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A Comparison of Methods to Evaluate the Response of Periphyton and Invertebrates to Wood Placement in Large Pacific Coastal Rivers

Abstract

The goal of our study was to evaluate the importance of placed wood for periphyton and invertebrates in two large Pacific Northwest rivers systems (bankfull width >30 m) using artificial substrates, a widely used method in small streams, and natural substrates including cobble and wood. Preliminary findings suggest that artificial substrates were ineffective at mimicking invertebrate densities and community structure and periphyton biomass found on natural substrates. Artificial substrates were also logistically difficult to place and retrieve. As current methods for sampling wood are not designed for periphyton collection and are logistically difficult in large systems, we developed a new method for sampling both invertebrates and periphyton from wood in large rivers where log jams can be large and deep pool habitats are prevalent. This method proved highly effective at a) sampling invertebrates as well as finer, more easily dispersed components of periphyton and b) detecting biological responses to wood placement. Furthermore, our findings suggest that wood can be an effective instream restoration method in large river systems because it can serve as both physical refugia during high flows and as an important substrate for periphyton and invertebrates. Finally, wood supports a unique community of invertebrates that are often understudied and therefore underrepresented in lotic system studies.

Introduction

The presence of wood has a strong influence on the structural and functional characteristics of aquatic ecosystems in the Pacific Coastal Ecoregion. Wood alters channel morphology by increasing pool frequency and hydraulic complexity and creates refugia for stream organisms during extreme floods (Sedell et al. 1991). Wood also regulates the export and retention of sediment and organic matter, and serves as a direct food source and substrate for bacteria and fungi (Tank and Winterbourn 1996), and for resting, ovipositing, pupating and emerging aquatic insects (Anderson et al. 1978; Benke et al. 1984). Over the past century, human activities such as logging, splash damming and channel alteration for navigation have altered the input, transport and storage of wood (Bilby and Bisson 1998; Diez, et al. 2000). The historic loss of wood to aquatic ecosystems has led to habitat degradation, resulting in a notable decrease in abundance, distribution and diversity of aquatic organisms from all trophic levels (Wondzell and Bisson 2003).

To mitigate these changes, wood placement has become a widely used instream restoration method, primarily for restoring stream habitat for salmonid fishes (Roni and Quinn 2001). Wood placement creates cover and habitat complexity for salmonids by increasing pool frequency and depth (e.g. Crispin et al. 1993; Reeves et al. 1997; Moerke et al. 2004). Therefore, the few attempts to monitor effects of wood placement have focused on numerical responses of juvenile salmonids (e.g. Slaney et al. 1994; Peters, Missildine and Low 1998). Large wood can also provide complex habitat space for periphyton and a diverse community of invertebrates (Dudley and Anderson 1982) ultimately influencing food resources available to fish. However, only a handful of studies have monitored macroinvertebrate response to any type of instream structure (Wallace et al. 1995; Gortz 1998; Lassonen et al. 1998; Larson et al. 2001; Brooks et al. 2002) and only one study to date has monitored periphyton response (Bond et al. 2006). Furthermore, many enhancement projects have focused on evaluating the response of small streams (< 12 meters bankfull width) to wood placement using techniques appropriate for these habitats (Roni et al. 2005), yet few studies have focused on large rivers (> 30 meters bankfull width).

With this in mind, the goal of this study was to evaluate the importance of placed wood for periphtyon and invertebrates in two large Pacific Northwest coastal rivers (bankfull width > 30 meters) using currently available and widely used small stream sampling methods and a newly developed method for collecting invertebrates

