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Large wood has been utilized in many restoration projects to improve in-stream habitat in the Pacific Northwest for salmon. However, the benefits of this practice remain the subject of ongoing debate and evaluation of these projects has scarcely been done for non-salmonid species such as lamprey. In this study we look at the impacts of a large wood restoration on larval Pacific *Entosphenus tridentaus* and Western Brook Lamprey *Lampetra richardsoni* and juvenile Coho Salmon *Oncorhynchus kisutch* by 1) identifying instream habitat characteristics that influence the presence of larval lamprey and abundance of juvenile Coho Salmon; and 2) evaluating how these characteristics are influenced by wood. To address habitat use, we determined presence of larval lamprey in 92 pools and abundance of juvenile Coho Salmon in 44 pools during summer low flows in a small coastal Oregon stream. We focused on a reach of stream where large numbers of large wood pieces and wood jams were introduced to retain sediment in the channel. Results indicate that presence of laval lamprey was associated with availability of fine sediment ($P < 0.001$) and deeper substrate ($P < 0.001$). The abundance of juvenile Coho Salmon (fish/pool) was associated with pool area ($r_s = 0.78$; $P \leq 0.001$) and to a weaker extent with the proportion of cobble and boulder substrates in pools ($r_s = -0.39$; $P \leq 0.01$). Pools with wood, regardless of whether they were formed by wood, had greater coverage of fine and deeper substrate ($P < 0.001$) and greater pool area ($P = 0.016$). Taken together, these results suggest that instream wood can provide habitat conditions

that larval lamprey and juvenile Coho Salmon use, and thus provide benefits to these species.

Responses of Juvenile Coho Salmon and Larval Lamprey to Instream Habitat Restoration in a Pacific Northwest Stream

by
Rosalinda Gonzalez

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Dean of the Graduate School

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Rosalinda Gonzalez, Author

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CHAPTER 1 –INTRODUCTION

Large wood is frequently used for stream restoration in the Pacific Northwest, USA, but the benefits of such restoration to fish remain the subject of ongoing debate (Burnett et al. 2008; Stewart et al. 2009; Whiteway et al. 2010). Much of this debate is fueled by variation in design, location, and the scale of restoration projects, as well as the quality of biological information used to quantify their effectiveness (Reeves et al 1991; Burnett et al. 2008; Roni et al. 2008). A further complicating factor is the possibility that different species, or even life stages within a species may respond uniquely to the effects of restoration. For example, in the Pacific Northwest stream restoration using large wood has focused on improving habitat for salmonid fishes (Thompson 2006, Stewart et al 2009). Other focal species, such as lamprey (Close et al. 2002), have very different habitat requirements (Beamish and Jebbink 1994, Beamish 1996, Smith et al. 2011), and we know considerably less about how they respond to restoration (Roni 2003; Nagayama et al. 2012). Thus, evaluation of the influences of stream restoration involving large wood for species which may require contrasting habitat conditions is important and still needed (Roni et al 2014).

In this study we evaluated the influence of large wood restoration on juvenile Coho Salmon *Oncorhynchus kisutch* and larval lamprey (Pacific Lamprey *Entosphenus tridentatus*, and Western Brook Lamprey *Lampetra Richardsoni)*. Our objectives were to 1) identify instream habitat characteristics that influence the presence of larval lamprey and abundance of juvenile Coho Salmon, and 2) evaluate how these characteristics are influenced by wood. For Coho Salmon, we focused on abundance of juveniles in pools during summer low flows as the response variable, hypothesizing that abundance should be positively correlated with a host of biotic and geomorphic variables previously reported to be important in the literature (Table 1). For lamprey, we sampled in the same season and focused on presence of larvae as the response variable, hypothesizing that presence would be more likely in habitats with greater availability of fine substrate (Table 2). Habitat factors associated with these species were evaluated in relation to the influences of large wood by comparing them in 1) pools formed by large wood versus pools formed by other influences, and 2) pools with and without large wood present. Through this sequence of analyses we were able to identify local habitat that influences either larval lamprey or juvenile Coho Salmon and determine how they were related to the presence of wood.

TABLE 1. —Hypothesized relationships between juvenile Coho Salmon abundance and the physical and biological parameters believed to influence their abundance. Trends for the hypothesized effects are denoted by – (negative) or + (positive).

Parameter	Hypothesized relationship	Reasoning
Coastal Cutthroat Trout biomass (g)	-	Higher biomass of predators will decrease the abundance of juvenile Coho Salmon in a pool.
Steelhead biomass (g)	-	Interspecific competition between steelhead and juvenile Coho Salmon will decrease the total number of juvenile salmonids a pool can support.[1]
Pool area (m^2)	+	More habitat area leads to higher abundance.[1]
Proportion substrate made up of cobble and boulder	+	Cobble and boulders are forms of cover that may provide fish with protection from predation[2,3,4] and more energetically favorable feeding locations.[5,6].
Bankfull width/ bankfull depth	+	Wider and shallower areas may serve as refuges during winter and spring high flow events.[7,8,9]
Residual pool depth	+ or -	Depth can provide refuge from terrestrial piscivores[6]. Alternatively, deeper pools may have larger fish in them which prey on smaller juvenile fish. [10]

[1]Chapman 1966, [2]Smith and Griffith 1994 (cobble), [3]Shuler et al.1994 (boulders), [4]Allouche 2002 (cover), [5]Fausch 1984, [6]Reinhardt et al 1997, [7]Nickelson et al. 1992b, [8]Moore and Gregory 1988, [9]Solazzi et al. 2000, [10]Schlosser 1987

TABLE 2.— Hypothesized associations between larval lamprey and the physical parameters believed to influence their presence.

Hypothesis	Reasoning
Lamprey presence will be higher for pools with more fine substrate	Larval lamprey are found in areas with fine substrate [1,2,3]
Lamprey presence will be higher for pools with greater substrate depth	Larval lamprey have been shown to select deeper substrate [4,5]
Transformers* will be more selective of their habitat	Older and larger larvae (TL 110-146 mm) have been found to select coarse substrate over fine substrate with the same preference for deeper substrate[5]

*Transformers were identified as larvae with a developed eye and/or an oral disk beginning to develop
[1.]Beamish and Jebbink 1994 [2.]Beamish 1996 [3.]Smith et al. 2011 [4.]Goodwin et al 2008 [5.]Aronsuu and Virkkalal 2013

CHAPTER 2 –METHODS

Study Site

This study was conducted in Little Wolf Creek, a tributary of the mainstem Umpqua River in southwest Oregon, USA (Douglas County, Lat 43°25′53″, Long 123°35′08″ referenced to North American Datum of 1927). Lithology of the catchment is dominated by Tyee sandstone, a softer rock that is highly erosive and producing a rich supply of finer grained sediment (O'Connor et al 2014). The area has a Mediterranean climate characterized by dry summers and flashy wet winters (Chang and Jones 2010; Filipe et al. 2013). Average water temperature recorded for the stream during our study (27 July-6 September 2012) was 16.74 ± 0.04^{0}C (USGS gage 14320934). Minimum discharge recorded in 2012 water year (October 2011-September 2012) was 0.01 m^3/s in late September and the maximum discharge recorded was 21.89 m^3/s in January.

Riparian foliage in the area includes Western Sword Fern *Polystichum munitum*, Salmonberry *Rubus spectabilis,* Oregon Myrtle *Umbellularia californica,* Douglas Fir *Pseudotsuga menziesii*, Red Alder *Alnus rubra*, Western Red Cedar *Thuja plicata*, and Big Leaf Maple *Acer macrophyllum*. Common fishes include Coastal Cutthroat Trout *Onchorhynchus clarkii clarkii*, Steelhead and resident Rainbow Trout *Oncorhynchus mykiss*, Coho Salmon, and Pacific and Western Brook Lamprey. Coho Salmon are listed as threatened in both Oregon and Northern California under the Endangered Species Act (Good et al. 2005) and Pacific and Western Brook Lamprey are currently listed as vulnerable and of concern in Oregon (Gunckel et al. 2009; Close et al. 2002).

The stream and riparian zones in Little Wolf Creek are managed by the Bureau of Land Management (BLM), whereas the upslope area is a matrix of private forest and BLM lands. Although not specifically documented, physical evidence suggests that splash damming and stream cleaning occurred in the area (Scott Lightcap, Bureau BLM, Roseburg District, personal communication, 2011; see also Miller 2010 and Bisson et al 1987). To replace lost wood and restore associated in-stream habitats (Dolloff and Warren 2003; Reich et al 2003; Zalewski et al 2003) the BLM placed 281 pieces of large wood into part of the stream between 2008 and 2009 (Jeffrey McEnroe and Scott Lightcap, BLM, Roseburg District, personal communication, 2011). Wood was arranged into loose aggregations, or compact assemblages that formed 37 log jams.

