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JUVENILE SALMON RESPONSE TO THE PLACEMENT OF ENGINEERED LOG JAMS (ELJS) IN THE ELWHA RIVER, WASHINGTON STATE, USA

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ABSTRACT

Engineered log jams (ELJs) are increasingly being used in large rivers to create fish habitat and as an alternative to riprap for bank stabilization. However, there have been few studies that have systematically examined how juvenile salmonids utilized these structures relative to other available habitat. We examined Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*) and trout (*O. mykiss* and *O. clarki*) response to the placement of engineered log jams (ELJs) in the Elwha River, Washington State, USA. We used summer snorkel surveys and a paired control-treatment design to determine how engineered log jams in a large river system affect the density of juvenile salmon. We hypothesized that densities of juvenile salmonids would be greater in habitats with ELJs than in habitats without ELJs in the Elwha River and that this ELJ effect would vary by species and size class. Juvenile salmonid density was higher in ELJ units for all control-treatment pairs except for one pair in 2002 and one pair in 2003. Positive mean differences in juvenile salmon densities between ELJ and non-ELJ units were observed in two of 4 years for all juvenile salmon, trout greater than 100 mm and juvenile Chinook salmon. Positive mean differences occurred in one of 4 years for juvenile coho salmon and trout less than 100 mm. The results suggest that ELJs are potentially useful for restoring juvenile salmon habitat in the Elwha River, Washington State, USA. Copyright © 2011 John Wiley & Sons, Ltd.

KEY WORDS: stream restoration; wood placement; fish response; Pacific Northwest

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INTRODUCTION

Wood and log jams have been found to play a significant role in the ecology and morphology of streams and rivers in a wide range of climates and physiographic regions including Asia (Rikhari and Singh, 1998), Australia and New Zealand (Webb and Erskine, 2003), Europe (Piegay and Gurnell, 1997), northeastern North America (Warren and Kraft, 2003), southeastern North America (Wallerstein *et al*., 1997), southwestern North America (Haden *et al*., 1999) and northwestern North America (Abbe *et al*., 2003; Montgomery *et al*., 2003). Wood accumulations in large river systems (e.g. bankfull width greater than 30 m), and resulting geomorphic and biological effects, have been greatly reduced throughout the world over the last several thousand years (Montgomery *et al*., 2003). North American Pacific Northwest watersheds have seen wood accumulations decline over the last century since the mid to late 1800s (Collins *et al*., 2002; Montgomery *et al*., 2003). Anthropogenic effects along large rivers typically include removal of wood accumulations within a river, degradation or total removal of riparian vegetation along banks, and 'simplification' of riverbank environments by armouring streambanks with large angular rock (riprap) for the purposes of bank protection and flood control (Schmetterling *et al*., 2001). The simplification of riverbanks is a contributor to the loss of salmonid habitats throughout the Pacific Northwest, in large part due to the loss of preferred habitat characteristics related to in-channel stream cover and habitat complexity (Schmetterling *et al*., 2001; Beechie *et al*., 2005).

Over the last decade, reach-scale rehabilitation projects using ELJs have been used across the Pacific Northwest of the United States to, in part, recover complexity to channel margin habitats in large rivers (Abbe *et al*., 2002). ELJ technology is based on the premise that the manipulation of fluvial environments, whether for traditional problems in river engineering (e.g. flood control, bank protection) or for habitat restoration, is more likely to be sustainable if it is done in a way that emulates natural landscape processes (Abbe *et al*., 2002; Brooks *et al*., 2006). For example, wood accumulation from natural log jams can form 'hard points' that provide long-term forest refugia (Abbe and Montgomery, 1996). Such natural hard points create stable foundations for forest growth within a dynamic alluvial environment subject to frequent disturbance (Abbe *et al*., 2002).

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Initial attempts to construct log jams in larger streams met with mixed success. Slaney *et al*. (1994) found that most wood placed in the Nechako River was mobilized during winter flows, with the exception of log jam structures called 'debris catchers (key pieces)'. Savery (2000) found that log jams placed in the Mashel River in the Puget Sound region of Washington State did not remain over the period of one winter, thus the effects on salmonids was minimal. Thus, while these larger stream wood placement projects provided instream cover and increased juvenile salmonid densities, their lack of long-term residence could not result in any long-term potential benefits.

