# A Comparison of the Hydraulic and Biological Effects of Large Woody Debris and an Engineered Alternative

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**Abstract**

The decline of fisheries and aquatic habitat in the Pacific Northwest is an important problem that has potentially serious and irreversible effects. On a national level, more than 50% of the animals listed as endangered or threatened are aquatic, and 39% of our native fishes are rare to extinct. Regionally, close to 1900 stocks of pacific salmon (Oncorhynchus spp.) in the United States, British Columbia, and the Yukon are at risk. The alteration of freshwater habitat has been cited as the largest single contributing factor (73%) in the decline of aquatic biodiversity (Naiman, 1998). This pilot study examines the hydraulic and biological effects of placing individual structures in lowland streams of Washington State. The test subjects are native large woody debris and an organic, engineered alternative to large woody debris (ELWd™). The engineered structures consist of an interlocking complex of small diameter poles that can be carried by hand and assembled on site. Like LWD, ELWd™ has a high hydraulic and surface roughness to trap sediment and debris. Unlike large woody debris, these structures are hollow and have a larger surface area that is convoluted with gaps. These physical differences may result in significant differences in the pattern of water flow and resultant scour and biological communities associated with these structures as compared to LWD.

## Introduction

Management of aquatic resources requires rehabilitation of freshwater habitat to improve essential elements such as spawning grounds and juvenile rearing areas for salmonids. Rehabilitation projects often incorporate large woody debris (LWD) to increase the complexity and improve the quality of aquatic habitat. Woody debris can cause scour, which creates deeper pools, while at the same time providing cover for fish. The scour is a result of wood debris interacting with varying flows in the river to move gravel and other substrates from original stream bed positions. The amount of substrate moved from a location by scouring forces depends upon time, flow, contact between the wood debris and the channel bed, and the size of substrate.

Additional physical factors of wood debris which determine the relative success of in-stream wood are mass, specific gravity, hydraulic roughness, maximum surface area and cross-section and length proportional to the stream channel width and depth (Beechie and

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Sibley 1997; Bilby and Ward 1989). In essence, the more wood surface that is in contact with the stream bed, the more potential there is to form additional aquatic habitat.

Consequently, logs are a major source of drifting invertebrates that serve as food for fish (Benke, 1984). Nilsen and Larimore (1973) noted that wood with a more irregular shape and more crevices provided more diverse habitat for invertebrates. Angermeier and Karr (1984) found that increases in the amount of LWD can be expected to increase fish species diversity and individual abundance. Similar results were found for invertebrate abundance and diversity. Benke et. al. (1985, p. 9) indicate that returning snags to streams has the potential to increase the abundance, diversity, and enhance the production of invertebrates and fish that depend on them for food. In the Pacific Northwest, placement of LWD in stream has been a common restoration technique. However, LWD is often difficult to find and transport, and expensive to purchase.

This pilot study compares the hydraulic and biological effects of placing individual structures in lowland streams of Washington State. The test subjects are native large woody debris and an organic, engineered alternative to large woody debris (ELWd™). The engineered structures consist of an interlocking complex of small diameter poles that can be carried by hand and assembled on site. Like LWD, ELWd™ has a high surface roughness that traps sediment and debris. Unlike large woody debris, these structures are hollow and have a larger surface area that is convoluted with gaps. These physical differences may result in significant changes in the hydrologic flow regime and biological communities associated with these structures compared to LWD.

The hydraulic evaluation of this project is a comparison of the flow of water around the ELWd™ structures and the natural logs at high flows in the study streams. Comparison at high flows consists of photographs of water patterns surrounding the wood and an assessment of log contact with the stream bed. Additional evaluation of scour is a channel bed grid survey which was conducted pre- and post-installation of the wood debris. The survey mapped a 9 by 5 meters section of the channel bottom at each log in a .5 by .5 meter grid. The two years of data will serve as a comparison of the scour effects of LWD versus the effects of ELWd™.