Overview of Sampling Design

A continuous 3km stretch of stream within part of Little Wolf Creek where wood additions were made was selected as our study reach. All sampling occurred during seasonal low flows in late summer (27 July-6 September 2012). Within the 3km study reach all habitat units were geomorphically categorized as a pool, riffle, or run/non-turbulence. In an effort to target predominantly juvenile Coho Salmon summer habitat (Nickelson et al 1992a, Young 2004), we focused sampling on pools (n = 92) within the study reach. All pools were sampled in a random order and fish and pool habitat data were collected within one day of each other. We chose to quantify abundance (fish/pool) for juvenile Coho Salmon because we were interested in how wood related influences on habitat increased overall numbers of fish in pools in the study reach. We chose to measure presence of lamprey (larvae and transformers, Table 2) because we lacked the time and resources to estimate their abundances. Accordingly, we opted to use new protocols that allowed us to efficiently detect lamprey (Dunham et al. 2013).

In-stream Habitat

In-stream habitat surveys quantified parameters hypothesized to influence juvenile Coho Salmon abundance and presence of larval lamprey (Tables 1 and 2). In each pool transects spaced at one meter intervals were placed perpendicular to the stream channel to measure substrate depth and type, and pool depth, . Pool area was determined using the sum of all individual areas between consecutive transects. At each transect we measured substrate type (see below) and depth (cm) at three evenly spaced points with a single maximum depth (cm) for the entire transect. Dominant size (b-axis) of substrate was quantified within a 10 cm radius of each of the four points sampled along each transect. Substrate was classified at four evenly spaced points along each transect and classified based on a modified Wentworth scale (fine < 2 mm, gravel 2-64 mm, cobble 64-256 mm, boulder > 256 mm, or bedrock). A metal rod was used to determine the maximum depth of substrate (cm), with depths binned as follows: 0, 1-10 cm, 11-50 cm, and >50 cm. The area in each pool made up of fine sediment was calculated by multiplying total pool area by the percent of the substrate in the pool composed of fine substrate (based on percentage of points sampled). The pool area made up of substrate with a depth of more than 10 cm was calculated by multiplying pool area by the percent of the substrate depths, regardless of its type, greater than 10 cm. Bankfull width and wetted width were measured every meter for pools less than 15 m long and every other meter for pools greater than 15 m long. Pool tail crest depth was also measured for each pool and was used with the maximum depths to calculate residual pool depth, which provides a flow independent measurement of pool depth (Lisle 1987). Lastly, the distance from the downstream edge of each pool to the mouth of the stream was measured directly using a referencing system established in a previous study (Clark et al 2014). Distances were measured along the length of the stream thalweg.

Fish sampling

We used mark-recapture to estimate abundance of juvenile Coho Salmon (Rodgers et al. 1992), with estimates completed in 45 randomly selected pools within the 3km reach. Depending on conditions, fish were captured using a combination of backpack electrofishing and seining. Because different methods were used for each pool we calculated capture probabilities separately for each pool. Prior to any sampling block nets were placed to prevent migration in or out of the pool, and nets were left in place until all sampling was complete. We sampled on two occasions (≥24 hours apart) and used a modified Lincoln-Peterson estimator for abundance and only calculated abundance in pools with recapture probabilities of 10% or greater (Chapman 1951; White et al. 1982). Fish captured on the first occasion were marked with a small dorsal or pectoral fin clip, returned to the study pool and allowed to recover overnight prior to recapture (Rosenberger and Dunham 2005). All fish lengths were measured (FL, mm) and only fish >45 mm were included in population estimates. All fish caught were identified to species except for trout smaller than 45mm which were classified as trout fry. To minimize stress to fish, we sampled only when temperatures were less than 18^{0}C.

To determine the presence of larval lamprey we sampled all 92 pools within the study reach using backpack electrofishing with lamprey specific settings (Dunham et al. 2013). We assumed that a single pass of electrofishing with lamprey specific settings was sufficient to ensure a high level of detectability (0.99). This assumption was based on estimates of capture probability reported by Dunham et al (2013), indicating that the capture probability for larger (≥75 mm) lamprey larvae is 0.36 (median) in streams with comparable characteristics. This level of capture probability guarantees that the probability of detecting lamprey is 0.99 or greater if at least 10 lamprey are present within a given pool ($1-(1-0.36)^{10}$). Accordingly, our interpretation of presence refers to the presence of 10 or more individuals.

All captured lamprey collected were weighed (g), measured (TL, mm), and classified as either an ammocoete or a transformer. Transformers were identified as larvae with a developed eye and/or an oral disk beginning to develop. Identification of species for larval lamprey was not possible in the field, and both Pacific and Western Brook Lamprey were potentially present (Renaud 2011, Schultz and DeLacy 1936). Given the difficulty of distinguishing between species of larvae in the field and their ecological similarity, we treated these species as ecological equivalents, with respect to habitat associations.

Large Wood Measurements

Once habitat characteristics associated with juvenile Coho Salmon and larval lamprey were identified (see Results), we wished to determine how these in turn were associated with large wood. We defined large wood as any piece of wood that was at least 3m long and 15cm in diameter (Jones et al 2014). We assessed the influence of wood on fish habitat by evaluating 1) characteristics of pools formed by wood and 2) habitat characteristics in pools with wood regardless of whether it served as the pool forming feature. Pool forming feature was classified as either large wood, root defended bank, bedrock, or channel curvature. Wood presence within a pool was determined during large wood surveys in which all large wood within the study reach was counted, placed into a binned length (3-6, 6-15, >15 m) and diameter category (15-30, 30-60, 60 cm), classified as naturally occurring or artificially placed wood and associated with a habitat unit number.

Statistical Methods

An alpha of 0.05 was used to determine significance for all statistical analyses (Murtaugh 2014). Analyses were completed using nonparametric Spearman correlations and Mann–Whitney *U*-tests, chi-square square test, and Mantel tests. Mantel tests were done using 9,999 permutations to test for possible spatial autocorrelation between fish in pools prior to testing any specific hypothesis on the presence or abundance of fish and pool habitat (Manly 1991; Ramsey and Schafer 2002). Mantel tests were conducted using the Vegan R package (Oksanen et al 2013) which requires the lattice (Sarkar 2008) and permute (Simpson 2014) packages in R version 2.15.3 (R Core Team 2013).

Fish and Habitat Associations

Spearman correlations (Ramsey and Schafer 2002) were conducted to relate abundance of juvenile Coho Salmon to each parameter hypothesized to influence their abundance (Table 1). Correlations between parameters were also evaluated to ensure that none of the parameters were correlated among themselves. Mann–Whitney *U*-test (Ramsey and Schafer 2002) were used to tests the association between lamprey presence and substrate depth and type. In order to test predictions from our hypotheses (Table 2) these comparisons were done separately for different life stages (larvae and transformers) and for lamprey presence regardless of life stage (n = 92).

Wood Influence on Instream Habitat

Mann–Whitney *U*-test (Ramsey and Schafer 2002) were conducted to evaluate if habitat characteristics associated with juvenile Coho Salmon abundance or the presence of larval lamprey (see results) were associated with large wood. Comparisons for each habitat parameter were done for pools formed by wood versus pools not formed by wood, and for pools with wood present versus pools without wood in them.

CHAPTER 3 –RESULTS

Pools in our study site were generally bedrock dominated (Table 3) with an average wetted width of 5.38±0.40 m, and an average depth ranging from 9.9 cm to 33.8 cm with a mean of 20.34±1.19 cm (Table 4). Average pool area composed of fine sediment was 27± 6.9 m^2 and average pool area composed of substrate deeper than 10cm was 11 ± 3.98 m^2. Pool area for the 92 pools sampled ranged from 9.18 m^2 to 205.14 m^2 , averaging 89.51 ± 14.49 m^2 (Table 4). The number of fish handled was 9,282 individuals: including 5,733 juvenile Coho Salmon (FL 26-160 mm), 895 ammocoetes (TL 12-171 mm, average length 92.81 ± 2.28 mm) and 104 transformers (TL 100-176 mm; average length 132.03 ± 2.53 mm). Within the study reach, 44 out of the 45 pools sampled for juvenile Coho Salmon had recapture probabilities of 10% or greater (ranging from 10-90%) allowing us to calculate population estimates and thus abundance. Juvenile Coho Salmon abundance was on average 104 ± 23fish/pool and density ranged from 0.60 to 1.93 fish/ m^2. Other organisms present included Sculpin, *Cottus sp.*, larval Coastal Giant Salamanders *Dicamptodon tenebrosus*, Red Legged Frogs *Rana aurora*, Signal crayfish, *Pacifastacus leniusculus*, a single Brown Trout *Salmo trutta* (FL 182 mm), Steelhead and resident Rainbow Trout (FL 60-177 mm, average biomass 32.84 ± 12.19 g), Coastal Cutthroat Trout (FL 96-280 mm, average biomass 75.63 ± 31.04 g), and a single juvenileChinook Salmon *Oncorhynchus tshawytscha* (FL 91 mm). Trout smaller than 45mm were not included in population estimates or classified to species (n = 306 fish FL 30-70 mm).