ELJ projects have incorporated improved engineering and construction techniques (Abbe and Montgomery 1996; Abbe *et al*., 2002; Nagayama and Nakamura, 2009). This has resulted in improved aquatic habitats and addressed traditional problems constraining habitat rehabilitation, such as bank and bridge protection, because they have remained stable despite being subjected to numerous large flow events (Abbe *et al*., 2002; Brooks *et al*., 2006; Coe *et al*., 2006). However, their longer-term biological and physical influence (e.g. greater than 3 years) has not typically been quantified (Brooks *et al*., 2006).

While the long-term biological influence of ELJs in larger river systems have not been addressed, there is ample evidence of a positive response by juvenile salmon to wood placement in the Pacific Northwest and other parts of the world (Cederholm *et al*., 1997; Inoue and Nakano, 1998; Roni and Quinn, 2001; Lehane *et al*., 2001; Miyakoshi *et al*., 2002). Slaney *et al*. (1994) 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. Fish densities have been positively correlated with an increase in wood cover and complexity in larger systems, and wood cover has been found to be the most important factor influencing the distribution and abundance of juvenile coho salmon (*O. kisutch*) (Peters, 1996). Inoue and Nakano (1998) found positive correlations at habitat-unit scale between woody-debris cover area and juvenile Masu salmon (*O. masou*) densities. Significant and positive responses to constructed debris dam structures were identified in age 0+, 1+ and 2+ salmonid density and biomass 1–2 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 (*O. mykiss*) increased in the treatment compared to the control in the Muhlebach River, a tributary to the Rhine River in Liechtenstein, and was also attributed to slower velocities and more cover (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).

In this study we examined the effects of ELJs on juvenile salmonid fish distribution and abundance over time in mainstem habitats of the Elwha River, a large western Washington river. We asked the general question of how do engineered log jams in a large river system affect the occurrence and density of juvenile salmonids? How do such changes in the occurrence, distribution and density of juvenile salmonids relate to changes in habitat condition? We hypothesize that the likelihood of occurrence and densities of juvenile salmonids will be greater in habitats with ELJs than in habitats without ELJs in the Elwha River. We also hypothesized that there would be differences in salmonid response as a function of species and size class. Specifically, we hypothesized that certain species such as juvenile coho, juvenile Chinook and trout less than 100 mm would respond more favourably to the constructed log jams because they have a greater preference for low velocity areas and cover, relative to trout greater than 100 mm.

STUDY AREA

The Elwha River drains a 700 km^2 watershed in the Olympic mountains of western Washington State, flowing northward into the Straight of Juan de Fuca (Figure 1). The Elwha River ecosystem falls within the Olympic Peninsula Province vegetation classification (Franklin and Dyrness, 1988). The lower Elwha falls within the western hemlock (*Tsuga heterophylla*) zone and are typically dominated by forests composed of Douglas fir (*Pseudotsuga menziesii*), mixed with western hemlock and western red cedar (*Thuja plicata*) above the floodplain. The Lower Elwha floodplain forest community are dominated by red alder (*Alnus rubra*), co-occurring with black cottonwood (*Populus balsamifera ssp. trichocarpa*), grand fir (*Abies grandis*) and bigleaf maple (*Acer macrophyllum*) in varying proportions. Currently the Lower Elwha floodplain is mixed in varying proportions of both these conifer and deciduous species.

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 reduced accessible anadromous habitat by 90% (Pess *et al*., 2008). 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, 2004). Floodplain logging, diking and channelization have further reduced habitat complexity in the Lower Elwha below the dams by dramatically reducing wood recruitment and loading (Kloehn *et al*., 2008; Pess *et al*., 2008).

