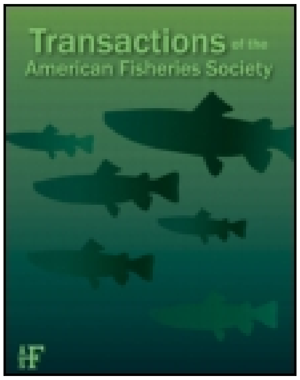

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Effectiveness of Instream Wood Treatments to Restore Stream Complexity and Winter Rearing Habitat for Juvenile Coho Salmon

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ARTICLE

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Abstract
Large wood and boulder placement projects have become common in the Pacific Northwest to restore complex stream habitat for juvenile Coho Salmon *Oncorhynchus kisutch* and other salmonids. We evaluated habitat responses at 91 large wood restoration projects in western Oregon from pretreatment to 1 year and 6 years after treatment. Large logs were arranged in jams without cabling or burial in the bottom or banks of the stream. Projects commonly treated 0.5–1 km of stream, but some extended up to 2.3 km. Significant changes in the amounts of large wood, complex pools, and predicted Coho Salmon rearing capacity were observed within 1 year of treatment. Six years after treatment, the amount of large wood, complex pools, and Coho Salmon rearing capacity remained significantly higher than pretreatment levels by 100, 800, and 32%, respectively, and the surface area of pools and gravel increased significantly over pretreatment levels by 15% and 8%, respectively. However, the amount of large wood decreased in a majority of projects during the 6 years after treatment reflecting net export out of the sites and a lack of recruitment from upstream or local sources. Site-specific responses in stream habitat were positive overall, but variability among sites suggested independent behavior. Responses of the restoration projects were weakly related to channel size, local lithology, or landscape cover, although retention of large wood was associated with lower gradient and coniferous forest cover. Despite the variability in project behavior, the findings indicate that large wood projects may play a role in maintaining and improving stream complexity and Coho Salmon rearing capacity in coast basins of Oregon, potentially compensating for the lack of natural recruitment of wood to the streams. Attention to location within the stream network and treatment details may improve performance of the restoration actions.

The implicit assumption underlying stream restoration is that improvements observed at a carefully designed and constructed site are biologically meaningful and can be replicated to increase stream complexity and salmon productivity at the watershed and Evolutionary Significant Unit (ESU) scales. Stream restoration projects are implemented by numerous individuals, agencies, and watershed groups with varying levels of expertise across a diverse landscape, although monitoring projects to assess the cumulative benefits to fish populations is limited. Yet, hundreds of millions of dollars have been spent over the past two decades to restore streams and watersheds in the U.S. Pacific Northwest investing in road repair, dam removal, upland management, instream passage, large wood and boulder additions, and riparian plantings.

One of the more popular restoration practices implemented by federal and state agencies, private land managers, and local watershed groups has been large wood treatments to actively restore stream complexity and improve aquatic conditions for salmon. Despite the dollars invested and kilometers of stream treated, the benefits of large wood projects to salmon productivity have been rarely documented nor has the stream habitat improvement at the regional or ESU scale been

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adequately addressed (Burnett et al. 2008). Monitoring project effectiveness requires defining expectations for each project (Rumps et al. 2007) and linking the restoration treatment to improved physical conditions and biological responses of salmon at multiple scales (Katz et al. 2007).

We examined 91 large wood projects using a pre- and post-treatment design to assess their potential influence on stream complexity and Coho Salmon *Oncorhynchus kisutch* habitat in the Oregon Coast and Lower Columbia River ESUs. Because the projects were designed to improve ecological and hydrologic stream function specifically for salmonids, we evaluated retention of wood structures, natural recruitment of additional wood, increase in pool number, area, and depth, retention of gravels and sorting of finer substrates, and increase in channel complexity (i.e., secondary channels and off-channel habitats such as alcove and backwater areas). Biological evaluation was based on modeled estimates of the potential carrying capacity and habitat quality for juvenile Coho Salmon during the overwinter life stage. The primary objectives of this paper were to (1) test for changes in physical characteristics and biological potential 1 year and 6 years after restoration treatment in coast and lower Columbia basin streams of Oregon, (2) evaluate restoration site responses relative to geomorphic and landscape variables, and (3) examine whether the restoration had a role in maintenance or recovery of rearing capacity and habitat at the ESU scale.

METHODS

Study streams.—Restoration sites were located in Oregon coast, lower Columbia River, and Willamette River basins within the rearing and spawning distribution of salmon and steelhead *O. mykiss* (Figure 1). The sites were spread among 27 salmon population units (basins) nested within seven monitoring strata