TABLE 3.—Summary of pool substrate composition and depth for all pools (n=92) sampled in Little Wolf Creek during the summer of 2012. Means and 95% confidence intervals are given for proportions.

	Bedrock	Boulder	Cobble	Fines	Gravel	Large wood	Organic debris
Average	0.34 ± 0.06	0.06 ± 0.01	0.10 ± 0.02	0.27 ± 0.04	0.20 ± 0.04	0.005±0.003	0.02 ± 0.007

TABLE 4.—Summary of physical characteristics of pools (n=92) sampled in Little Wolf Creek during the summer of 2012. Means and 95% confidence intervals are given.

	Max depth (cm)	Bankfull width (m)	Wetted width (m)	Average depth (cm)	Unit length (m)	Area (m^2)	Residual pool depth (cm)	Pool volume (l*w*h) (m^3)	Bankfull width/bank full depth	Distance to mouth of stream (m)
Average	55.45 ± 4.13	16.14 ± 0.95	5.38 ± 0.40	20.34 ±1.19	15.48 ± 1.85	89.51 ± 14.49	38.92 ± 3.79	18.95 ± 3.54	9.84 ± 0.75	1931.27 ± 166.47

Fish and Habitat Associations

We found no evidence of spatial autocorrelation as indicated by Mantel's tests of associations between pool locations (distance to the mouth of the stream) and the abundance (fish/pool) of juvenile Coho Salmon (Mantel's $r = 0.07$; $P = 0.06$) or the presence of lamprey in pools (Mantel's $r = -0.02$; $P = 0.79$). This lack of autocorrelations was also true when we analyzed the presence of ammocoetes and transformers separately (Mantel r = -0.02; $P = 0.79$; r = 0.06, $P = 0.07$). None of the parameters hypothesized to influence fish abundance were correlated to one another (Table 5). Analysis of habitat associations showed that abundance of juvenile Coho Salmon was significantly correlated with only two parameters, pool area ($r_s = 0.78$; $P \leq 0.001$; n= 44; Figure 1) and proportion of cobble and boulder substrates in pools ($r_s = -0.39$; $P \leq 0.01$). Variation in fish abundance was higher when the proportion of substrate in a pool composed of cobble and boulder was lower, and as the proportion of cobble and boulder increased the variation in juvenile Coho Salmon abundance and overall abundance lowered (Figure 2).

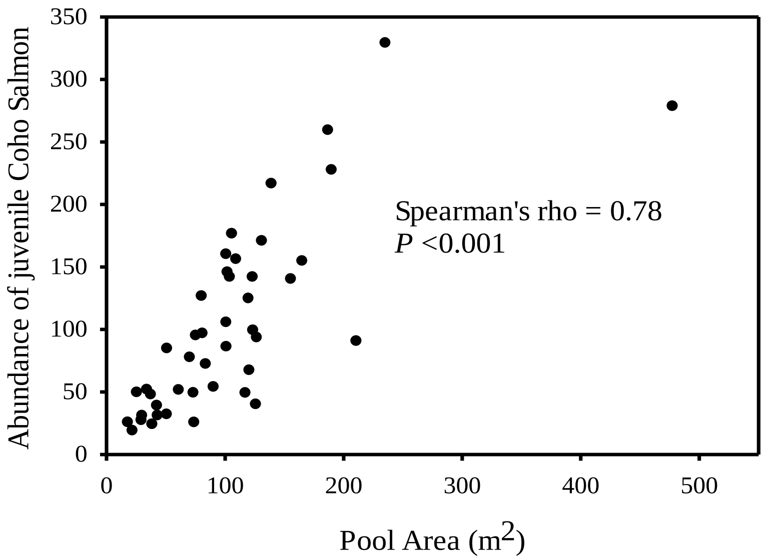


FIGURE 1. — Abundance of juvenile Coho Salmon in pools in relation to the area of pools sampled in Little Wolf Creek in the summer of 2012

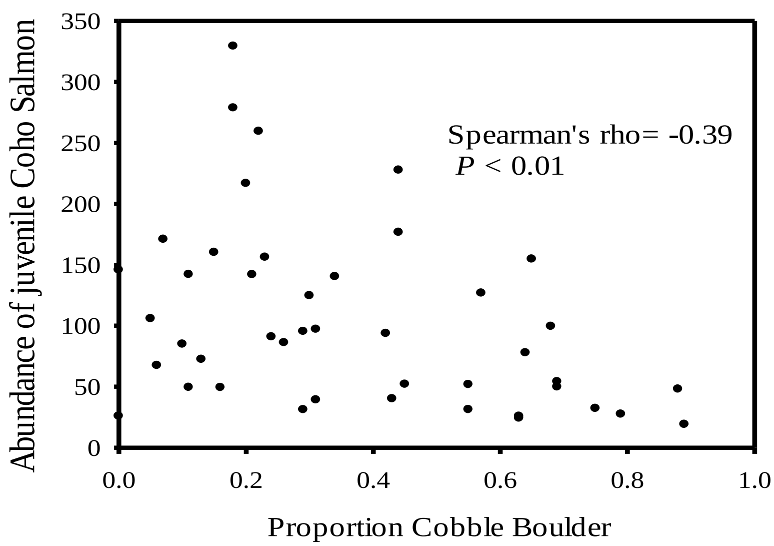


FIGURE 2 — Abundance of juvenile Coho Salmon in pools in relation to the amount of pool substrate made up of cobble and boulders in Little Wolf Creek in the summer of 2012.

TABLE 5.— Correlation matrix showing the relationship between each parameter hypothesized to influence the abundance of juvenile Coho Salmon and the relationship between these parameters. Fish lengths and biomass were based on the average for each pool. The first number in the table is the Spearman rho and the second number is the p-value. P values less than 0.05 were considered significant. Relationships were only looked at for pools where juvenile Coho Salmon abundance could be calculated (n=44).

Parameter	Coho abundance (fish/pool)	Rainbow Trout Biomass (g)	Coastal Cutthroat Trout Biomass (g)	Pool area (m^2)	Bankfull width/ bankfull depth	Residual pool depth (cm)	Proportion cobble boulder
Rainbow Trout biomass (g)	0.07, 0.67	-					
Coastal Cutthroat biomass (g)	0.23, 0.13	0.22, 0.16	-				
Pool area (m^2)	**0.78, ≤ 0.001**	-0.02, 0.91	0.30, 0.05	-			
Bankfull width/ bankfull depth	-0.06,0.7	0.01, 0.96	-0.12, 0.42	-0.075, 0.63	-		
Residual pool depth (cm)	0.03, 0.83	-0.01, 0.97	0.19, 0.21	0.22, 0.16	-0.10, 0.51	-	
Proportion cobble boulder	**-0.39, 0.01**	0.13, 0.42	0.04, 0.78	-0.29, 0.06	0.00, 0.99	0.22, 0.15	-
Distance to mouth of the stream (m)	0.02,0.90	-0.17, 0.27	-0.03, 0.8	-0.04, 0.77	0.06, 0.69	0.04, 0.80	0.02, 0.88

Presence of larvae lamprey was associated with availability of fine and deeper substrate (Figure 3). Pools with lamprey present had more coverage of fine (U = 257.0; P < 0.001) and deeper substrate (U = 317.5; P < 0.001). Considering only ammocoetes, 66 out of 92 pools had ammocoetes present and ammocoetes were similarly associated with greater coverage of fine (U = 257.0; P < 0.001) and deeper substrate (U = 415.0 ;P < 0.001). Considering only transformers, 13 out of the 92 pools had transformers present. Transformers were also associated with greater coverage of fine (U = 317.5; P < 0.001) and deeper substrate (U = 32.0; P < 0.001).