The biological evaluation of this project consists of a comparison of the invertebrate and fish populations associated with ELWd™ and native large woody debris. Differences in the surface area of ELWd™ and water flow around the structures may affect the abundance and distribution of invertebrates on the wood surface and in the substrate downstream. Additionally, differences in turbulence may change the quality of pool habitat downstream from the structures, which may be reflected in the distribution or abundance of fish species.

The development of ELWd™ provides a new approach to reintroducing LWD into impacted systems. The use of ELWd™ is not intended to replace the natural recruitment of woody debris. This approach is designed to supplement the sources of LWD to maintain and enhance fish habitat until the natural riparian forest can regenerate. The ability to use small diameter wood instead of large logs would allow more projects to be completed at a lower financial and environmental cost. This study is intended to evaluate the performance of these structures prior to their possible widespread use.

## Methods

*Design of the Engineered Structures*

Engineered large woody debris, ELWd™ is a product designed for use as an alternative to heavy, expensive and increasingly rare native large woody debris in aquatic and upland habitat rehabilitation projects. The intended purpose of a lightweight and portable log substitute is for natural resource managers without road access to river sites or resources for large machinery can install large woody debris as a component in habitat rehabilitation. The structures consist of six to eight small diameter poles, obtained from pre-harvest thinnings and other refuse from the timber industry, which are paired in size. These pairs are drilled with a set of holes at each end into which a spar and wedge are inserted to hold the structure together. Three to four pairs of poles are used to form the interlocking structure. See Figure 1.

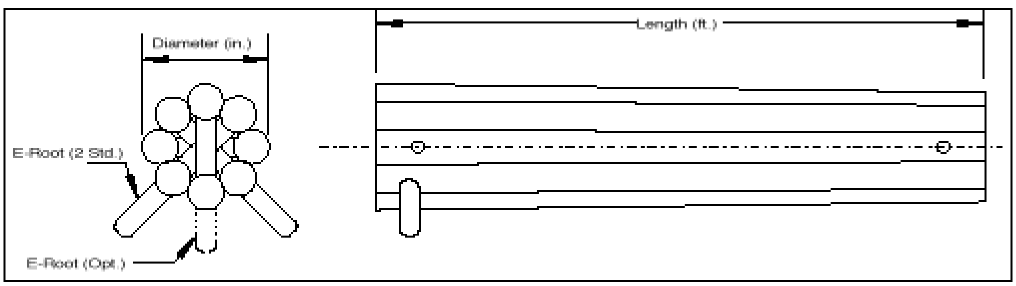


Figure 1. Design of engineered wood structures.

The available structures range in lengths from 3.6 to 7.3 meters and diameters from .4 to .94 meters. It is the intention of the designer to have these structures available as kits, which would be delivered to the staging area of rehabilitation sites. The structures would then be carried, pole by pole, to the intended location. The average weight of a single dry twenty-four foot pole is 82 kilograms. As a result, the completed structures are lightweight, 659 kilograms, as compared to natural wood which weighs approximately 2045 kilograms, depending upon tree species.

*Study Sites*

Four pairs of engineered wood structures and natural logs were placed in the lowest reach of the Mashell River, a tributary to the Nisqually River, near the intersection of State Highways 161 and 7. The reach is a plane bed channel with a substrate dominated by cobble and gravel. The stream banks consist of loosely consolidated alluvium and are easily eroded. The average width of the river is 26 meters and pools are generally formed by interaction of water with areas of the stream bank which are naturally cemented. There is little overstory present as the riparian area burned approximately 40 years ago and consists primarily of cottonwood, alder, and willow. Due to the lack of conifers, near-term recruitment of LWD is limited to the hardwood species currently present on the stream banks.

The longevity of wood in the study reach is unknown. There is relatively little wood located in the stream channel. Wood present in the channel is either wedged firmly into the bank or lying parallel to the stream bank. Wood appears to have little or no influence in the Mashell River. Aerial photographs reveal the river changed course within the last three years. The current lack of wood may be linked to high flows associated with the channel avulsion. The existence of several large jams on the lower stream banks, out of bankfull width, supports this idea.

