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Responses of Benthic Fishes and Giant Salamanders to Placement of Large Woody Debris in Small Pacific Northwest Streams

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Abstract.—The placement of large woody debris (LWD) to improve or restore habitat for fishes is a common practice in North American streams, and the responses of salmonids to this practice have frequently been examined. In contrast, little information exists on the effects of LWD placement on nonsalmonid fishes and amphibians. In this study, I examined the responses of giant salamanders *Dicamptodon* spp., juvenile lampreyss *Entosphenus tridentatus* and *Lampetra* spp., reticulate sculpins *Cottus perplexus*, and torrent sculpins *C. rhotheus* to artificially placed LWD by sampling 29 small streams with paired treatment and reference reaches. Densities and mean lengths of giant salamanders, reticulate sculpins, torrent sculpins, and lampreyss did not differ significantly between treatment and references reaches. I also examined whether the observed responses were correlated with differences in physical habitat between reference and treatment reaches. Lampreys densities ($\log_{10}$[treatment] − $\log_{10}$[reference]) and length of age-1 and older reticulate sculpins ($\log_{10}$[treatment] − $\log_{10}$[reference]) among streams were positively correlated with LWD within the wetted channel. Lampreys length was also positively correlated with differences in percentages of pool area. These results indicate that artificial LWD placement may benefit lampreys and age-1 and older reticulate sculpins (two species known to prefer pools) but have little effect on other nonsalmonid species.

Enhancement and restoration of aquatic habitats in western North America has focused primarily on improving habitat in small streams for one or two species of salmonid fishes (Reeves et al. 1991). In the Pacific Northwest and many coastal regions with anadromous species, this emphasis on salmonids has produced inconsistent results, because a variety of factors during the marine and freshwater life history stages can influence the abundance and survival of these fish (Hunt 1988; Reeves et al. 1991; Bisson et al. 1992). Chapman (1996) and others have emphasized the need for a more comprehensive evaluation of restoration that includes examining the response of nonsalmonids to habitat enhancement. However, the response of nonsalmonid fishes or other aquatic vertebrates to restoration or enhancement has seldom been examined. Hunt (1988) found that only 1 of 41 stream habitat enhancement projects in Wisconsin examined the response of nonsalmonid fishes. Angermeier and Karr (1984) examined responses of 10 warmwater fishes to wood removal and placement in a small Illinois stream and found that most fish species and age-classes larger than 75 mm were more dense in stream sections with woody debris. Lonzarich and Quinn (1995) found no effect of cover (woody debris) and depth on habitat use, growth, or survival or threespine stickleback *Gasterosteus aculeatus* or coastrange sculpins *Cottus aleuticus* in an artificial stream channel.

The effects of habitat alteration and degradation in streams have been assessed successfully by using fish communities in other parts of North America, particularly the Midwest and southwestern United States (e.g., Gorman and Karr 1978; Schlosser 1982; Fausch and Bramblett 1991). However, most small coastal Pacific Northwest streams are inhabited by three to five species of salmonids, two to three species of sculpins *Cottus* spp., two to three species of lampreys *Lampetra* and *Entosphenus* spp., and one to two species of dace *Rhinichthys* spp. (Wydowski and Whitney 1979; McPhail and Lindsey 1986). Few small streams (less than 12 m bankfull width) in the region are inhabited by more than five to seven species. Physical barriers to migration may further reduce the number of fish species present in reaches of small streams. Little is known about the effects of habitat improvement on these species, but as existing information on habitat preferences suggests, species that prefer pools may respond positively to restoration activities intended to increase pool area and complexity. For example, larval lam-

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preys *Entosphenus tridentatus* and *Lampetra* spp. inhabit the benthos of pools and other slow-water habitats (Wydowski and Whitney 1979; Scott and Crossman 1998) and are likely to be found in greater densities in stream reaches with high percentages of pool area and fine sediment. In contrast, other benthic fishes such as cottids are common in pools and riffles (Wydowski and Whitney 1979; Scott and Crossman 1998), and their response to habitat improvement is unclear. In addition to fishes, giant salamanders *Dicamptodon* spp., a large (up to 300 mm long) benthic predator that inhabits small Pacific Northwest streams, are also known to be sensitive to habitat alterations (Murphy and Hall 1981; Hawkins et al. 1983; Corn and Bury 1989).