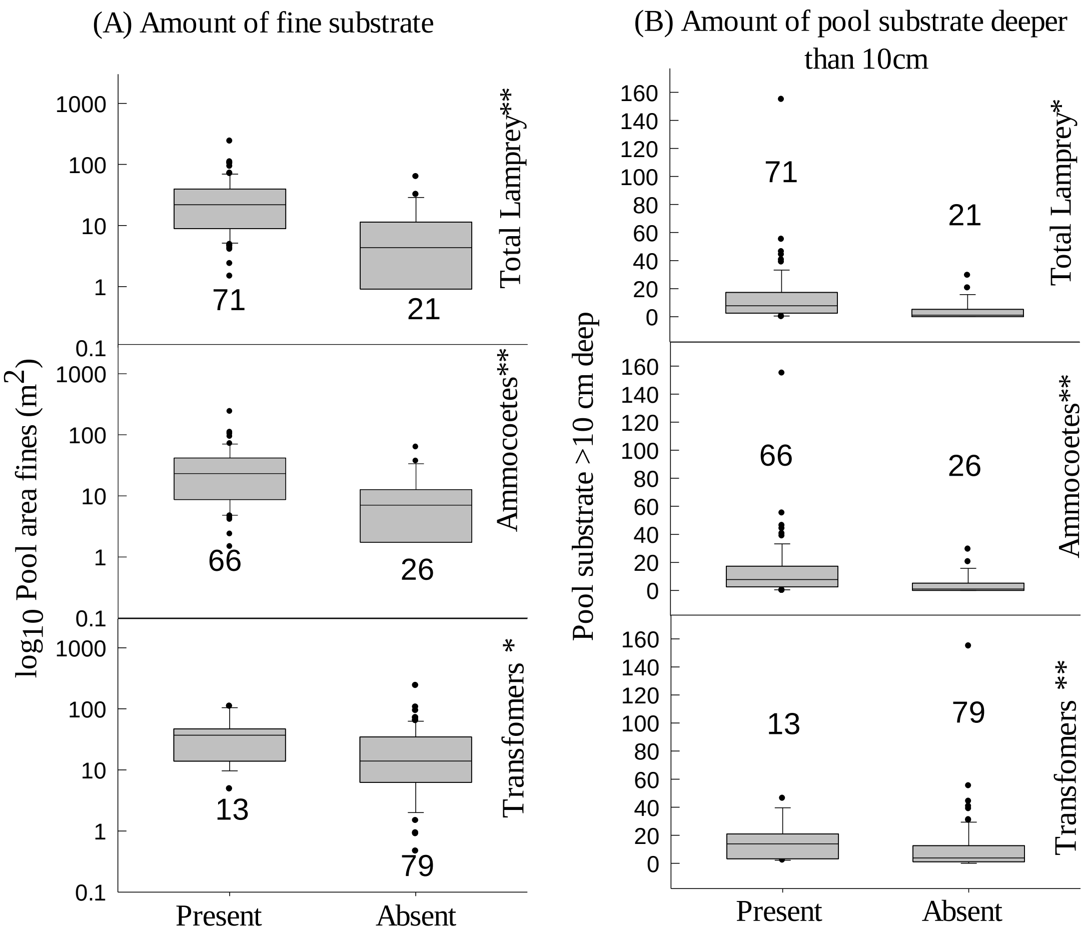


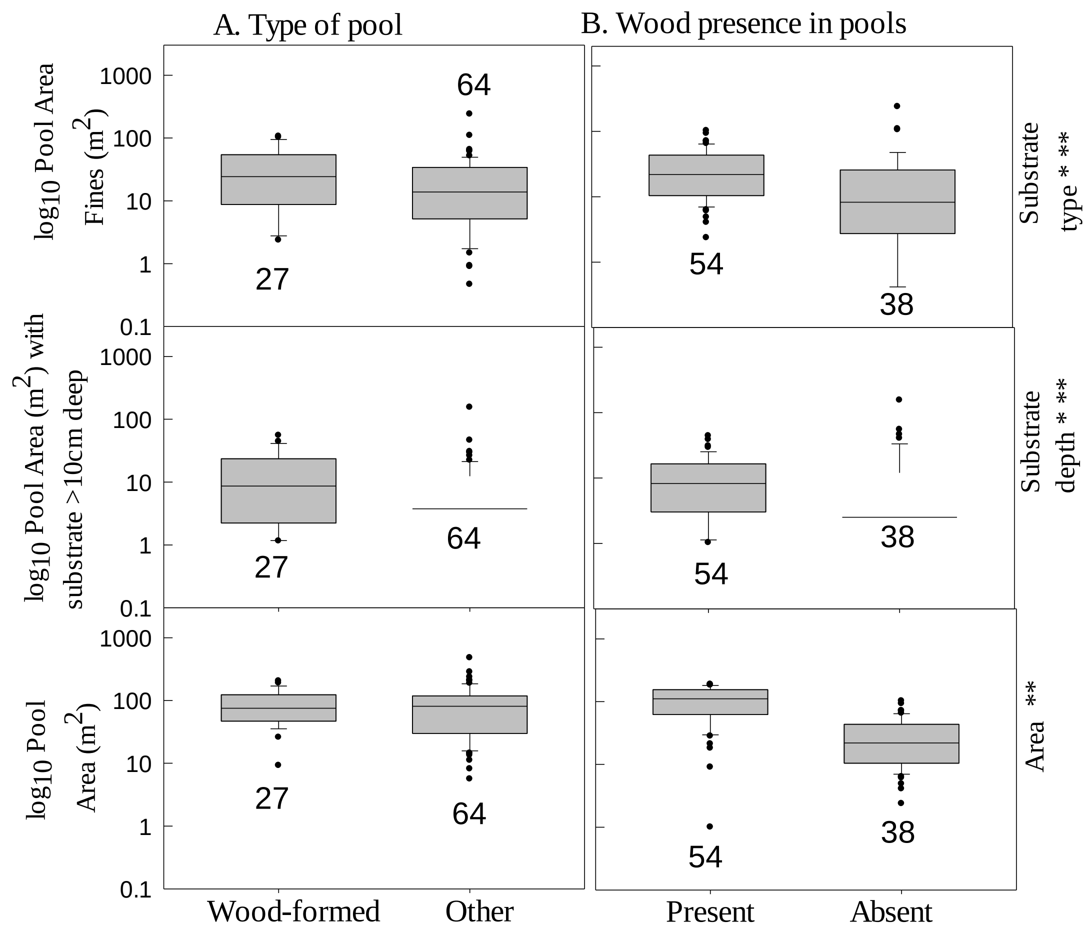
FIGURE 3. Comparisons of the amount of fine substrate in a pool (A) and the amount of substrate deeper than 10 cm (B) in pools where lampreys are present or absent. The number associated with each box plot indicates the number of pools with lampreys present or absent (n= 92 total pools). Statistical significance is denoted by asterisks $P < 0.05$*, $P < 0.001$ ** and are calculated using Mann-Whitney U-test. Please note that the left panel is log transformed.

Large wood summary

During our wood surveys we found 584 pieces of large wood within our study reach. Of the 352 pieces found in pools, 241 were classified as natural-occurring and 111 were classified as artificially-placed. Natural and artificial wood differed in size ($X^2 = 73.4$, $P < 0.001$, $df = 8$, Appendix Figure A.1 and Table A.5), specifically in length ($X^2 = 56.9$, $P < 0.001$, $df = 2$, Appendix Figure A.1 and Table A.5) with most of the natural wood being 3-15 m long and most artificial wood being 6-15m long. However, natural and artificial wood did not differ in diameter ($X^2 = 0.138$; $P = 0.93$, $df = 2$ Appendix Figure A.1 and Table A.5), most wood was 30-60 cm diameter. When we evaluated both length and diameter combined for wood in pools most natural wood was 3-6 m long with a diameter of 15-30 cm (n = 63) and most artificial wood was 6-15 m long with a diameter of 30 cm (n = 22). The least common length and diameter dimensions for artificial and natural wood were pieces >15 m long with a diameter of 15-30 cm. We were unable to independently evaluate the impacts of artificial and natural wood on habitat characteristics due to natural and artificial wood being intermixed in the stream. Thus, we evaluated overall large wood impacts on habitat characteristics regardless of whether wood was natural or artificial.

