THE OREGON PLAN *for Salmon and Watersheds*

Effectiveness Monitoring Report for the Western Oregon Stream Restoration Program, 1999-2008

Report Number: OPSW-ODFW-2010-6

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INTRODUCTION

State and federal agencies have invested millions of dollars to restore streams and watersheds in the Pacific Northwest over the past two decades. In Oregon alone, over 500 million dollars has been spent on completed projects from 1995 to 2007 (Oregon Watershed Enhancement Board 2009). Restoration practitioners have distributed the investment among watershed scale activities such as road repair, dam removal, and upland management, and stream scale activities such as passage, instream complexity, and riparian plantings. The Western Oregon Stream Restoration Program (WOSRP) was established to work in cooperation with private and corporate landowners to restore stream habitat for juvenile and adult salmonids. In addition to the WOSRP, the Oregon Watershed Enhancement Board (OWEB) funds restoration projects with local watershed councils, who commonly partner with state and federal agencies. Eight WOSRP restoration biologists in Tillamook, Newport, Charleston, Gold Beach, Roseburg, Clackamas, and Salem select sites and implement projects consistent with the criteria described in Thom et al (2001). A monitoring component is integrated in the program, with surveys coordinated and reported by a biologist in Corvallis. The goal of the monitoring program is to assess the long term effectiveness of instream restoration projects implemented by WOSRP, and to evaluate progress towards salmon conservation and recovery goals in Oregon's coastal basins.

The WOSRP restoration sites are distributed throughout the Willamette, Lower Columbia, and coastal drainages. Restoration treatments added large wood and/or boulders, improved fish passage, planted trees in riparian areas, or were a combination of the three. Large wood was placed in complex jams at intervals throughout the stream to increase stream roughness and complexity. Boulders were sometimes used in conjunction with wood jams to provide stability to the structures, and prevent large wood from moving downstream and posing a hazard to culverts and bridges. Bedrock dominated streams were often treated with boulders to collect gravel and cobble, intended to aggrade the streambed. In the future, large wood may be added to these streams. Fish passage projects opened previously inaccessible habitat to juvenile and/or adult salmonids while riparian plantings and fencing were designed to improve riparian vegetation and bank structure. The project length varied from site to site. Fish passage sites were quite short, but provided access to kilometers of fish habitat, and large wood sites were up to several kilometers in length.

Large wood and boulder placement projects have become commonplace in the Pacific Northwest to restore complex stream habitat for juvenile coho and other salmonids (Katz et al. 2007, Roni et al. 2008). Detailed assessments have been published for individual projects or experiments (e.g. Moore and Gregory, 1988, Nickelson et al. 1992, Cederholm et al.1997). More extensive evaluations have used a post treatment design (Hicks et al 1991, Roni and Quinn 2001), but none have used a pre- and post treatment design. In this paper we evaluate habitat changes at 103 restoration projects in western Oregon from pre-treatment to one year post treatment to 6 years following treatment. Projects commonly treated 0.5 – 1 km of stream, but some extended up to 6 km. The projects we evaluated in this paper were treated with large logs, usually arranged in jams, and were not cabled or driven into banks or bottom. As of 2008, the OWEB and WOSRP projects have treated approximately 750 km of stream with large wood (Figure 1), 120 km with boulders, and over 4,000 km of stream have been made accessible by replacing and/or removing culverts. Each year, OWEB receives 210 grant applications for restoration projects. These projects generally adhere to a similar selection process and design, so the results of this study can be expected to apply more broadly within the Pacific Northwest.

Roni et al (2008), in a synthesis paper, summarized many of the potential physical benefits of restoration; these include pool depth and frequency, habitat complexity, woody debris, and sediment retention and quality of spawning gravel. Some projects in deeply incised channels have reduced the incision and increased bed elevation. Evaluations of biological responses have been confounded by natural variability of populations, duration of study, or length of stream examined. For example, determination of success based on spawning ground counts is problematic because of variation in ocean survival. However, longer duration and watershed scale studies have shown positive responses of juvenile and adult salmon (Johnson et al 2005). Burnett et al. (2008) conducted a systematic review of peer-reviewed articles to examine the effects of large wood placement on salmonid abundance, growth, or survival, or on overall stream habitat complexity. Few publications were both relevant and met the rigorous standards outlined in their review. Although the review supported short term improvements in habitat complexity, the relationship to salmonid productivity was less definitive. Notable exceptions included Johnson et al. (2005) cited above, and Solazzi et al. (2000). An alternative approach to directly assessing biological response is to model potential changes in abundance or productivity. The Habitat Limiting Factors Model (Reeves et al. 1989, Nickelson et al.1992a, Nickelson 1998) was developed to quantify the carrying capacity of coastal streams for juvenile coho during the summer and winter. Use of this model is appropriate because most of the instream restoration projects in western Oregon were intended to improve habitat for juvenile coho. In this paper, we evaluated the physical response directly, and quantified the potential response of juvenile coho salmon by application of the Habitat Limiting Factors Model.