The overall objective of my study was to determine if the artificial placement of large woody debris (LWD) causes significant changes in the abundance of local salamanders and benthic fish. Specifically, I tested the null hypotheses that (1) paired treatment and reference (control) reaches would not differ in densities of fish and salamanders, (2) the size of fish and salamanders would not differ between treatment and reference reaches, and (3) the magnitude of fish and salamander response to treatment would not depend on the magnitude of change in habitat

Methods

I used the extensive posttreatment design (Hicks et al. 1991) to compare the response of juvenile salmonids to artificially placed LWD. This design involves comparison between treatment and reference reaches at a large number of sites after restoration and has been used to assess habitat alterations on salmonids (e.g., Murphy and Hall 1981; Grant et al. 1986; Reeves et al. 1993; Roni and Quinn 2001). Twenty-nine streams in western Washington and Oregon (Figure 1) with paired treatment and reference reaches were sampled once in August or September between 1996 and 1998. Treatment was defined as the artificial placement of LWD within the active stream channel. I selected paired treatment and reference reaches 75–120 m long in each stream. Study reaches were at least 10 times longer than the bank-full width; most reaches were 100 m long. Treatment and reference reaches within a given stream were always the same length and typically were 100 m or more apart, though this was not possible at all sites (Table 1).

The selection of study streams with paired treatment–reference reaches was based in part on physical and biological stream characteristics, including stream size, bank-full width, channel type, and fish species composition. Reaches within a stream were selected only if they were of similar slope, width, discharge, and length. The proximity of the reaches ensured that discharges between reaches were essentially identical, though the distribution of point velocities might differ. More than 100 LWD placement projects were examined in western Washington and Oregon, but only 29 had suitable treatment and reference reaches with similar flow, channel width, gradient, confinement, and riparian vegetation. Projects were included only if artificially placed LWD remained in the channel after several high water events, usually over several winters.

To classify habitat units within each stream reach, I used the methods and habitat types described by Roni (2002). The total surface area of each habitat was estimated by measuring the total habitat length and multiplying by the average of three to five measurements of width. Discharge was estimated with a flowmeter immediately after each survey. The diameter class (small: 10–20 cm, medium: 20–50 cm, and large: >50 cm) and length of all pieces of natural and artificially placed LWD within the wetted stream channel that were greater than 10 cm in diameter and 1.5 m long were recorded. The function of an individual piece of LWD was classified into one of three categories based on its influence on pool formation and channel scour: (1) dominant, primary factor contributing to pool formation; (2) secondary, influence on zone of channel scour but not responsible for pool formation; or (3) negligible, possible provider of cover but not involved in scour (Montgomery et al. 1995). In addition, I visually estimated the percentage of each piece of LWD that was in the low-flow wetted channel and within the bank-full channel.

Multiple-removal elecrofishing was used to estimate the abundance of fish and giant salamanders within each habitat unit and stream reach (Carle and Strub 1978). I sampled each habitat separately by placing 3.2-mm-mesh block-nets at the upstream and downstream boundaries to prevent immigration or emigration during electrofishing. Three samples (passes) were removed from each habitat and a fourth was made if fish numbers had not decreased by 50% or more between the second and third passes. All fish captured were anesthetized with tricaine methanesulfonate (MS-222), identified, measured to the nearest millimeter, and then released. Multiple-removal estimates were