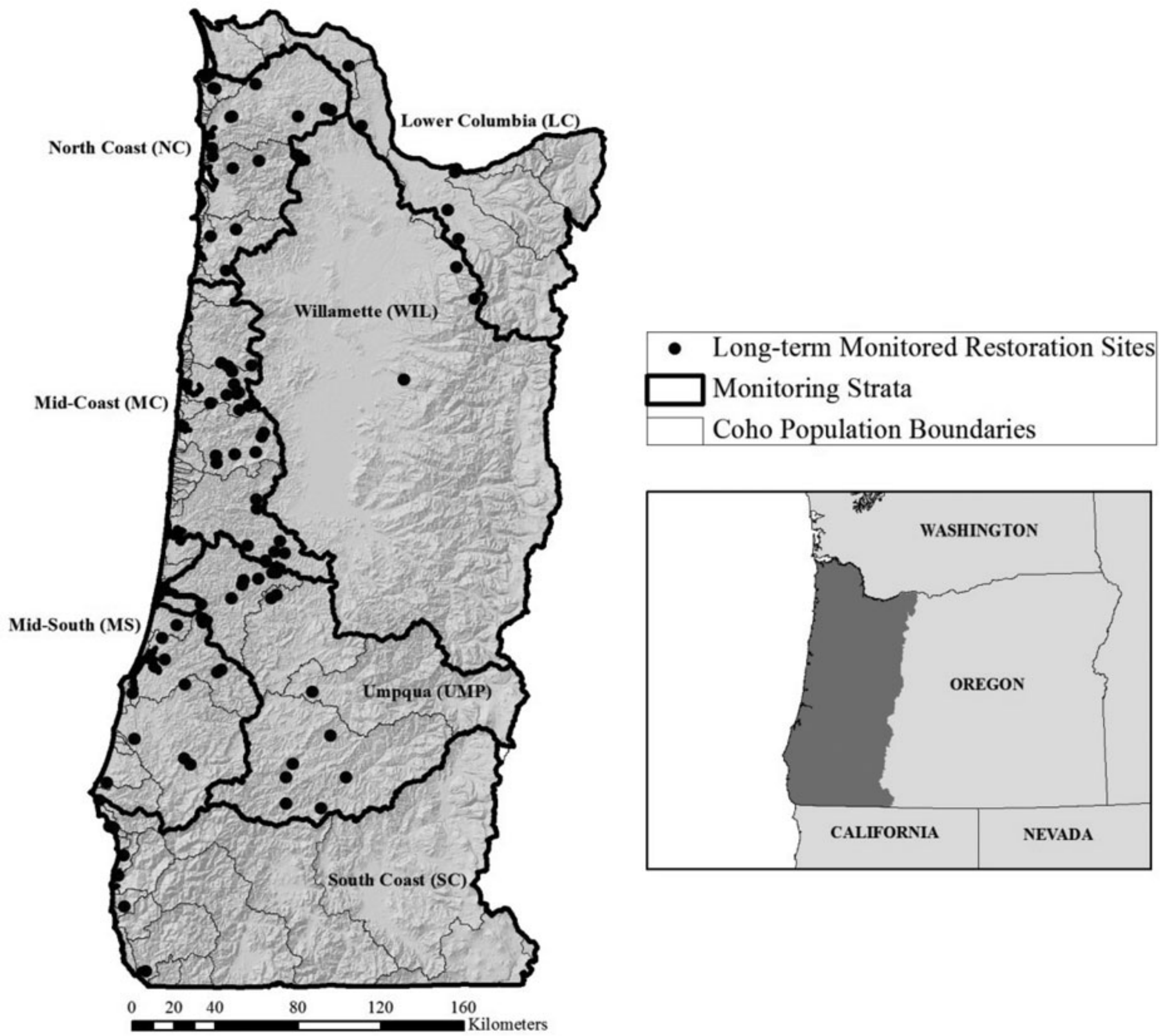

FIGURE 1. Location of 91 large wood projects implemented in the Lower Columbia, Coast, and Southern Oregon–Northern California Coast ESUs from 1999 to 2005. Monitoring strata are identified.

(Myers et al. 2006; Lawson et al. 2007; Figure 1). Restoration treatments occurred from 1999 through 2005. We surveyed 91 restoration sites before treatment, and 1 and 6 years after treatment from 1999 to 2011. All surveys were conducted during the winter to provide an accurate assessment of overwinter rearing potential for juvenile Coho Salmon. Seven of the sites lacked pretreatment surveys. Surveys ranged from 0.5 to 2.2 km for a total of 63 km of stream length surveyed across 91 sites.

The restoration sites were identified and treatments designed by Oregon Department of Fish and Wildlife (ODFW) district restoration biologists. The following criteria were used to consider sites for restoration treatment based on potential importance to juvenile Coho Salmon (Burnett et al. 2007) and high probability of retention of structures (Thom 1997; Roper et al. 1998): channel width (5–25 m), low gradient (0–3%), moderate to high amount of pool habitat (35–50%), and low structural complexity (wood or boulders), as recommended in Oregon Department of Forestry (ODF) and ODFW guidance document (ODF and ODFW 2010) and in Thom et al. (2001). Each restoration biologist submitted a selection of the projects to the monitoring biologist prior to treatment. The selection was not random, but the monitoring biologist surveyed as many projects as possible.

The reaches actually selected for restoration were primarily single-thread pool–riffle and plane-bed channel types (0–3% average slope; Montgomery and Buffington 1997), channels having 5–15 m active channel width and incised within terraces (entrenchment ratio, 1–2.2; Rosgen 1994), and having a valley floor greater than 2.5 times the active channel width (Figure 2). Treatments consisted primarily of large wood placed as multipiece jams, usually in pools. Wood was generally placed with at least one end resting between trees on the adjacent terrace.

