Juvenile and adult salmonid response to the placement of logjams in the Elwha and Stillaguamish Rivers: preliminary results

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Introduction

The placement of physical structures such as logs in river systems to create pools, alter channel morphology, provide cover and habitat for fish and other aquatic organisms, began in the early 1930s (Tarzwell 1934, White 1996, Roni et al. in press). Log structure placement was one of the first "instream" enhancement methods used to mitigate for habitat degradation, and increase fish production in streams and rivers (Tarzwell 1934). Instream structures may include boulder or log weirs, dams and deflectors, cover structures, rootwads and brush bundles, and more recently the construction of log jams in large rivers (Roni et al. in press). Although the placement of logs and log structures have been widely practiced, their effectiveness have not been systematically evaluated (Roni et al. in press). The need for monitoring and evaluation has been noted before (Tarzwell 1937; Reeves et al. 1991), and is as pressing a need in the 21st century as it was in the early part of the 20th century (Roni et al. 2001a, 2002, Roni et al. in press).

Past evaluations of instream enhancement of aquatic ecosystems have largely focused on responses of physical habitat. Many studies in the Pacific Northwest have reported significant changes and increases in pool frequency, pool depth, woody debris, spawning gravel, and sediment retention following placement of instream log structures (e.g., Cederholm et al. 1997, Reeves et al. 1997, Roni and Quinn 2001). Biological evaluations of different restoration techniques have been less frequent than evaluations of the response of physical variables, and have produced inconsistent results depending upon the technique, region, species, and life stage examined (Roni and Quinn 2001, Roni et al. in press).

The vast majority of biological evaluations have focused juvenile anadromous

salmonids (Roni and Quinn 2001). In a review of the effectiveness of instream restoration efforts for Pacific salmon, Roni et al. (2001a, 2002) found that while many studies reported positive responses of juvenile coho salmon (*Oncorhynchus kisutch*), steelhead trout (*O. mykiss*), and cutthroat trout (*O. clarki*) to instream restoration, few of these were statistically significant.

The adult salmonids response to enhancement structures has been limited to a few studies, but some authors have demonstrated adult salmon and trout use for spawning at structures with gravel accumulations (Crispin et al. 1993, Avery 1996, House 1996, Gortz 1998). The effects of habitat alteration and degradation in streams have also been assessed successfully using fish communities (e.g., Simon 1998) consequently such metrics may be appropriate for habitat enhancement. Monitoring the response of the entire fish community is important in determining whether instream techniques are "restoring" streams rather than just manipulating habitat for individual species (Roni et al. in press). Equally important to monitoring responses of fishes to restoration, is the need to examine the response of invertebrates, which are an important food source for fishes and highly sensitive to habitat alteration and disturbance (Merrit and Cummins 1996, Karr and Chu 1999).

The majority of physical and biological evaluations of instream enhancement projects have been on smaller streams (e.g., less than 12 meters bankfull width) (Roni and Quinn 2001), with few attempts in streams larger than 30 meters (Slaney et al. 1994, Savory 2000). The few attempts in larger streams have met with mixed success. Savory (2000) found that wood placed in the Mashel River in the Puget Sound region of Washington State did not remain over the period of one winter. Slaney et al. (1994) found that most

wood placed in the Nechako River was mobilized during winter flows, with the exception of logjam structures called “debris catchers (key pieces).” Slaney et al. (1994) also reported that placement of debris catchers in the Nechako River resulted in an increase in salmonid fry densities and adult trout due to the increase in instream cover. Peters et al. (1998) also found that increased fish densities were positively correlated with an increase in wood cover.

Monitoring goal and hypothesis

The monitoring goal of the logjam placement projects in the Elwha and North Fork Stillaguamish Rivers was to examine the effects of constructed logjams on fish abundance, primary productivity, and secondary productivity in mainstem habitats. Specifically, how do logjams in large river systems (e.g., bankfull width greater than 30 meters) affect the distribution and abundance of juvenile and adult salmonids? How do such changes in the distribution and abundance of juvenile and adult salmonid relate to changes in habitat type and relative primary productivity? The focus of this preliminary report will be on the former because not enough information has been gathered on the latter to date. Both monitoring goals have implications relating a change in fish habitat to a change in salmonid survival.

Our hypotheses is that habitats with constructed logjam structures in a larger river system will have greater abundance of individual salmonid species. The constructed logjams reaches will expand the distribution of all fish species in habitat areas, raltive to those without constructed logjams due to the increase in wood abundance and habitat complexity (table 1). This effect will also be seen immediately adjacent to and downstream of the structures, but decrease further away from the logjam structures.

Table 1. Biological response hypotheses for Elwha and North Fork Stillaguamish

Elwha Juveniles

Species	*Effect of ELJ*
Coho, chinook	Positive
Rainbow/Steelhead, chum	No effect

Elwha Adults

Species	*Effect of ELJ*
Chinook, steelhead, trout, char	Positive
Sculpin, stickleback	No effect

Stillaguamish Juveniles

Species	*Effect of ELJ*
Coho, chinook	Positive
Rainbow/Steelhead	No effect

Stillaguamish Adults

Species	*Effect of ELJ*
Chinook, pink, sockeye, chum, steelhead, resident trout, sea-run cutthroat, char	Positive
Whitefish, suckerfish, sculpin, stickleback	No effect

Questions

We attempted to answer several specific questions in the Elwha and Stillaguamish. The three main questions in the Elwha are:

1) Are fish densities higher in areas with logjams?
2) Are fish densities higher in areas adjacent to logjams?
3) And where are fish densities highest in a river cross-section (e.g., middle vs edge)?

The four main questions in the Stillaguamish include:

1) Did the construction of the ELJ's redistribute the holding adult salmonids?
2) Are the numbers of fish different between pools with and without ELJs?
3) Does fish use differ for habitat unit types?
4) And was there an increase in fish in the treatment reaches relative to the control reaches after the ELJs were constructed?

Study Area

There are two study areas the monitoring covered – the Elwha and North Fork Stillaguamish Rivers (figures 1, 1a, and 1b).

Elwha River

The Elwha River drains a 700km2 watershed in the Olympic mountains of Washington State, flowing northward into the Straight of Juan de Fuca (figure 1a). Over 85% of the watershed is within the boundaries of Olympic National Park. Construction of two dams in the early 1900s on the Elwha River in Western Washington reduced accessible anadromous habitat by 90%, and led to a loss of mainstem and floodplain habitat below the dams (McHenry et al. 2000). Downstream of the dams river sinuosity is reduced and river incision has isolated the mainstem channel from its floodplain, mainly

due to the lack of sediment and wood recruitment from upstream sources (Pohl 1999). Chinook salmon (*O. tshawytscha*) spawning habitat area below the dams has been reduced by 86% since the late 1930's as the river's ability to transport bed-load sediment has exceeded recruitment from new sources (McHenry et al. 2000). Floodplain logging, diking, and channelization have reduced habitat complexity by dramatically reducing wood recruitment and loading.

The Elwha dams have altered the biological and physical characteristics of downstream reaches, and these reaches were historically some of the most productive salmon habitat in the Pacific Northwest (DOI 1995). Implementation of the The Elwha River Ecosystem and Fisheries Restoration Act (1994) calls for removal of both dams on the Elwha. Both dams are scheduled for removal in 2005. The Elwha Klallam Tribe has initiated a large-scale restoration strategy in the lower Elwha River in order to: 1) improve current habitat conditions, and 2) to "prepare" the lower Elwha River, and its floodplain, for the significant increase in sediment supply due to the removal of the Elwha dams. Specifically, their goal is to re-introduce large-scale log jams (constructed log jams) in a 3 mile long treatment reach of the lower Elwha floodplain in order to; 1) protect existing side-channels that function, 2) activate new and abandoned side-channels, and 3) capture wood being recruited from upstream sources (McHenry et al 2000). Below the dams, the Elwha River is a low gradient (slope of 0.34%), pool-riffle, meandering alluvial channel, with a cobble/gravel channel bed. Between 1999 and 2001 11 logjams were constructed between river mile 2.3 and 2.5 of the lower Elwha. Six were constructed in 1999, two in 2000, three in 2001, and five in 2002. The logjams function by: 1) altering flow patterns through diversion, deflection, or restriction, 2) protecting or

enhancing eroding banks, 3) and providing cover and deepwater habitat for juvenile and adult salmonids (McHenry et al 2000).