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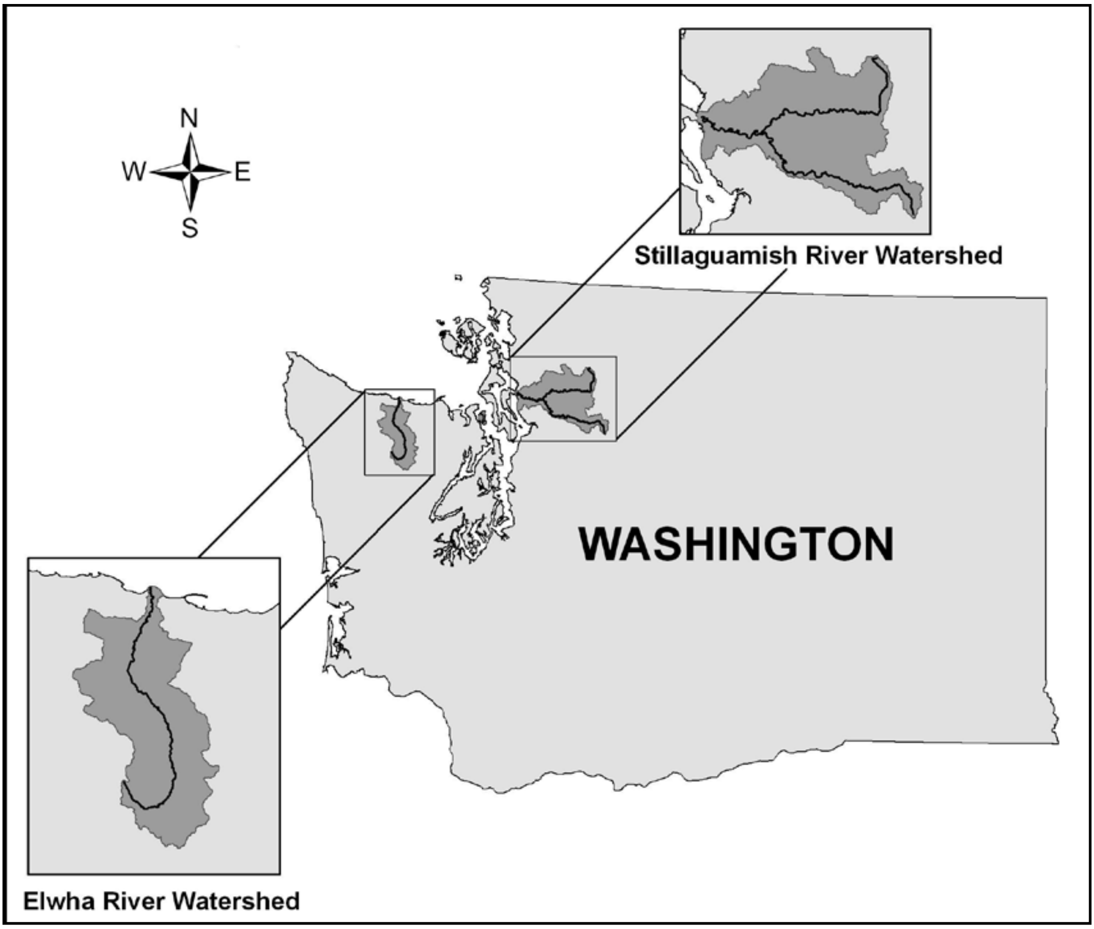

Figure 1. Location of the Elwha and North Fork Stillaguamish Rivers, WA.

and periphyton from wood in large rivers. Specifically, we compared invertebrate densities and communities and periphyton biomass on artificial substrates, a common method for reducing heterogeneity inherent in natural substrates and a standard means for between-habitat comparisons, and on natural substrates including cobbles and wood to determine if these methods alone would yield contrasting results.

Methods

Study Areas

Our two study areas are located in the Olympic Mountains and North Cascades, WA (Figure 1). The Elwha River is located on the Olympic Peninsula, WA, and flows northward 72 km out of the Olympic Mountains to the Strait of Juan de Fuca, 8.3 km west of Port Angeles (Munn et al. 1998) (Figure 1). More than 80% of the 692 km^2 basin lies within Olympic National Park. The river is regulated by two hydroelectric dams—the Elwha Dam at river kilometer (rkm) 8 and the Glines Canyon Dam at rkm 13—both of which are impassable to fish. Lack of sediment and wood recruitment from upstream has reduced channel sinuosity and increased river incision (Pohl 1999). The dams have also blocked 115 rkms of pristine anadromous salmonid habitat since the early 1900s. The study area was located approximately 3-6 rkm below the dam and was a low-gradient, meandering alluvial channel with a cobble/gravel bed. In 1999-2001, 11 Engineered Log Jams (ELJs) (Abbe et al. 1997) were placed between rkm 3.7 and rkm 4.0 in what will hereafter be referred to as the treatment reach. The ELJs were placed primarily to provide bank protection and salmonid habitat. An additional five ELJs were placed in the same section of river between 2002 and 2003. The reference reach was located directly upstream.