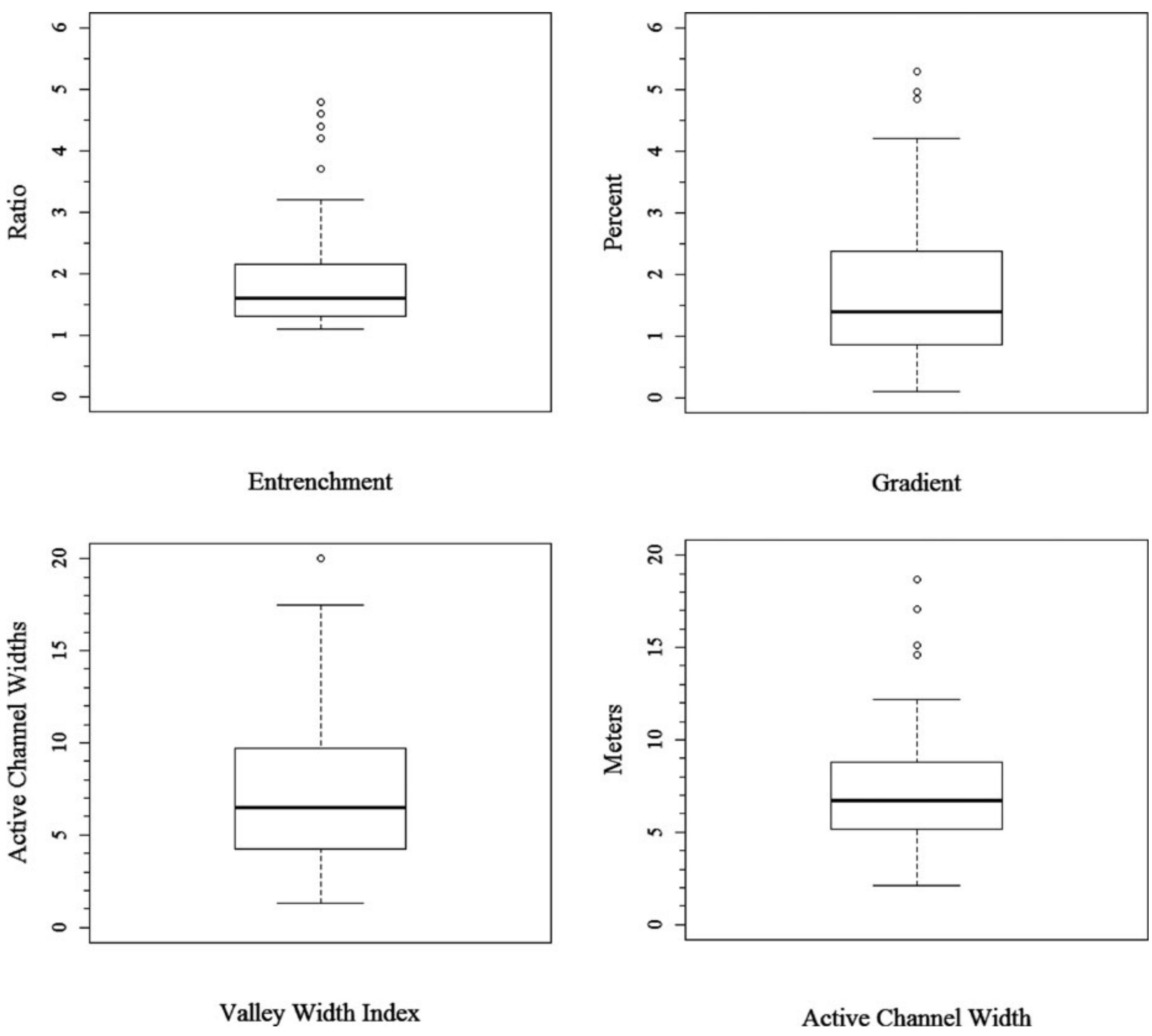

FIGURE 2. Geomorphic characteristics of restoration sites prior to treatment. Entrenchment is expressed as the ratio of flood-prone width to active channel (bank-full) width (Rosgen 1994). Valley width index is the ratio of active channel width to valley floor width. Gradient is the average water surface slope of the site.

Wood was not cabled or tied to boulders or riparian trees, nor driven into the banks or bottom. The large wood pieces were a minimum length of 1.5–2 times the active channel width and 25–60 cm in diameter (ODF and ODFW 2010), and did not include rootwads. The median number of wood pieces placed in streams was 30 per kilometer, or approximately three pieces per 100 m, and usually massed as jams of at least five pieces.

Field surveys.—Physical habitat surveys (Moore et al. 2007) were completed at each site during the winter (generally February or March) to establish baseline conditions preceding restoration treatment, which occurred the following summer or fall. Each site was then resurveyed in the winter 1 and 6 years after treatment. Field surveys described channel dimensions, gradient, morphology, habitat unit type and size, depth, substrate, boulders, large wood, bank condition, shade, and riparian characteristics in primary and secondary channels. Pools were identified following nomenclature in Bisson et al. (1982) and Hawkins et al. (1993). All wood pieces larger than 3 m in length and 0.15 m in diameter were recorded by diameter and length and identified as a natural or placed piece, and if that piece was part of a jam (five or more pieces of wood). These surveys have adequate precision for examining status and trends of pools, large wood, and substrate based on criteria outlined in Roper et al. (2010) and Anlauf et al. (2011a).

Habitat-limiting factors model.—We did not empirically estimate the actual habitat capacity of the restoration sites during the winter. Difficulties in estimating juvenile populations during the winter and annual variation in populations prevent meaningful comparisons across sites and years without intensive and long-term sampling (Rodgers et al. 1992; Johnson et al. 2005). Therefore, the habitat capacity for juvenile Coho Salmon (expressed as number of winter parr per kilometer) was estimated with the Habitat Limiting Factors Model (HLFM; Nickelson et al. 1992, 1993; Nickelson and Lawson 1998). The model was based on field determination of winter abundance at the habitat unit (e.g., pool, riffle, rapid) and stream scales. Mark–recapture and depletion estimates of juvenile Coho Salmon were conducted in streams and only during years of "full seeding" (>25 adult Coho Salmon spawners/km; Solazzi et al. 2000) to estimate habitat capacity for each habitat unit type. Habitat capacity was related primarily to the habitat unit type and wetted surface area. Additionally, the HLFM model was modified to include the positive influence of large wood on juvenile Coho Salmon rearing capacity (HLFM version 7; Anlauf et al. 2009). To estimate potential habitat capacity at the site or reach scale, rearing densities (number of parr per meter) were assigned to each habitat unit type and wood loading, and the density was then multiplied by the surface area of each unit, summed across habitat units within a reach or section of stream, and standardized to a kilometer of stream. The habitat capacity of a reach was also correlated to overwinter survival rate from parr to smolt life stage (Nickelson 1998). Habitat capacity during the winter increases with the amount of total pool habitat, and the highest values are attributed to slow-water pool habitat such as beaver ponds, off-channel alcoves, and pools with abundant wood. The HLFM metric also serves as an integrated indicator of pool and stream complexity. The stream reaches considered to have high habitat capacity are defined as those reaches capable of producing enough Coho Salmon smolts to replace the spawner population during periods of low ocean survival (Nickelson 1998).

Analysis.—Habitat features (Table 1) were summarized and standardized to a fixed length. We used paired *t*-tests to assess the change in large wood, pools, channel complexity, substrate, and habitat capacity at restoration treatment sites. The differences in habitat capacity and wood volume data were log transformed to meet the assumption of normality. Three sets of comparisons were conducted for each habitat metric: (1) pretreatment to 1 year posttreatment, (2) pretreatment to 6 years posttreatment, and (3) 1 year posttreatment to 6 years posttreatment. Because the site data are paired, we analyzed the mean difference between pretreatments and posttreatments to test each hypothesis at a *P*-value of 0.05 (two-sided test).

Linear regression at the site scale was used evaluate the change in wood volume, pool habitat, gravel, sand and organics, and habitat capacity at each restoration site across years. Seven sites with no pretreatment data were excluded. The time series was run as year 0 (pretreatment) and years 1 and 6 (posttreatment). The response represents the percent change at each site averaged over 7 years. The time-series data were too few (i.e., three visits) for each site to permit evaluation of serial correlation in the residuals (Ramsey and Schafer 2013). Although the statistical routine calculated *P*-values with the Mann–Kendall test (Mann 1945; Hipel and McLeod 1994), our purpose here was to compare site-scale responses within and among monitoring strata in the lower Columbia River and Oregon coast ESUs.