Large wood and Habitat Characteristics

We found that large wood increases the number of pools available to fish. Large wood also influenced parameters associated with fish presence or abundance in our study: greater coverage of fine substrate, deeper substrate, and pool area (Figure 4). We found that 27 of pools in the study reach were formed by large wood (n = 91, one pool did not have a pool forming feature recorded for it). These wood-formed pools had greater coverage of fine ($U = 618.0$; $P = 0.03$) and deeper substrate ($U = 624.5$; $P = 0.04$), but did not have greater pool area ($U = 817.0$; $P = 0.69$) when compared to pools formed by other features. In looking at all pools with wood (Figure 4) relative to those without wood in them we found that pools with wood in them had greater coverage of fine ($U = 581.0$; $P \leq 0.001$), and deeper substrate ($U = 678.5$; $P = 0.01$) and larger pool areas ($U = 721.5$; $P = 0.016$).



* Pool forming feature p<0.05 **wood presence P < 0.05 calculated using Mann–Whitney *U*-test

FIGURE 4. Comparison of habitat characteristics in pools formed by wood versus other features (A), and pools with large wood in them versus pools without large wood (B). Significance is denoted by asterisks: * pool forming feature P <0.05, **wood presence P < 0.05. Please note that the data are log transformed.

CHAPTER 4 –Discussion

This study provides evidence in support of a linkage between large wood and habitat conditions that support juvenile fishes. This conclusion stems from three major findings : 1) juvenile Coho Salmon are more abundant in larger pools; 2) larval lamprey are more prevalent in pools with greater surface area of fine sediment, and greater sediment depth, regardless of sediment type and 3) each of these habitat conditions is positively associated with instream large wood. We discuss these findings in more detail below, including their relevance for stream restoration involving placement of large wood.

Fish Response

Juvenile Coho Salmon

We found a significant correlation between the abundance of juvenile Coho Salmon and pool area. In the simplest sense this may be because larger pools should have space to accommodate more individuals. Other studies evaluating habitat associations of juvenile Coho Salmon have used different measures of standing stock, such as linear fish density (fish*m^{-1}; Roni and Quinn 2001), areal fish density (fish*m^{-2}; Nickleson et al 1992a, Giannico and Hinch, 2003 Flitcroft et al. 2011), biomass (g, Fausch and Northcote 1992), or biomass density (g*m^{-2}; Whiteway et al. 2010). Many of these measures are highly correlated. For example in my study abundance was correlated with areal density (r_s = 0.463, p=0.002). In contrast to abundance as a response, I found that areal density of juvenile Coho Salmon was not associated with pool area (r_s=0.11, p=0.49). Thus, although densities of fish did not increase with pool area, overall numbers of fish were nonetheless greater in larger pools (while density remained relatively constant). It could have been possible that larger pools had characteristics that led to both greater abundance *and* density of juvenile Coho Salmon, and similar associations have been reported elsewhere (Roni and Quinn 2001, Whiteway et al. 2010).

Although we hypothesized that abundance of juvenile Coho Salmon should be positively associated with the proportion of substrate composed of cobble or boulder (Table 1), we found the reverse to be true (Table 5). This reversal may be due to the fact that predators such as Coastal Cutthroat Trout and Coastal Giant Salamander (*Dicamptodon tenebrosus*) also rely on larger cobbles and boulders for cover during low flows in summer (Andersen 2008, Leuthold et al. 2012). This explanation however is partly countered by the fact that we observed no relationship between abundance of juvenile Coho Salmon and the biomass of Coastal Cutthroat Trout in pools. Further evaluation of these relationships in a more experimental setting that would allow for more precise control over variability in the population of predators and instream cover (cobbles and boulders) would be valuable in better resolving these relationships.

Most of the variables we hypothesized to be important for juvenile Coho Salmon (Table 1) were not associated with their abundance. Abundance of juvenile Coho Salmon was not associated with biomass of juvenile Steelhead, which may be expected since juvenile Coho Salmon have been found to exclude young Steelhead and Coastal Cutthroat Trout from pools during the summer, due to the fact that juvenile Coho Salmon are naturally larger (by virtue of their earlier timing of emergence) and competitively dominant to Steelhead (Hartman 1965; Glova 1986; Young 2004). The lack of expected relationships between juvenile Coho Salmon abundance and geomorphic variables other than pool area (i.e., bankfull width to depth ratio and residual pool depth) may indicate that juvenile Coho Salmon respond more to contemporary habitat conditions (as indicated by pool area at the time of sampling). Residual pool depth, which indicates zero-flow conditions (Lisle 1987) and bankfull width to depth ratio, may be considered to represent habitat available to juvenile Coho Salmon at higher flows given that wider and shallower areas may be indicative of side channels and low velocity refugia which are positively correlated with juvenile survival (Moore and Gregory 1988, Nickelson et al. 1992b., Solazzi et al. 2000).

Larval Lamprey

Our findings indicate that larval lamprey are more prevalent in pools with greater surface area of fine sediment and deeper (> 10cm deep) substrate. The association we observed with fine sediment agrees with results of studies of the larvae of other lampreys, including Southern Brook Lamprey (*Ichthyomyzon gagei*, Beamish and Jebbink 1994), American Brook lamprey (*Lethenteron appendix (*formerl*y Lampetra appendi)* Beamish and Lowartz 1996), Sea Lamprey (*Petromyzon marinus*), Least Brook Lamprey (*Lampetra aepyptera*, Smith et al. 2011), Far Eastern Brook Lamprey (*Lethenteron reissneri*, Sugiyama and Goto 2002), as well as Pacific Lamprey (Roni 2003,Torgersen and Close 2004, Claire et al 2007). Favorable conditions also include areas with eddies or backwaters, the inside of bends, or behind obstructions, and where organic matter accumulates (Hardisty and Potter 1971). Associations we observed with deeper substrate were also similar to results from studies of other larval lampreys (European Brook Lamprey *Lampetra planeri,* Goodwin et al 2008*;* European River Lamprey *Lampetra fluviatilis*, Goodwin et al 2008, and Aronsuu and Virkkala 2013). Additionally, we found that ammocoetes and transformers were associated with similar habitat conditions (Figure 3). We did not consider composition of sediment in quantifying sediment depths in Little Wolf Creek, but sand was present throughout our study area and larger particles were generally embedded in fine sand or silt. Aronsuu and Virkkala (2013) found that larger lamprey avoided larger substrates for constructing burrows when they were not embedded in finer particles. In summary, larval lamprey in this study appeared to use habitats that are very similar to other lamprey species and similar work on species considered herein. These commonalities likely result from similarities in the body plans of the larvae of different lamprey species and their common need to construct burrows in fine sediment.

Impacts of Large Wood on Habitat Factors Selected by Fish

Large wood within pool and pools formed by large wood were associated with habitat features linked to the abundance of juvenile Coho Salmon and presence of larval lamprey. We found that pools with wood compared to pools without wood had larger pool areas, and more fine and deeper substrate. Pools with wood as the pool-forming feature had more fine and deep substrate but not larger pool areas when compared to pools formed by other means. Our findings also suggest that the presence of wood in the stream may have created pools where none existed previously (Roni 2003, Mossop and Bradford 2004, Allan and Castillo 2008).

These results are consistent with past research which shows that instream large wood plays an important role in changing channel morphology, forming pools, retaining organic matter, gravel, and sediment (Cederholm et al 1997, Allan and Castillo 2008). Large wood has also been shown to increase pool area within streams (Bilby and Ward 1989), and in small forested streams large wood has been reported to create up to 59-90%

of all pools (Dolloff and Warren 2005, Andrus et al. 1988, Hedman 1996). Little Wolf Creek is dominated by Tyee sandstone which is highly erodible and results in a rich supply of fine sediment (O'Connor et al 2014) that is easily transported out of the system in the absence of structures such as large wood (Montgomery et al 2003).

CHAPTER 5 –Conclusion

Although earlier work in Little Wolf Creek did not find clear relationships between large wood and spawning habitat selection by adult Coho Salmon (Clark et al. 2014). In contrast, results of this study suggest that juvenile life stage (actually produced by adults studied by Clark et al. 2014) of this species responds positively to habitat conditions associated with large wood. This finding is consistent with other work indicating that large wood restoration can 1) improve habitat conditions likely to benefit juvenile Coho Salmon in winter (Jones et al. 2014, Roni et al. 2014), 2) increase overwinter survival (Solazzi 2000), and 3) increase abundance in summer (Johnson 2005). Furthermore, our work shows that larval lamprey may also benefit from increased retention of fine sediment linked to effects of large wood and large wood restoration (see also Nagayama et al. 2008, and Roni 2003). This retention may be particularly important in streams draining basins with a high supply of fine sediment (O'Connor et al. 2014). Accordingly, we provide support for the general finding that large wood restoration can benefit juvenile Coho Salmon, but also larval lamprey in some geomorphic contexts. Whereas our study was able to evaluate the short-term influences of large wood on fish and habitat, the question of responses over longer time frames still remains. A recent study of multiple large wood restoration projects in the Oregon Coast Range indicates a net loss of wood over relatively short time frames (6 yr) due to a lack of natural wood recruitment, presumably with loss of benefits of large wood (Jones et al 2014). These findings, in concert with other work on patterns of natural wood recruitment in streams (e.g., Burnett and Miller 2007, Meleason 2003, McDade 1990) indicate that restoration of large wood in streams over longer time frames may be more tied to restoration of the process of wood recruitment and less on active placement of wood in streams.