North Fork Stillaguamish River

The Stillaguamish is located along the southwest margin of the North Cascades, approximately 85 km northeast of Seattle (figure 1b). The project site is located on the North Fork Stillaguamish approximately 8 km east of Oso, north of Washington State Highway 530. The project was first conceived in 1996 for enhancement of salmon habitat. This goal was based on a comprehensive assessment of habitat conditions and historic change that identified a need to develop and maintain pool habitat as a key to recovery efforts for chinook salmon (Pess et al. 1998).

The ELJ project reach has a drainage area of approximately 300 km2 and is a low-gradient (<0.01) meandering gravel-bed channel that has repeatedly migrated across the floodplain during the past century. Over 70% of the watershed is classified as forest lands, while the floodplain is a mix of forested floodplain, agricultural lands, and rural residential. Natural logjams historically stabilized gravel bars in the North Fork Stillaguamish, allowing vegetation to take hold and create in-channel “islands” that resulted in an anastomosing channel network. Gravel bars and forest encompass most of the floodplain, but some homes and pastures are located along the lower portion of the surveyed reach. Estimates of the one- and five-year recurrence interval peak flows at the USGS gage at Arlington, Washington, are 257.5 cubic meters/second (cms) and 424.5 cms, respectively (Abbe et al. in press).

In the summer of 1998, five experimental constructed logjams designed to mimic natural logjam hydraulics were constructed upstream of the C-Post Bridge. Four of the logjams were meander type jams designed to deflect flow on only one side. The

remaining ELJ was a bar apex type designed to accommodate flow around either side. The North Fork Stillaguamish project also included the acquisition of 29 hectares of conservation easement within the channel migration zone (Abbe et al. in press). This area is set aside to permit natural migration of the channel and migration induced by the installation of the logjams.

Figure 1. Map of the Puget Sound Region.

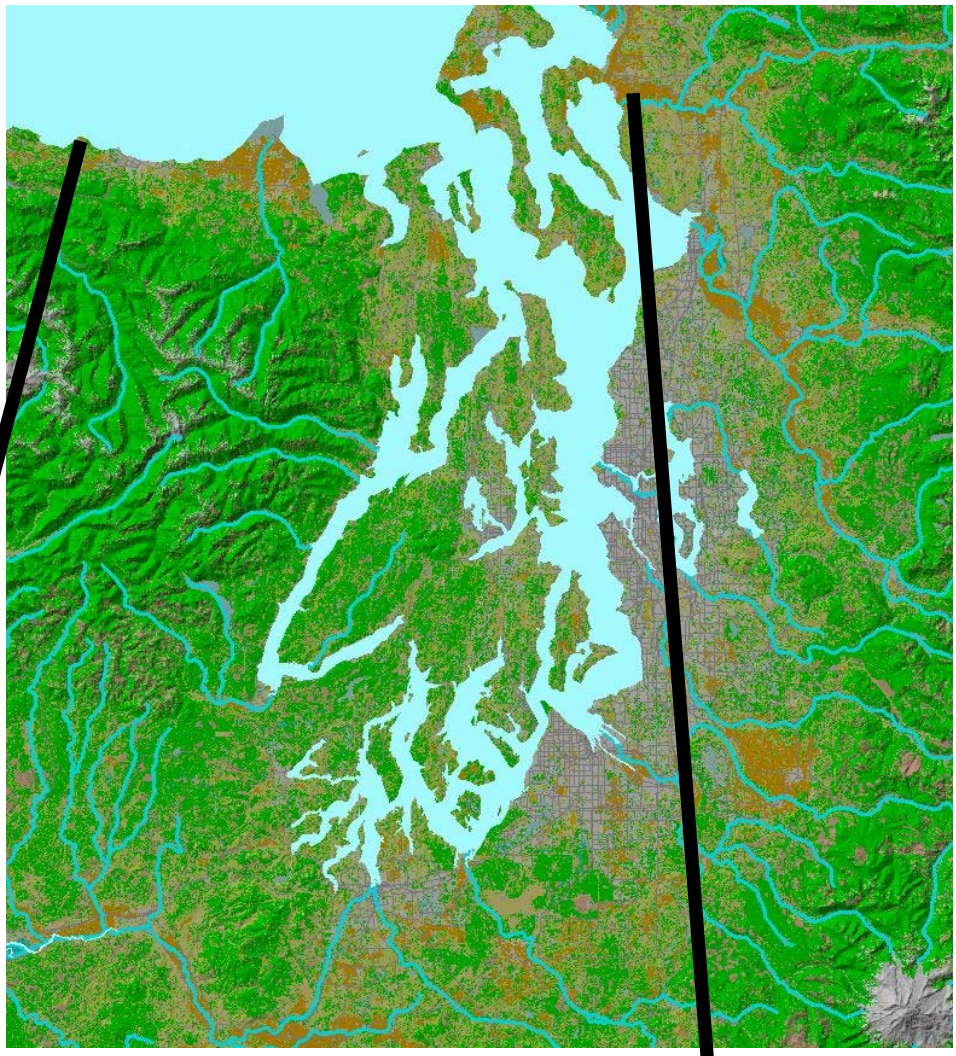
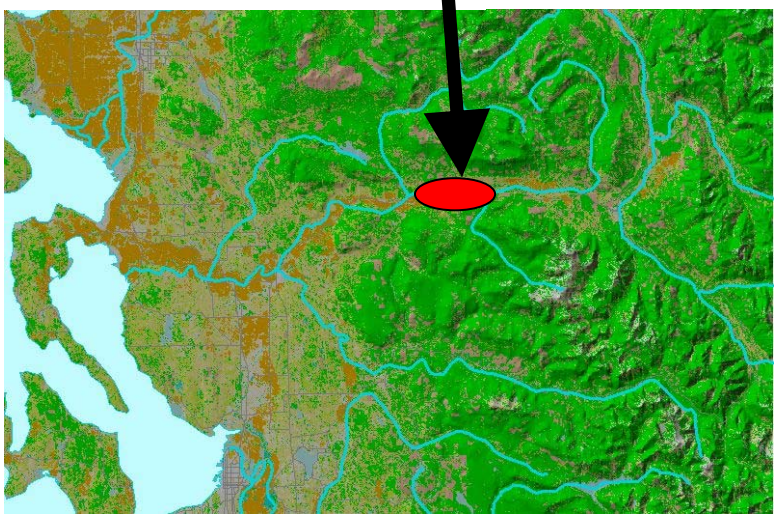


Figure 1a. Elwha River.
Red denotes study reach

Figure 1b. Stillaguamish River.
Red denotes study reach



Methods

Data collection

sample design

We collected data on fish habitat, juvenile fish use, adult fish use, periphyton and benthic invertebrates, and organic matter and nutrient export to compare between habitat units with and without constructed logjams in the mainstem Elwha and North Fork Stillaguamish Rivers (table 2). Fish abundance and productivity parameters are measured seasonally in at habitat types and reaches with (treatment) and without (control) constructed logjams. For the Elwha and North Fork Stillaguamish river logjams we collected post-construction juvenile fish and productivity data at the control and treatment reaches. Additionally, we have three years of pre logjam construction adult salmonid data, as well as post-construction data, in the control and treatment reaches for the Stillaguamish.

fish habitat classification

We completed fish habitat surveys prior to any juvenile and adult enumeration efforts in order to identify; 1) the distribution of habitat types within each reach, and 2) select which habitat units to sample for juvenile salmonid distribution and abundance. We used a four level hierarchical habitat classification system described by Hawkins et al. (1993), and modified by Peters et al. (1998) (table 3). Level 1 identifies the channel type, level 2 breaks out areas by velocity, level 3 uses turbulence as a break between habitat areas, and level 4 identifies the various habitat units (pool types, riffles, glides, etc.) of the channel. Habitat units also changed over time due to changes in river morphology and flow between sampling events. Breaks between units changed and new units were formed either on a seasonal or yearly basis and were documented in each survey.