Macroinvertebrate communities include representative taxa of Ephemeroptera, Plecoptera, Trichoptera, Diptera, Coleoptera and Oligochaeta with Ephemeroptera as the dominant taxa. Fish species include coho salmon (*Oncorhynchus kisutsch),* sculpin (*Cottus spp.)* cutthroat trout (*Oncorhynchus clarki),* and rainbow trout (*Oncorhynchus mykiss)*. Additionally, lampreys and cyprinids are present.

Five pairs of wood components were placed in Griffin Creek, which is a 14.5 kilometer long second-order tributary to the Snoqualmie River. The creek supports a run of wild Coho and is responsible for approximately 20% of coho salmon production in the Snohomish Basin. The study site is at RKM 5.65 and serves as a Washington State Department of Fish and Wildlife index reach for Coho. The study site is a plane bed reach with no variation in substrate and has a gradient of approximately 0.3%. Average channel width of Griffin Creek is 2.8 meters and average low flow depth is 15 centimeters. Successful channel spanning pools are formed solely by woody debris. The wood is either wedged into the bank or spans the channel with debris trapped underneath. Residual pool depths of channel spanning pools range from .37 to 1.07 meters deep. Lateral scour pools have formed along banks as well as under live and leaning trees. These pools are significant refuge for adult and juvenile during periods of high flow. Lateral pools are of poor quality during the summer months and fish present in them are stressed due to high temperatures. Fish species include coho salmon, (*Oncorhynchus kisutsch),* sculpin (*Cottus spp.)* cutthroat trout (*Oncorhynchus clarki),* and rainbow trout (*Oncorhynchus mykiss)*. Additionally, lampreys and cyprinids are present. Macroinvertebrate diversity is high with seven different families of Ephemeroptera, and all functional feeding groups represented.

*Hydraulic Design and Placement*

The hydraulic design of the project is intended mainly to compare the interaction of the two wood components with the substrate of the plane bed reaches. The design places the wood components in ELWd$^{TM}$ - LWD pairs, the order of which was randomized. The log pairs were chosen in order compare logs in similar local hydraulic conditions on the river. In order to minimize interaction between the 7.3 meter long, 60 centimeter diameter wood components, they were placed 30 meters apart. All pieces were angled downstream 35-40° from perpendicular to the bank. The logs are positioned with the rootwad on the bank with one-third of the length on the bank the remainder of the length is within the bankfull channel. All pieces are loosely tethered (10 meters of slack) with 1.3 cm galvanized steel wire rope to nearby trees. Fire hose was wrapped around the tree bole to protect the living tree. The purpose of the loose tethering is to allow the river to place the logs where receding waters leave them, rather than to affix the log in place.

High flow observations occurred on five occasions during the winter months. These observations generally took place days after large rain events. Each log was observed during a two hour time period in order to reduce variability. Observations included movement of the logs from the original position, change in angle of the log in relation to the bank, position of the log in relation to the channel bed and photographs of patterns of flow around the log. Photographs were taken from several vantage points during each visit. Each log had an established photo station, which provided a view of the entire log. When possible, up close photos were taken of the parts of the log which were influenced by the stream.

The first year survey of the channel bed took place before or just after placement of the wood structures into the streams (October 1999). The second year survey took place in July 1999. Surveys took place 3 meters up and downstream of the logs in a 0.5 by 0.5 meter grid pattern. The close pattern is intended to capture changes in detail of the channel bed. Survey data were entered into Surfer, a software program by Golden Software. The data were transformed into three-dimensional surface plots of the channel bottom. Volumetric change in substrate surrounding the logs will be calculated using the two years of data.