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APPENDICES

TABLE A.1 Individual pool salmonid data in pools included in analyses of fish-habitat relationships in Little Wolf Creek

Habitat unit	Pool area (m^2)	Juvenile Coho Salmon abundance (fish/pool)	Juvenile Coho Salmon density (fish /m2)	Average juvenile Coho Salmon biomass (g)	Average juvenile Coho Salmon length (mm)	Average Steelhead biomass (g)	Average Coastal Cutthroat Trout biomass (g)
1	73.3	49.27	0.67	2.86	56.28	29.36	274.5
3	235.27	329.15	1.4	2.18	52.9	0	247.85
5	100.92	160.15	1.59	2.32	52.82	165.4	0
13	131.05	170.82	1.3	1.89	46.52	0	0
18	125.95	40	0.32	2.78	57.36	148.09	203.74
20	38.54	24.14	0.63	1.56	46.36	0	0
21	123.18	142	1.15	2.29	50.39	30.98	150.78
28	102.04	145.74	1.43	2.03	49.87	22.4	0
31	126.82	93.5	0.74	2.09	53.17	57	74.58
32	477.6	278.51	0.58	2.27	51.61	0	295.71
36	73.93	25.56	0.35	2.32	52.88	0	0
39	50.88	32	0.63	2.46	55.38	89.92	0
50	105.82	176.55	1.67	2.21	54.34	0	0
52	18	25.67	1.43	3.04	57.61	0	0
61	30.1	31	1.03	2.13	53.24	70.1	53.2
63	90.26	54	0.6	2.02	49.38	0	0
67	165.14	154.69	0.94	2.41	53.65	80.14	98.4
70	75.34	95.19	1.26	2.68	56.09	105.6	208.88
72	70.26	77.67	1.11	2.1	52.71	73.34	0
76	117.16	49.19	0.42	2.58	57.64	0	0
84	83.72	72.33	0.86	2.66	55.93	78.49	141.1

86	51.02	84.75	1.66	2.48	55.29	146.2	0
91	43.11	31.06	0.72	2.23	53.8	9.77	140.7
96	81.02	96.85	1.2	2.24	52.05	73.83	0
102	109.32	156.17	1.43	2.15	53.05	75.3	163.28
112	120.52	67.31	0.56	2.48	53.81	73.87	0
121	25.64	49.63	1.94	1.9	49.65	0	0
123	60.94	51.58	0.85	1.84	49.4	9.1	0
133	29.44	27.33	0.93	2.02	51.24	0	0
134	210.69	90.67	0.43	2.1	49.56	0	0
143	104	141.92	1.36	2.02	51.8	0	0
145	37.46	47.88	1.28	2.53	54.7	0	70.44
147	119.78	124.7	1.04	2.41	52.05	0	0
153	34.16	51.84	1.52	2.07	52.15	23.1	0
154	42.53	39	0.92	3.06	57.24	31.95	212.93
160	189.92	227.57	1.2	2.09	50.42	40.8	173.53
165	186.86	259.4	1.39	1.56	46.65	0	0
167	101.06	105.67	1.05	1.86	52.27	33.6	0
169	139.16	216.58	1.56	2.36	53.4	42.86	260.64
174	123.63	99.33	0.8	2.52	51.55	0	283.01
175	80.2	126.7	1.58	2.3	51.5	90.64	44.4
179	22	19	0.86	2.35	50.92	0	0
183	155.56	140.33	0.9	2.16	51.2	0	0
188	101.15	86.08	0.85	3.26	54.84	0	230.08

TABLE A.2 Individual Lamprey presence absence data collected in pools included in analyses of fish-habitat relationships in Little Wolf Creek (1= presence, 0=absence).

Habitat Unit	All lamprey	Ammocoetes	Transformers	Average ammocoete length (mm)	Average transformer length (mm)	Average transformer Weight (g)
1	1	1	1	126.13	140.86	5.46
3	1	1	1	86.60	131.31	4.26
5	1	1	0	105.83	-	-
7	1	1	0	80.00	-	-
9	1	1	0	95.00	-	-
13	1	1	0	136.00	-	-
15	0	0	0	-	-	-
18	1	1	1	99.45	134.89	4.67
20	1	1	0	122.00	-	-
21	1	1	0	130.33	-	-
24	1	1	0	109.00	-	-
25	1	0	0	17.50	-	-
28	1	1	1	66.11	164.00	8.60
31	1	1	0	112.71	-	-
32	1	1	0	102.95	-	-
33	1	1	0	86.25	-	-
35	1	1	0	112.00	-	-
36	0	0	0	-	-	-
37	1	1	0	104.00	-	-
39	1	1	0	125.00	-	-
40	0	0	0		-	-
42	1	1	0	74.60	-	-

45	1	1	0	34.80	-	-
48	1	1	0	65.20	-	-
50	0	0	0	-	-	-
52	0	0	0		-	-
55	1	1	0	155.00	-	-
57	0	0	0	-	-	-
59	1	1	0	146.50	-	-
61	1	1	0	136.00	-	-
63	1	1	0	129.00	-	-
65	0	0	0	-	-	-
67	1	1	0	154.50	-	-
69	1	1	0	72.08	-	-
70	1	1	1	95.13	131.00	4.70
72	1	0	0	144.00	-	-
74	0	0	0	-	-	-
76	0	0	0	-	-	-
78	0	0	0	-	-	-
84	1	1	0	134.33	-	-
86	1	1	1	111.31	143.00	5.93
89	1	1	0	97.69	-	-
91	1	1	0	132.83	-	-
93	1	1	0	53.75	-	-
95	1	1	1	60.00	139.00	4.30
96	1	1	1	107.95	131.36	4.41
98	1	0	1	-	132.00	4.20
100	0	0	0	-	-	-
102	1	1	0	131.00	-	-
104	0	0	0		-	-

107	1	1	0	87.43	-	-
110	1	1	0	79.50	-	-
112	1	1	0	111.53	-	-
114	1	1	0	94.00	-	-
116	1	1	0	99.00	-	-
119	1	1	0	79.75	-	-
121	0	0	0	-	-	-
123	1	1	0	101.50	-	-
125	1	1	0	58.60	-	-
129	0	0	0	-	-	-
131	0	0	0	-	-	-
133	1	1	0	89.50	-	-
134	1	1	0	65.57	-	-
135	1	1	0	102.67	-	-
137	1	1	0	86.89	-	-
139	1	1	0	78.63	-	-
141	0	0	0	-	-	-
143	1	1	0	134.20	-	-
145	1	1	0	141.00	-	-
147	1	1	0	114.43	-	-
152	0	0	0	-	-	-
153	1	1	0	105.38	-	-
154	1	1	0	109.86	-	-
156	1	1	0	43.00	-	-
158	1	1	1	79.50	132.00	4.30
160	1	1	0	112.18	-	-
162	1	1	0	38.77	-	-
163	1	1	0	86.67	-	-

165	0	0	0	-	-	-
167	1	1	0	98.40	-	-
169	1	1	0	69.06	-	-
172	0	0	0	-	-	-
174	1	1	0	111.23	-	-
175	1	1	1	113.83	155.00	5.83
177	1	1	0	115.00	-	-
179	0	0	0	-	-	-
180	1	0	0	74.00	-	-
182	0	0	0	-	-	-
183	1	1	0	129.67	-	-
185	1	0	1	-	124.00	3.50
187	1	1	0	61.00	-	-
188	1	1	1	100.92	126.95	3.86

*Average ammocoete weight is not included due to some ammocoetes being to light for their weight to be calculated with our scale

TABLE A.3 Characteristics of substrate in pools included in analyses of fish-habitat relationships in Little Wolf Creek.