Table 2. Sample design for juvenile fish, adult fish, and primary productivity data

	Juvenile fish data	**Adult fish data**	**Primary productivity data**
Elwha	Control and treatment* Post-construction		Control and treatment Post-construction
North Fork Stillaguamish	Control and treatment Post-construction	Control and treatment Pre-construction Post-construction	Control and treatment Post-construction

*Control reaches are those without constructed logjams. Treatment reaches are those with constructed logjams.

Table 3. Description of level one of the four-level habitat classification system (Adapted from Peters et al. 1998).

Habitat Type	**Description**
Main channel (mc)	Mainstem river
Braided main channel (bc)	Two or more channels separated by bar or bars which lack vegetation or are sparsely vegetated with immature trees.
Side channel (sc)	A channel separated from the main channel by well vegetated riparian woodlands
Overflow channels (oc)	small channels that inter-connect a side channel to the main channel
Tributary mouth (tm)	Mouth of a tributary stream entering the main channel
Slough (sl)	slough formed when sediment and organic debris block the head of a braid or branch of a main channel (very slow water velocity)

Table 3 – continued. Description of levels two through four of the four-level hierarchical habitat classification system system. (Adapted from Peters et al. 1998).

Level 2	**Level 3**	**Level 4**	**Description**
Fast Water (fw)			riffles; rapid, shallow stream sections with steep water surface gradient
	Turbulent (tur)		Channel units having swift current, high channel roughness (large substrate), steep gradient, and nonlaminar flow and characterized by surface turbulence.
		Fall (fa)	steep vertical drop in water surface elevation
		Cascade (cd)	series of alternating small falls and shallow pools, usually boulder, bedrock
		Rapid (rb)	deeper stream section with considerable surface agitation and swift current; large boulders and standing waves often present.
		Riffle (ri)	shallow, lower-gradient channel units with moderate current velocity ans some partially exposed substrate (usually cobble).
		Chute (ch)	narrow, confined channel with rapid, relatively unobstructed flow and bedrock substrate.
	Non-Turbulent (nt)		channel units having low channel roughness, moderate gradient, laminar flow, and lack of surface turbulence.
		Sheet (sh)	shallow water flowing over smooth bedrock
		Run (rn)	shallow water flowing over a variety of different substrates; also termed “glide” or “raceway” by some authors.
Slow Water (sw)			
	Scour Pool (sp)		formed by scouring action of current
		Eddy (ed)	formed by circular current pattern created by bank obstruction, usually occur along the bank
		Trench (tr)	formed by scouring of bedrock. Usually located in the main channel
		Mid-Channel (mc)	form in main channel by channel constriction at head of pool

Table 3-continued. Description of levels two through four of the four-level hierarchical habitat classification system . (Adapted from Peters et al. 1998).

Level 2	Level 3	Level 4	Description
		Mid-Channel (mc)	form in the main channel by channel constriction at the head of the pool
		Convergence (cv)	form in the main channel by converging streams
		Lateral (lt)	formed in the main channel where flow is deflected by a partial channel obstruction (streambank, rootwad, log, or boulder); for example at the outside bends in the channel of meandering streams, deeper on one side than the other and form as a result of a deflector at the head of the pool
		Plunge (pp)	form in the main channel, deeper upstream, and are formed by water droping vertically over a channel obstruction
		Deposition (de)	Depositional area within a scour pool. Usually along the point bar of a lateral scour pool.
	Dammed Pool (dp)		water impounded by channel blockage
		Debris	formed by rootwad and logs
		Beaver	formed by beaver dam
		Landslide	formed by large boulders
		Backwater	formed by obtructions along banks
		Abandoned Channel	formed alongside main channel, usually associated with gravel bars

For each habitat unit, we measured surface area, estimated bank cover for each bank (table 4), identified the dominant and sub-dominant channel substrate type, determined habitat complexity, and the dominant pool forming factor (PFF) (figure 2, table 5). In pool habitats we measured maximum depth and minimum outlet depth in order to determine a residual pool depth. The North Fork Stillaguamish includes wood counts because the snorkel surveys were started prior to any efforts to quantify total wood loadings (table 5).

juvenile fish use

We conducted seasonal (e.g., spring, summer, fall, winter flow conditions) snorkel surveys within selected habitat units within the control and treatment reaches. We identified all juvenile and adult fish species during the snorkel surveys and visually estimated fish lengths for each observation (table 5). Night snorkels were necessary during the winter and spring seasons as juvenile salmonids are generally cryptic during daylight when water temperatures are below 10 degrees centigrade (Hillman et al. 1992).

Fish census was conducted by dividing each habitat unit into three to four sections of similar size, called snorkel lanes (figure 3). A snorkeler in each lane moved upstream and counted and identified each fish seen. On several occasions we did multiple snorkel counts within one unit in order to get an estimate of the variation in snorkel count due to differences in timing and personnel (Hankin and Reeves 1988, Hankin and Mohr 2002). We calculated fish abundance based on the number of species observed by size class of fish per habitat unit (m2).

Table 4. Description of the cover elements identified for each habitat unit. (Adapted from Peters et al. 1998).

Cover Type	Description
Boulder (bl)	Rock >=256 mm
Bedrock (br)	Exposed solid rock
Cobble (cb)	Rounded rocks 64-256 mm
Deep water (dw)	Water depths >1m (other cover takes precedence)
Vegetation (vg)	Live, terrestrial vegetation
Aquatic Plants (apl)	Live, non woody aquatic vegetation
Riprap (rr)	Angular boulder sized rock placed for bank protection
Undercut banks (ub)	Submerged area underneath an overhanging bank
Branch (bh)	Woody debris < 20 cm in diameter, not accumulated in debris piles
Bank roots (br)	Roots of live trees and shrubs in the water
Debris piles (dp)	Numerous or single types of wood cover accumulated in a pile or jam
Single log (sl)	Woody debris > 20 cm diameter, not accumulated in debris piles
Rootwad (rw)	Roots and lower trunk of non-growing trees
No Cover (nc)	Substrate < cobble size, depth < 1.0 m, and none of the above present.

Figure 2. Fish habitat survey field form used in Elwha and North Fork Stillaguamish Rivers.

Habitat survey field form

Date: _____ Weather _____ Page Of

River: _____ Gradient _____

RM: _____ Bflwdth _____

Segment # _____ Flow _____

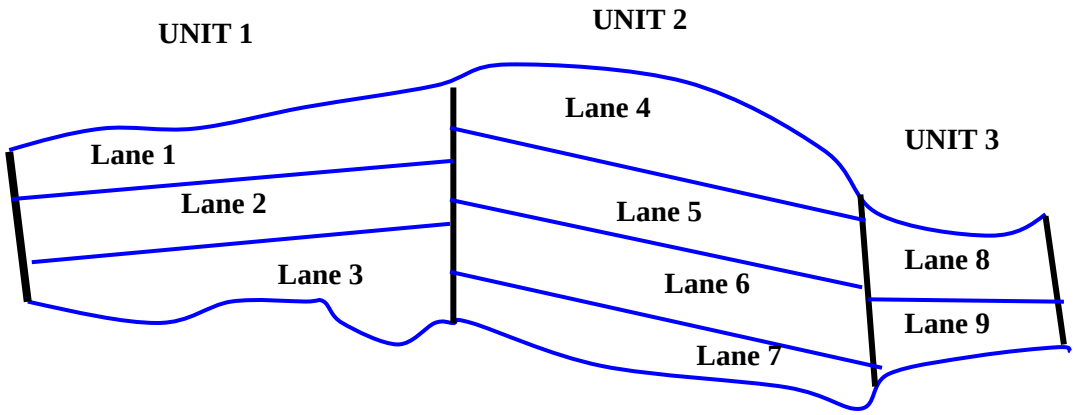
Observers _____

Hab Ref #	Habitat type				Lgth(m)	Width(m)			Depth		Left bank	Right bank	Cover type	D/SD ss	Cmplx	Sgrvl	PFF	Comments
	1	2	3	4		1	2	3	Max	Tail								