The North Fork Stillaguamish River is a 684 km^2 drainage basin located on the southwest margin of the North Cascades in northern Snohomish and southeastern Skagit Counties, approximately 85 km northeast of Seattle, WA (Figure 1). Timber harvest and road-building in the headwaters have reduced wood inputs. The study area was located 8 km east of Oso, north of Washington state highway 530. The area is a low-gradient, meandering gravel-bed channel with a drainage area of 300 km^2. In 1998, four meander-type ELJs and one bar apex-type ELJ were placed in the treatment reach between rkm 35.3 and rkm 36.0 to provide holding pools for salmonids. The reference reach was located directly upstream.

Sample Design

Samples were collected in reaches with ELJs (treatment) and in reaches without ELJs or naturally occurring large wood (reference). Natural and artificial substrates were sampled from multiple sites within each reach (Table 1). Natural substrates included wood from ELJs in treatment reaches and cobbles in reference reaches. Ceramic tiles were also sampled in each reach. All substrates were collected from sites with similar depths and velocities (Table 2). Due to high winter and spring flows, samples were collected in late summer 2002.

TABLE 1. Number of sites sampled from each reach in the Elwha and Stillaguamish Rivers in September 2002. Each substrate was sampled for both periphyton and invertebrates.

	Artificial Substrate		Natural Substrate	
River	Reach	Tile	Wood (ELJ)	Cobble
Elwha	Treatment	3	3	0
	Reference	2	0	2
Stillaguamish	Treatment	3	3	0
	Reference	2	0	2

Sample Collection

Artificial Substrates

Unglazed square ceramic tiles (15 cm x 15 cm x 0.5 cm deep) were glued onto a square wood base (15 cm x 15 cm x 91.75 cm deep). In treatment reaches, tiles were attached to ELJs using wood screws. Due to safety concerns, tile placement on ELJs was restricted to shallow, trailing edge surfaces, accessible by wading or climbing. In reference reaches, tiles were mounted on cinderblocks and placed along the river margins. Tiles were placed in August 2002 and then sampled in September 2002. Tiles were retrieved by placing a 20-µm mesh net over each tile to prevent loss of sample during removal from the water. Using a toothbrush, half of the area was scrubbed for periphyton and half for invertebrates. Invertebrate samples were preserved in 70% ethanol and taken back to the lab for later identification and enumeration. Invertebrates were removed from each sample using a Meiji zoom dissecting microscope (EMZ, 0.7 – 4.5x). Aquatic insects were identified to Order with the exception of Chironomidae. Non-insect invertebrates were identified to lowest possible taxonomic level. The periphyton sample was stored in water in a dark container, chilled, and processed within 24 hours.

TABLE 2. Depth and velocities for sites sampled in treatment and reference reaches in the Elwha and Stillaguamish rivers in September 2002. Reach differences were tested using a one-way ANOVA ($p < 0.10$).

	Elwha			Stillaguamish		
	Site	Depth (m)	Velocity (m s^{-1})	Site	Depth (m)	Velocity (m s^{-1})
Treatment	1	0.305	0.000	1	0.381	0.000
	2	0.274	0.000	2	0.457	0.000
	3	0.457	0.000	3	0.488	0.000
	Mean (± SE)	0.345 ± 0.098	0.000 ± 0.000	Mean (± SE)	0.442 ± 0.032	0.000 ± 0.000
Reference	1	0.030	0.000	1	0.533	0.000
	2	0.122	0.050	2	0.244	0.000
	Mean (± SE)	0.076 ± 0.046	0.025 ± 0.025	Mean (± SE)	0.389 ± 0.145	0.000 ± 0.000
p value		0.044	0.272		0.984	–

The periphyton sample was split equally, half for ash-free dry mass (AFDM) and half for chlorophyll *a*. Because periphyton samples tended to be heterogeneous in consistency, each volume was subsampled three times to adequately ensure a representative sample. The chlorophyll subsamples were filtered onto 47-mm GF/F filters (1.0 µm retention) and frozen. Filters were then extracted in 90% methanol for 22 hours and chlorophyll concentrations were analyzed using a TD-700 laboratory fluorometer. AFDM subsamples were filtered onto pre-ashed, pre-weighed (Sartorius balance (BP1215), ± 0.1 mg) 47-mm GF/F filters. Filters were dried at 100°C for 24 hours, weighed, ashed at 500°C for three hours, and reweighed. Subsample data were averaged to yield a single measurement for each substrate.