Habitat Unit	Bedrock	Boulder	Proportion Cobble	Fines	Gravel	Large wood	Organic Debris	Area x proportion fines	Area with substrate >10cm deep
1	0.21	0.04	0.04	0.61	0.04	0	0.07	44.5	2.62
3	0.35	0.01	0.04	0.46	0.13	0	0.01	109.23	46.21
5	0.44	0.06	0.06	0.38	0.02	0	0.04	37.85	16.82
7	0.78	0	0	0.22	0	0	0	30.52	2.35
9	0.75	0	0	0.25	0	0	0	10.59	1.76
13	0.12	0	0	0.81	0.07	0	0	106	40.47
15	0.56	0	0.01	0.31	0.09	0	0.03	32.12	3.06
18	0.21	0.1	0.16	0.29	0.16	0	0.07	37.04	3.7
20	0	0	0.23	0.23	0.4	0	0.15	8.67	2.89
21	0.32	0.04	0.04	0.51	0.03	0.07	0	63.21	55.11
24	0.61	0	0.07	0.25	0.08	0	0	30.6	4.83
25	0.76	0.01	0.04	0.08	0.08	0	0.03	8.95	0
28	0	0	0	1	0	0	0	102.04	29.54
31	0	0.06	0.28	0.56	0.08	0.03	0	70.46	38.75
32	0.31	0	0.02	0.5	0.16	0	0	238.8	154.78
33	0.37	0.02	0.03	0.42	0.13	0.02	0.02	31.12	2.49
35	0.17	0.08	0	0.25	0.44	0	0.06	16.83	26.17
36	0.31	0.1	0.1	0.06	0.43	0	0	4.35	7.61
37	0.53	0.13	0.13	0.06	0.16	0	0	2.36	1.18
39	0.08	0.08	0.08	0.17	0.58	0	0	8.48	2.83
40	0.02	0.13	0.1	0	0.75	0	0	0	0
42	0.45	0.01	0.21	0.29	0.04	0	0	39.69	18.98
45	0.72	0.05	0.07	0.12	0.03	0	0.02	7.76	0

48	0	0.03	0.19	0.38	0.33	0	0.08	36.11	9.03
50	0.42	0.03	0.18	0.1	0.24	0	0.04	10.72	0
52	0.89	0	0	0.11	0	0	0	2	0
55	0.25	0.13	0	0.44	0.13	0	0.06	6.25	5.36
57	0.83	0.08	0	0	0.08	0	0	0	0
59	0.61	0	0.04	0.11	0.25	0	0	4.05	2.7
61	0.57	0	0.07	0.14	0.21	0	0	4.3	0
63	0.2	0.1	0.35	0.1	0.24	0	0.01	8.9	2.51
65	0	0.08	0.67	0.08	0.17	0	0	0.92	0
67	0.11	0.1	0.2	0.21	0.36	0.02	0	35.39	15.73
69	0.02	0.05	0.25	0.45	0.23	0	0	92.95	23.24
70	0.14	0.09	0.06	0.57	0.14	0	0	43.05	16.74
72	0.02	0.25	0.32	0.34	0.07	0	0	23.95	3.19
74	0.56	0.25	0.13	0.06	0	0	0	0.9	0
76	0.3	0.09	0.07	0.53	0	0	0	62.67	29.29
78	0.33	0.08	0.5	0.08	0	0	0	0.47	0
84	0.56	0.06	0.06	0.31	0	0	0	26.16	3.92
86	0.54	0	0.08	0.23	0.02	0.06	0.06	11.69	2.13
89	0.25	0.06	0.01	0.53	0.09	0	0.06	41.22	12.6
91	0.05	0.07	0.32	0.32	0.16	0.02	0.07	13.72	11.76
93	0.15	0.04	0.13	0.5	0.19	0	0	14.59	2.43
95	0.27	0.1	0.07	0.42	0.13	0.02	0	37.38	16.45
96	0.31	0.06	0.02	0.27	0.23	0	0.1	21.94	11.82
98	0.36	0.07	0.04	0.43	0.11	0	0	36.81	13.81
100	0.73	0	0.15	0.08	0.05	0	0	4.16	0
102	0.34	0.08	0.06	0.43	0.09	0	0	47.21	13.67
104	0.46	0	0.04	0.18	0.32	0	0	4.5	1.8

107	0.5	0.02	0.05	0.17	0.27	0	0	14	3.82
110	0.28	0	0.06	0.39	0.25	0.03	0	24.29	8.68
112	0.51	0.01	0	0.43	0.05	0	0	51.87	15.07
114	0.7	0	0.03	0.13	0.08	0.02	0.03	18.6	1.58
116	0.8	0	0	0.12	0.08	0	0	14.49	0
119	0.13	0.14	0.02	0.16	0.54	0	0.02	8.73	7.76
121	0	0	0.03	0.31	0.66	0	0	8.01	11.22
123	0.05	0	0	0.4	0.55	0	0	24.38	30.47
125	0.64	0.01	0	0.16	0.16	0	0.03	30.02	22.12
129	0.52	0.02	0.08	0.19	0.17	0	0.02	15.14	1.51
131	0.33	0.17	0.33	0	0.17	0	0	0	0
133	0	0.25	0.18	0.21	0.36	0	0	6.31	3.15
134	0.44	0.01	0.07	0.31	0.15	0	0.01	65.06	7.75
135	0.56	0	0.15	0.23	0.06	0	0	17.17	9.37
137	0.59	0.01	0.05	0.26	0.07	0	0.02	34.72	7.55
139	0.34	0.16	0.12	0.3	0.08	0	0.01	61.15	7.89
141	0.89	0	0	0.11	0	0	0	6.07	0
143	0.72	0.01	0.01	0.07	0.18	0	0	7.65	9.18
145	0	0	0.11	0.13	0.77	0	0	4.68	13.38
147	0.27	0.07	0.09	0.41	0.14	0	0.02	49.2	23.53
152	0	0	0.19	0.31	0.44	0.06	0	2.87	1.15
153	0.33	0.15	0.23	0.23	0.08	0	0	7.69	0
154	0.13	0.22	0.03	0.47	0.06	0	0.09	19.94	6.65
156	0	0.1	0.05	0.5	0.25	0	0.1	8.49	2.55
158	0	0.04	0.04	0.29	0.58	0	0.04	4.86	4.17
160	0.18	0	0.04	0.38	0.4	0	0.01	71.22	44.09
162	0.35	0.05	0.06	0.12	0.4	0	0.02	34.69	20.24

163	0.56	0.03	0.03	0.06	0.33	0	0	6.95	2.78
165	0.72	0	0.02	0.06	0.19	0	0	12.06	4.52
167	0.9	0	0.02	0.05	0.02	0	0.01	4.59	0
169	0.66	0.01	0.05	0.14	0.13	0	0	19.66	0
172	0.25	0.04	0	0.36	0.36	0	0	9.95	1.99
174	0.18	0.04	0.23	0.14	0.41	0	0	17.66	30.91
175	0.24	0.19	0.15	0.18	0.22	0	0.01	14.48	2.23
177	0.22	0.22	0.19	0.06	0.28	0	0.03	1.47	0.74
179	0	0.39	0.21	0.11	0.29	0	0	2.36	0
180	0	0.2	0.3	0.2	0.25	0.02	0.02	9.25	1.03
182	0	0	0	0.55	0.25	0.03	0.18	14	10.82
183	0.53	0.01	0	0.12	0.33	0	0.02	18.06	10.73
185	0	0.02	0.2	0.14	0.61	0	0.03	12.25	20.41
187	0.02	0.08	0.21	0.44	0.19	0.04	0.02	36.77	9.59
188	0.19	0	0.04	0.54	0.23	0	0.01	54.37	21.49

Table A.4 Distances of each study pool to the mouth of Little Wolf Creek, the feature forming each pool, area and maximum depth of pools, ratio of bankfull width (cm) to bankfull height (cm), residual pool depth, and presence of wood

Habitat unit	Distance to mouth of stream	Pool forming feature	Area (m2)	Max Depth (cm)	Bankfull width /BF height	Residual pool depth (cm)	Wood presence
1	561.00	Wood	73.30	55.00	6.41	48	1
3	600.50	Bedrock	235.27	57.00	10.76	44	0
5	640.40	Bedrock	100.92	78.00	11.82	55	0
7	663.70	Bedrock	140.84	35.00	10.02	25	0
9	686.60	Wood	42.34	40.00	8.34	27	1
13	755.20	Wood	131.05	43.00	11.92	18	0
15	818.70	Bedrock	104.00	43.00	9.77	29	0
18	839.60	Bedrock	125.95	65.00	17.08	45	1
20	839.60	Wood	38.54	27.00	12.00	7	0
21	862.80	Wood	123.18	52.00	9.60	22	1
24	910.60	Bedrock	122.40	39.00	7.91	26	0
25	929.60	Bedrock	113.36	32.00	8.33	17	0
28	984.00	Wood	102.04	51.00	12.98	38	1
31	1043.80	Wood	126.82	52.00	7.76	37	1
32	1052.20	Bedrock	477.60	65.00	6.53	48	0
33	1113.80	Wood	74.68	47.00	10.00	17	1
35	1154.90	Channel Curvature	67.30	36.00	14.02	28	0
36	1166.70	Channel Curvature	73.93	50.00	9.39	34	0
37	1183.50	Wood	37.78	64.00	10.24	42	1