Project effectiveness monitoring requires linking the restoration treatment to improved physical conditions for and biological response of salmon (Katz et al. 2007) and defining desired outcomes (Rumps et al. 2007). Because the WOSRP projects were designed to improve ecological and hydrologic stream function specifically for salmonids, we evaluated 1) retention of wood structures, 2) natural recruitment of additional wood, 3) increase in pool number, area, and depth, 4) retention of gravels and sorting of finer substrates, and 5) increase in channel complexity – secondary channels and off-channel habitats. Biological evaluation was based on estimates of the potential carrying capacity for juvenile coho during the overwinter life stage. The primary objectives of this evaluation are to test for these changes one year following treatment and 6 years following treatment. Secondarily, we evaluated the response of the projects by geographic location and position along the stream network.

Previous WOSRP monitoring reports (e.g. Jacobsen and Jones 2003, Jacobsen et al. 2007) have focused on conditions one year following treatment, with relatively few sites assessed 2-3 years following restoration. Since 2003, the restoration projects have increased in complexity – more and larger pieces and jams, and treated more kilometers of stream length per site. The WOSRP program has provided a unique opportunity to evaluate the effects of restoration projects over longer times and broader geographic scales than previously feasible.

We have been surveying the restoration sites in both summer and winter to monitor changes in stream habitat and evaluate the success of treatments, such as the placement of wood and/or boulders and fish passage. Surveys are logistically easier to manage in the summer, but surveys conducted during the winter provide a more timely and accurate assessment of over-winter rearing potential for juvenile coho. Because we have paired surveys, we are able to assess the added value of revisits across seasons. We test the hypothesis that habitat characteristics at the restoration sites do not change from summer to winter. The findings permit us to modify the survey program if the information is duplicative, and use the resources in another fashion.

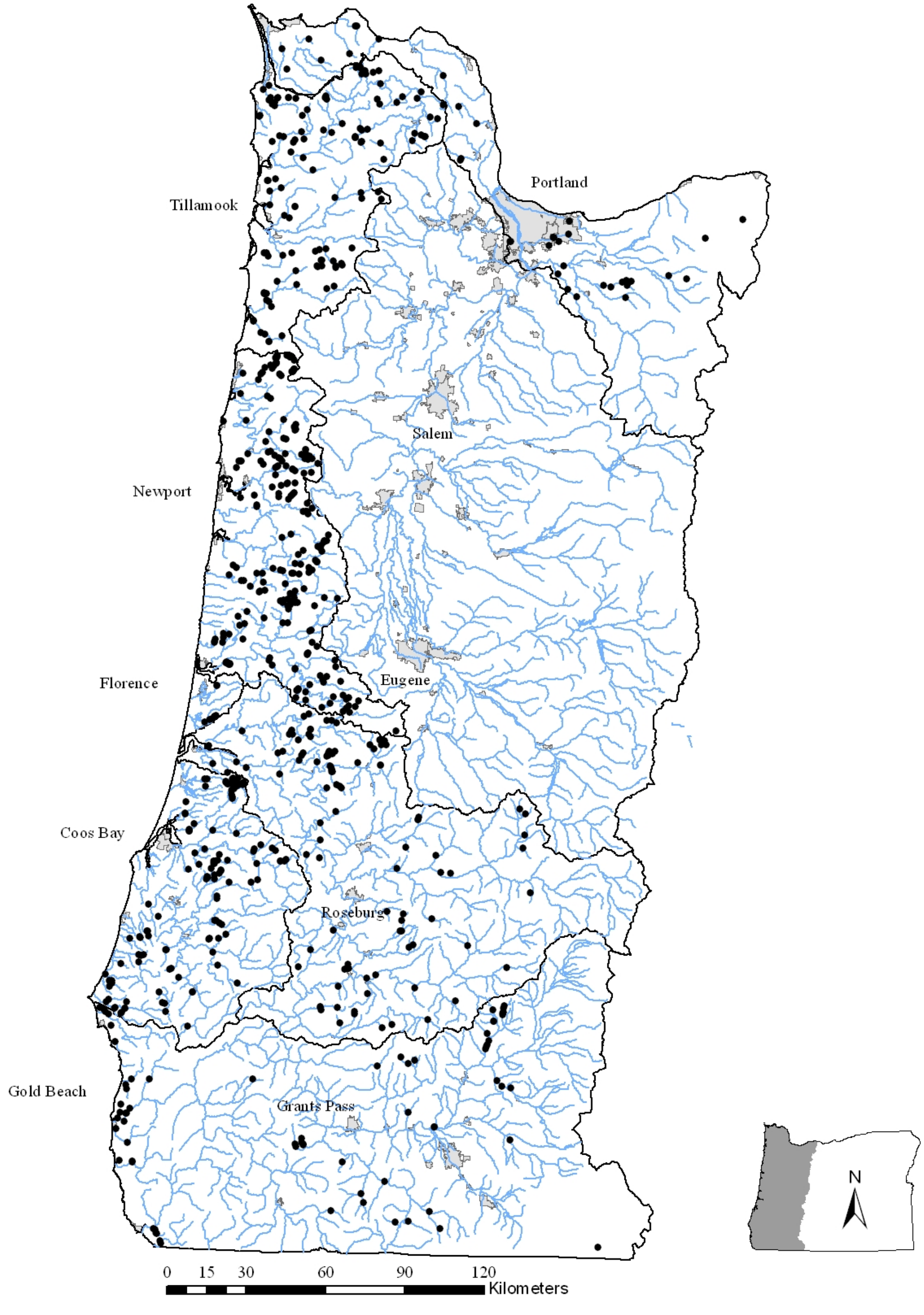

Figure 1. Location of 689 large wood projects implemented from 1995-2007 in OWEB database.