Table 5. Habitat, fish, and environmental data categories in database for Elwha and North Fork Stillaguamish

Categories
Unit and sub unit identity
Unit, lane or physical feature above, below and on either side of the current lane
Bank location (river right, left or middle)
Presence or absence of a logjam
Flow type (main or secondary flow)
A 4 level hierachical habitat categorization, subunit type
Habitat complexity
Proportion of unit in 18 different location/habitat categories (e.g. right bank cobble, or left bank riffle-glide)
Length, width and area of lane
Dominant and subdominant substrate type
Pool forming factor
Main cover type.
Total wood (N.F. Stillaguamish)
Wood > 20cm DBH (N.F. Stillaguamish
Wood > 50cm DBH (N.F. Stillaguamish)
Fish species
Fish size class
Day or night snorkel
Date
Season
Year
Flow
Weather

Figure 3. Example of snorkel lanes delineated within habitat units prior to snorkeling



adult snorkel surveys

We conducted adult snorkel surveys during the summer in the North Fork Stillaguamish. As opposed to juvenile snorkels, observers in each lane moved downstream and counted each fish seen. Eight adult snorkel surveys were conducted within 4 contiguous reaches from river mile 25 to river mile 21 between late July to mid-September. Because adult fish are less localized than juveniles, data from all lanes that were snorkeled were combined for each unit. We counted all adult species by habitat unit, with the exception of scuplin (*Cottus spp*.), which were enumerated during juvenile snorkel surveys.

periphyton and benthic invertebrates

To determine the response of lower trophic levels to log jams, periphyton and benthic invertebrates are being sampled monthly from June to October in at least three control units and three constructed logjams for the Elwha and North Fork Stillaguamish. We used artificial substrata- constructed of wood and unglazed ceramic tiles to measure periphyton biomass and insect abundance. Three wood blocks (15 x 15 x 4 cm) constructed of western red cedar are attached to each of the three logjams and to inorganic substrate in three units without log jams. Blocks are placed at similar water depths across habitat type. Periphyton and insects accumulating on these tiles are collected monthly.

A diver retrieves blocks from each constructed logjam by placing an aquarium net downstream of each block and gently removing the block from a logjam. Upon retrieval, each tile is gently brushed with a toothbrush and rinsed with distilled water using a squirt bottle onto a 250-µm sieve sitting on a plastic bucket. Periphyton material collected in

the bucket is stored in dark film containers and analyzed for periphyton ash-free dry mass (a measure of total organic material on tile) and chlorophyll *a* (a measure of algae biomass). Insects collected on the sieve are transferred to 250 ml plastic containers filled with 100% ethanol. Stoneflies, caddisflies, and mayflies are identified to genera while chironomids are identified to family or tribe. Biomass of dominant taxa are determined using drying and ashing ovens. Using similar methods, periphyton and invertebrates accumulating on unglazed ceramic tiles (15 x 15 x 4 cm) are sampled in riffles/run habitat adjacent to pool units (i.e., those with log jams and those without).

nutrient export and invertebrate drift

During the next year we plan to collect nutrient export and invertebrate drift to assess; 1) whether constructed logjams function to retain nutrients in a fluvial system, and 2) gage the difference in productivity between side-channel to mainstem habitats. We will collect samples 6 times a year for nutrient chemistry and suspended organic matter.

Effort to date

Elwha

We have completed one season's worth of habitat surveys and juvenile snorkel surveys on the Elwha river (table 6). In addition we have completed one additional winter habitat and juvenile snorkel survey on the Elwha River. In addition, we have collected some adult fish data during our juvenile snorkel counts. Periphyton and benthic invertebrate response, as well as organic matter and nutrient export data has also been collected, however, due to high winter flow events no data was collected during the winter of 2001-2002.

Table 6. Biological response of logjam effort from summer of 2000 to present

River	Habitat surveys	Juvenile snorkel surverys	Adult snorkel surveys	Periphyton and benthic invertebrate response	Organic matter and nutrient export
Elwha	5	5	0	Initiated	Initiated
North Fork Stillaguamish	4	2	16	Initiated	Initiated

North Fork Stillaguamish

Sixteen snorkel surveys have been conducted from the summer of 2000 to the present, with one adult snorkel survey being conducted every week for eight weeks (table 6). In addition, two juvenile snorkel surveys have been completed – one during the summer of 2001 and one during the winter of 2002. Periphyton and benthic invertebrate response, as well as organic matter and nutrient export data has also been collected, however, due to high winter flow events no data was collected during the winter.

Additional adult snorkel efforts from 1996 to 2000 occurred on the North Fork Stillaguamish (table 7). In each year since 1996 at least one adult snorkel survey was completed from river mile 25 down to river mile 21. Adult snorkel surveys efforts in 1998 and 1999 included at least 4 snorkels. All of this data was used in our analysis of adult fish densities in the North Fork Stillaguamish.

Data analysis

To date, the analysis for the Elwha and Stillaguamish has focused on graphical display of the data, with some simple supporting statistics. We used bar plots to display the presence/absence results and box plots for the density given presence. We used two simple statistical tests to compare lanes with and with out logjams and middle lanes to edge lanes. For the presence/absence results we used a two-sample comparison of proportions test (Zar 1996). If fish presence occurred then a non-parametric wilcoxon test was used to compare densities (Zar 1996).

Table 7. Adult snorkel surveys from 1996 to 2000 in the North Fork Stillaguamish

	1996	**1997**	**1998**	**1999**
North Fork Stillaguamish	1	1	2 (14)*	6

*14 snorkels were completed over a period of two weeks during the construction of logjams near the c-post bridge

Results

Fish density, occupancy, and species richness in the Elwha River

Installation of logjams has increased abundance of juvenile salmonids (figure 4). Almost all species of salmonids were more likely to be present in lanes with logjams and occurred at higher densities than units without logjams. The species/size class combinations for which this pattern was most prominent were chinook 50 – 100 mm, trout 50-100 mm and 100-200 mm, coho fry, and resident rainbow and cutthroat. Trout fry (< 50 mm) were one significant exception. Fish occupancy and density was also significantly less for sculpin and stickleback. Species richness was highest in primary & secondary habitat created by logjams such as pools and sidechannels (figure 5).

Examination of multiple variables in relation to fish density in the Elwha reveals that several variables are significant (table 8). Logjams affect the density of juvenile salmonid species in all seasons. Certain species and size classes, such as chinook 50 to 100mm, chinook greater than 100mm, coho fry, and trout greater than 200mm, have greater occupancy and higher densities in slower v. faster water environments. These same species and size classes also respond favorably to greater habitat complexity (e.g., more instream cover due to wood) than other species or different size classes of the same species. Other factors such as channel location (e.g., edge v. middle of channel) are significant for all species and size classes during specific seasons (e.g., spring) (table 8).

Figure 4. Density and proportion of fish present by species and size class in the Elwha River 2000 to 2002. The shaded bars represent lanes with logjams while the white bars represent edge lanes without logjams. The bars in the bottom panel represent the proportion of lanes occupied by that species/size class. The box plots in the upper panel describe the distribution of fish densities for lanes that are occupied. Statistically significant results are represented with asterisks.