Natural Substrates

Cobbles of similar size (average diameter 10 cm) were collected from margins at multiple sites within reference reaches by placing a 20-µm net over the cobble and gently removing it from the benthos. Two cobbles were collected, one for invertebrates and one for periphyton, from site. Cobbles were then placed into Ziploc bags and taken back to the lab for processing. Cobbles were brushed with a toothbrush and rinsed with distilled water. Invertebrates and periphyton samples were processed as described for artificial substrates and biomass per unit area was determined using the whole cobble surface area (adapted from Dall 1979).

As existing methods for sampling wood are not designed for collecting periphyton in large rivers where log jams form extensive pool habitat (Anderson et al. 1978; Benke et al. 1984; Magoulick, 1998; Braccia and Batzer 2001), ELJs were sampled using a new method (Figure 2). This new method most resembles the standard scraping method for cobbles outlined in Aloi (1990) and was adapted from a method used to collected hyporheic invertebrates (Clinton et al. 1996). A PVC pipe (diameter 10 cm) was placed on a shallow, trailing edge surface of the ELJ to delineate a sampling area. To ensure a water-tight seal, a neoprene base was attached to the base of the PVC pipe. The delineated surface (70.88 cm^2) was then brushed with a coarse bristle brush attached to a hose. As the wood was scraped, the loosened material was immediately drawn into a 4 L sample bottle by a manual bilge pump. The pumped sample was then filtered through a

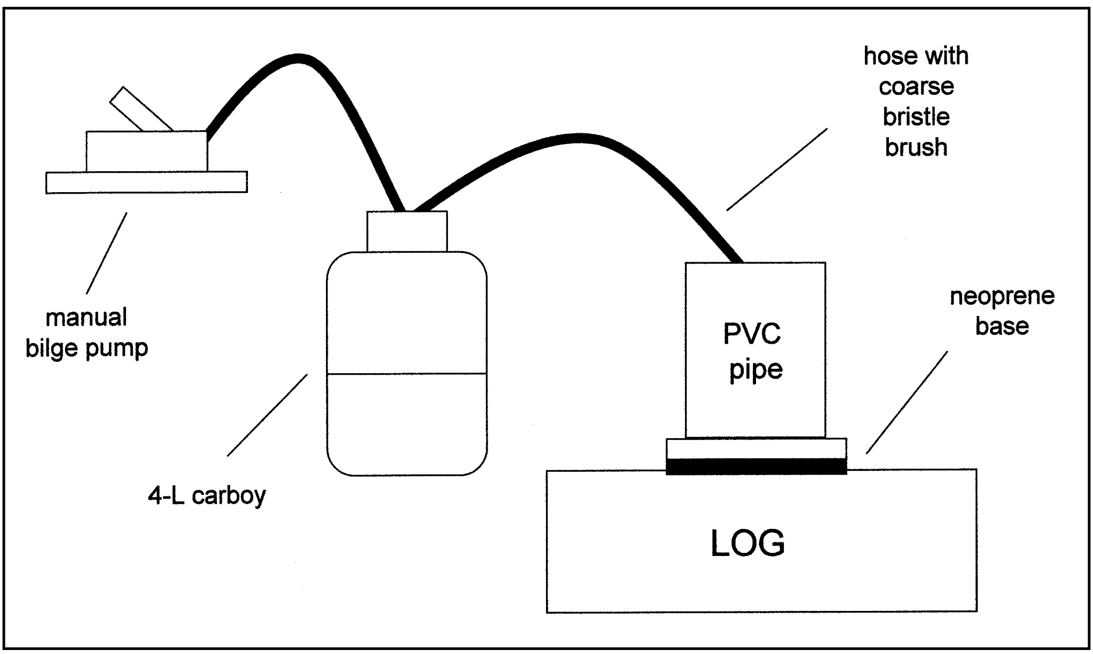

Figure 2. Schematic of the device used to sample placed log jams in the Stillaguamish and Elwha Rivers in 2002. A manual bilge pump collects periphyton and associated invertebrates from the delineated surface of the wood as the operator gently brushes the surface with the coarse bristle brush.