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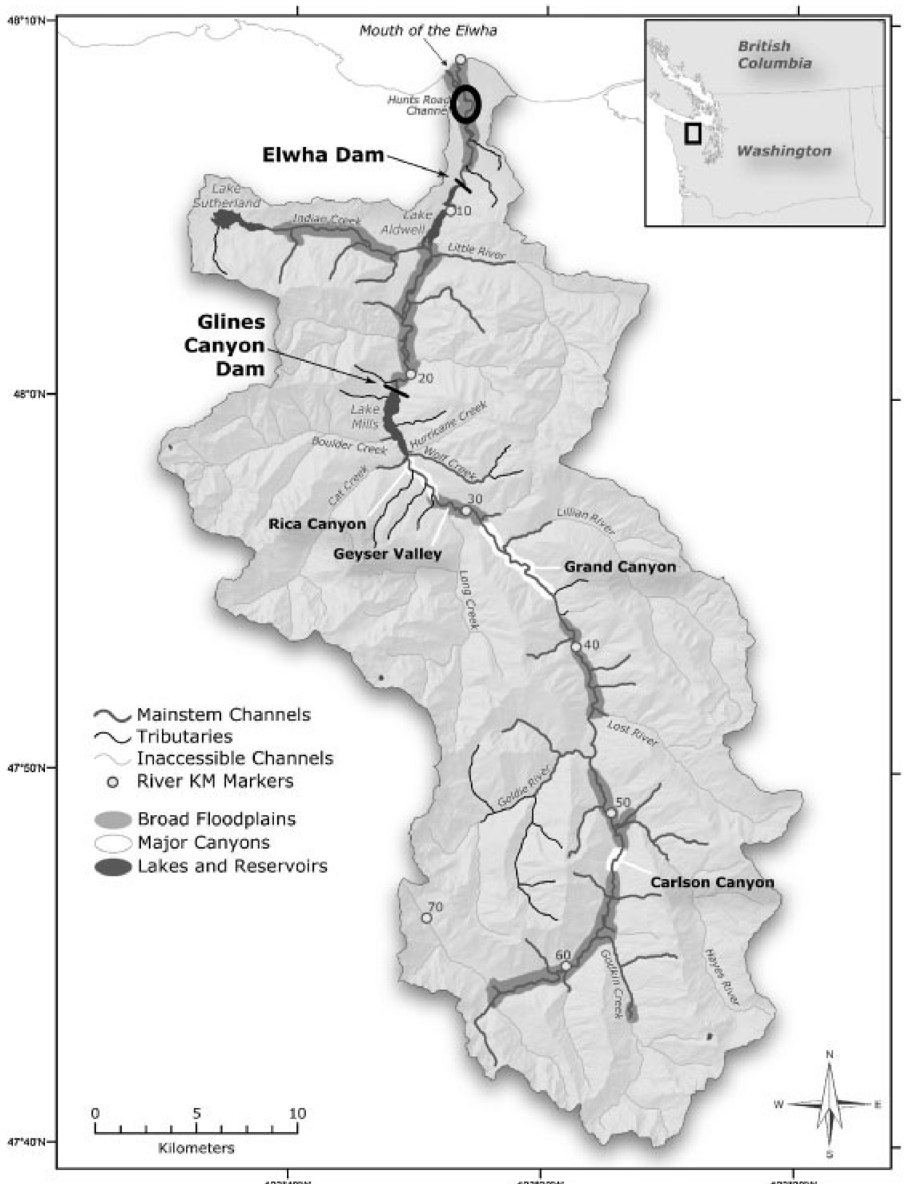

Figure 1. Map of Washington State and the Elwha River watershed. Study area is denoted by solid black circle.

The Elwha dams have altered the biological and physical characteristics of downstream reaches (Pess *et al*., 2008). Implementation of the Elwha River Ecosystem and Fisheries Restoration Act (1992) called for removal of both dams on the Elwha (DOI, 1995). Both dams are expected to be removed starting in 2011. 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 resulting from the removal of the Elwha dams. Specifically, their goal is to re-introduce large-scale log jams in a 4.8 km long treatment reach of the lower Elwha floodplain in order to: (1) maintain existing side-channels, (2) activate new and abandoned side-channels and (3) capture wood and sediment recruited from upstream sources (McHenry *et al*., 2000). Below the dams, the Elwha River is, in general, a low gradient (slope of 0.34%), pool-riffle, meandering alluvial channel, with a cobble/gravel channel bed. Between 1999 and 2004, 21 log jams were constructed between river kilometre 2.7 and 4.0 of the lower Elwha (Figure 2). Six were constructed in 1999, two in 2000, three in 2001, five in 2002, three in 2003 and two in 2004. The log jams function by altering flow patterns through diversion, deflection or restriction, and protecting or enhancing eroding banks (McHenry *et al*., 2000).

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Figure 2. Photograph of a typical engineered log jam on the Elwha River, Washington State, USA. This figure is available in colour online at wileyonlinelibrary.com

METHODS

Study design and data collection

We collected data on juvenile fish use and fish habitat to compare habitat units with ('treatment') and without ('control') ELJs in the mainstem Elwha River (Figure 3). Seasonal fish habitat and density surveys were conducted between 2000 and 2003 in four to six habitat units with and without constructed log jams. Each unit was adjacent to a stream bank and averaged 54 m in length (±29 m), 11 m in width (±8 m) and 643 m^2 in total area (±553 m^2). Habitat unit width, length, maximum depth and minimum depth were measured for each unit. Fish habitat surveys were conducted prior to juvenile fish enumeration efforts to identify the distribution of habitat types within each reach.