39	1195.70	Wood	50.88	47.00	9.37	27	1
40	1201.90	Wood	46.70	80.00	9.21	46	0
42	1230.00	Bedrock	138.04	52.00	21.44	39	1
45	1279.10	Bedrock	66.55	44.00	13.35	33	1
48	1323.70	Root Defended Bank/ close walls	96.30	68.00	5.88	49	1
50	1361.60	concrete/ Bedrock	105.82	52.00	5.87	42	0
52	1379.80	concrete	18.00	43.00	7.42	39	0
55	1388.00	Bedrock	14.28	36.00	4.22	30	0
57	1408.20	Bedrock	13.36	41.00	6.60	27	0
59	1425.90	Bedrock	37.80	47.00	2.98	36	1
61	1446.80	Bedrock	30.10	40.00	2.81	24	0
63	1462.90	Bedrock	90.26	56.00	5.40	47	1
65	1500.00	Boulder	11.07	37.00	5.66	21	0
67	1523.40	Wood	165.14	97.00	7.70	76	1
69	1530.20	Wood	204.48	59.00	18.47	45	1
70	1556.10	Wood	75.34	70.00	8.88	48	1
72	1589.80	Bedrock	70.26	58.00	10.07	38	1
74	1600.10	Bedrock	14.35	49.00	7.10	24	0
76	1622.80	Bedrock	117.16	147.00	8.10	119	1
78	1647.80	Bedrock	5.58	59.00	2.59	43	0
84	1709.80	Bedrock	83.72	62.00	5.38	47	1
86	1735.69	Wood	51.02	44.00	10.41	30	1
89	1763.40	Bedrock	77.86	68.00	10.72	45	0

91	1807.00	Channel Curvature	43.11	52.00	24.14	38	1
93	1798.10	Root Defended Bank	29.18	33.00	11.15	21	0
95	1821.80	Bedrock	89.70	108.00	9.74	73	1
96	1838.00	Bedrock	81.02	60.00	9.06	47	0
98	1904.50	Bedrock	85.90	42.00	11.49	30	1
100	1922.70	Bedrock	55.51	33.00	9.53	21	0
102	1953.40	Bedrock	109.32	49.00	5.68	18	1
104	1979.80	Bedrock	25.20	36.00	5.00	21	0
107	2024.80	Bedrock	81.45	49.00	6.73	38	1
110	2050.90	Wood	62.46	61.00	8.58	45	1
112	2083.90	Bedrock	120.52	58.00	10.19	43	1
114	2165.60	Wood	145.42	44.00	7.65	34	1
116	2209.50	Bedrock	122.36	37.00	8.29	25	0
119	2252.40	Wood	54.30	58.00	12.13	48	1
121	2269.90	Wood	25.64	36.00	15.11	25	0
123	2290.40	Boulder	60.94	52.00	9.82	32	0
125	2309.00	Bedrock	183.30	72.00	6.83	49	0
129	2394.80	Bedrock	78.74	42.00	12.04	16	1
131	2431.40	Bedrock	8.08	40.00	11.35	26	0
133	2435.40	Root Defended Bank	29.44	62.00	10.17	45	1
134	2441.10	Bedrock	210.69	92.00	9.80	77	1
135	2476.00	Bedrock	74.93	84.00	7.97	72	1

137	2510.00	Bedrock	132.86	51.00	8.77	43	1
139	2542.10	Root Defended Bank	205.14	64.00	9.10	41	1
141	2581.20	Bedrock/Root defended bank	54.66	40.00	12.22	30	1
143	2600.90	Bedrock	104.00	52.00	9.97	41	1
145	2632.90	Root Defended Bank	37.46	62.00	12.39	16	0
147	2638.20	Boulder & rootwad	119.78	85.00	12.18	70	1
152	2708.60	Wood	9.18	20.00	10.21	7	0
153	2756.30	Bedrock	34.16	42.00	14.20	29	1
154	2768.40	Wood	42.53	74.00	15.71	46	1
156	2793.00	Channel Curvature	16.98	48.00	8.48	33	0
158	2823.30	Root Defended Bank	16.66	38.00	8.91	30	1
160	2866.30	Stump/Wood	189.92	96.00	16.87	71	1
162	910.00	Bedrock	283.30	69.00	7.22	56	1

163	2946.00	Bedrock/Root defended bank	111.22	41.00	9.49	36	0
165	2969.30	Bedrock	186.86	37.00	8.73	11	1
167	3011.90	Bedrock	101.06	38.00	11.68	32	0
169	3052.60	Bedrock	139.16	45.00	8.02	24	0
172	3102.40	Bedrock	27.87	47.00	13.20	38	1
174	3119.00	Wood	123.63	83.00	11.63	68	1
175	3131.20	Wood/Bedrock	80.20	46.00	9.43	28	1
177	3149.00	Boulder	26.46	53.00	7.31	41	0
179	3159.10	Boulder	22.00	89.00	6.91	63	0
180	3154.50	Boulder	45.20	55.00	9.66	36	1
182	3189.60		25.46	63.00	13.07	51	1
183	3208.60	Bedrock	155.56	40.00	9.31	24	1
185	3246.10	Root defended Bank	87.10	101.00	12.35	93	1
187	3271.20	Wood	83.13	68.00	15.31	46	1
188	3284.70	Wood	101.15	67.00	6.18	51	1

Large wood summary data

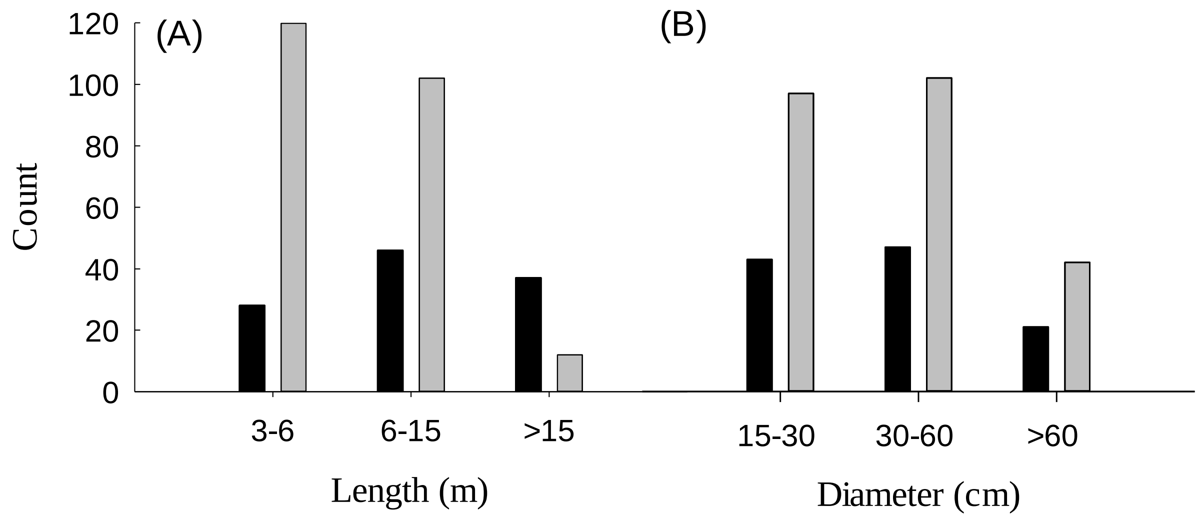

Figure A.1. Comparison of artificial (black) and natural wood (grey) and wood length (A) and diameter (B) in all pools sampled (n = 352 pieces of wood). Natural and Artificial wood varied in length (X^2=56.9, P<0.001, df=2) but did not vary in diameter (X^2=0.138, P=0.93, df=2).

TABLE A.5 Diameter (D) and length (L) bins used to classify wood in Little Wolf Creek.

	3 to 6L 15&30D	6 to 15L & 15-30D	>15L& 15-30D	3 to 6L &30-60D	6 to15& 30-60D	>15Land 30-60D	3 to 6L &>60D	6 to 15L &>60D	>15L &>60D
Artificial	18	22	3	10	18	19	0	6	15
Natural	63	30	4	45	49	8	19	23	0