Habitat response to large wood treatment might have been influenced by stream, landscape, or environmental factors over the 6-year period. We examined the difference in value from pretreatment to 6 years posttreatment for each habitat response variable in relation to channel size and gradient, underlying lithology, land cover, and precipitation using multiple linear regression (Kaufmann and Hughes 2006; Anlauf et al. 2011b; Firman et al. 2011). The five response variables, which represent important habitat features for adult and juvenile Coho Salmon, were large wood volume, percent pool habitat, percent gravel, percent silt and sand (collectively referred to as fines), and habitat capacity for juvenile Coho Salmon (Table 1). The independent predictor variables selected were: channel width, average gradient of site, lithology (four categories), land cover (10 categories), and precipitation (mean and maximum; Table 1). Channel width and gradient were collected during field surveys at the site. Lithology, land cover, and precipitation were summarized from a GIS at the sixth field hydrologic unit (HU) scale as the percent of the total area each category within the HU. Lithology data were obtained from a U.S. Geological Survey (USGS) spatial geologic map (Walker et al. 2003). Land cover data were derived from the USGS National Land Cover Database (Homer et al. 2004). Mean precipitation values (1961–1990) for the sixth field HU were summarized from the Precipitation

TABLE 1. Description of instream habitat features and predictor variables. All habitat features were summarized for a site and standardized to a fixed length.

Parameter	Unit	Description
		Habitat feature
Wood volume	m^3/100 m	Volume of wood per 100 m of primary channel length.
Wood pieces	Number/100 m	Pieces of wood per 100 m of primary channel length.
Pool frequency	Number	Number of active channel widths per pool (scales to channel size).
Pool density	Number/100 m	Number of pools per 100 m primary channel length (scales by length of stream).
Pool habitat	Percent	Area of all pools as a percentage of total wetted channel area.
Residual pool depth	Meters	Depth of pool below the pool tail crest averaged across all pools in the site.
Alcove/beaver ponds	Percent	Area of alcove and beaver pools as a percentage of total wetted channel area.
Complex pools	Percent	Area of pools with >20 m^3 volume of large wood as a percentage of total wetted channel.
Second channel area	Percent	Area of secondary channels as a percentage of total wetted channel area.
Fines	Percent	Percentage of streambed area classified as sand, silt, and organic substrates (<2 mm).
Gravel	Percent	Percentage of streambed area classified as gravel (2–64 mm diameter).
Habitat capacity	Parr/km	Number of juvenile Coho Salmon that a stream can potentially support in the winter (modeled with HLFM).
		Predictor variable
Gradient		Mean stream gradient for survey site (Moore et al. 2007).
Active channel width		Mean active channel width for survey site (Moore et al. 2007).
Precipitation		Mean and maximum precipitation for sixth field hydrologic unit (HU) associated with site (Daly et al. 2008).
		Land cover[a]
Agriculture		Agriculture cropland and improved pasture lands.
Deciduous		Deciduous forests including cottonwood riparian, oak–Pacific madrone, Oregon ash–black cottonwood, Oregon white oak–ponderosa pine woodland.
Conifer		Conifer forests including Douglas-fir, western hemlock, grand fir, Siskiyou mixed conifer.
Mixed		Mixed conifer and broadleaf deciduous forests.
Recent timber harvest		Recent timber harvest areas.
Urban–industrial		Urban and industrial areas.
		Lithology[b]
Sedimentary		Sedimentary geologies (e.g., limestone, siltstone, sandstone).
Sedimentary and volcanic		Mixed sedimentary and volcanic geologies.
Volcanic		Volcanic rock types (e.g., pyroclastic, schists).
Intrusive rocks		Intrusive rock types (e.g., tonalite, granodiorite).

[a]Homer et al. (2004).
[b]Walker et al. (2003).

Elevation Regressions on Independent Slopes Model (PRISM; NWCC 1998; Daly et al. 2008).

All variables were continuous and the number of parameters was limited in each model. A series of models were run for each response variable. Landscape predictor combinations for candidate models included geomorphic variables only, just land cover variables only, and combinations of geomorphic and land cover variables identified as strongly correlated with the response variable. Akaike information criterion for small sample sizes (AIC_c) was used to select the final model from a set of competing models based on the delta AIC_c values. For each candidate model, variance inflation factors (VIFs) were calculated to detect multicollinearity among the landscape parameters. A VIF value greater than 5 indicates a collinearity problem (Ott and Longnecker 2001). The proportion of variability explained by each model was estimated with the adjusted R^2. A P-value was also generated to assess the significance of the individual predictor variables for each model.

RESULTS

The restoration sites selected for treatment were within spawning and rearing habitat for Coho Salmon and steelhead, had a median gradient of 1.5%, and contained small to

TABLE 2. Mean, SD, and *P*-value (alpha = 0.05) of paired *t*-tests (two-tailed) that compare pretreatment (Pre), 1 year posttreatment (Post-1), and 6 years posttreatment (Post-6).

	Treatment mean (SD)			*P*-value		
Habitat metric	Pre- ($n = 84$)	Post-1 ($n = 86$)	Post-6 ($n = 91$)	Pre–Post-1 ($n = 79$)	Post-1–Post-6 ($n = 86$)	Pre–Post-6 ($n = 84$)
Wood volume (m^3/100 m)	11.8 (9.6)	27.5 (13.8)	22.5 (11.34)	<0.01	<0.01	<0.01
Wood pieces (number/100 m)	11.9 (7.18)	18.5 (9.1)	17.1 (7.7)	<0.01	0.08	<0.01
Second channel area (%)	4.7 (4.8)	5.3 (8.8)	4.4 (4.6)	0.73	0.56	0.53
Pool frequency (number per pool)	7.8 (15.6)	6.6 (6.0)	6.5 (4.8)	0.48	0.91	0.24
Pool density (number/100 m)	3.0 (1.4)	2.9 (1.3)	3.2 (1.4)	0.82	0.26	0.13
Pool habitat (%)	37.6 (19.5)	38.2 (21.0)	43.3 (22.0)	0.42	0.01	<0.01
Alcove/beaver ponds (%)	1.8 (3.2)	1.9 (3.8)	2.0 (5.5)	0.67	0.86	0.92
Complex pools (%)	0.4 (1.4)	3.4 (5.2)	3.5 (8.3)	<0.01	0.77	<0.01
Residual pool depth (m)	0.56 (0.21)	0.53 (0.21)	0.51 (0.18)	0.01	0.28	<0.01
Fines (%)	30.2 (15.1)	30.5 (15.0)	29.1 (16.0)	0.89	0.36	0.03
Gravel (%)	38.0 (14.5)	38.8 (15.1)	41.0 (16.2)	0.38	0.13	<0.01
Habitat capacity (parr/km)	883.7 (774.8)	1,034.9 (827.5)	1,168.6 (1,110.3)	0.04	0.23	<0.01

medium-sized channels (median, 7 m active channel width) (Figure 2). The sites had adequate pool habitat (average, 38%), but limited wood volume (<10 m^3/100 m) and channel complexity (secondary channels < 5% of surface area). Median modeled habitat capacity for juvenile Coho Salmon was low (700 parr/km) relative to typical values for moderate or good habitat (>900 and >1,850 parr/km, respectively; Anlauf et al. 2009).