METHODS

Study Streams

Streams selected for restoration projects had a medium channel width (5-25m), low gradient (0-3%), moderate to high amount of pool habitat (35-50%), and low structural complexity (wood or boulders), as recommended in Thom et al. (2001). The sites were located primarily in Oregon coastal basins, but also in the Willamette and Lower Columbia basins. Treatments consisted primarily of large wood placed as multi-piece jams in pools. The large wood pieces were a minimum of 1.5 times the active channel width and 25.4cm (10 inches) in diameter. The median number of wood pieces placed in streams was 30 per kilometer, or approximately 3 pieces per 100m. The wood was usually massed as jams of at least 5 pieces.

From 1996 to 2008, we monitored 318 WOSRP restoration sites, approximately 301 km of stream length. We examined the results of restoration treatments at 103 sites where we had paired summer and winter pre-treatment and 1-year post treatment surveys. The post treatment surveys were conducted within the first year after treatment (Figure 2, Appendix A-1). Of the 103 sites, 82 were treated with wood, 10 were treated with a combination of wood and boulders, and 11 addressed fish passage. The sites were well distributed; 52% are located in the north and mid-coast regions, 20% in the mid-south and south coast regions, and 17% in the Umpqua River basin. Another 7% are located in the lower Columbia River basin and 4% are located in the Willamette River basin.

We also had 46 restoration sites with paired summer-winter pre-treatment and post treatment surveys conducted 1 year and 6 or 7 years after treatment (Figure 2, Appendix A-2). Of the 46 sites, 38 had paired surveys 1 and 6 years following treatment and 8 sites had paired surveys only 6 years following treatment. Of these sites, 40 were treated with wood, 4 were treated with a combination of wood and boulders, one was treated with boulders only, and one addressed fish passage. The sites resurveyed six years following treatment had a similar spatial distribution; 59% were located in the north coast and mid-coast, 11% in the mid-south and southern coast, and 22% in the Umpqua River basin. Few were located in tributaries to the lower Columbia River (6%) and the Willamette River (2%).