*Biological Methods*

Biological sampling at each pair of logs was conducted on the same day within each field site to reduce variability within each pair. Biological sampling consisted of invertebrate sampling and fish sampling. Invertebrate samples were removed from log surfaces using a small bottle-brush in a 30 cm x 30 cm area for two minutes. Organisms were captured in a modified mobile drift net (mesh size 500 µm) and rinsed into a 500 µm sieve and preserved in the field . Log surface samples were collected in October 1998, March 1999, June 1999, and August 1999. Invertebrate samples were also taken from the substrate directly downstream from each log. Organisms were collected using a 500 micron modified Surber sampler. A 30 cm x 30 cm area was disturbed for 2 minutes to a depth of 10 cm. Invertebrates were rinsed into a 500 µm sieve and preserved in the field. Benthic samples were collected in July 1998 and August 1999. All samples were sorted, identified, and counted under 15X magnification in the laboratory at the University of Washington. Aquatic larvae were identified to genus when possible except for Chironomidae, Simuliidae, and Capniidae, which were identified to family.

Water quality data was collected in February 1999, June 1999, and August 1999 to test the possibility of a strong correlation between chemical parameters and biological conditions. Water quality parameters measured at each log were pH, dissolved oxygen, conductivity, turbidity, and dissolved nutrients. The pH was measured using an Orion Model 210A digital meter. Dissolved oxygen and conductivity were measured using YSI Model 55 Handheld Systems. The analyses of dissolved nutrients and turbidity were conducted at the University of Washington Oceanography Laboratory.

Electrofishing was used at both sites in July 1998 to establish baseline data on the species present. Following construction, snorkel surveys were conducted in March 1999, May 1999 and July 1999. Data were collected on the species, size class and number in each size class from 10 m downstream to the tip of each log. These data were compared with the distribution of fishes in control areas. The communities of invertebrates in each sample were described using ten different metrics (Table 2). Karr (1999) used these metrics to calculate a Benthic Index of Biotic Integrity. The values of each metric were compared using a paired t-test (p value=0.10) to compare the mean of the differences in value for each pair of log sampled in October 1998.

## Results

*Hydraulic Results*

The high flow and preliminary observed scour results are listed below in Table 1. Overall, 78% of the wood components moved from the original position, half of those moved were ELWd$^{TM}$. Six of the eighteen placed logs moved entirely out of position. Either the wood was lost or moved to the end the 10 meter tether. Engineered structures comprised 83% of the moved category. Two logs were lost on the Mashell River. The tethers failed during a storm in November. Both pieces were found two weeks later on the banks of the Nisqually River. A natural log, found 2.5 km from its origin, was deposited on a gravel bar. The second, an engineered structure, was found 4.5 km from its origin. A spar had come loose at the nose (small end) of the log and the ballast was absent, thereby contributing to the distance gained by the ELWd$^{TM}$.

| Mashell River | | Status | Griffin Creek | | Status |
|---|---|---|---|---|---|
| Log 1 | LWD | tip pushed to bank, scour at tip | Log 1 | LWD | tip pushed to bank, scour at tip |
| Log 2 | ELWd | missing 12/5/98* | Log 2 | ELWd | log pushed to bank, scour at tip |
| Log 3 | ELWd | end of tether, ballast missing | Log 3 | LWD | maintained position, scour at tip |
| Log 4 | LWD | missing 12/5/98* | Log 4 | ELWd | tip pushed to bank, scour at tip |
| Log 5 | LWD | remained on bank | Log 5 | ELWd | end of tether, parallel to bank |
| Log 6 | ELWd | end of tether, no scour | Log 6 | LWD | tip pushed to bank, scour at tip |
| Log 7 | ELWd | end of tether, on bank | Log 7 | ELWd | maintained position, scour at tip |
| Log 8 | LWD | end of tether, mild scour | Log 8 | LWD | log pushed to bank, no scour |
| missing logs located on Nisqually River* | | | Log 9 | ELWd | no change ascertained |
| LWD 2.5 km from origin, ELWd 4.5 km from origin. | | | Log 10 | LWD | tip pushed to bank |

**Table 1: High flow and scour results.**

Wood components which maintained contact with the channel bed induced more scour than those that did not maintain contact. Overall, ELWd$^{TM}$ stayed in contact with the stream bottom due to the decreased buoyancy caused by the ballast. The native wood generally lifted off the bottom when high flows occurred. The point of contact with the stream bank acted as a pivot point for the native wood to lift out of contact with the channel bed. As a result, scour during high flows did not take place with natural wood to the degree in which it took place with the engineered structures.