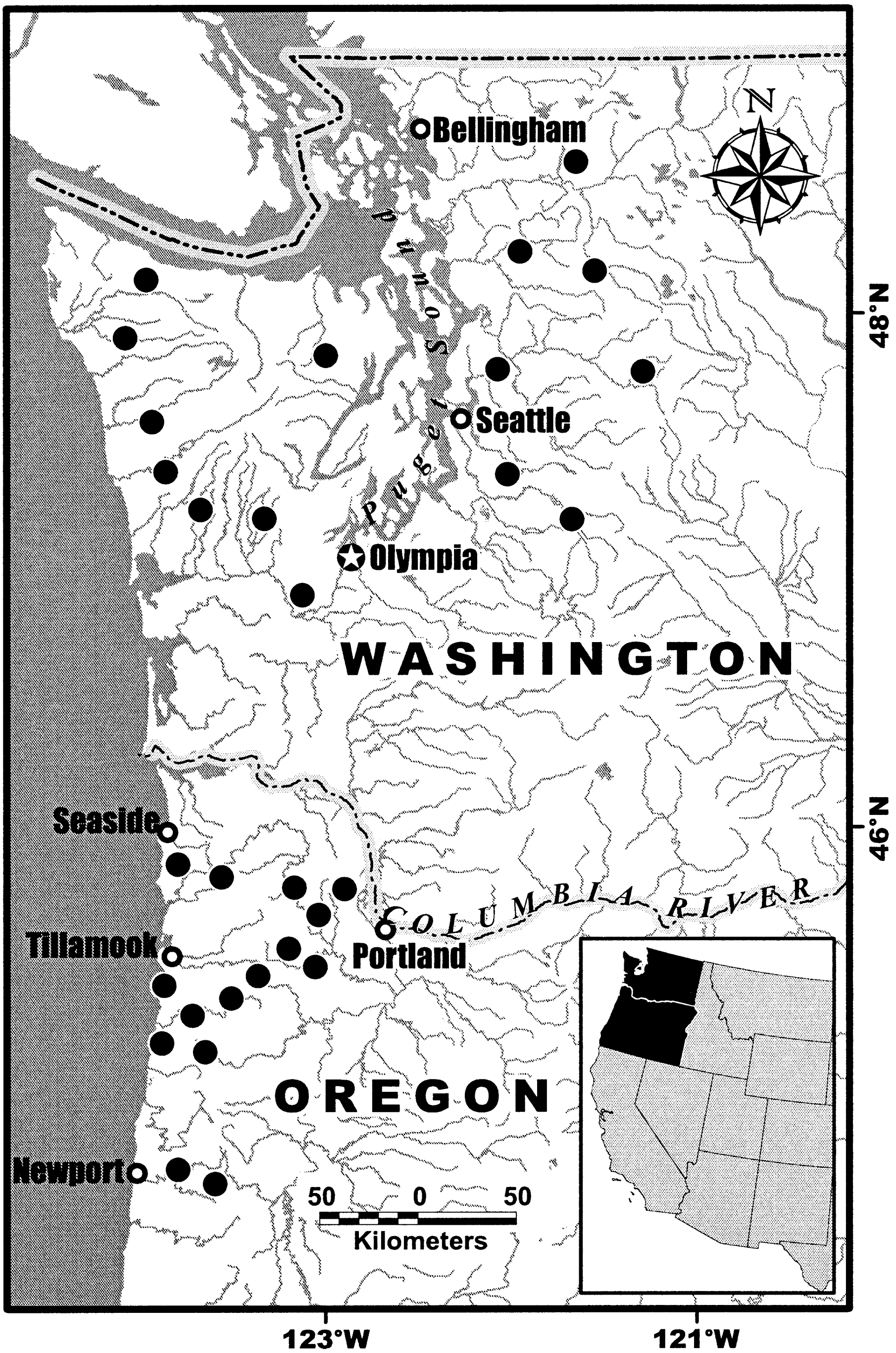

FIGURE 1.—Map of 29 study streams in western Oregon and Washington sampled between 1996 and 1998.

not applied to lampreys because of low capture efficiency (capture probability <0.25 in many habitats). Therefore, I used the total number captured in three removals as an estimate of total abundance for lampreys.

Based on length-frequency distributions, all sculpins larger than 60 mm were considered age-1 and older and all those smaller than 60 mm were considered age-0. Because I could not reliably distinguish between Cope's giant salamander *Di-*

TABLE 1.—Total stream length sampled, distance between study reaches, age of project, and total large woody debris (LWD) in reference (R) and treatment (T) reaches of study streams in western Oregon and Washington. Total LWD was further categorized as pieces that were artificially placed, functioning (creating pools), or in the low-flow wetted channel. Total length sampled represents the combined length of reference and treatment reaches sampled in each stream; reaches within a stream were equal length. Project age represents the number of years between LWD placement and my surveys. Each stream was sampled once in August or September between 1996 and 1998.

Stream and statistic	Total stream length sampled (m)	Distance between reaches (m)	Project age	Artificially placed (T only)	Large woody debris					
					Functioning		In low-flow channel		Total	
					R	T	R	T	R	T
Oregon										
Bear	200	1,500	4	11	1	5	4	18	9	40
Bergsvik	200	100	3	3	0	5	3	18	8	40
Bewley	200	100	3	6	0	2	8	16	11	35
Buster	200	100	2	14	2	3	22	11	41	27
Deer	150	25	3	6	5	4	23	13	34	31
Elliott	220	200	1	12	2	1	8	9	29	57
Farmer	200	100	3	13	0	5	16	18	41	46
Kenusky	200	50	3	6	0	3	11	20	26	66
Killam	200	100	3	8	1	1	4	10	17	39
Klootchie	200	200	3	8	0	3	9	23	27	50
Lobster	200	100	11	6	0	6	14	33	40	70
Louisignont	200	100	2	8	2	6	8	14	18	28
Little Nestucca (South Fork)	210	150	3	10	0	6	7	18	11	39
Rock (North Fork)	200	75	3	7	1	4	8	21	27	48
Tobe	200	100	4	10	0	8	8	28	28	52
Washington										
Beaver	160	200	3	11	7	8	18	37	25	54
Benson	200	300	7	18	2	6	9	14	18	40
Burn	200	75	5	15	2	8	10	56	35	80
French	240	300	6	42	2	8	5	29	23	55
Harris	200	150	12	12	0	9	11	13	22	24
Hoppers	150	25	1	10	5	10	22	33	33	35
Hyas	200	1,000	6	16	0	5	2	21	0	42
Laughing Jacobs	200	50	2	35	2	5	20	14	61	66
Midnight	200	400	4	24	1	9	5	16	27	28
Newbury	200	200	12	9	1	4	1	13	9	20
Porter	200	300	5	22	2	4	12	36	25	62
Punch	200	150	12	9	8	9	33	29	63	59
Shuwah	180	50	1	12	6	9	13	23	38	47
Soosette	200	200	3	28	1	2	5	7	9	48
Paired *t*-tests results										
Test statistic					−7.51		−4.70		−6.76	
P-value					<0.01		<0.01		<0.01	
Degrees of freedom ($n - 1$)					28		28		28	