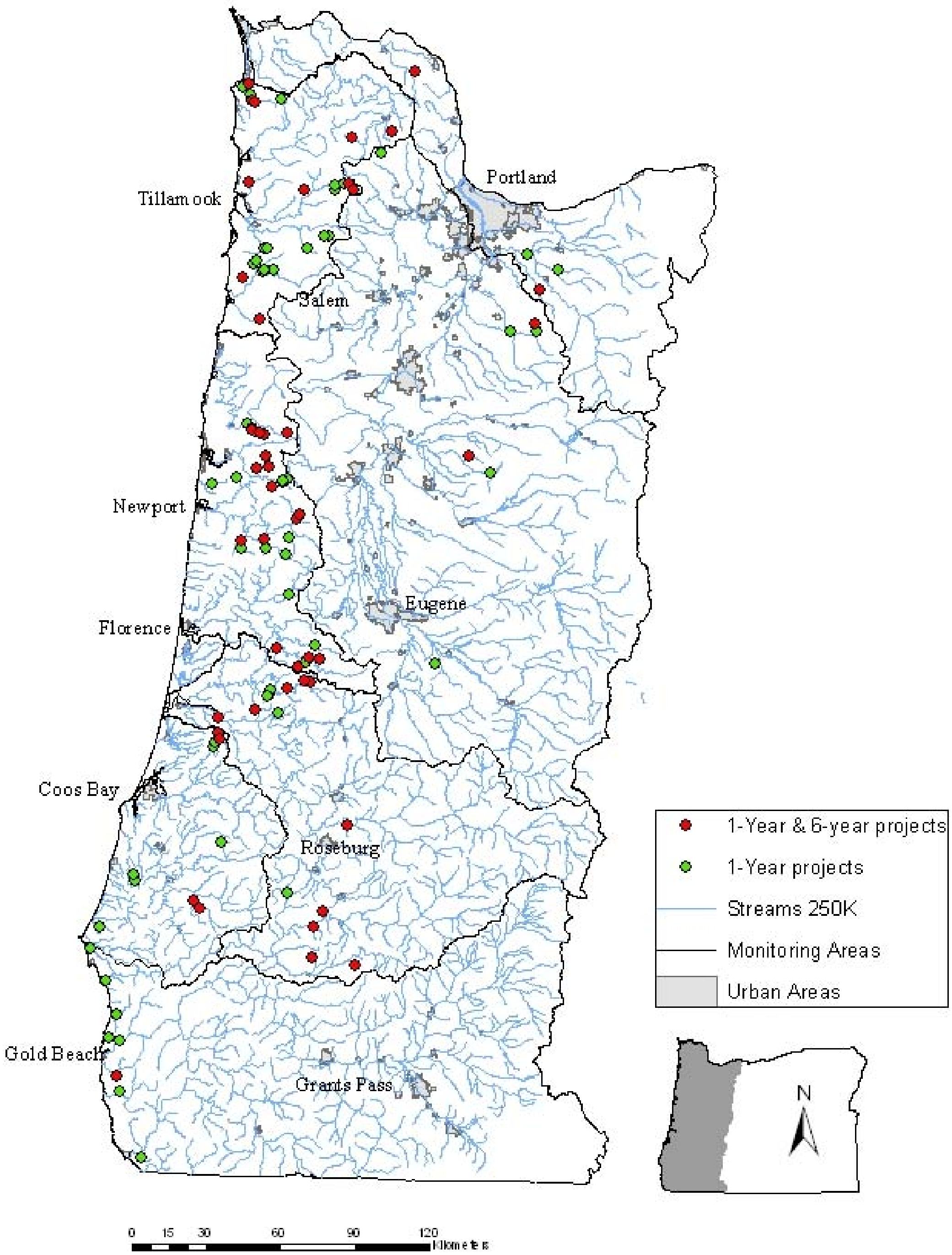

Figure 2. Location of monitored sites. Green sites were monitored pre-treatment and one year following treatment (n=103), and red sites were monitored pre-treatment and 1 and 6 years following treatment (n=46).

Field Surveys

Winter and summer habitat surveys were completed at each site to establish baseline conditions immediately preceding restoration treatment. Streams were treated in the summer or fall. Each site was then surveyed in the winter and summer of the year immediately following treatment. A subset of sites was surveyed six or seven years after the stream was treated, five years after the first post treatment survey. For example, pre-treatment surveys were conducted in the winter of 2002 and in the summer of 2002. The streams were treated in late summer or fall of 2002 and received a post treatment survey in the winter of 2003 and in the summer of 2003. A subset of these sites received an additional post treatment survey in the winter of 2008 and in the summer of 2008.

Physical habitat survey methods were modified from the ODFW Aquatic Inventories protocols (Moore et al 2007). Modifications to the survey methods included:

- Survey segments were typically 500m for years 1999-2003 and the entire length of treatment in years thereafter (range: 400-6,000m).
- All habitat unit lengths and widths were measured.
- Wood diameter and length were estimated prior to 2004 and measured thereafter.
- Riparian transects were conducted in at least 3 locations spaced at equal intervals throughout summer surveys. For sites longer than 1,200m, additional riparian transects were taken.
- Winter surveys did not assess stream shading, quantity of large boulders, undercut banks, active erosion, or riparian conditions. These attributes were assumed similar to conditions during the summer surveys.

Location of restoration Sites

Site location was assessed relative to the spawning and rearing distribution of coho salmon and to reaches of high intrinsic potential for the sites within the Coast Coho ESU. The spawning and rearing distribution was based on a 1:24K digitized map layer developed by the Research and Monitoring Program of ODFW. The reaches of high intrinsic potential are those stream reaches with low gradient, moderate size, and wide valley floor; these reaches may have historically provided very important habitat for juvenile coho during the winter. The reaches were mapped by the Coastal Landscape and Modeling Study (Burnett et al. 2007).

Analysis

We assessed habitat metrics that describe large wood, pool character, channel complexity, substrate, and juvenile rearing capacity. Individual variables include wood volume per 100m, wood pieces per 100m, key wood pieces per 100m, pool frequency, percent surface of pools, percent surface area of slackwater pools (dam pools, beaver pools, alcoves, backwater), percent surface area in secondary channels, percent sand and organics in the substrate, percent gravel, and the number of coho parr the stream segment could support (carrying capacity).

Five sets of comparisons were conducted on each metric:

1) summer to winter pre-treatment
2) summer to winter post treatment
3) pre-treatment to one year post treatment
4) pre-treatment to 6 year post treatment
5) one year post treatment to 6 year post treatment

The winter rearing capacity for juvenile coho salmon (winter parr/km) was calculated with the Habitat Limiting Factors Model version 7. A complete description of the HLFM estimates using winter and summer survey data is presented in Anlauf et al. (2009). Boxplots were used to describe the general properties of each dataset (without transformation) including the mean, median, quartiles, and range of data. Cumulative distribution frequency plots display the full range of data for each treatment block.

Because the data are paired, we analyzed the mean difference between pre- and post treatment or summer and winter, to test each hypothesis. A series of paired t-tests (based on the difference of the means, see hypothesis below) and a Wilcoxon signed rank test (uses the median, no parameter estimates or confidence intervals were calculated) were employed. Several variables were log transformed to meet assumptions of normality: pool frequency, key wood pieces, percent secondary channel area, and winter parr/km. The t-test sufficed because the data were transformed and the distributions normalized adequately. The results of the two tests were similar, so we only report the t-test results.

Paired t-test hypothesis

$\mu d = \mu 1 - \mu 2$

Ho:

1. $\mu d \leq Do$ (Do is a specified value, often 0)
2. $\mu d \geq Do$
3. $\mu d = Do$

Ha:

1. $\mu d > Do$ (Do is a specified value, often 0)
2. $\mu d < Do$
3. $\mu d \neq Do$

Outcome,

1. We reject Ho if $t \geq t\alpha$
2. We reject Ho if $t \leq t\alpha$
3. We reject Ho if $|t| \geq t\alpha/2$

where $\mu 1$ is pre-metric mean, $\mu 2$ is the post-metric data, μd is the difference between $\mu 1$ and $\mu 2$ and t corresponds to the t statistic used in the t-test.