The majority of scour associated with both the engineered structures and the natural wood took place at the tip of the log which generally maintained contact with the stream bed. Additionally, scour took place on the upstream side of certain logs and directly under the log where the water was forced underneath. Scour pockets underneath the log were not measured, as the log could not be moved during the survey. Instead, the graphing package interpolates between points, to determine the elevation of the bed underneath the log. Therefore, certain depths of scour, mostly underneath the logs are underestimated. Figure 2 illustrates the scour pocket surrounding an engineered structure.

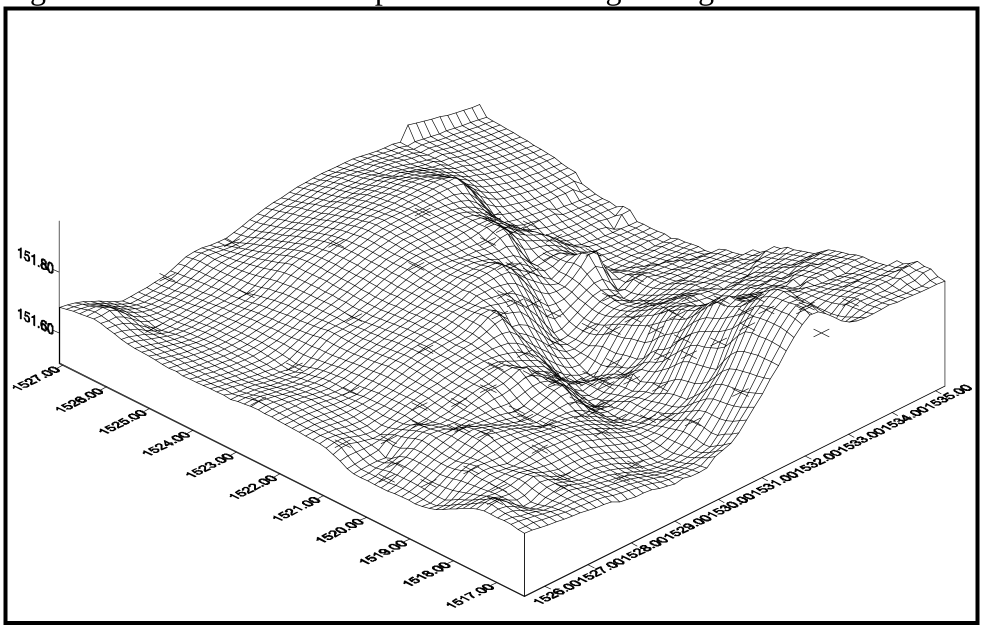


Figure 2: Log 7 Griffin Creek; Engineered Large Woody Debris, resultant scour, see scale of elevation in feet.

Figure 2 does not contain the log itself, the elevation points taken on the log distort the surface map, and does not allow the scour to be revealed. The line of scour visible in the center of the figure is the upstream edge of the scour. The log is directly above the scour line and is responsible for the small pit in the right center of the figure. Preliminary volume of scour caused by Log 7 is 1 cubic meter. The area downstream with a higher elevation is a gravel bar that did not increase in area as a result of scour induced by the engineered structure. Due to the preliminary nature of the scour data, it will not be discussed further.

*Biological Results*

There were no statistically significant differences between the invertebrate samples collected from the traditional LWD and ELWd™ for any of the ten metrics or the total IBI scores. The significance levels for all eleven tests were between 0.196 and 1.00 (Table 2), confirming that the populations of invertebrates associated with the two types of structures were not significantly different from an ecological perspective. No strong relationships were found between the water quality parameters and the biological measures using either simple linear regression or curvilinear estimation techniques ($r^2 < 0.33$).