camptodon copei and Pacific giant salamander *D. tenebrosus*—which may not be separate species (Corkran and Thoms 1996)—I refer to them collectively as giant salamanders. Similarly, I could not reliably distinguish between larval (ammocoetes) Pacific *Entosphenus tridentatus*, river *Lampetra ayresi*, and western brook lampreys *L. richardsoni*, so I refer to these collectively as lampreys.

Differences in habitat, LWD, and abundance and length of fish and salamanders between treatment and reference reaches were compared by using paired *t*-tests. I used a 0.01 level of significance (~0.05 divided by the number of tests on a dataset) to compensate for the large number of *t*-tests (Zar 1999). Fish densities were log-transformed to meet basic assumptions of a *t*-test (normal distribution, equal variances). I used multiple regression to examine the relationship(s) between fish response ($\log_{10}$[treatment density/reference density]) and difference in physical variables, including pool area, total LWD in wetted channel, LWD creating pools, channel slope, and geographic region (Washington or Oregon). Pool area and LWD levels are known to be correlated with abundance and size of salmonid fishes, and geographic region and

TABLE 2.—Physical characteristics of western Oregon and Washington study streams and reaches sampled during August and September 1996–1998 and results of paired *t*-tests for comparison of reference (R) and treatment (T) reaches. The drainage area (area) for a given stream was calculated as total drainage area upstream of the restoration site. Geology and elevation are from unpublished U.S. Geological Survey data. Geology abbreviations are as follows: Ign = igneous, Gla = glacial–fluvial, Vol = volcanic, and Sed = sedimentary. Precipitation, elevation, bankfull width, slope, number of pools, and percent pool area are for the study reaches in each stream.

Stream and statistic	Dominant geology	Elevation (m)	Area (ha)	Precipitation (cm/yr)	Bank-full width (m)		Slope (%)		Number of pool units		Percent pool area	
					R	T	R	T	R	T	R	T
Oregon												
Bear	Vol	244	1,580	320	10.0	10.2	1.2	1.5	3	5	0.29	0.79
Bergsvick	Sed	122	540	308	10.0	8.5	1.0	0.9	4	8	0.81	0.76
Bewley	Sed	12	639	235	6.7	7.0	0.5	1.1	5	7	0.55	0.62
Buster	Sed	232	1,627	228	7.6	8.0	0.8	0.5	5	4	0.89	0.79
Deer	Sed	219	414	169	4.6	4.5	0.4	1.2	9	8	0.86	0.90
Elliott	Vol	427	720	236	10.4	11.6	1.4	2.4	5	7	0.55	0.55
Farmer	Sed	73	727	260	7.1	7.4	1.8	1.6	4	4	0.34	0.42
Kenusky	Vol	207	1,158	167	6.4	6.4	1.5	1.2	7	6	0.65	0.64
Killam	Vol	110	863	298	7.0	11.6	3.2	3.0	5	4	0.37	0.49
Klootchie	Sed	61	1,011	299	9.3	8.4	2.2	1.9	5	8	0.36	0.64
Lobster	Sed	207	1,254	233	9.3	10.5	1.8	1.7	4	8	0.44	0.65
Louisignont	Vol	244	1,715	201	10.1	9.1	0.8	0.6	6	8	0.78	0.85
Little Nestucca (South Fork)	Sed	122	981	250	9.3	9.9	0.9	1.6	4	8	0.25	0.77
Rock (North Fork)	Vol	390	1,893	286	9.8	10.0	1.3	0.7	3	6	0.25	0.52
Tobe	Vol	165	680	236	5.9	5.8	2.5	2.8	4	6	0.38	0.51
Washington												
Beaver	Gla	233	124	189	5.8	5.1	1.8	2.3	8	7	0.72	0.74
Benson	Sed	320	459	217	12.3	11.0	1.8	1.9	6	4	0.35	0.31
Burn	Sed	481	733	227	6.3	6.4	2.2	2.0	7	6	0.55	0.69
French	Ign	172	1,783	213	16.4	16.6	2.3	2.2	2	6	0.18	0.25
Harris	Vol	292	311	354	7.3	7.0	1.1	1.0	5	6	0.29	0.66
Hoppers	Vol	73	467	269	4.3	4.1	0.8	0.7	5	10	0.78	0.96
Hyas	Sed	121	2,000	290	11.2	13.2	1.3	0.7	1	4	0.36	0.59
Laughing Jacobs	Gla	23	335	119	7.2	6.3	2.5	2.3	5	7	0.19	0.38
Midnight	Ign	598	567	212	5.4	5.8	3.9	4.5	4	6	0.31	0.34
Newbury	Vol	170	302	317	5.6	6.0	1.8	1.9	6	6	0.45	0.46
Porter	Vol	122	2,388	170	9.9	10.1	1.3	2.3	3	4	0.56	0.67
Punch	Sed	110	271	353	7.6	9.4	3.6	3.2	11	12	0.53	0.44
Shuwah	Sed	197	305	297	6.5	6.5	1.4	1.9	7	6	0.56	0.80
Soosette	Gla	45	1,225	108	8.7	13.5	1.7	1.7	2	5	0.19	0.29
Paired *t*-test results												
Test statistic					−1.55		−1.02		−3.85		−4.52	
P-value					0.13		0.32		<0.01		<0.01	
Degrees of freedom ($n - 1$)					28		28		28		28	