20-µm mesh sieve to separate particulates from water; water was discarded as it was assumed to contain little to no chlorophyll or organic matter. This method allowed us to sample both periphyton and invertebrates on large logs without removing sections of them. It also allowed us to sample pool habitats with no flow because the manual bilge pulls the sample into the container as the surface is being scraped, thereby reducing sample loss. For safety reasons, we were unable to access deep and fast flowing portions of the log jams. Also, burrowing invertebrates were not sampled with this method. It was only feasible to collect samples from a few ELJs. Therefore, two samples, one for invertebrates and one for periphyton, were collected from 3 ELJs in both rivers. The samples were processed as described above.

Data Analysis

Chlorophyll and organic matter concentrations, and invertebrate densities among reaches were analyzed separately for artificial and natural substrates to determine whether the methods alone would yield different results. Log-transformation of some of the data was required to meet the assumptions of normality and equal variances. A t-test ($\alpha = 0.10$) was used to test for differences between reaches in chlorophyll concentration, organic matter concentration and invertebrate density accumulating on ceramic tiles and on natural substrates (wood vs. cobbles) (Systat, version 11).

Results

Artificial Substrates

No significant differences in mean organic matter or chlorophyll concentration were found on ceramic tiles placed on ELJs or on tiles in the reference reach in either the Elwha or Stillaguamish rivers (P>0.10). Mean organic matter and chlorophyll concentrations were similar in both reaches on the Elwha, although concentrations tended to be highest in the reference reach (Table 3). Similarly, on the Stillaguamish mean organic matter and chlorophyll concentrations were highest in the reference reach (Table 3).

No significant differences in mean total invertebrate densities were found between reaches in either the Elwha (log-transformed, P=0.11) or the Stillaguamish (log-transformed, P=0.82). Mean total invertebrate density was highest in the reference reach in the Elwha, and was marginally higher in the treatment reach on the Stillaguamish (Table 3). The invertebrate community in both rivers was comprised primarily of Chironomidae and a group of invertebrates classified as 'other.' 'Other' taxa included cyclopoid and harpacticoid copepods, ostracods, mites, oligochaetes, nematodes and tardigrades. In the Elwha river, 'other' dominated in the treatment reach (> 50%), whereas Chironomidae dominated in the reference reach (> 80%) (Figure 3). The difference between community composition in the treatment and reference reaches was less pronounced in the Stillaguamish. Chironomidae and 'other' each comprised approximately half of the community in the treatment reach (Figure 3). In the reference reach, Chironomidae dominated (> 50%), and 'other' and Ephemeroptera represented approximately 40% and 10% of the community, respectively (Figure 3).

Natural Substrates

In the Elwha, mean organic matter concentration was 20 times higher on wood in the treatment reach than on cobble in the reference reach (Table 3); however, this difference was not significant (P=0.43) due to low sample size and high variation. The difference between mean chlorophyll *a* on wood in the treatment reach and cobble in the

TABLE 3. Mean organic matter and chlorophyll *a* concentrations, and invertebrate densities (± SE) on artificial and natural substrates in the Elwha and Stillaguamish Rivers in September 2002.