RESULTS

The pre-treatment stream sites met the criteria for restoration treatment. The sites were low gradient (<4%) and medium size, with a mean and median of 7.8 and 7.0 meters active channel width respectively. The sites were structurally simple, but with adequate pool habitat. The stream reaches averaged 36% pools habitat, low levels of large wood, and low winter rearing capacity for juvenile coho salmon. Most sites, 85% and 63% respectively, were located within the spawning or rearing distribution of coho salmon and in areas of high intrinsic potential for juvenile coho.

Survey Season

Information collected during the summer was very similar to that collected during the winter. The paired t-tests showed significant differences in wood pieces, percent pools, and secondary channel area in the pre-treatment surveys (Table 1) and a significant difference in percent pool in the post treatment surveys (Table 2). While significant, the differences in wood pieces and secondary channel area were small in the pre-treatment surveys. The primary difference across the seasons was in the amount of surface area of pool habitat between summer and winter surveys. The rearing capacity (winter parr per km) was significant (p=0.053) in the pre-treatment surveys. The difference may be related to the slightly higher percent of pool habitat which increases the area available for rearing, or in the ability to estimate winter rearing capacity with summer data, using the regression relationship described in Anlauf et al. (2009).

Table 1. Mean values and significance of paired t-tests for surveys that compared pre-treatment surveys in the summer and winter. Significant p values (<0.05) are in bold (d.f. = 95).

Habitat metric	Winter	Summer	p-value
Wood volume per 100m	14.0	12.6	0.12
Wood pieces per 100m	13.7	11.8	**<0.01**
Key wood pieces per 100m	0.4	0.4	0.89
Pool frequency	2.9	2.9	0.98
Pools (%)	35.9	42.1	**<0.01**
Slackwater pools (%)	4.2	5.4	0.13
2^{nd} channel area (%)	4.6	4.0	**<0.01**
Sand/organics (%)	27.6	28.3	0.48
Gravel (%)	36.5	34.4	0.11
Winter parr per km	872.0	938.0	0.05

Table 2. Mean values and significance of paired t-tests for surveys that compared one-year post treatment surveys in the summer and winter. Significant p values (<0.05) are in bold (d.f. = 95).

Habitat metric	Winter	Summer	p-value
Wood volume per 100m	29.8	31.7	0.33
Wood pieces per 100m	17.8	18.4	0.71
Key wood pieces per 100m	1.7	1.9	0.27
Pool frequency	2.7	2.9	0.07
Pools (%)	36.1	42.8	**<0.01**
Slackwater pools (%)	4.8	6.4	0.25
2nd channel area (%)	4.8	4.9	0.11
Sand/organics (%)	27.9	29.1	0.33
Gravel (%)	37.4	35.3	0.08
Winter parr per km	1704.0	1833.0	0.82

We report the pre-post findings based on the winter surveys because the results are similar to that based on the summer survey pre-post data. Additional details are presented as cumulative distribution frequency graphs in the Appendix.

One Year Post Treatment

The treatments resulted in significant increases in amounts of large wood (pieces, volume, and key pieces), complex pools (pools with $>20m^3$ volume of wood), and rearing capacity within the first year (Table 3). The median values for rearing capacity were considerably lower than the means, but increased from 547 to 709 parr per km. The increases were an immediate effect of the addition of large wood placement in pools. Few, if any, of the additional pieces entered the project area through natural recruitment. Amount of pool habitat or substrate composition did not change.

Five Years Post Treatment

Sites showed similar changes 6 years following treatment; large wood measures, complex pools, and winter rearing capacity were significantly higher (Table 4). The median values of winter rearing capacity increased from 679 to 974 parr per km. However, significant differences in additional variables were observed between pre-treatment and 6 years post treatment. The amount of surface area of pools increased, and the relative amount of gravel increased while the fine sediments decreased. No changes were observed in secondary channel or alcoves and beaver ponds.

Table 3. Mean values and significance of paired t-tests for winter surveys that compare pre-treatment to one year post treatment variables. Significant p values (<0.05) are in bold (d.f. = 102). Complex pools are scour pools with >20m^3 of wood.

Habitat metric	Pre Mean	Post Mean	p-value
Wood volume per 100m	13.6	29.0	**<0.01**
Wood pieces per 100m	13.3	17.7	**<0.01**
Key wood pieces per 100m	0.4	1.6	**<0.01**
Pool frequency	2.9	2.7	0.36
Pools (%)	36.2	37.2	0.46
Slackwater pools (%)	4.0	4.6	0.39
2nd channel area (%)	4.6	4.8	0.15
Alcove/beaver ponds (%)	0.03	0.03	0.85
Complex pools (%)	0.01	0.04	**<0.01**
Sand/organics (%)	27.0	27.0	0.97
Gravel (%)	36.2	37.0	0.40
Winter parr per km	1190.4	1683.7	**0.02**

Table 4. Mean values and significance of paired t-tests for winter surveys that compare pre-treatment to six year post treatment variables. Significant p values (<0.05) are in bold (d.f. = 45). Complex pools are scour pools with >20m^3 of wood.