| Metric tested | Significance |
| --- | --- |
| Total Taxa Richness | 0.271 |
| Number of Long-Lived Taxa | 0.266 |
| Number of Intolerant Taxa | 0.178 |
| Percent Tolerant Individuals | 0.901 |
| Mayfly Taxa Richness | 0.276 |
| Stonefly Taxa Richness | 1 |
| Caddisfly Taxa Richness | 0.621 |
| Number of Clinger Taxa | 0.308 |
| Percent Predator Individuals | 0.596 |

**Table 2: Results of paired t-test for each metric**

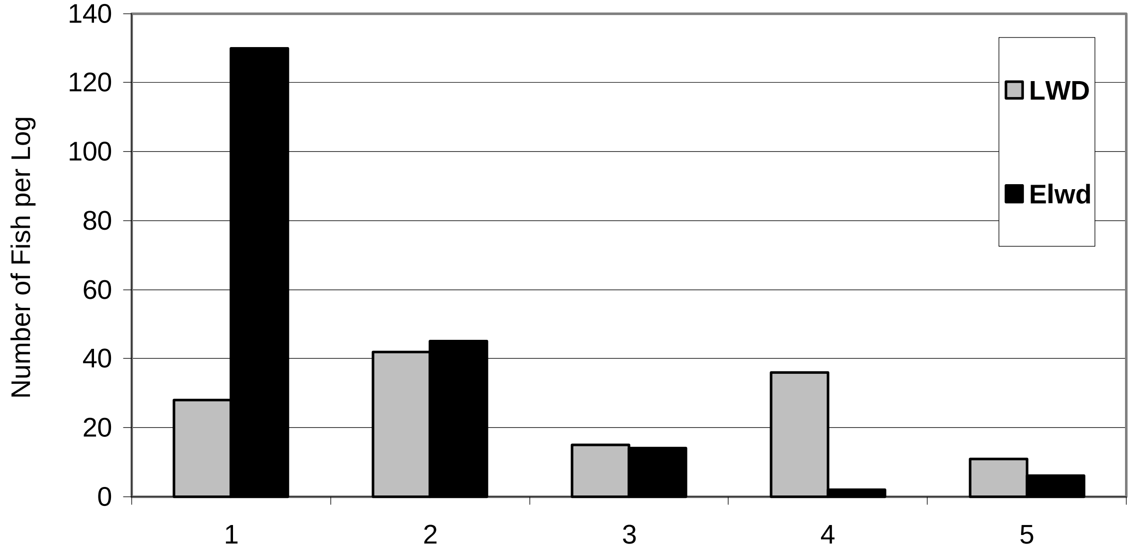


**Figure 3: Distribution of *Oncorhynchus kisutch*, Griffin Creek, July 1999. Numbers in x-axis refer to pair numbers**

The fish data collected from snorkel surveys revealed that independent factors were more critical in fish distribution than the type of wood placed. Figure 3 shows the number observed at each log of *Oncorhynchus kisutch* during the July 1999 snorkel survey at Griffin Creek. At pair number one, the ELWd™ recruited other wood that created significant backwater habitat. In pair number four, there was no significant scour associated with the ELWd™ structure resulting in a lack of backwater habitat.

Figure 4 shows the distribution of *Oncorhynchus mykiss* in the July 1999 snorkel survey at the Mashell River. At pair number one, the winter high flows moved the engineered wood onto the bank, preventing further scour. At pair number two, a point bar upstream formed an eddy at the LWD, while the engineered wood experience significant current. At pair number three, the ELWd™ created a lateral scour pool for fish, while the traditional wood offered little protection from the flow. When compared to natural woody debris in the system, there were significantly more fish at the larger, naturally established jams.