differences in LWD placement techniques (structure type) are thought to affect fish response to LWD (Roni and Quinn 2001). Sites with larger physical responses to restoration were predicted to have larger vertebrate responses. All ratios of treatment to reference (e.g., pool area, pieces of LWD) were also log-transformed ($\log_{10}x$) to normalize residuals and meet statistical assumptions of linear regression.

Results

The study streams ranged from 4 to 12 m in bank-full width and from 0.5% to 4.2% slope (Tables 1, 2). Annual precipitation varied from 107 to 315 cm. Predominant forest types were primarily Douglas fir *Pseudotsuga menziesii*, Sitka spruce *Picea sichensis*, and western hemlock *Tsuga heterophylla*. Watershed geology was mostly volcanic, sedimentary, or glacial-fluvial, which varied by site but was consistent for reaches within a stream. Elevation of study sites ranged from 12 to 789 m, and drainage areas upstream of study reaches ranged from 124 to 2,388 ha (Table 2). Treatment and reference reaches were of similar slope and channel width, whereas treated reaches exceeded reference reaches with regard to total pool area and total number of pools (Table 2). Total LWD (n/100 m), total functioning LWD, and total

TABLE 3.—Total number of each species and age-class in reference (R) and treatment (T) reaches in western Oregon and Washington study streams sampled in August or September 1996–1998. Densities (fish/m) can be calculated by dividing the number by the total length sampled (Table 2). Number and density of salmonid fishes captured are reported in Roni (2000). Age 1+ = age 1 and older.

Stream and statistic	Giant salamanders		Larval lampreys		Reticulate sculpins				Torrent sculpins			
					Age 0		Age 1+		Age 0		Age 1+	
	R	T	R	T	R	T	R	T	R	T	R	T
Oregon												
Bear	7	4	5	112	68	90	211	57				
Bergsvick			2	50	39	87	51	53	11	84	30	36
Bewley	1	3	15	38	83	116	106	91				
Buster		2	136	62	36	63	4	18	71	31	33	46
Deer			14	3	73	121	9	15				
Elliott	7	2			78	165	80	131				
Farmer	7	8			66	110	142	152				
Kenusky			31	97	56	83	51	30	20	5	38	23
Killam	1	1			35	26	85	166	27	16	104	151
Klootchie		1	11	134	26	81	45	65	17	29	80	56
Lobster (South Fork)	11	21	46	43	267	269	66	89				
Louisignont	10	4	20	91	77	130	31	39	76	60	36	42
Little Nestucca	5	21	7	88	67	258	51	115				
Rock (North Fork)	10	4			82	66	133	74	4	3	14	6
Tobe	23	37		11	68	142	94	165				
Washington												
Beaver	3	3										
Benson	3	8							63	96	135	92
Burn	12	6										
French	3	24							35	54	113	117
Harris	11	15			33	30	53	29				
Hoppers			38	22	72	29	51	35	22	15	10	23
Hyas			1	15	17	45	17	52	22	60	92	119
Laughing Jacobs	1		6	6					3	3	9	16
Midnight	27	19			33	97	44	136				
Newbury					48	59	74	63				
Porter		10	111	34	79	90	38	42	217	245	165	196
Punch	1		7	17	9	57	8	34	22	58	32	22
Shuwah			28	25	27	4	58	7	19	17	38	13
Soosette			14	2					31	44	70	131
Paired *t*-test results												
Test statistic	−0.99		−2.43		−2.43		−0.84		−0.71		−0.03	
P-value	0.34		0.03		0.02		0.41		0.49		0.98	
Degrees of freedom ($n - 1$)	14		16		22		22		15		15	

LWD in the wetted channel were significantly higher in the treatment reaches than in the reference reaches (Table 1).