Habitat metric	Pre Mean	6-yr Post	p-value
Wood volume per 100m	12.9	24.2	**<0.01**
Wood pieces per 100m	12.3	18.8	**<0.01**
Key wood pieces per 100m	0.5	0.9	**0.01**
Pool frequency	3.0	3.1	0.95
Pools (%)	36.3	44.0	<**0.01**
Slackwater pools (%)	3.5	4.6	0.40
2nd channel area (%)	5.4	4.6	0.30
Alcove/beaver ponds (%)	0.03	0.02	0.77
Complex pools (%)	0.00	0.03	<**0.01**
Sand/organics (%)	29.9	22.8	<**0.01**
Gravel (%)	36.1	41.5	<**0.01**
Winter parr per km	800	1246	<**0.01**

However, changes in habitat variables between 1 and 6 years following treatment were more subtle (Table 5). Sites lost a significant number of key pieces (> 60 cm dbh and > 12 m length) and volume of large wood. A few more pieces of wood (>0.15 cm dbh and >3m length) were recruited to the sites (p=0.07). The amount of fine sediments lowered significantly at p=0.052, though only by a few percent. The median rearing capacity remained steady from one to six years following treatment at 1036 and 998 parr per km respectively.

Table 5. Mean values and significance of paired t-tests for winter surveys that compare one year post treatment to 6 years post treatment variables. Significant p values (<0.05) are in bold (d.f. = 45). Complex pools are scour pools with >20m^3 of wood.

Habitat metric	1-yr Post	6-yr Post	p-value
Wood volume per 100m	29.3	24.2	**0.01**
Wood pieces per 100m	17.2	18.8	0.07
Key wood pieces per 100m	1.4	0.9	**0.02**
Pool frequency	3.0	3.1	0.91
Pools (%)	41.4	43.9	0.18
Slackwater pools (%)	6.0	4.6	0.36
2nd channel area (%)	4.5	4.6	0.33
Alcove/beaver ponds (%)	0.03	0.03	0.61
Complex pools (%)	0.05	0.03	0.17
Sand/organics (%)	26.6	22.8	0.05
Gravel (%)	39.0	41.5	0.23
Winter parr per km	1296	1246	0.84

Overall, treated streams showed improved habitat complexity. A summary of the findings are presented in Table 6. Additional improvements in stream quality, including a reduction in fine sediment and bedrock and an increase in pool habitat and canopy, were long-term results of stream restoration projects. While the surface area of pool habitat increased six years following treatment, the residual pool depth and the number of pools did not change significantly. Cumulative distribution frequency plots that display the range of values from pre-treatment to one year post and 6 years post treatment are presented in Appendix B.

Table 6. Descriptive results of cumulative distribution frequency graphs of 1-year post treatment surveys (n=137) and 6-year post treatment surveys (n=55) compared to pre-treatment conditions (Appendix B). The variable stayed the same (=), increased (+), or decreased (-) after 1 or 6 years post treatment.

	1 -Year Post Treatment	**6 -Year Post Treatment**
Percent fines in riffle units	=	−
Percent gravel in riffle units	+	+
Percent bedrock in all habitat units	=	−
Density of wood pieces	+	+
Density of key wood pieces	+	+
Density of wood volume	+	+
Percent pool habitat	=	+
Residual pool depth	=	=
Percent slackwater pools	=	+
Percent channel shading	=	+
Parr per square meter	+	+
Parr per kilometer	+	+

Treatment Type

Streams were treated with either wood only, a combination of wood and boulders, or boulders only. Forty streams with six-year post treatment surveys were treated with large wood only (Table 7). Thirty-three of forty sites gained between 2 m^3/100m and 50 m^3/100m of wood. Only 7 streams lost wood volume. Seventy-two percent of the sites increased the amount of gravel, and 65% gained in surface area of pools. Half of the sites realized increase in large wood and surface area of pools, and for the most part, increases in gravel.

Five streams with six-year post treatment surveys were treated with a combination of large wood and boulders (Table 8). Four of these streams gained between 3 m^3/100m and 27 m^3/100m of wood. The wood and boulder treatment projects gained gravel (with one exception), and increased the surface area of pools in 4 of 5 sites. Three of the five sites increased the amount of wood, gravel, and pools from pre-treatment to 6-years post treatment

Only one stream with a six-year post treatment survey was treated with boulders only (Table 9). The restoration site lost 5m^3/100m of wood, and the surface area of gravel increased slightly.

Overall, sites had a large initial increase in wood volume immediately after treatment. The streams treated with wood only had some loss in wood volume over five years, but retained larger amounts of wood volume long-term when compared to pre-treatment levels (Figure 3). Similar results were observed in streams treated with a combination of wood and boulders (Figure 4).

Table 7. Comparison of wood volume, percent gravel, percent pools, and percent slackwater pools for streams treated with wood only from pre-treatment to 6-years post treatment (n=40). The values are the amount gained or lost (-) over the 6 year time period.