Daytime summer snorkel surveys were conducted within each of the habitat units in the control (i.e. non-ELJ) and treatment (i.e. ELJ) areas (Table I). A snorkeler in a habitat unit moved upstream and counted and identified each fish seen in the unit. The number of snorkelers in each varied as a function of the size of the unit. Typically there was one snorkeler per unit, however in the larger units two to three snorkelers per unit, thus the unit was portioned equally width wise. Fish species, total count and visually estimated lengths were tallied by each snorkeler and this information was given to an individual along the bank who was watching the snorkel activity and recording the fish counts and lengths for each habitat unit observation. Species identified during the snorkel surveys included Chinook salmon (*O. tshawytscha*), coho salmon, adult pink salmon (*O. gorbuscha*), rainbow trout, cutthroat trout (*O. clarki*), bull trout (*Salvelinus confluentus*) and three-spine stickleback (*Gasterosteus aculetus*). Sculpin (*Cottus* spp.) were identified to genus during snorkel surveys; however, two species dominate in the Lower Elwha—torrent (*Cottus*

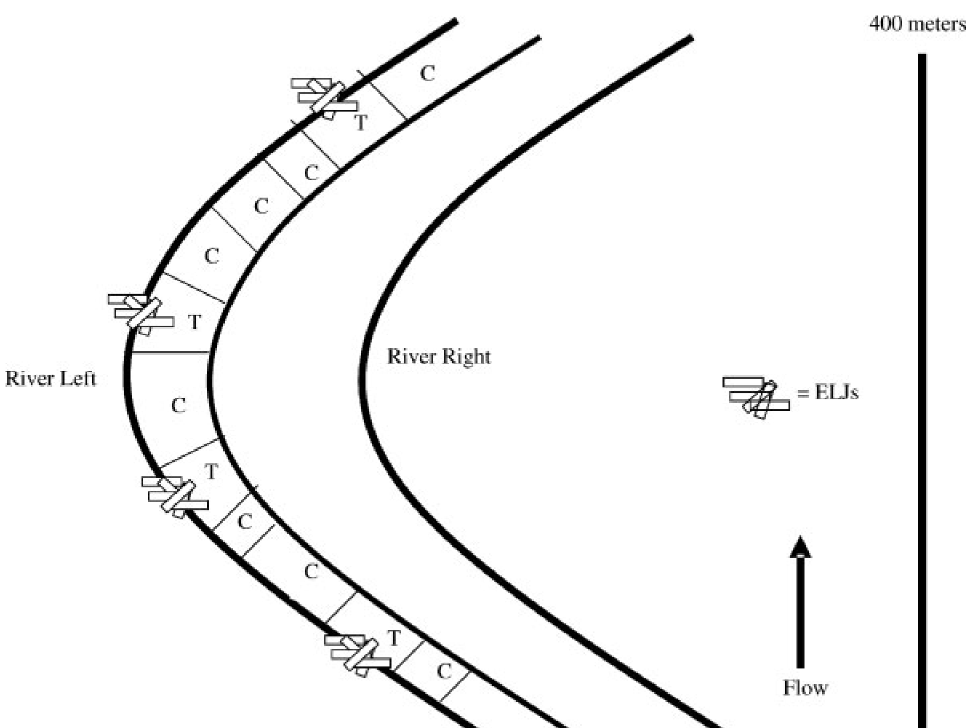

Figure 3. Schematic of ELJ placement and study design. 'T' denotes the treatment units, while 'C' denotes the control habitat units.

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Table I. Environmental conditions associated with habitat and fish surveys in the Elwha River 2000–2003

Year	Discharge during fish surveys (cm^{-3}/s)	Low flow discharge (cm^{-3}/s)	Temperature (°C)	Visibility	Number of snorkelers
2000	17.7	10.8	17	>4 m	4
2001	18.0	8.8	16	>3 m	6
2002	25.5	8.0	15	>2 m	5
2003	11.3	5.9	17	>4 m	6

rhotheus) and reticulate (*C. perlexus*) sculpin. Length categories for juvenile salmon were <50 mm, 50–100 mm, 100–200 mm and greater than 200 mm. Lengths of non-salmon species were not estimated. We calculated fish density by dividing the number of fish observed by species and size class by the area snorkelled.