Species commonly captured during electofishing included juvenile coho salmon *Oncorhynchus kisutch*, cutthroat trout *O. clarki*, steelhead *O. mykiss*, adult and juvenile torrent sculpins *C. rhotheus*, reticulate sculpins *C. perplexus*, Pacific and Cope's giant salamander, and larval Pacific lampreys, river lampreys, and occasionally brook lampreys. The densities of giant salamanders, lampreys, reticulate sculpins, and torrent sculpins were similar between paired treated and reference reaches of streams (Table 3). Physical habitat variables were not correlated to densities ((log$_{10}$[treatment]—log$_{10}$[reference]) of giant salamander, to age-0 or age-1 and older reticulate sculpins, or to torrent sculpins (Table 4). However, LWD in the wetted channel was positively correlated with lamprey density (Figure 2).

Mean length of fish and salamanders did not differ between treatment and reference reaches for any species (Table 5). The difference in mean length of age-1 and older reticulate sculpins was positively correlated with the difference in LWD in the wetted channel, and the difference in lamprey length was positively correlated with the percentage pool area (Figures 3, 4). Age-0 reticulate sculpin length was correlated (differed) with geographic region but was not correlated with any physical variables (Table 4). No single physical variable or combination of physical variables was

TABLE 4.—Results of stepwise multiple regressions between physical variables and fish and salamander responses to large woody debris (LWD) placement in western Oregon and Washington streams sampled in August and September 1996–1998. The values shown are the *t*-statistic and the *P*-value for each variable. All variables with a *P*-value greater than 0.05 were excluded from the model; asterisks indicate which variables were significant. Age 1+ = age 1 and older.

Variable	Giant salamanders	Larval lampreys	Reticulate sculpins		Torrent sculpins	
			Age 0	Age 1+	Age 0	Age 1+
Density response						
Percent pool area	0.11, 0.91	0.46, 0.65	9.79, 0.34	1.57, 0.14	0.94, 0.37	0.08, 0.94
Total LWD in low-flow channel	0.40, 0.70	4.48, <0.01*	0.13, 0.90	0.41, 0.69	0.87, 0.40	0.18, 0.86
LWD forming pools	1.10, 0.30	1.12, 0.28	0.96, 0.35	0.74, 0.47	0.65, 0.53	0.08, 0.94
Channel slope	1.19, 0.26	0.01, 0.99	0.21, 0.84	0.16, 0.88	0.27, 0.61	0.27, 0.79
Geographic region (state)	1.23, 0.25	2.03, 0.06	0.87, 0.40	0.25, 0.81	1.49, 0.17	0.55, 0.60
Degrees of freedom	14	16	22	22	15	15
Length response						
Percent pool area	0.20, 0.85	4.24, <0.01*	0.09, 0.93	0.60, 0.55	0.98, 0.35	0.27, 0.79
Total LWD in low-flow channel	0.10, 0.93	0.67, 0.52	0.14, 0.89	2.20, 0.04*	0.20, 0.85	0.18, 0.86
LWD forming pools	1.05, 0.33	1.40, 0.19	0.40, 0.70	1.04, 0.31	0.03, 0.97	0.27, 0.79
Channel slope	0.34, 0.74	0.17, 0.87	0.47, 0.64	1.96, 0.06	0.25, 0.81	0.80, 0.44
Geographic region	0.75, 0.48	0.11, 0.92	2.58, 0.02*	1.31, 0.21	0.33, 0.75	0.35, 0.74
Degrees of freedom	12	13	22	22	15	15

correlated with length for any other species (Table 4). The difference in length and the difference in density between treatment and reference reaches were not correlated with each other for giant salamanders (df = 13, $F = 0.18$, $P = 0.06$, $r^2 = 0.27$), lampreys (df = 12, $F = 0.18$, $P = 0.68$, $r^2 = 0.02$), age-0 (df = 21, $F = 0.06$, $P = 0.81$, $r^2 < 0.01$) or age-1 reticulate sculpins (df = 21, $F = 1.69$, $P = 0.21$, $r^2 = 0.08$), or age-1+ torrent sculpins (df = 15, $F = 0.55$, $P = 0.55$, $r^2 = 0.03$). Difference in length was negatively correlated with difference in density for age-0 torrent sculpins (df = 13, $F = 7.26$, $P = 0.02$, $r^2 = 0.38$; length = 0.079 × density− 8.56). However, when the single outlier was removed, no significant relationship was detected (df = 12, $F = 2.19$, $P = 0.17$, $r^2 = 0.17$).