MA	Basin	Stream	Site No.	Active Channel Width (m)	Wood Volume (m3/100m)	% Gravel	% All Pools	% Slackwater Pools
NC	Miami	Peterson Creek	54	7.6	9	17	8	-1
NC	Necanicum	Beerman Creek	6	7.1	22	14	14	1
NC	Necanicum	Johnson Creek	38	5.1	5	-4	0	-3
NC	Necanicum	Mail Creek	48	7.5	5	-23	11	0
NC	Nehalem	Coal Creek	16	6.7	-22	-23	-3	-7
NC	Nehalem	North Fork Wolf Creek	95	10.5	9	12	41	30
NC	Nestucca	Baxter Creek	2	6.2	15	4	-15	0
NC	Nestucca	Farmer Creek	30	5.3	33	5	-8	-1
NC	Wilson	Cedar Creek	13	15.1	11	1	-24	0
NC	Wilson	Devils Lake Fk Wilson R (Upper)	133	7.8	16	-13	14	-1
NC	Wilson	Devils Lake Fk Wilson R	27	8.4	24	15	24	25
MC	Alsea	Cherry Creek	15	6.9	-4	-8	-5	-3
MC	Alsea	Honeygrove Creek	35	9.2	4	5	10	-3
MC	Alsea	Little Lobster Creek	43	10.1	8	5	32	-10
MC	Alsea	Seeley Creek #2	60	8.1	12	17	-7	-4
MC	Siletz	Little Rock Creek	44	5.9	7	-4	-13	-1
MC	Siletz	Long Prairie Creek (Lower)	46	9.0	9	-7	12	-20
MC	Siletz	Long Prairie Creek (Upper)	47	6.0	21	27	37	-1
MC	Siuslaw	Camp Creek	11	5.5	28	-8	18	3
MC	Siuslaw	Dogwood Creek	28	7.6	3	9	25	2
MC	Siuslaw	Oxbow Creek	53	6.8	22	14	21	1
MC	Yaquina	Bales Creek	1	8.5	22	-5	4	-2
MC	Yaquina	Deer Creek #2	23	8.0	29	10	20	14
MC	Yaquina	Feagles Creek	31	9.5	-3	1	-5	-2
MC	Yaquina	Salmon Creek	58	7.0	20	4	-8	10
MC	Yaquina	Wolf Creek	108	6.5	12	5	16	2
MS	Coquille	Rasler Creek	55	4.9	18	11	11	-1
MS	Millicoma	Fish Creek	32	6.3	4	-2	31	9
UMP	Smith	Clabber Creek	77	5.6	12	15	9	0
UMP	Smith	Panther Creek	96	8.4	23	3	6	2
UMP	Smith	Salmonberry Creek	99	4.7	50	30	26	1
UMP	S. Umpqua	Catching Creek	127	6.5	7	-16	9	0
UMP	S. Umpqua	Starvout Creek	151	5.7	15	8	-8	0
UMP	Umpqua	Charlotte Creek	14	10.2	10	18	2	-2
UMP	Umpqua	Wood Creek	65	4.4	-3	7	-10	-2
SC	Hunter	Little SF Hunter Creek	45	10.1	-2	1	0	0
LC	Clackamas	Golf Creek	33	2.7	-4	8	-5	-1
LC	Clatskanie	Buck Creek	73	7.1	-10	8	14	28
LC	Molalla	Canyon Creek	12	6.1	3	16	-5	0
W	S. Santiam	Roaring River Tributary	56	5.4	28	6	-15	-10

Table 8. Comparison of wood volume, percent gravel, percent pools, and percent slackwater pools for streams treated with wood and boulders from pre-treatment to 6-years post treatment (n=40). The values are the amount gained or lost (-) over the 6 year time period.

MA	Basin	Stream	Site No.	Active Channel Width (m)	Wood Volume (m3/100m)	% Gravel	% Pools	% Slackwater Pools
MS	Coquille	Myrtle Creek	144	19.7	6	30	29	0
MS	Millicoma	WF Millicoma River #1 (Upper)	64	11.4	27	-19	6	1
UMP	N. Umpqua	Clover Creek	130	5.3	13	4	24	0
UMP	Umpqua	Lane Creek	41	4.1	7	33	-4	-2
UMP	Umpqua	Weatherley Creek	150	11.3	3	1	14	0

Table 9. Comparison of wood volume, percent gravel, percent pools, and percent slackwater pools for streams treated with boulders only from pre-treatment to 6-years post treatment (n=40). The values are the amount gained or lost (-) over the 6 year time period.