		Elwha		Stillaguamish	
		Treatment	Reference	Treatment	Reference
Artificial Substrates	Organic Matter mg cm^{-2}	0.002 ± 0.000	0.003 ± 0.001	0.003 ± 0.000	0.004 ± 0.001
	Chlorophyll ug cm^{-2}	0.842 ± 0.554	0.884 ± 0.220	0.523 ± 0.370	0.844 ± 0.409
	Total Invertebrates cm^{-2}	0.780 ± 0.122	2.425 ± 1.105	9.745 ± 9.425	8.630 ± 4.162
Natural Substrates	Organic Matter mg cm^{-2}	0.039 ± 0.020	0.002 ± 0.001	0.008 ± 0.002	0.007 ± 0.003
	Chlorophyll ug cm^{-2}	7.026 ± 3.695	0.953 ± 0.019	1.739 ± 0.310	3.207 ± 1.131
	Total Invertebrates cm^{-2}	8.550 ± 0.355	2.440 ± 2.750	61.120 ± 35.332	10.405 ± 1.065

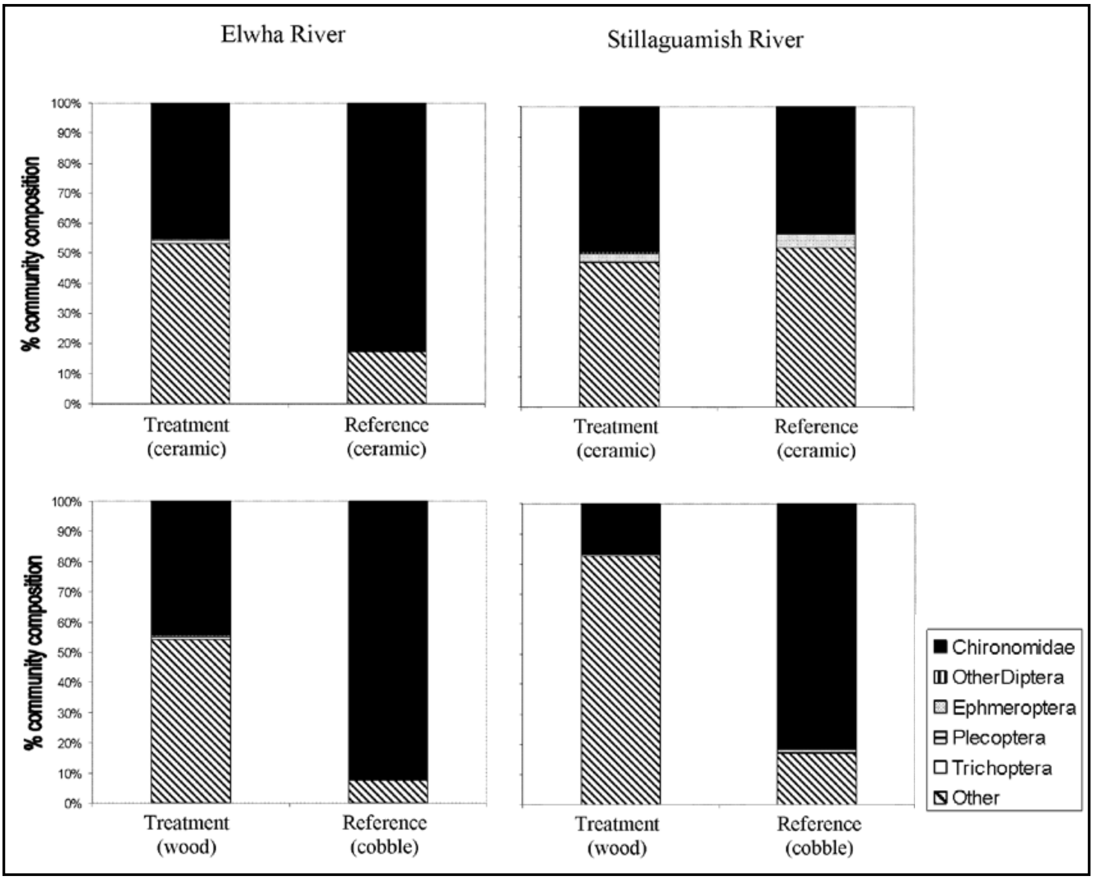

Figure 3. Invertebrate community composition (%) on artificial and natural substrates in the Elwha and Stillaguamish Rivers in September 2002. Invertebrate community composition was averaged over multiple sites within a reach. The 'other' group includes cyclopoid and harpacticoid copepods, ostracods, mites, oligochaetes, nematods and tardigrades.