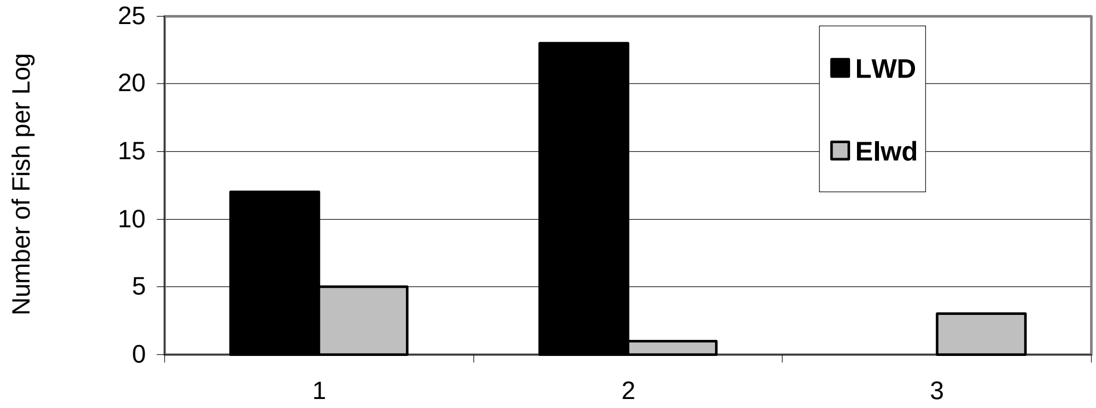


**Figure 4: Distribution of *Oncorhynchus mykiss,* Mashell River July 1999. Numbers in x-axis refer to pair numbers**.

**Discussion**

*Hydraulic*

Engineered structures are more prone to moving out of original location than large woody debris. The two components were placed identically and the ELWd™ moved regardless of whether it was upstream or downstream of its LWD pair. The natural wood in the study was never moved other than to be pushed to the river bank. Weight differences between the two components are the most likely explanation for this fact. Additionally, the engineered structures which stayed in place on Griffin Creek were aided by an additional element, engineered roots or e-roots. Three of these 'roots' are attached to the butt (large end) of the structures in order to increase drag. The addition of the roots helped to lodge the structure on the bank and prevented it from moving.

The engineered structure which was discovered intact on the Nisqually river did not perform as expected. It was assumed that once a spar failed in the structure, the entire structure would fail as it was carried downstream by the river. The relevance of this incomplete failure is that the spar and wedge construction of the ELWd™ is stronger than expected.

*Biological*

There were no significant differences in the invertebrate communities associated with LWD and ELWd™ during this initial sampling interval. The multiple metric approach provides a well-rounded analysis to evaluate ecological health from a variety of different community based parameters. The lack of significant difference in all eleven biological measures is a clear signal that the structures are functioning at a similar ecological level as invertebrate habitat.

Fish inhabited areas with backwater, cover, and high food availability. These factors were independent of the type of wood placed, however, much of the backwater habitat in Griffin Creek was associated with some type of woody debris. Particularly for the over-wintering juveniles, the existence of backwater habitat is of critical importance for fish abundance. In the Mashell River, neither type of placed wood was large enough to consistently create significant backwater habitat. The size of the placed logs was much more appropriate for a stream the size of Griffin Creek.

## Conclusions

ELWd™ is best suited for use in small stream systems (<6 cms average maximum flow) that are lacking in woody debris. Although engineered structures are lightweight, they are comparable to natural wood in the ability to create areas of scour. The ballast and subsequent lack of buoyancy is a factor which must be considered when installing the ELWd™ in a habitat rehabilitation project. The ballast serves to make the hollow structure behave like a solid structure and may not be necessary in all applications of ELWd™. It is important to consider the flexibility and ease of use of the engineered structures as compared to natural large wood.

The results of this study show a comparable performance as a substrate for invertebrate colonization for the engineered structures with larger diameter single logs. Fish distribution was independent of the type of log placed, but in smaller systems the engineered wood functions as well or better than traditional LWD. ELWd™ is not intended to supplement the natural recruitment of wood in the long term, but may serve as an adequate temporary improvement for fish habitat until the natural riparian corridor regenerates. The use of this type of technology may provide necessary alterations to degraded sections of spawning and rearing habitat for anadramous and resident freshwater fish without the cost of acquiring and manipulating large pieces of wood. Additional study is necessary to determine the longevity and long term physical and biological performance of engineered large woody debris.

## Acknowledgements

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