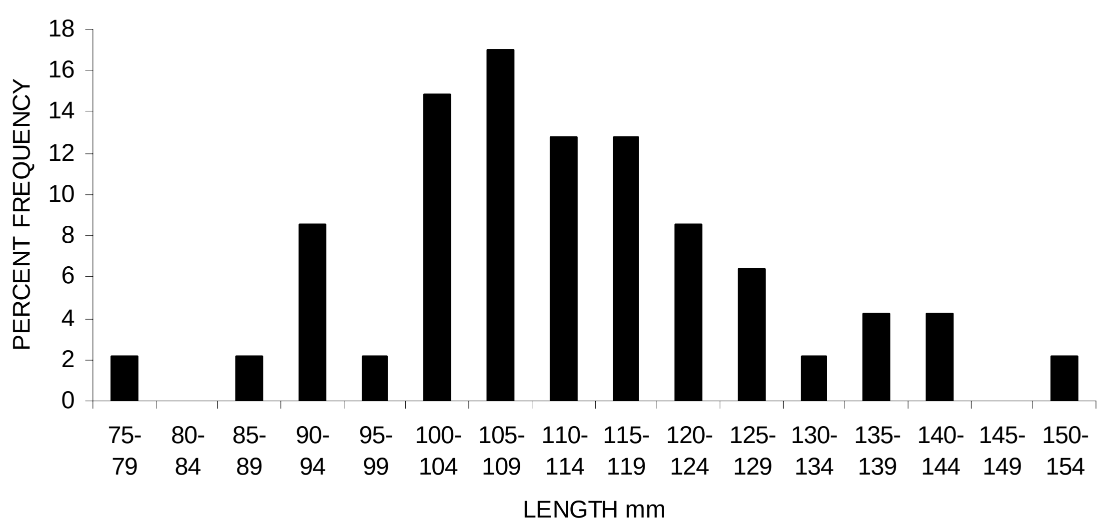

Figure 23. Length frequency of juvenile steelhead trapped during the winter in the South Alouette River, near Maple Ridge, BC.

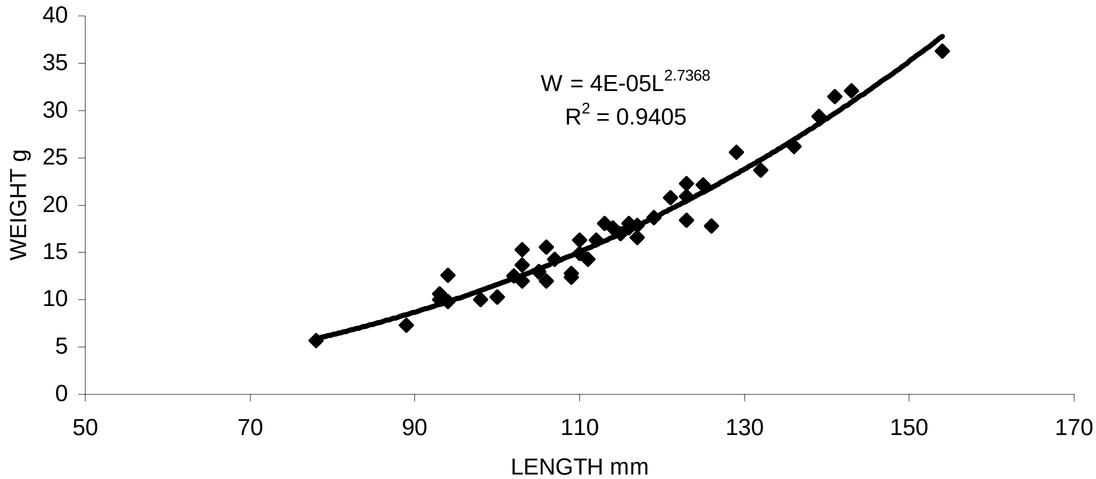

Figure 24. Weight-to-length relationship of juvenile steelhead trapped during the winter in the South Alouette River, near Maple Ridge, BC.

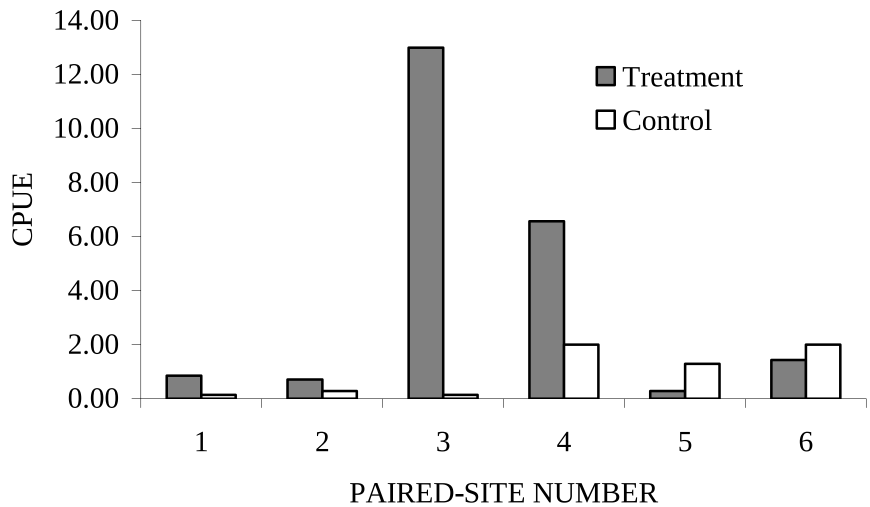

Figure 25. CPUE of juvenile coho by treatment/control site pairs trapped during the fall in the South Alouette River, near Maple Ridge, BC.

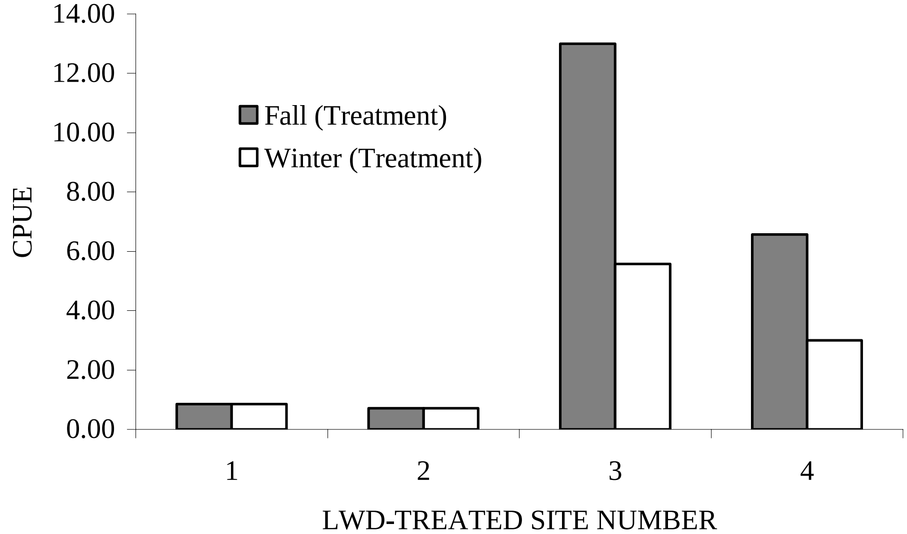

Figure 26. Comparison between the fall and winter LWD-treated sites for juvenile coho trapped in the South Alouette River, near Maple Ridge, BC.