Response of Individual Habitat Features and Sites to Restoration Treatment

The placement of large wood into the streams initiated a succession of effects on pools, substrate, and rearing capacity, which was modified by high winter flows and further movement of wood and sediment. Large wood volume increased by an average of 150% 1 year after treatment (Table 2) as a direct result of large wood placement in pools. While in the five subsequent years the wood volume, on average, declined ($P <$ 0.01), it remained 100% higher than the pretreatment levels (Table 2). Of the 86 sites examined, 14 (16%) gained pieces and volume while 9 sites (10%) gained volume and lost small pieces. However, 61 sites (71%) lost wood between year 1 and year 6. Changes in large wood volume at individual sites indicated that 15 sites (18%) lost wood volume to levels below that of the pretreatment surveys (Figure 3). Sites in the lower Columbia River and Mid-Coast basins lost wood volume more often, 69% and 35% respectively, than did sites in the other basins (0–12%; Figure 3).

Pools became more complex, larger, and shallower over the 6-year period. The percent of complex pools increased as a direct result of the large wood additions to pools. Pools maintained complexity through 6 years posttreatment even though wood levels decreased in most sites between 1 and 6 years after treatment (Table 2). The change in total surface area of pools relative to the wetted channel area (i.e., pool habitat) of the sites did not change within the first year, but increased on average by 6% of total wetted channel area at the end of 6 year posttreatment (Table 2). This represents a 15% increase in surface area of pools across all the sites. The site-specific analysis of pool habitat indicates that increases were on the order of 5%/year and the sites that decreased were on the order of 1–2%/year and up to 5%/year (Figure 3). All sites in the mid-South Coast basins showed positive trends in pool habitat (Figure 4). Residual pool depth was significantly shallower following treatment (Table 2), decreasing on average by 5 cm, about 10% of the average residual depth. Changes in pool frequency and pool density were not observed (Table 2). Given that the wood was placed in pools, we did not expect to see an increase in the number of pools unless the wood moved and settled within an alluvial section of the reach.

The wood treatments might have influenced the sorting of substrate sizes within the reach. Significant increases in the percent of gravel and reductions in the percent of fines were detected from pretreatment to 6 years posttreatment (Table 2). The site-specific analyses of gravel and fine substrate highlight the variability in site responses (Figures 3, 4). The median percent change was positive in all geographic areas, although responses varied most in the North Coast and South Coast basins.

Channel complexity and floodplain connectivity was assessed through measures of surface area of secondary channels and off-channel habitats such as backwaters, alcoves, beaver ponds, and isolated pools. No changes were observed over the 6-year period.

The modeled habitat capacity of the restoration sites increased following treatment (Table 2), which could reflect both an increase in pools with wood and the presence of beaver ponds and off-channel habitat such as alcoves (Nickelson et al. 1992).