Constraints related to the study design and data collection

To control unexplained spatial variation in fish densities and avoid confounding treatment effects with location, we selected a control unit for each ELJ unit. Controls were selected such that they were close to the treatment unit and were similar to the pre-treatment conditions of the treatment unit. Some control and treatment units were immediately adjacent to each other introducing the possibility of the units affecting each other through non-localized habitat effects and fish movement. However, this movement would likely decrease differences between the units, thereby producing conservative results. One of the primary goals of the restoration action was to allow juvenile salmonids greater access to what was perceived by the project proponents as higher habitat quality. Thus, the increase in fish density estimates may be a redistribution of juvenile fish. In addition, there are only 8 km of anadromous habitat below the Elwha River dams and finding a 'true' control with a buffer between the treatment and control would have resulted in examining either a slightly steeper, more confined stream reach, or a tidally influenced stream reach. Both were not viable options, because habitat differences would have resulted in larger differences in salmonid density, distribution and abundance than the potential effects of the ELJ treatment.

Engineered log jams have a pre-determined structure consisting of large key pieces anchoring a matrix of smaller wood. There was considerable space within each complex structure that cannot be viewed from the periphery of the log jam. We therefore limited sampling events to periods when flow was sufficiently low to allow snorkelers to safely venture into the log jams and view these spaces.

Snorkel surveys have been shown to be an effective sampling method for both day and night sampling (Roni and Fayram, 2000). However, sampling large river systems to estimate relative use patterns for juvenile salmonids is an inherently difficult task and has numerous limitations regardless of the method used (Beechie *et al*., 2005). In particular deep and turbid water can contribute to increased observation error for snorkel surveys (Thurow *et al*., 2006). To reduce observation error we used the same core group of experienced snorkellers for the duration of the study, limited sampling to periods of good visibility (i.e. >2 m), only focused on the bank units, which were shallower, for the analysis, and averaged counts of multiple snorkelers for units that were especially challenging (e.g. some log jams). To assess variability in counts between snorkelers, we had multiple snorkelers conduct counts in several units. We found that the between snorkeler variability (±15%) was much less that the variability between units (±80%). Large numbers of hatchery origin Chinook salmon were present in the units during our surveys. These fish were generally easy to distinguish from the wild fish based on size (hatchery fish were greater than 100 mm in length, while all wild fish were between 35 and 80 mm in length), and were recorded in a separate category.

Data analysis

The fish density data from all snorkel counts had a non-normal, over-dispersed distribution with no salmonids in over 10% of the habitat units and over 250 salmonids observed in another 10% of the habitat units. We accounted for this in our analysis by locally pairing ELJ and non-ELJ units to reduce variability due to location, applying a cube root transform to stabilize the variance of the densities, and using permutation tests which require fewer assumptions than standard parametric tests. For the permutation test we used the mean difference between treatment and control as the metric and used a one tail hypothesis (see Good, 2005 for a simple introduction to permutation tests).

The permutation test was repeated for the five species groups (Chinook, coho, trout <100 mm, trout >100 mm and juveniles), during each of the four sampling events. While we did not adjust alpha for multiple tests, the results focus only on general patterns, avoiding

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conclusions based on one or two unique results. While larger individual analyses, including more of the data, would have likely increased the power to detect effects and simplified reporting of the results, the small sample sizes, varying unit boundaries across time, and high fish variability imposed on the design by river dynamics and restoration schedules made more complex models unfeasible. Conclusions focused on patterns across multiple sampling events and species/size classes.

RESULTS

Juvenile salmonid density ranged from 0 to 2.7 fish m^{-2} with a median of 0.12 and standard deviation of 0.53 (Table II). The control and treatment medians were 0.05 and 0.25, respectively. There was a large amount of variability in densities between units by annual sampling events (Table II, Figure 4). Densities of juvenile salmonids were on average higher in ELJ units in 18 of the 20 species

Table II. Mean density (fish m^{-2}) of juvenile salmon in habitat units with and without ELJs, Elwha River 2000–2003