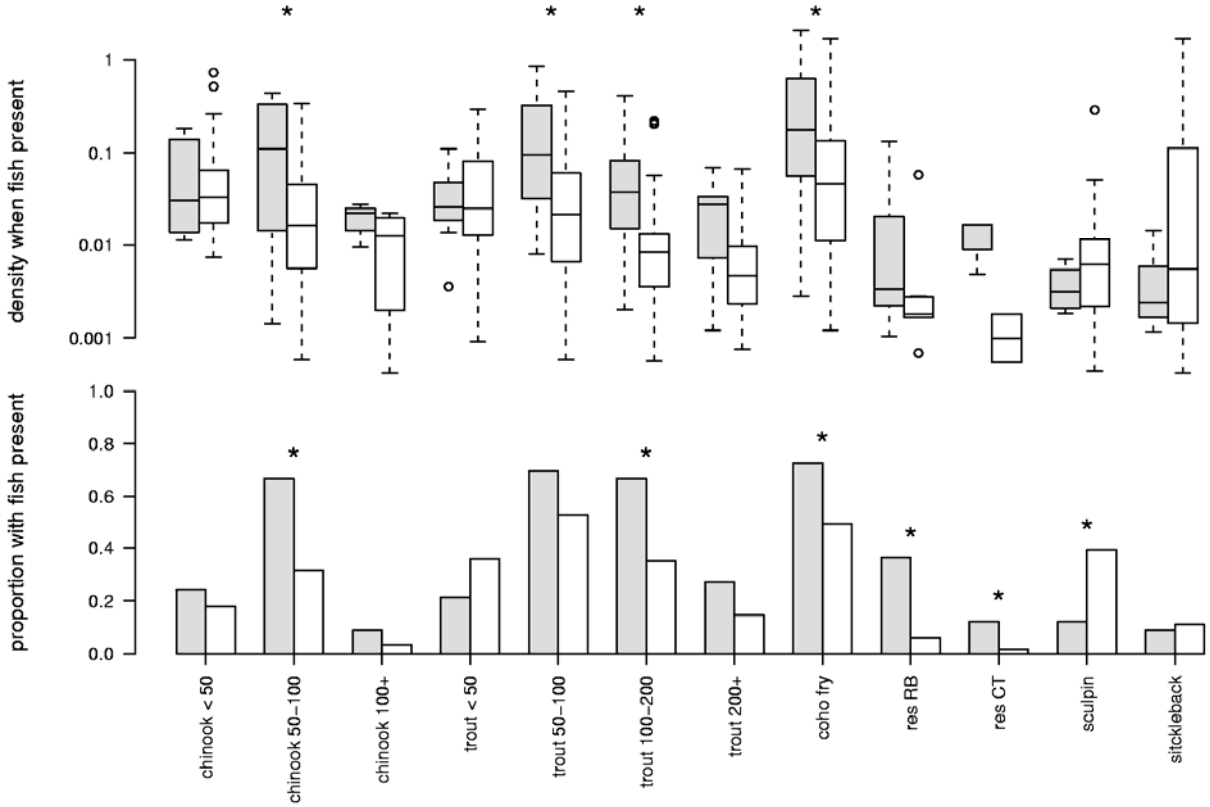


Figure 5. Differences in species richness by habitat type in the Elwha River. Summer of 2000.

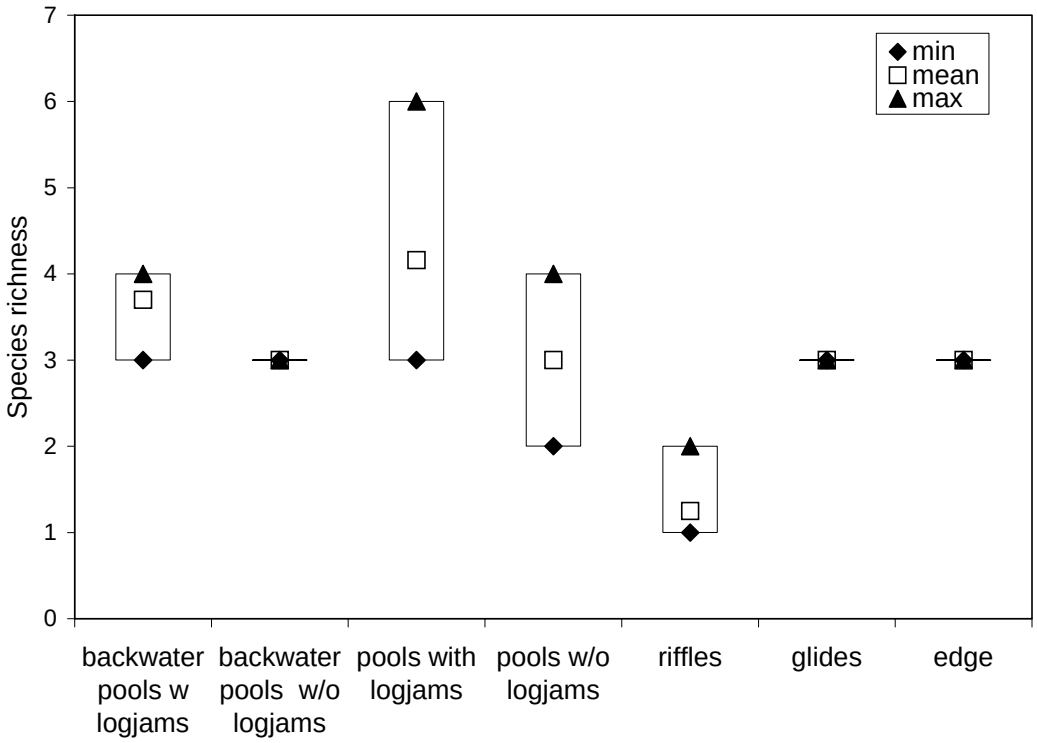


Table 8. Relationships between specific habitat and environmental variables and fish density in the Elwha River. Fish density is measured as log[(fish + 1)/length of unit.

	Significant (0.05) All species and size classes	**Significant (0.05) Some species and size classes**	**No significant difference**
All seasons	Logjams	Habitat complexity Level 1,2 and 4 habitat units Dominant substrate	Level 3 habitat units Main cover type Flow location Edge of channel v. middle of channel Pool forming factors
Spring	Fast v. slow water Edge of channel v. middle of channel	Logjams Level 4 habitat units Main cover type	Level 1 and 3 habitat units Habitat complexity Flow location

Periphyton and benthic invertebrates observations in the Elwha

Preliminary results for primary productivity show no obvious difference between tiles placed in constructed log jams and those placed on the streambed. Invertebrate abundance was dominated by dipterans (almost exclusively chironomidae) followed by ephemeroptera, plecoptera, and trichoptera. Floodplain habitats saw the highest abundance of both mainstem and floodplain channels, with chironomids being the most dominate.

Adult fish density, occupancy, and species richness in the North Fork Stillaguamish

Adult chinook, and adult salmonids in general, redistributed themselves into the newly constructed logjams (figures 6 and 7). An increase in habitat quality is thought to have led to the redistribution in adult chinook within the treatment reach (RM 21 to 21.5). Constructed logjams in the North Fork Stillaguamish have increased pool frequency, pool depth, and in-channel wood cover. Pool frequency increased immediately after logjam construction from 1 pools/km to 5 pools/km and has remained at that level. Residual pool depth in the treatment reach also increased after logjam construction, increasing from an average of 0.4 m to 1.5 m (figure 8). Now, instead of congregating in one pool, chinook redistributed throughout the treatment reach, utilizing the increase in pool availability and quality.

Pools associated with logjams contained higher numbers for some species and lower numbers for others (figure 9). Chinook and sea-run cutthroat were more numerous in pool associated with constructed logjam (figure 9). However, mountain whitefish (*Prosopium williamsoni*) showed the opposite trend, even though mountain whitefish were most numerous in pools, in general (figure 10). Fish numbers also differed for habitat unit types (figure 10).

Figure 6. Adult Chinook use of the treatment reach (RM 21 to 21.5) in the North Fork Stillaguamish pre v. post logjam construction.