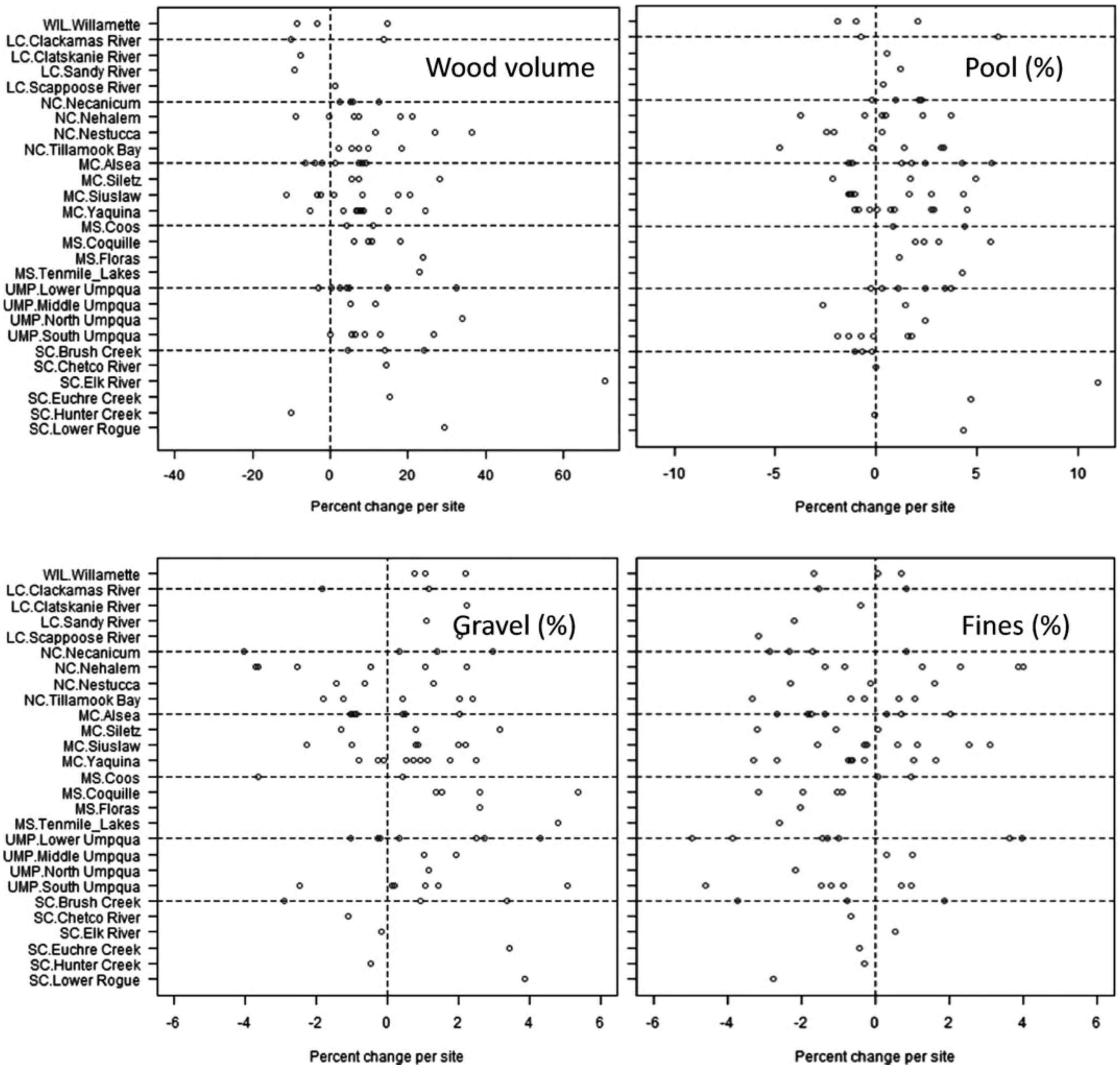

FIGURE 3. Site-specific responses of large wood volume, pool surface area (%), gravel (%), and fine substrate (%) from pretreatment (year 0) to posttreatment (years 1 and 6) ($n = 84$) displayed by monitoring strata (separated by horizontal dashed lines). Each circle represents a site. Sites are organized by basin within a monitoring stratum and either placed within the lower Columbia River basin (WIL, LC) or ordered north to south on the coast (NC, MC, MS, UMP, and SC). Abbreviations are defined in Figure 1. The *x*-axis represents the average change from year 0 to year 6.

The habitat capacity primarily increased with an increase in complex pools and surface area in pool habitat, although three sites had a large increase in beaver ponds. The sites that had a negative change suffered a reduction of beaver ponds (five sites), large wood (one site), or surface area of pools (16 sites). The North and Mid-Coast Coho Salmon populations had the greatest variation in responses (Figure 5), and also started with the highest modeled habitat capacity before treatment. Overall, habitat capacity of restoration sites increased 27% (median) and 32% (average) after treatment increasing from a mean of 833 parr/km to 1,168 parr/km (Table 2).

Association with Geomorphic and Landscape Predictors

The variation in response variables explained through multiple linear regressions of stream and landscape predictors failed

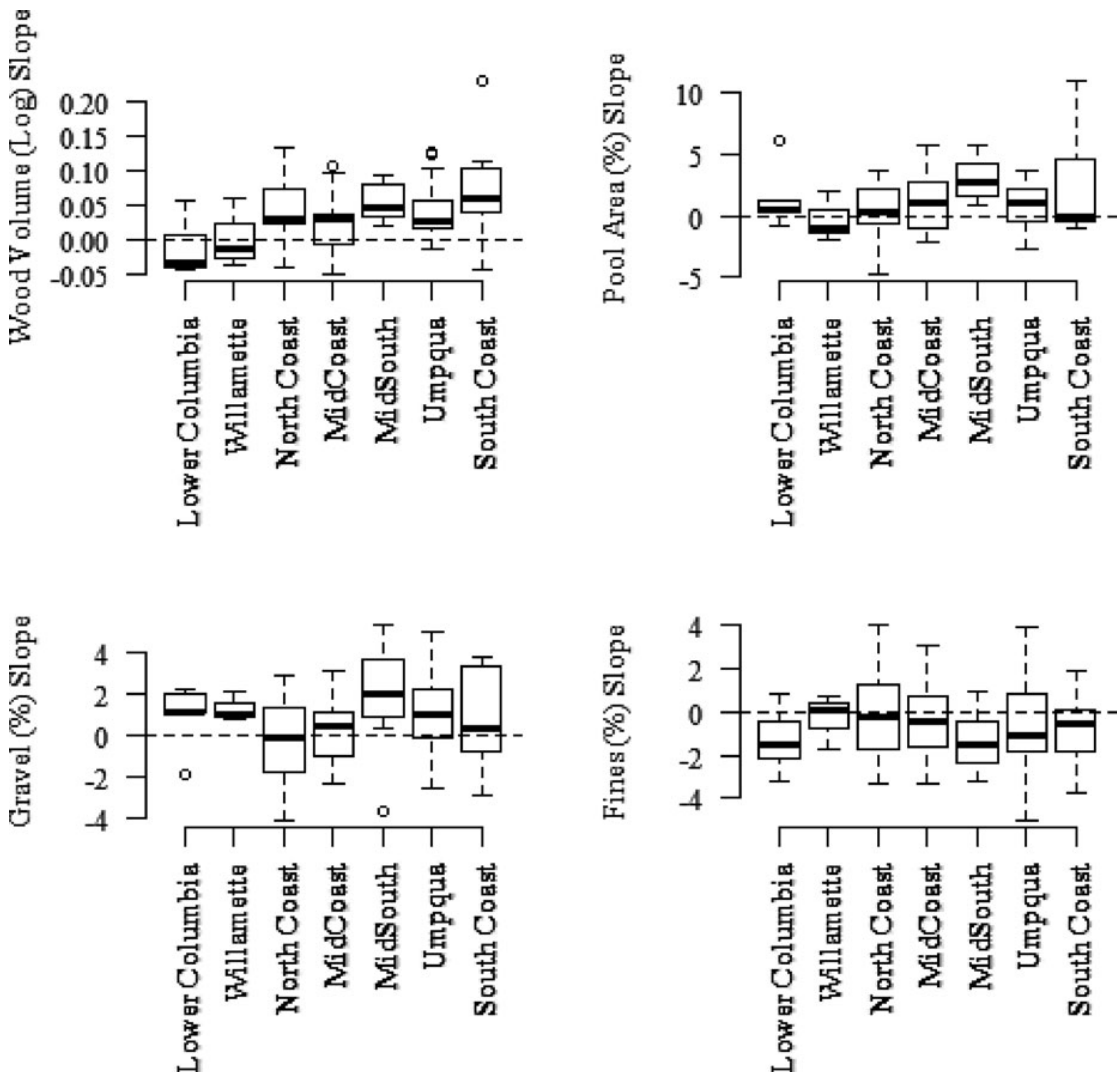

FIGURE 4. Median values, quartiles, and 95% confidence bounds of responses of sites within monitoring strata. Slope is the average change from year 0 to year 6.

to provide strong evidence of linkages (Table 3). The models accounted for less than 14% of the variation in any response variables. Significant predictor variables included gradient, land use (agriculture, recent timber operations), mean precipitation, and forest cover (coniferous). Underlying geology and stream size were not significant factors related to habitat responses during monitoring at 6 years posttreatment.