Chinook	Coho	Trout <100 mm	Trout >100 mm	Juveniles	Year	Control (C) or Treatment (T)	Pair
0.442	1.19	0.85	0.255	2.738	2000	T	1
0.02	0	0.029	0.003	0.052	2000	C	1
0.039	0.055	0.017	0.006	0.117	2000	T	2
0	0	0.012	0.003	0.015	2000	C	2
0.036	0.024	0.042	0.007	0.102	2000	T	3
0.005	0.02	0	0.008	0.029	2000	C	3
0.091	0.066	0.024	0.054	0.223	2000	T	4
0	0	0.005	0.007	0.013	2000	C	4
0.111	0.486	0.153	0.069	0.792	2001	T	5
0	0.041	0.306	0.001	0.348	2001	C	5
0.071	0.303	0.035	0.007	0.413	2001	T	6
0	0	0.112	0	0.112	2001	C	6
0.128	0.687	0	0	0.815	2001	T	7
0.02	0.085	0.018	0.011	0.134	2001	C	7
0.041	0.183	0.224	0.047	0.484	2001	T	8
0	0	0.083	0	0.083	2001	C	8
0.014	1	0.309	0.014	1.337	2001	T	9
0	0.177	0.052	0	0.23	2001	C	9
0	1.685	0.144	0.016	1.846	2001	T	10
0	0.003	0.252	0	0.255	2001	C	10
0.021	0	0.062	0	0.083	2002	T	11
0	0	0.038	0	0.038	2002	C	11
0.078	0	0.247	0	0.326	2002	T	12
0	0	0	0	0	2002	C	12
0.121	0	0.085	0.013	0.206	2002	T	13
0.192	0.469	0.052	0.002	0.714	2002	C	13
0.018	0	0.092	0.014	0.124	2002	T	14
0	0	0.067	0.074	0.117	2002	C	14
0.019	0.013	0.031	0	0.064	2002	T	15
0	0	0.044	0	0.044	2002	C	15
0.027	0	0.182	0.002	0.211	2002	T	16
0	0	0.052	0	0.052	2002	C	16
0.066	0	0.562	0.075	0.703	2003	T	17
0.002	0	0.007	0	0.009	2003	C	17
0	0.011	0.003	0.015	0.021	2003	T	18
0.007	0	0.064	0.012	0.082	2003	C	18
0.003	0.018	0	0.065	0.061	2003	T	19
0.035	0	0.022	0	0.057	2003	C	19
0.025	0.051	0.106	0.021	0.204	2003	T	20
0.017	0.008	0.008	0.051	0.059	2003	C	20
0	0.072	0.609	0.075	0.756	2003	T	21
0	0.003	0.009	0	0.011	2003	C	21
0.018	0	0.179	0.091	0.272	2003	T	22
0	0	0.008	0	0.009	2003	C	22

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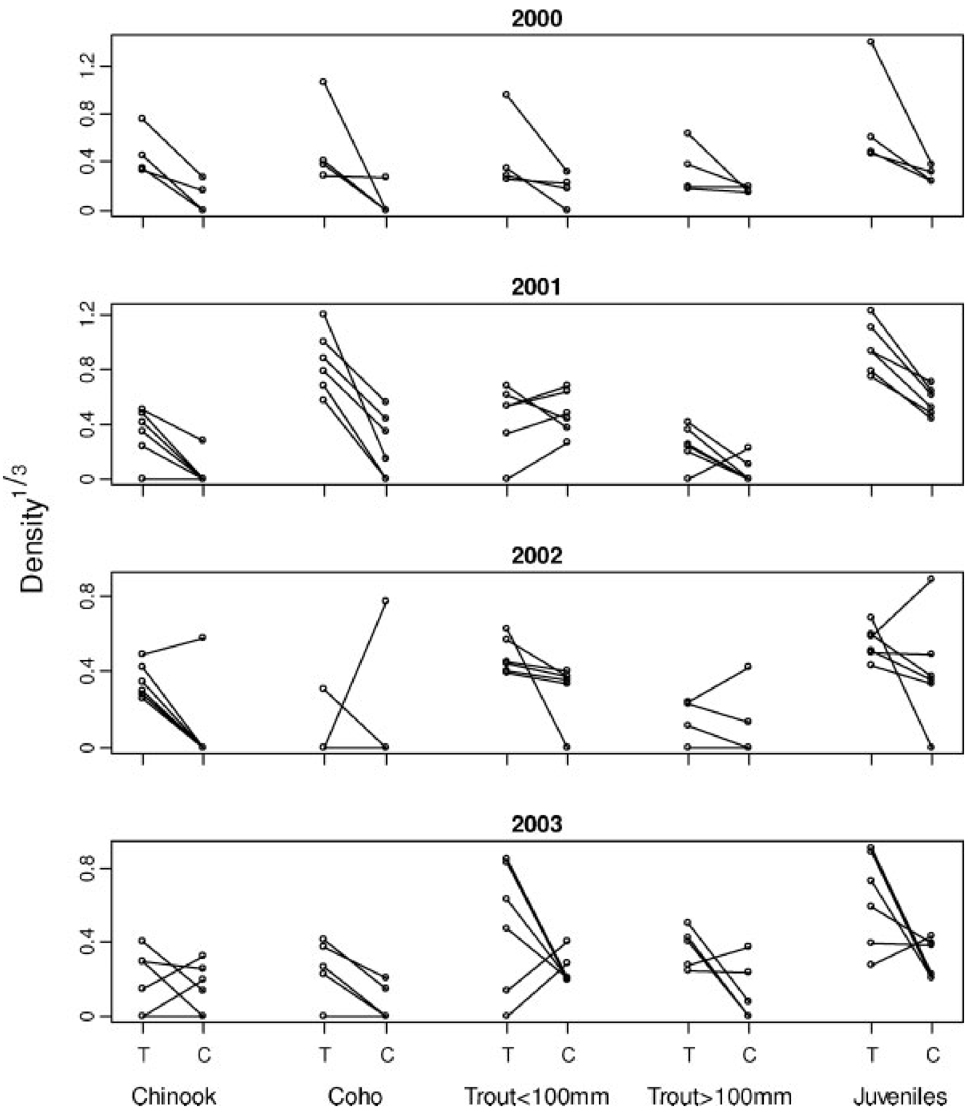