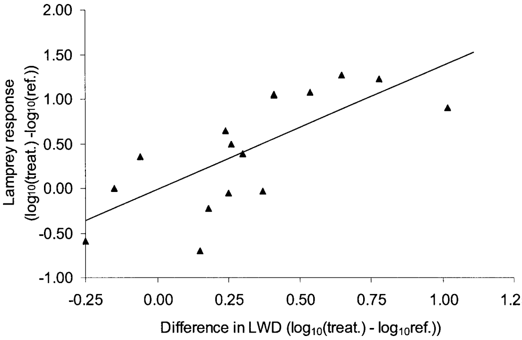

FIGURE 2.—Relationship between difference in lamprey density response to restoration and difference in large woody debris (LWD): lamprey response = 1.391 × LWD− 0.010 ($P < 0.01$, $r^2 = 0.57$).

Discussion

Stream restoration efforts in the Pacific Northwest have focused on salmonid fishes and have assumed that these efforts have little or no positive or negative effect on nonsalmonid fishes (Reeves et al. 1991; Roni 2000). My results from 29 LWD restoration projects support this contention. I found no significant difference in sculpins, giant salamander, or lamprey density or size as a result of LWD placement, though I did observe positive correlations between lampreys and age-0 reticulate sculpin response to LWD and pool area. Several factors may explain the lack of response observed for these species, including habitat preferences of individual species, sample size, or failure to measure physical habitat variables important to each species.

Habitat preferences differ among species and age-classes and have often been used to explain differences in responses of various fishes to habitat alteration (Roni 2002). Pool-dwelling species such as juvenile coho salmon and, to a lesser extent, cutthroat trout respond positively to LWD placement during summer and winter (Cederholm et al. 1997; Roni and Quinn 2001). Juvenile lampreys tend to occupy pools and other slow-water habitats (Wydowski and Whitney 1979; Scott and Crossman 1998). Age-0 and age-1 and older reticulate sculpins also tend to occupy pools, particularly in

TABLE 5.—Average lengths (mm) of fishes and salamanders in reference (R) and treatment (T) reaches of western Oregon and Washington study streams sampled in August and September 1996–1998. Mean length was only calculated if $n > 2$ in a given stream reach. Age 1+ = age 1 and older.

Stream and statistic	Giant salamanders		Larval lampreys		Reticulate sculpins				Torrent sculpins			
					Age 0		Age 1+		Age 0		Age 1+	
	R	T	R	T	R	T	R	T	R	T	R	T
Oregon												
Bear	130	200	90	104	45	45	69	70				
Bergsvick				119	51	49	75	79	53	44	86	92
Bewley		134	98	108	53	54	74	71				
Buster			95	106	47	49	64	67	51	51	87	91
Deer			117	106	47	46	70	65				
Elliott	163				54	53	68	68				
Farmer	151	197			56	55	67	68				
Kenusky			93	93	56	50	68	68	51	52	94	86
Killam					55	57	72	73	48	55	87	86
Klootchie			99	109	55	51	75	78	52	48	93	96
Lobster	149	111	71	87	51	50	67	67				
Louisignont	90	209	128	119	50	48	67	66	47	51	89	82
Little Nestucca	152	144	70	112	50	52	69	75				
Rock	123	127			55	51	68	69	55	41	74	73
Tobe	97	100		128	51	51	72	70				
Washington												
Beaver	155	156										
Benson	141	145							58	56	75	75
Burn	131	186										
French	151	151							55	56	85	89
Harris	103	115			50	47	74	71				
Hoppers			102	113	44	48	84	78	55	56	85	90
Hyas				108	43	48	70	79	35	35	88	81
Laughing Jacobs			111	136					56	56	76	73
Midnight	127	144			48	52	77	78				
Newbury					47	47	72	73				
Porter			101	106	47	45	79	77	52	49	79	83
Punch			131	125	47	48	74	76	54	52	87	81
Shuwah			128	132	47	56	78	72	52	46	83	75
Soosette			107						32	29	89	86
Paired *t*-test results												
Test statistic	−1.89		−2.30		0.31		−0.40		1.30		0.80	
P-value	0.83		0.04		0.76		0.70		0.21		0.44	
Degrees of freedom ($n - 1$)	12		13		22		22		15		15	

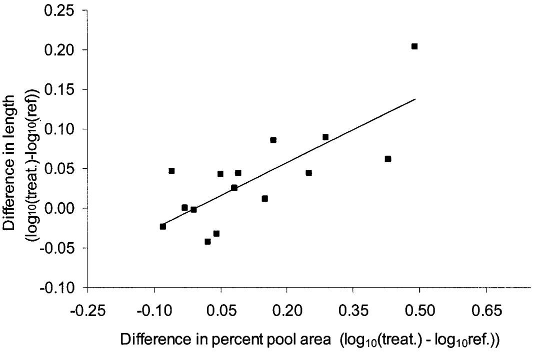

FIGURE 3.—Relationship between difference in lamprey length and difference in percent pool area in 29 study streams sampled between 1996 and 1998: lamprey length response = 0.278 × percent pool area + 0.0011($P < 0.01$, $r^2 = 0.60$).