DISCUSSION

Restoration treatments implemented across a diverse region within small and medium-sized pool–riffle and plane-bed streams improved site function and salmon habitat on average, but responses varied among sites and basins within the first 6 years. Many sites met the short-term goals of restoration, which was to increase the amount of large wood, pool area, and complexity and to retain gravels. Trends in these variables at most sites were positive, but large wood decreased between years 1 and 6 at almost 75% of the sites. Few sites recruited new wood, and changes in channel complexity and floodplain connectivity were not observed in the 6 years since treatment. However, on average the large wood placements increased overwinter rearing capacity for juvenile Coho Salmon through improved pool complexity and surface area. Site-specific responses were not strongly related to landscape, stream, or environmental variables. These physical changes during the first year following treatment are not unexpected (Roni et al. 2008; Whiteway et al. 2010). Six years of monitoring is not long term, but relative

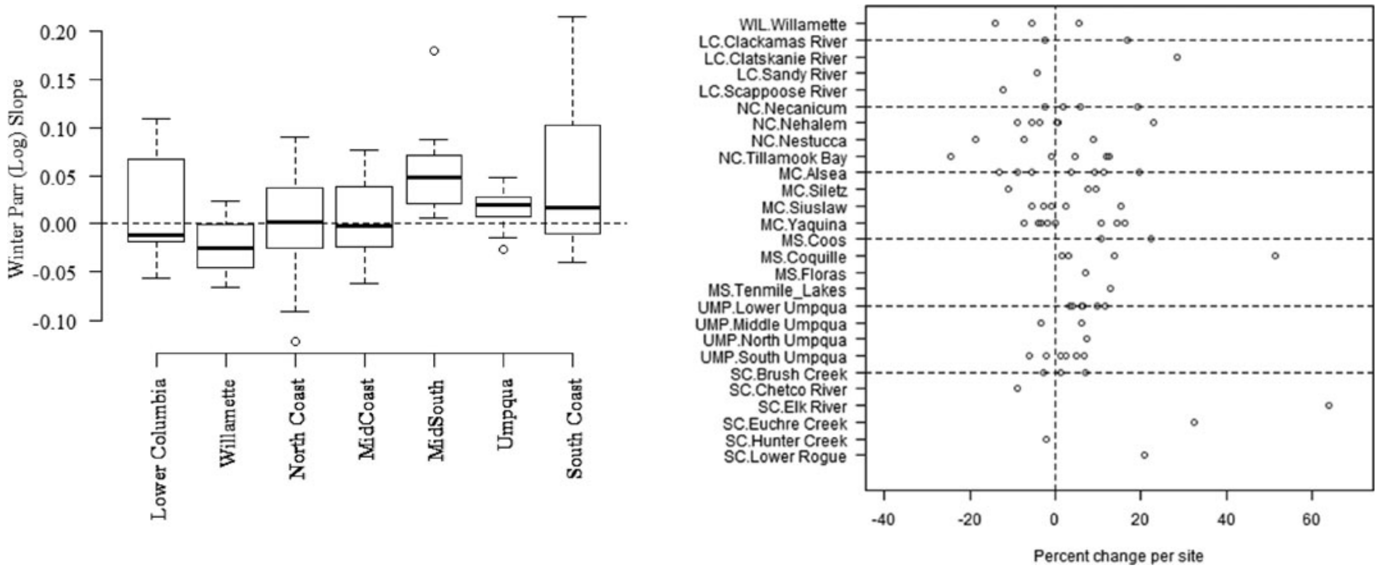

FIGURE 5. Site-specific trends of modeled habitat capacity from pretreatment (year 0) to posttreatment (years 1 and 6) ($n = 84$) displayed by monitoring strata (separated by horizontal dashed lines). Each circle represents a site. Sites are organized by basin within monitoring strata and either placed within the lower Columbia basin (WIL, LC) or ordered north to south on the coast (NC, MC, MS, UMP, and SC). Abbreviations are defined in Figure 1. The *x*-axis represents the average change from year 0 to year 6. The boxplots display medians, quartiles, and 95% CIs.

to previous studies where the life span of monitoring averages 3 years (Whiteway et al. 2010), this study of 91 sites in western Oregon provides additional insight on the longevity and response of projects.

The legacy of anthropogenic activities on streams in western Oregon has changed forest cover, watershed processes, and the geomorphic template, leaving many streams incised within their floodplains, commonly down to bedrock, and with limited opportunity for natural recruitment of large wood (Hall et al. 1987; Beckham 1990; Miller 2010). The appeal to add large wood to simplified aquatic systems is justified by its role in structuring channel morphology, influencing the formation of pools, sorting sediments, and providing food and cover for aquatic organisms (reviewed in Cederholm et al. 1997). While watershed recovery is the ultimate goal and the context within which site-specific actions are implemented (Beechie et al. 2008; Bisson et al. 2009), natural recovery of watershed components such as large coniferous trees are on the order of decades under current conditions and riparian management (Meleason et al. 2003). Large wood in Oregon's coastal streams is not increasing across the coast basins (Anlauf et al. 2011a; Ward et al. 2012), and the amount of instream large wood within the nonforested landscape is significantly declining (K. Anlauf-Dunn, unpublished data). Given the current and future status of natural recruitment, these projects provided an opportunity to examine whether restoration with large wood has a role in supplementing natural processes and has the potential to improve salmon habitat at a regional scale.

These projects were placed within streams considered to have a high intrinsic potential for supporting salmon populations and historically were thought to provide productive rearing habitat

TABLE 3. Final model selections and adjusted R^2 for each restoration treatment response variable. Response variables reflect the change in value from time 0 to time 6. Significant predictor variables ($P < 0.05$) are in bold text.

Response	Model	Adjusted R^2
Percent pools	14.224 − (2.669 × **Gradient**) − (0.012 × Mean precipitation) + (2.049 × **Agriculture**) + (0.659 × Recent timber)	0.138
Percent gravel	14.313 − (0.032 × **Mean precipitation**) + (0.267 × Metamorphic) + (0.455 × Recent timber) − (0.387 × Urban industrial)	0.080
Percent fines	−3.172 − (0.137 × Metamorphic) + (0.101 × Mixed) − (1.055 × Recent timber)	0.071
Wood volume	11.749 − (1.827 × **Gradient**) + (0.089 × **Conifer**) − (1.193 × **Recent timber**) − (0.243 × Urban industrial)	0.140
Winter capacity	−373.599 + (63.330 × Active channel) − (71.739 × Gradient) + (138.767 × **Agriculture**) + (5.297 × Conifer)	0.120

for Coho Salmon and other salmonids (Burnett et al. 2007). Lower gradient reaches in stream networks (<4%) are commonly found within intensively managed landscapes, which places Coho Salmon habitat at the intersection of historically productive habitat and an altered ecological landscape (Burnett et al. 2007).