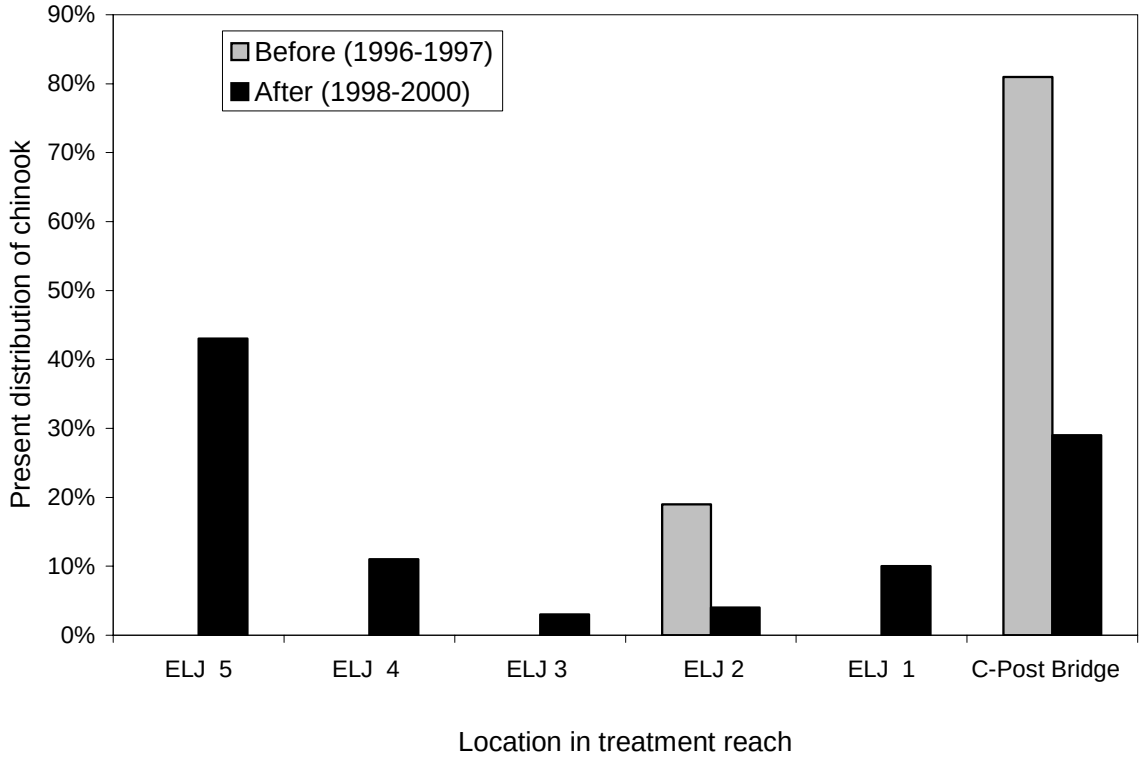


Figure 7. Adult salmonid use of the treatment reach (RM 21 to 21.5) in the North Fork Stillaguamish pre v. post logjam construction.

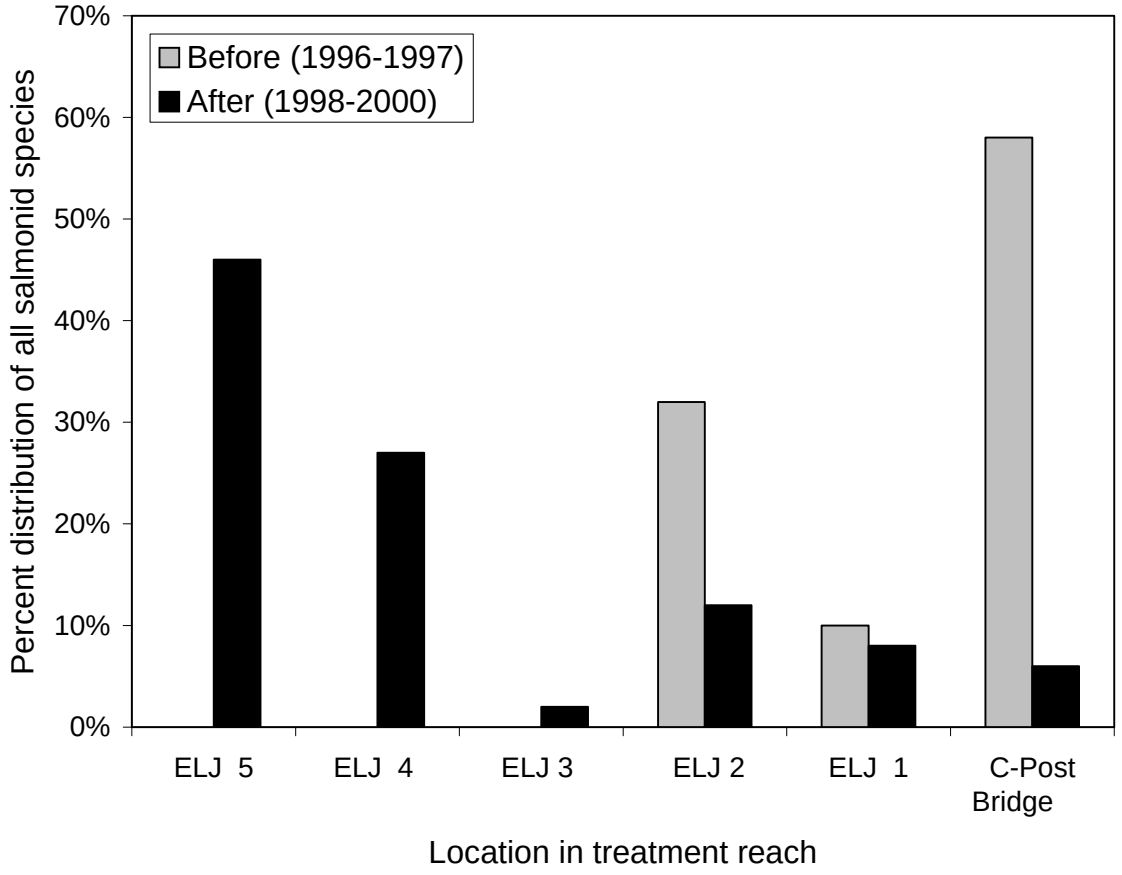


Figure 8. Total number of pools and residual pool depth in the treatment reach (RM 21.5 to 21) North Fork Stillaguamish.

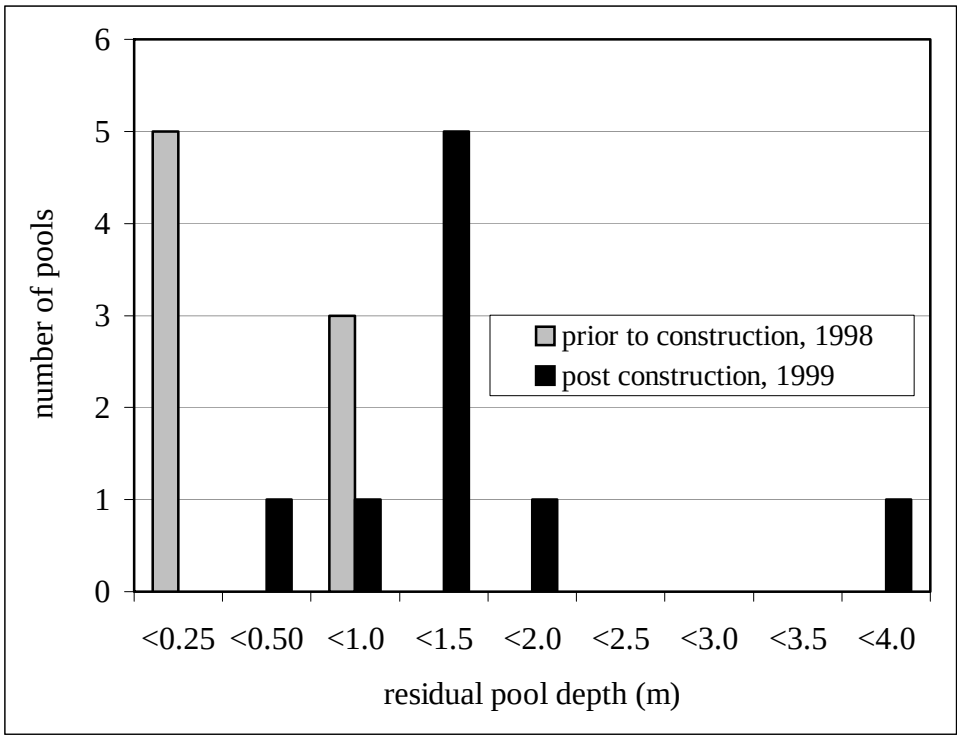


Figure 9. Density and proportion of adult chinook, mountain whitefish, and sea-run cutthroat trout present in pools formed by constructed logjams (yes), and those not formed by constructed logjams (no).