reference reach was less pronounced than with mean organic matter, but the trend was similar (Table 3). Mean chlorophyll *a* concentrations were 7 times higher on wood in the treatment reach than on cobble in the reference reach, but again there was no significant difference between reaches (P=0.15, log-transformed). In the Stillaguamish, mean organic matter concentrations were not significantly different between reaches (P=0.73, log-transformed); however, mean chlorophyll concentration was significantly higher in the reference reach (P=0.08, log-transformed). Although we did not test for significant differences between artificial and natural substrates, there were striking differences in organic matter and chlorophyll *a* concentration between wood on ELJs and ceramic tiles in treatment reaches. In the Elwha, mean organic matter and chlorophyll concentrations were 20 times and 8 times higher, respectively, on wood than on tiles in the same reach. The trend was similar but less pronounced in the Stillaguamish, with mean organic matter and chlorophyll *a* concentrations 3 times higher on wood on ELJs than on tiles in the same reach.

In the Elwha, total invertebrate density was significantly higher (P=0.02) on wood in the treatment reach than on cobble in the reference reach (Table 3). A similar trend of higher densities on wood in the treatment reach was found in the Stillaguamish; however, the difference was not significant (P=0.20, log-transformed). Again, we observed noticeable differences in invertebrate densities between wood and ceramic tiles in treatment reaches. Invertebrates densities were 11 times higher on wood in the Elwha and 6 times higher on wood in the Stillaguamish than on tiles in the same reach. Similar to ceramic tiles, the invertebrate community in both rivers was comprised primarily of Chironomidae and 'other.' However, differences in community composition between reaches in both rivers were more pronounced on natural substrates. In the Elwha, 'other' dominated the treatment reach (> 50%), whereas Chironomidae dominated in the reference reach (> 90%) (Figure 3). Similarly, in the Stillaguamish 'other' comprised > 80% of the community in the treatment reach and Chironomidae comprised > 80% of the community in the reference reach.

Discussion

The two methods used to assess the biological response of large rivers (watershed > 500 km^2) to log jam placement generated contrasting results, despite high variability due to low sample size. No statistical differences between reaches in periphyton biomass or invertebrate densities were found on ceramic tiles. In contrast, there were some differences between wood in treatment reaches and cobbles in reference reaches. Differences in periphyton biomass were likely underestimated because only particulates on wood were analyzed. Analysis of discarded water collected (n = 104) in subsequent years indicated that 11-66% of AFDM and 5-66% of chlorophyll in the sample was lost by filtering the sample through a 20-µm mesh sieve.

Differences between these two methods were less pronounced in the Stillaguamish. A post-sampling power analysis indicated that a sample size of > 200 samples per reach (P=0.05) would be needed to detect a statistical difference in periphyton biomass and invertebrate densities in the Stillaguamish River. In contrast, a sample size of ~11 per reach would be needed to detect a difference in organic matter and chlorophyll concentrations, and invertebrate densities in the Elwha River. This difference may be due to reduced habitat complexity on the Elwha River where reduced sediment supply due to the presence of the dams has resulted in a particle size distribution that is truncated towards larger substrates such as cobbles. In contrast, the Stillaguamish River is free flowing with higher habitat complexity due to a diversity of particle sizes.

Was it appropriate to use artificial substrates in large river systems (> 500 km^2)? In smaller systems, the use of artificial substrates (usually ceramic tiles) has been justified for a number of reasons, the most common being that they can be less variable than natural substrates, allowing for between habitat comparisons (Aloi 1990). Other reasons include decreased cost of sampling, ease of obtaining a quantitative sample and reduced disruption of habitat (Lamberti and Resh 1985). The ideal artificial substrate, however, must be representative of the natural substrate in terms of community composition and abundance, have a coefficient of variation equal to or less than that of the natural substrate, require a short enough exposure time to accomplish research goals, and be easily retrievable (Aloi 1990). Given these requirements and the preliminary findings of this study, we conclude that ceramic tiles were not appropriate for use in lower Elwha and North Fork Stillaguamish rivers for several reasons.