The potential of channel-spanning wood jams to trap natural wood and debris floating downstream was an objective of the placements, but additional wood recruitment was not observed at many sites. In fact, the movement of wood out of the sites after initial placement occurred across the geographic range of the projects. The number of pieces of wood did not change significantly between years 1 and 6, but changes in wood volume suggest that large pieces were not replaced by pieces of similar size. Because these wood pieces were placed unanchored in streams of small to moderate size, it is possible that the exported wood lodged farther downstream and is now serving a hydrologic or biological function. Durability of log structures can be affected by flood magnitude, stream size, size of wood, wood location relative to channel edge, anchoring, and upslope landslides (Roper et al. 1998). In an old-growth Douglas-fir *Pseudotsuga menziesii* system, downstream movement of wood was strongly related to length of log and presence of rootwad in relation to channel width, but final resettlement of the wood depended on wood size and ability of wood jams downstream to capture the pieces (Lienkaemper and Swanson 1987). The restoration projects experienced the full range of environmental conditions normal for the Pacific Northwest. During the time period of this study, each of the major coast basins in western Oregon experienced a significant flood event according to USGS flow records. However, the North Coast and Mid-Coast basins had the third and second highest floods based on 71 and 91 years of records, respectively. Although the loss of large wood from the projects was not strongly associated with gradient, stream size, or precipitation, a more detailed site-specific analysis may reveal underlying mechanisms. A site- and reach-level examination of the interaction of placed wood jams with the wetted and bank-full channel and adjacent landforms, coupled with knowledge of the riparian and bedload conditions upstream, may reveal causal factors that influence export of placed wood and recruitment of new wood.

The regression models revealed weak correlations of treatment responses with geomorphic, climate, and landscape predictors. The challenge of associating the habitat metric response to the restoration treatment with geomorphic or landscape features was echoed by the difficulty in explaining variability in stream habitat features with natural and management-influenced predictors across all streams types in Oregon coast basins (Anlauf et al. 2011b). Anlauf et al. (2011b) suggested that immutable predictors such as stream power, climate, geology, and topography accounted for the majority of variability in stream habitat, while management-influenced predictors such as roads, forest cover, and land use accounted for small amounts of variation (up to 28% partial R^2) in pool frequency, substrate composition, and wood volume. In contrast to the site-to-site variability incorporated in the Anlauf et al. (2011b) study, we were assessing variation in responses within a narrow range of stream size and channel type for similar treatments. It may be necessary to focus attention at the site level, incorporating thalweg profiles and cross-section transects coupled with examination of habitat responses relative to channel, terrace, and floodplain dynamics. While we focused our monitoring on fish habitat responses, incorporating a more quantitative approach to geomorphic assessment may shed additional insight on fish habitat and channel behavior. Building expertise at the individual site and scaling up may provide complementary information to a broad-scope study such as this one.

Determining biological effectiveness of restoration projects has been particularly problematic. A systematic review by Burnett et al. (2008) revealed few studies that adequately addressed the effectiveness of large wood projects to fish. Stewart et al. (2009) suggested that the response of fish populations to restoration projects is neither strongly positive nor negative, while others (e.g., Cederholm et al. 1997; Roni and Quinn 2001; Johnson et al. 2005; Whiteway et al. 2010) demonstrated increases in abundance or survival, although differences existed by species and season. Long-term studies on trout in the intermountain west indicated positive responses to large wood placement (White et al. 2011) and to instream structures coupled with channel reconstruction and flow restoration (Pierce et al. 2013). We suggest that favorable changes in substrate and pool density and complexity improved the habitat for juvenile and adult salmon based on documented habitat–fish relationships. We did not directly assess the biological response in terms of fish density or survival, but the HLFM and other literature indicate a significant improvement in habitat capacity and quality during the summer and winter (Nickelson et al. 1993; Cederholm et al. 1997). The HLFM model indicated a potential average increase of 285 juvenile Coho Salmon/km in the winter, which in turn increases some low (<900 parr/km) and moderate (900–1,850 parr/km) capacity sites to moderate and high (>1,850 parr/km) capacity (Anlauf et al. 2009). The increase in winter habitat capacity and the number of high capacity sites has a direct influence on the viability of Coho Salmon populations (Nickelson and Lawson 1998). The addition of large wood also might have improved the overwinter survival of steelhead (Johnson et al. 2005) and Coastal Cutthroat Trout *O. clarkii clarkii* (Solazzi et al. 2000).

It is difficult to design a replicated and unbiased control-treatment (or reference-treatment) experiment because restoration sites were selected with particular geomorphic criteria, and the selected sites might have had a higher intrinsic potential than did nearby sites chosen as reference or control sites. However, the before–after study design, geographic scope, variety of sites, and time span in this evaluation permit broad-based conclusions about the effectiveness (or responses) of the projects. Here, we demonstrated an increase in surface area of pools and sorting of substrate in addition to increased large wood in the majority of the projects. In contrast to 14% of the projects losing more wood than was placed, 38% of the projects experienced increased wood volume, pool area, and gravel after 6 years, while only 3% lost wood pieces and volume, pool area, and gravel from pretreatment conditions. These project responses, based on noncabled wood treatments implemented across western Oregon by 24 biologists (Joseph Sheahan, Western Oregon Stream Restoration Program, personal communication) may be a realistic representation of the effects of these types of projects in coastal drainages over a 6-year period. Defining success in terms of hydrologic function, geomorphic complexity, or biological effectiveness clearly, though, is a difficult proposition and needs further study.

Agencies in the Pacific Northwest are confronted with how best to restore watersheds and fish populations in the face of a greatly altered landscape, disturbance regimes, a changing climate (Beechie et al. 2012), and limited funds. With a backdrop of stable trends in stream habitat (Anlauf et al. 2011a), a decline in legacy wood with limited recruitment of new large wood (Meleason et al. 2003), and a shortage of high quality salmon habitat (ODFW 2007), agencies have aggressively promoted instream large wood restoration. As part of a comprehensive restoration strategy, the Oregon Watershed Enhancement Board (OWEB 2011) has supported 1,100 large wood projects in 1,200 km of streams in lower Columbia River and coast basins from 1995 to 2011 to fulfill immediate salmon habitat needs. Because we have not randomly sampled these projects, we cannot extrapolate our findings to other sites, but would expect if projects are similarly designed and placed following the recommended guidelines (ODF and ODFW 2010), then many are benefiting stream function and salmonid habitat. Although 1,200 km is only 10% of available Coho Salmon spawning and rearing habitat in these ESUs, the projects may contribute to stabilizing and improving habitat quality in potentially productive habitat.

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