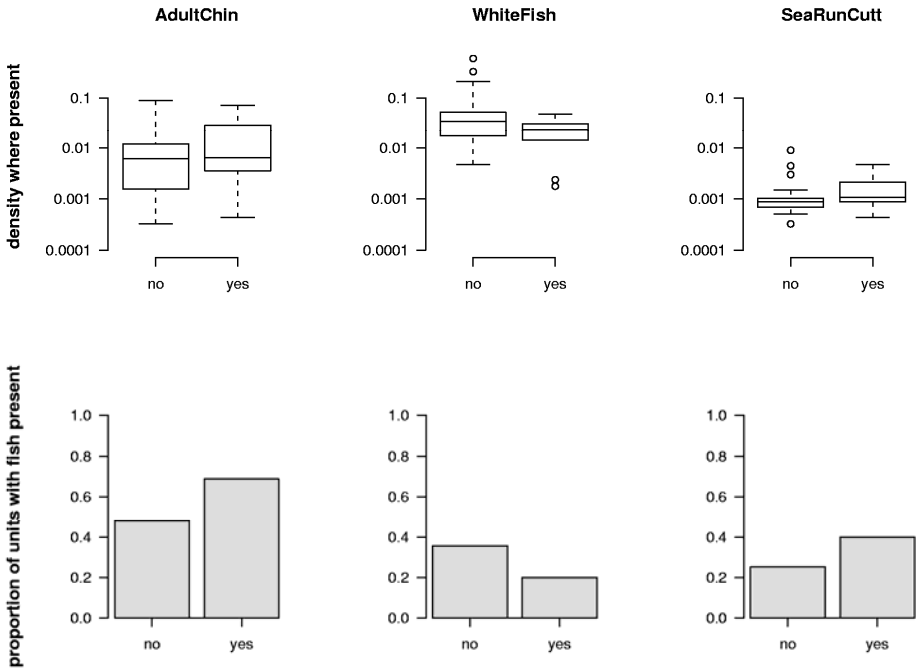
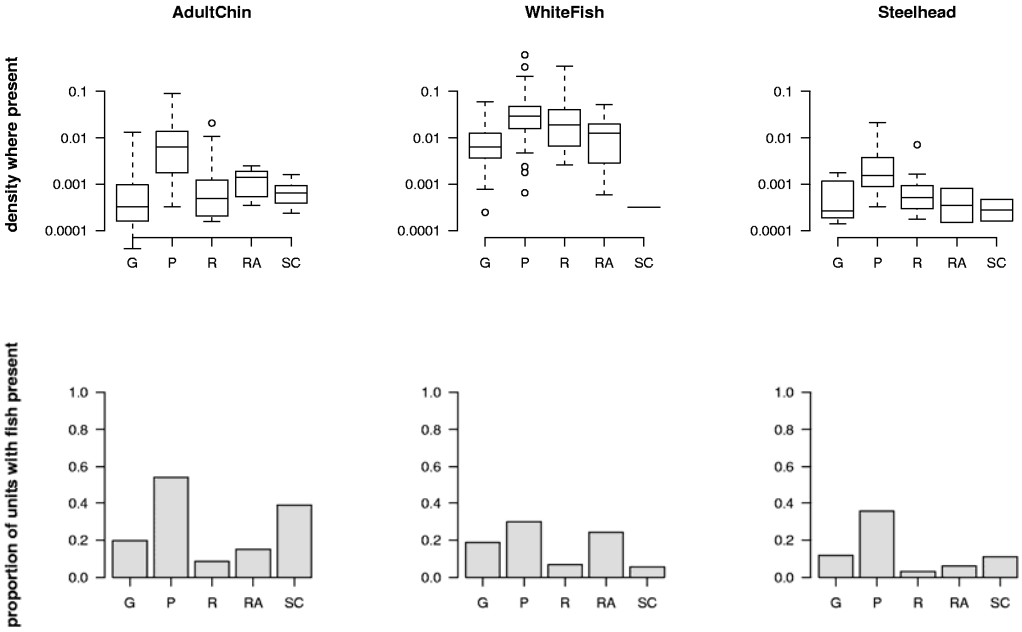


Figure 10. Fish density and proportion of fish present by habitat type in the North Fork Stillaguamish – RM 25 to RM 21. The habitat unit types on the x-axis are G-glide, P-pool, R-riffle, RA-rapid, and SC-side channel. For all three species, numbers were highest in the pool units.



Chinook, mountain whitefish, and steelhead were all most numerous in pools, while chinook and steelhead made moderate use of side channels, white fish were much less common, concentrating instead in rapids and glides. Species richness was highest in pools followed by side channels (figure 11). The numbers of fish in the two treatment reaches did not appear to increase relative to the control reaches after logjam construction (figure 12). This pattern held when looking only at pools and looking at the results by year.

Figure 11. Differences in species richness by habitat type in the North Fork Stillaguamish 1996 to 2001. The habitat unit types on the x-axis are G-glide, P-pool, R-riffle, RA-rapid, and SC-side channel.

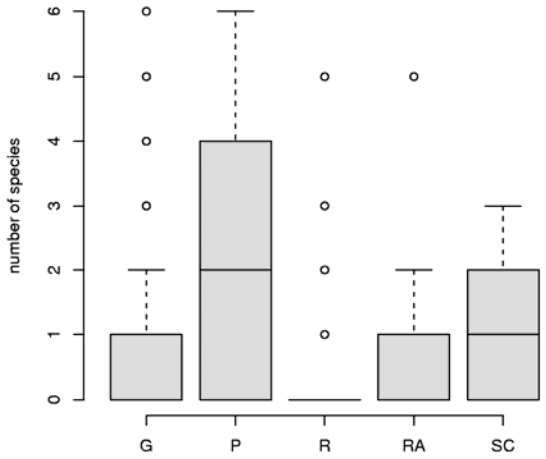
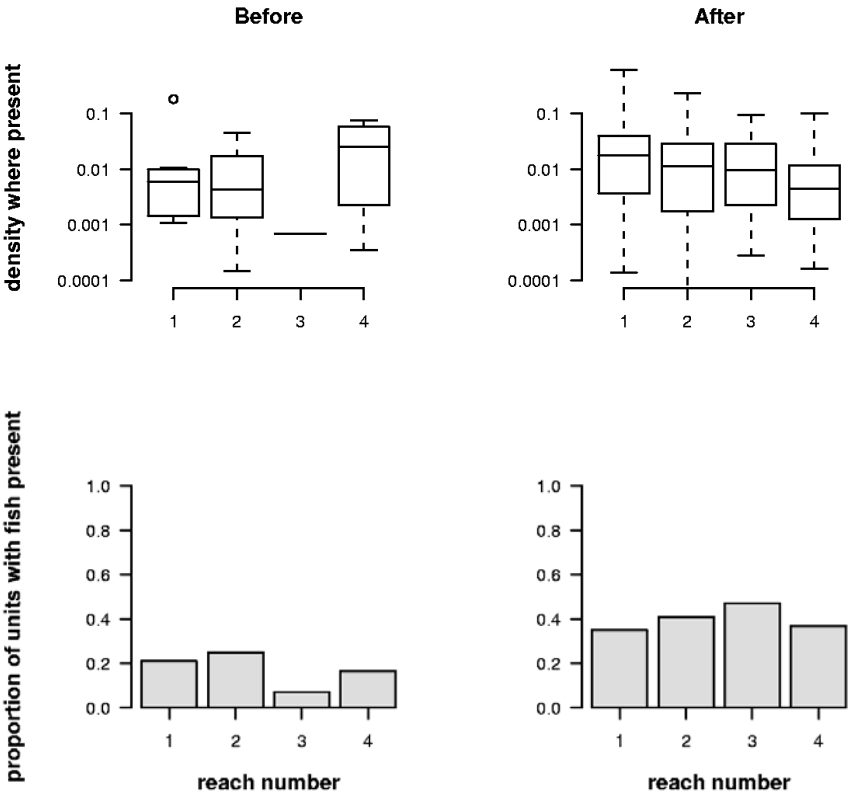


Figure 12. Density and proportion of fish present in treatment (constructed logjams added) and control (no constructed logjams added) reaches in the North Fork Stillaguamish. Constrcuted logjams were added between RM 21 and 21.5 (reach number 4) and 22.5 and 23 (reach number 2). RM 25 to 23 (reach 1) and RM 22.5 to 21.5 (reach 3) were left as controls. The plots on the left display the data prior to logjam construction, while the plots on the right represent the post-installation results.