Figure 4. Density$^{1/3}$ of treatment and control habitat units by salmon species and size class (2000–2003) in the Elwha River, Washington State, USA. 'T' denotes the treatment units, while 'C' denotes the control habitat units. Lines connecting circles indicate which habitat units were paired. Multiple lines indicate more than one pairing.

group by year comparisons (Table II). These differences were significant in two of the 4 years for juvenile Chinook, trout greater than 100 mm, and all juvenile salmon, and in one of 4 years for coho salmon and trout less than 100 mm (Table III). Strongest differences by year occurred in 2001, followed by 2002 and 2003 (Table III). Differences between the ELJ and non-ELJ habitat units were also expressed in terms of juvenile salmon density$^{1/3}$ (Figure 4). Overall densities were similar in terms of magnitude; however, densities in ELJ habitat units were consistently higher than in non-ELJ units for all species, with the exception of trout less than 100 mm (Figure 4).

DISCUSSION

Examination of all juvenile salmon suggests significantly higher mean densities in habitat units with ELJs than habitat units without ELJs in the Elwha River, with patterns varying by species and year (Tables II and III, Figure 4). Other studies have shown similar patterns of higher densities of juvenile salmon associated with wood accumulations due to a combination of low-velocity microhabitats and associated overhead cover (Shirvell, 1994; Roni and Quinn, 2001; Beechie *et al*., 2005). ELJs allow for the convergence and divergence of flow in and around the obstructions resulting in an increase in slower water habitats adjacent

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Table III. Mean density (fish m^{-2}) difference between habitat units with (treatment) and without (control) ELJs by salmon species and size class in the Elwha River, Washington State, USA 2000–2003

Year	Sample Size	Chinook	Coho	Trout < 100mm	Trout > 100mm	Juveniles
2000	4	0.146 (0.06)	0.329 (0.06)	0.222 (0.06)	0.075 (0.13)	0.768 (0.06)
2001	6	0.058 (0.03)	0.673 (0.02)	0.007 (0.63)	0.024 (0.05)	0.754 (0.02)
2002	6	0.019 (0.03)	−0.074 (0.75)	0.080 (0.02)	−0.008 (0.50)	0.020 (0.17)
2003	6	0.010 (0.34)	0.023 (0.06)	0.236 (0.11)	0.053 (0.05)	0.317 (0.05)

Permutation test *p*-values are in parentheses.

to faster water habitats, and the potential use of wood as in-channel cover (Brooks *et al*., 2006). As with previous studies, the pattern of use we found varied by species, size class and year.

Juvenile Chinook consistently exhibited significantly higher densities in habitat units with ELJs in two of the 4 years of sampling (Table III). Smaller Chinook juveniles, particularly ocean-type, the majority of Elwha River Chinook, typically occupy low-velocity habitats with a variety of cover types (Healey, 1991; Beechie *et al*., 2005). Juvenile coho salmon also exhibited consistently higher densities and use in habitat units with ELJs (Figure 4). Coho fry also tend to occupy low-velocity habitats in the summer and winter months, and exhibit a greater preference towards complex cover such as wood accumulations (Roni and Quinn, 2001; Giannico, 2000; Beechie *et al*., 2005).

Trout densities and utilization of habitats with ELJs varied by size class in the Elwha River. Trout greater than 100 mm showed greater affinity to habitat units with ELJs, both in significance level and densities than trout less than 100 mm. Previous research also suggests that *O. mykiss* are typically associated with a broader range of velocities and cover types, and are particularly associated with cobble-boulder cover types (Beechie *et al*., 2005). In addition, the combination of low velocity areas with overhead cover adjacent to higher velocity areas can create rearing space next to feeding opportunities for larger trout (Hughes and Dill, 1990; Lima and Dill, 1990).