First, despite low sample size, artificial substrates showed different trends in periphyton biomass, and invertebrate density and composition: therefore, artificial substrates did not appear to mimic natural substrates. We speculate that differences between natural and artificial substrates were primarily due to substrate type, as sites within each reach were similar in both depth and velocity. Inadequate exposure times may also have contributed to differences between artificial and natural substrates. Tile exposure periods in colonization studies have ranged from 1 day to 3 years, with most exposing tiles for 1 month (Aloi 1990). Short exposure times are relevant for studies focusing on colonization and community development (Roemer et al. 1984), but in studies focusing on standing stocks, the exposure time must be long enough for the community to fully develop (Tuchman and Blinn 1979). Since placement, log jams on the Elwha and Stillaguamish Rivers have been inundated and have withstood 43 flood events up to 949 cubic meters per second (http://nwis.waterdata.usgs.gov/wa/nwis/peak). Many studies have shown that log jams create refugia for stream organisms during extreme flood events (Sedell et al. 1991, Wondzell and Bisson 2003). As a result, log jams are likely to have well established algal and invertebrate communities relative to other habitats with less stable substrate. In this study, a one month exposure time did not appear to be sufficient to approximate communities on the highly stable wood substrate found in log jams in these large rivers suggesting that longer exposures times must be considered for more stable substrates.

Second, the artificial substrates are difficult to place and retrieve in large rivers. We were unable to place a sufficient number of artificial tiles at various sites because of time constraints and flow conditions. Many people were needed to carry cinderblocks and placement was time-consuming, thus few tiles were actually placed. In addition, many sites were too deep so tiles were placed in channel margins. By late summer, tiles were dewatered because water levels had dropped substantially, effectively reducing tile sample size. This is a common problem in small systems but is often counteracted by the placement of large numbers of tiles to account for loss.

Because we suspected that artificial substrates would be unsuitable in these systems, we also sampled natural substrates. Methods for collecting cobbles are well established (Aloi 1990 and references therein) and, based on our findings, are suitable for use in both small and large rivers. However, sampling wood in large rivers is logistically difficult because log jams are large and associated pool habitats are deep. Typical approaches for sampling wood include placing clean wood and allowing for colonization, scraping wood surfaces and sweeping with a net, while assuming no loss in the transfer to the net, and removing sections of a log or entire logs (Anderson et al. 1978; Benke et al. 1984; Magoulick, 1998; Braccia and Batzer 2001). Moreover, all of these methods were designed for invertebrate collection and assume minimal loss of sample. This assumption would not hold for the collection of finer, more easily dispersed components of periphyton. The method developed in this study is suitable for collecting both invertebrates and periphyton on log jams in large rivers. It is simple and effective in these large systems and it allowed us to collect both invertebrates and periphyton quantitatively with minimal losses. It could also be easily used on a boat in slow-flowing, deep rivers. Differences in invertebrate density between cobble and wood substrates were likely underestimated as wood-burrowing invertebrates were not sampled with this method. As with any other method for sampling wood, working in and around large log jams raises considerable safety concerns; as a result, we were unable to fully evaluate the importance of log jams as substrate for periphyton and invertebrates due to inaccessibility to all sections of the log jams.

The goal of our study was to evaluate the importance of placed wood for periphyton and invertebrates in two large Pacific Northwest rivers systems using methods widely developed for small streams and a newly developed method for sampling wood in large rivers. Based on data collected from natural and artificial substrates, we conclude that small stream methods were ineffective at detecting responses of periphyton and invertebrate communities in relation to log jam placement in large rivers. Small stream methods were ineffective because 1) artificial substrates did not mimic the natural substrate and 2) they were logistically difficult to place and retrieve. In addition, current methods for sampling wood are not designed for periphyton collection and are logistically difficult in large systems where log jams are large and pool habitats are prevalent.

Finally the preliminary findings of this study suggest that wood can potentially support high levels of productivity in large river systems by serving as both a highly stable, physical refugia during high flows and as an important substrate for periphyton and invertebrates, including a group often understudied and underrepresented in lotic systems. Monitoring is essential for evaluating the effectiveness of restoration activities. This paper has identified considerable limitations of the use of small system methods for monitoring restoration in large rivers. The method developed in this study will provide an integrated biological assessment of wood placement as a restoration technique and will be incorporated into a more rigorous, comprehensive evaluation of the biological response to Engineered Log Jam (ELJ) placement in Pacific Northwest rivers.

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