Discussion

Densities of specific juvenile salmonids such as chinook, trout, and coho were higher in constructed logjams in the Elwha and Stillaguamish River basins. Much of the correlation between the logjams and these species was related to the amount of slower water habitat and complex instream cover in the form of wood. Slower water habitats that had wood as a dominant cover source had higher densities of specific size classes of chinook, coho, and trout. Trout fry (< 50 mm), sticklebacks, and cottids were significant exceptions. Trout fry were related to slower water habitats that were not associated with wood. We hypothesize that this is explained by their preference for the cobble bed and bank areas along the margins, which are common in the lower Elwha due to restricted sediment supply.

Juvenile salmonid associations with slower water and wood cover may be related to several factors depending on the time of year including: 1) protection from current, particularly during higher flows, 2) food availability during times when growth is critical to survival, 3) or camouflage from predators especially during seasonal low flow periods (Angermeir and Karr 1984, Lehane et al. 2002). Logjam placement may be supporting some or all of these functions. For example, during spring flows are typically higher than other seasons in the Elwha, with the exception of large winter flood events. Slower water environments, such as edge areas along the river margin become more important because many of the juvenile salmonids are not large enough to maintain a position in faster water. The combination of slower water edges areas, plus added protection and reduced

velocities on the downstream side of logjams, make such habitat critical to juvenile salmonids in the Elwha during the spring.

The positive response of juvenile salmonid abundance and density to wood placement is similar to what others have found in rivers in the Pacific Northwest and the other parts of the world (Slaney et al. 1994, Peters 1998, Inoue and Nakano 1998, Roni and Quinn 2000, Lehane et al. 2001, Miyakoshi et al. 2002). As mentioned before, both Slaney et al. (1994) and Peters et al. (1998) reported a positive correlation between salmonid fry densities, such as chinook, coho, and trout, and wood cover at the habitat-unit scale.

Inoue and Nakano (1998) found positive correlations at habitat-unit scale between woody-debris cover area and juvenile Masu salmon (*Oncorhynchus masou*) densities. Significant and positive responses to constructed debris dam structures were identified in 0+, 1+, and 2+ salmonid density and biomass one to two years after wood placement in Douglas River, Ireland (Lehane et al. 2001). Between 40% and 69% of the total variation in density and biomass was attributed to environmental variables associated with the structures such as an increase in water depth, pool habitats, and instream cover in the form of vegetation and wood (Lehane et al. 2001). Abundance and biomass of juvenile brown (*Salmo trutta*) and rainbow trout increased in the treatment compared to the control in the Muhlebach, a tributary to the Rhine River in Liechtenstein (Zika and Peter 2002). This increase was attributed to slower velocities and more cover associated with the treatment areas (Zika and Peter 2002). Densities of juvenile masu salmon during the winter months were significantly correlated to wood cover availability in the Masuhoro River Japan (Miyakoshi et al. 2002). This relationship decrease in other seasons, such as fall, implying that cover availability may be more important during certain times of the

year, which may vary by species and life stage (Angermeier and Karr 1984, Miyakoshi et al. 2002).

Adult chinook and other salmonids redistributed themselves into the newly constructed logjams. Logjams in the treatment reach increased the overall habitat quality of specific habitat units, and the overall treatment reach, by increasing pool frequency, depth, and the amount of instream cover associated with each habitat unit. Other studies have also found correlations between such physical characteristics and oversummering of salmonids (Nakamoto 1994, Torgersen et al. 1999). The distribution of oversummering steelhead in the New River, northwestern California, was more strongly controlled by physical characteristics (e.g., pool size, substrate, cover, and flow) than by the availability of thermal refugia (e.g., cool water areas) (Nakamoto 1994). The distribution of spring-run chinook salmon in the North and middle Forks of the John Day River, in eastern Oregon, was related to patterns of stream temperature and pool frequency (Torgersen et al. 1999). Only a few favorable locations were selected in a 50 and 70 km sections of river which abundant pools and temperatures less than 25°C (Torgersen et al. 1999).

Species richness was highest in pools created by natural and constructed logjams in both the Elwha and Stillaguamish. The increase in habitat complexity (e.g., depth, structure, and velocity refuge) on a habitat unit scale in the treatment reaches of the Elwha and Stillaguamish are correlated with greater amount of juvenile and adult salmonid species richness. An increase in depth provides refuge from terrestrial predators. An increase in physical structure provides visual isolation that can minimize competitive predator-prey interactions, allows fish to spend more time feeding, and creates greater opportunities for fish to identify and access optimal foraging locations. It

also minimizes the negative effects of high water velocity by providing refuge from higher flow events that can potentially decrease survival.

A key assumption that we have been using to determine the juvenile and adult salmonid response to increases in instream habitat complexity is that the "spatial variation in population density arises from, and accurately reflects, underlying differences among habitats (Belanger and Rodriguez 2002)." Although this may be true in general, it is important to identify that it may also breakdown under certain circumstances. For example, juvenile density estimates measured only during one season may not be the most critical stage that determines survival to adulthood. Another example is the large variation in density estimates due to large-scale fish movements away from specific habitats due factors such as changes in food availability, predator population changes, or other environmental factors.

Another method that can be used to measure differences in habitat quality is measures of local fish movement into and out of specific habitats. Measuring the amount of habitat-specific immigration and emigration, coupled with measurements of growth within each habitat unit and reach, can potentially provide a more reliable way to determine the mechanistic basis for habitat selection (Belanger and Rodriguez 2002).

Next Steps

Based on the preliminary results we believe that a logical next step to determining the biological response of juvenile fish to constructed logjams is to focus on movements into and out of logjam associated habitats and reaches. Specifically, we need to tag and

recapture juvenile salmonids over space and time in order to have a better understanding of how the logjams affect their growth and overall survival. Attaining information on juvenile salmonid immigration and loss rates, coupled with actual measurements of individual growth, would allow us to better determine if the differences in salmonids densities between habitats we have observed are significant to the overall population.

This past spring we conducted a mark and re-sight experiment in order to identify how juvenile chinook utilize logjam and non-logjam habitats. We marked 1000 juvenile chinook salmon from the Stillaguamish Tribal Hatchery in Arlington, WA, to determine fish use of logjams during their outmigration. During two days in May, four batches of fish were marked, each with a different color of paint injected into the anal and dorsal fins. This allowed visual identification of the juvenile fish during subsequent snorkeling efforts. Two batches of fish were released into logjams, and two were released in areas without logjams. Snorkelers were present to observe the behavior of the fish as they were being released, which occurred on May 21, 2002. Turbidity was high on the day of release, thus visibility was limited to between 0.5 and 1.0 meters. Of the fish released into the logjams, a few entered the jams. The majority immediately headed for open water and quickly disappeared. Nearly all fish released in areas without logjams appeared to school up and quickly head downstream. Our intention was to snorkel the areas where fish were released for several nights after release, but due to the turbidity and the fact that most of the fish seemed to leave the release area immediately, the decision was made not to snorkel. This decision was supported by the appearance of two marked fish in a smolt trap 35 river miles downstream approximately two and three days after release. We concluded that the fish were released too late - they were too far along in the

smoltification process to want to remain in the river. The tagging method, however, does hold promise and we will attempt the same mark and resight experiment next year at an earlier time.

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