Cover in general, and complex wood cover in habitat units has been shown to increase juvenile salmonid densities (Gowan and Fausch, 1996; Peters, 1996; Beechie *et al*., 2005). Beechie *et al*. (2005) found age-0 coho, age-0 steelhead and age-1 or older steelhead selecting banks with the most complex wood cover. Peters (1996) found a similar pattern for these and other salmonids including juvenile Chinook. Complex cover also provides visual isolation for salmonids, protects them from visual predators, reduces antagonistic interactions with conspecifics, and can decrease territorial needs (Imre *et al*., 2002). All of these attributes are particularly important during low flow periods such as the summer. The combination of lower velocity areas, deeper habitat units and complex wood cover all contribute to the change in juvenile salmon densities and suggest that ELJs are potentially useful for restoring juvenile salmon habitat in the Elwha River.

One trend that is apparent is the decline in the difference between the control and treatment sites over time (Table III and Figure 4). The decline in mean density difference between the treatment and control habitat units is similar to what other studies have found with respect to smaller streams, where decreases in salmonid density effect size decreased after 2 years (Whiteway *et al*., 2010). One main hypothesis that has been put forth is that in-stream structures eventually fail and do not support the long-term utilization of these habitats (Frissell and Nawa, 1992; Thompson, 2006; Whiteway *et al*., 2010). However, it is important to note that many of these in-stream structures have not been monitored over an adequate time period to report the overall stability of the structures as well as the accompanying fish use associated with them (Whiteway *et al*., 2010).

The ELJs in the Elwha River have been monitored for their physical stability over the same time period as the fish surveys and have proved to be stable with little significant change in position or surface area noted despite frequent inundation from floods including two peak floods that rank within the top 10% of floods recorded for over 100 years of record (McHenry *et al*., 2007, report to Salmon Recovery Funding Board). In addition pool development occurred rapidly around the constructed ELJs, with 95% of the ELJs built since 2000 developing scour pools, the deepest of which has a maximum depth exceeding 5 m, and pool surface area increasing from 15% to 48% (McHenry *et al*., 2007, report to Salmon Recovery Funding Board). The ELJs also had a significant effect on sediment storage within the project reach where a 60% increase in the amount of sediment stored in gravel bars occurred from 2000 to 2004 (McHenry *et al*., 2007, report to Salmon Recovery Funding Board). Associated with these changes we also observed a significant reduction in bed substrate grain size in the vicinity of several ELJs, with the mean particle size changing from large cobble to gravel (McHenry *et al*., 2007, report to Salmon Recovery Funding Board).

So why is the inter-annual variation in mean juvenile salmonid density so great? We hypothesize that there are

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several factors which affect the results including variation in annual adult salmon returns, differences in summer low flows and the increasing number of other ELJs constructed in the Elwha during the study period. The annual number of returning adult Chinook salmon spawning in the Elwha ranged between 655 and 1045 (Washington Department of Fish and Wildlife, unpublished data) and increased each year, which could result in a larger number of juvenile Chinook salmon, and more utilization of 'less preferential' habitats, in this case being the control habitat units. No estimated number of adult steelhead or coho salmon spawners is available to describe trends in their adult population abundance. Low flows could either concentrate juvenile salmonids in areas associated with the ELJs, or result in areas of the ELJs not being watered and thus reduced the use of the treatment habitat units. The number of ELJs in the Elwha increased from a total of 8 in 2000 to 19 by 2003, an increase of almost 3 per year (McHenry *et al*., 2007, report to Salmon Recovery Funding Board). The increase in the number of ELJs beyond the study reach can also result in a dispersion of juvenile salmonids, which could also have an effect on the juvenile densities of salmonids found over time in the study reach. Our dataset is limited to only 4 years and is ultimately incomplete to quantify the effects of each potential variable but all of the preceding variables have been shown by others to affect the density of juvenile salmonids (Roni and Quinn, 2001; Niemelä *et al*., 2005).

In conclusion the consistent positive mean differences in juvenile salmon densities between ELJ and non-ELJ units that were observed in two of four years for all juvenile salmon suggest that ELJs are potentially useful for restoring juvenile salmon habitat in the Elwha River, Washington State, USA. These results are consistent with other studies that suggest in-stream restoration projects can improve salmonid density, and is an important 'temporary tool' while larger scale more process-based watershed restoration actions are implemented (Roper *et al*., 1997; Roni *et al*., 2002; Whiteway *et al*., 2010). The large-scale restorative action that will occur in the near-term in the Elwha basin is the removal of two large impassable dams that will open over 70 km of the historically available anadromous salmonid habitat (Pess *et al*., 2008).

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