the presence of torrent sculpins (Bond 1963; Finger 1982; Roni 2002). Thus the lack of significant response by lampreys and reticulate sculpins to LWD placement lampreys was surprising, given the significant increase in pool area between treated and reference reaches and the strong responses detected for other species that prefer pools. However, similar to the response reported for juvenile coho salmon (Roni and Quinn 2001), lamprey response to LWD placement was positively correlated with both LWD and pool area. Woody debris traps fine sediment, reduces velocity, and forms pools (Bisson et al. 1987). Thus a positive relationship between these two physical variables and larval lampreys was predicted, given their affinity for pools and fine sediment. Abundance of reticulate sculpins, another species known to inhabit

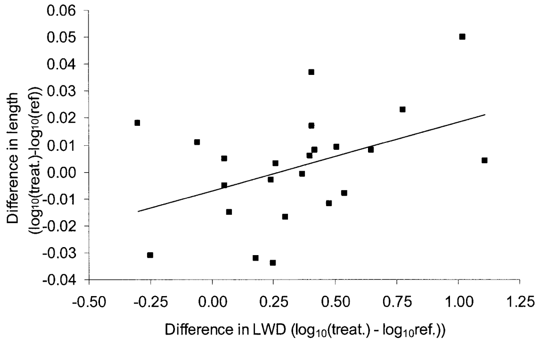

FIGURE 4.—Relationship between difference in mean length of age-1+ reticulate sculpins and difference in large woody debris (LWD) in low-flow channels for 29 study streams sampled between 1996 and 1998: difference in length = $0.0254 \times \text{LWD} - 0.00696$ ($P = 0.04$, $r^2 = 0.19$).

pools, did not seem to respond to wood placement or changes in pool area. However, the difference in the mean length of age-1 and older reticulate sculpins (treatment—reference) was positively correlated with the difference in LWD in the wetted channel. Accordingly, large increases in LWD levels within the active stream channel may increase growth of reticulate sculpins or provide better habitat for larger and older individuals. Presumably this would result from improved feeding opportunities or shelter from predation.

Torrent sculpins and age-0 giant salamanders occupy riffles and fast-water habitats (Wydowski and Whitney 1979; Kelsey 1995). Reduction in riffle area was negatively correlated with steelhead response to restoration (Roni and Quinn 2001), but no relationship was detected for torrent sculpins or giant salamanders. Because placement of LWD did not decrease riffle area between treatment and reference reaches (Roni and Quinn 2001), the lack of response of torrent sculpins and giant salamanders was expected. Age-1 and older giant salamanders occupy pools rather than riffles (Kelsey 1995), but I could not separate salamanders into age-classes based on length because so few were captured in each stream. Because age-0 and older salamanders may have very different responses to LWD placement, combining age-classes may have masked numerical responses. In addition, giant salamanders inhabit streams with slopes ranging from 1% to more than 15%, and my results may have differed had I sampled steeper streams.

Multiple-removal electrofishing is a reliable method for estimating abundance of juvenile salmonids (Hankin and Reeves 1988) but is less reliable for benthic species, particularly lampreys (Pajos and Weise 1994). The number of lampreys was difficult to estimate by multiple-removal electrofishing because they burrow deep into fine sediment and many could have escaped detection. Lamprey densities are also affected by depth, subsurface substrate size, and stream size (Kelso 1993). However, I did not quantify subsurface sediment size and found no relationship between stream size and lamprey response to restoration. Additional work is needed to estimate lamprey densities accurately and to examine what habitat factors may be important in influencing their response to LWD placement and habitat restoration.

Seasonal habitat preferences and responses to LWD have been reported for salmonid fishes (Nickelson et al. 1992; Roni and Quinn 2001), but little information exists on the habitat preferences of sculpins, lampreys, and giant salamanders during winter. I sampled only during late summer, but fish response to LWD placement may differ among seasons, particularly winter and summer. I attempted electrofishing during winter months, but this technique was precluded by high flows, low temperatures, and low capture efficiency. Additional research on the winter ecology of these and other nonsalmonid fishes is clearly needed and will require innovative sampling techniques.

In summary, LWD placement had little effect on the density and size of nonsalmonid fishes and giant salamanders. Lampreys and age-1 and older reticulate sculpins appeared to increase in density and size with the largest changes in LWD. Additional monitoring should be conducted on reticulate sculpins and lampreys to further elucidate their response to artificially placed LWD. Little is known about the competitive interactions of most of the species I examined; additional experiments on competition under different habitat manipulations are also needed. In general, however, the benefits of LWD projects for coho salmon (typically the species for which they are designed) do not seem to come at a cost to the rest of the vertebrate community.

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