MA	Basin	Stream	Site No.	Active Channel Width (m)	Wood Volume (m3/100m)	% Gravel	% Pools	% Slackwater Pools
MC	Siuslaw	Esmond Creek (Lower)	137	13.0	-5	12	-1	-1

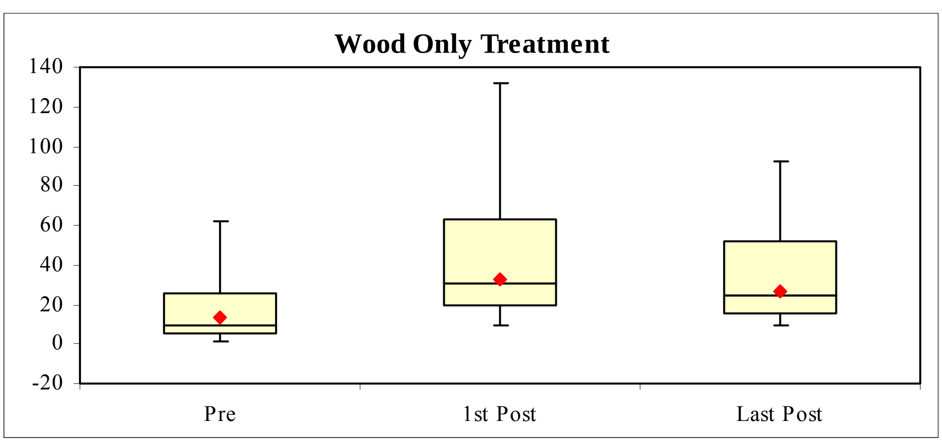

Figure 3. Comparison of wood volume (m^3/100m) from pre-treatment to the first and last post treatment surveys of streams treated with wood only (n=40).

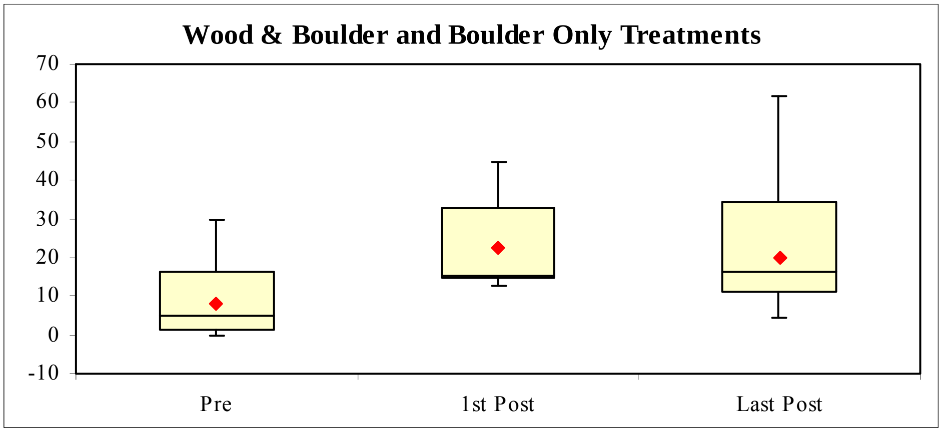

Figure 4. Comparison of wood volume (m^3/100m) from pre-treatment to the first and last post treatment surveys of streams treated with a combination of wood and boulders or boulders only (n=6).

Winter Rearing Capacity for Juvenile Coho Salmon

An increase in the percentage of scour pools, alcoves and beaver ponds, and complex lateral scour pools (pools with more than 20m^3 of wood) improves the carrying capacity of streams for juvenile coho, estimated as the density of parr per kilometer and parr per square meter. At the restoration sites, the percentage of scour pools steadily increased one year and six years after streams were treated with wood and/or boulders (Figure 5). Alcoves and beaver ponds increased from the pre-treatment survey to the first post treatment survey and greatly increased in select streams by the 6-year post treatment survey (Figure 6). Overall, complex lateral scour pools increased over a six year period, though they declined slightly from the first to last post treatment survey (Figure 7). The estimates of parr per kilometer and parr per 100 square meters increased from the pre-treatment survey to the first and last post treatment surveys (Figure 8-9).

Inspection of individual sites revealed that those wood and wood/boulder treatment sites, n=20 and n=3 respectively, that increased in large wood, gravel, and pool area (Table 7) also increased in estimated carrying capacity for juvenile coho with one exception. Considering all sites, 28 of 46 sites maintained an increase in carrying capacity after 6 years.

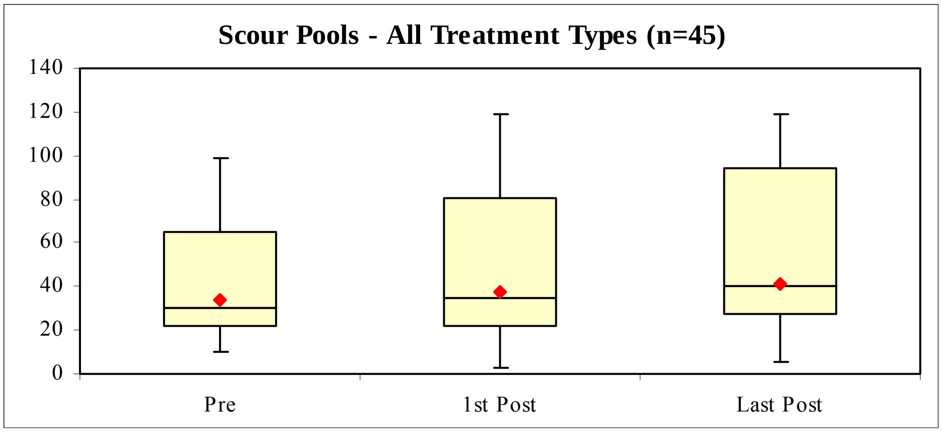

Figure 5. Comparison of percent scour pools from pre-treatment to the first and last post treatment surveys of all treated streams (n=45).

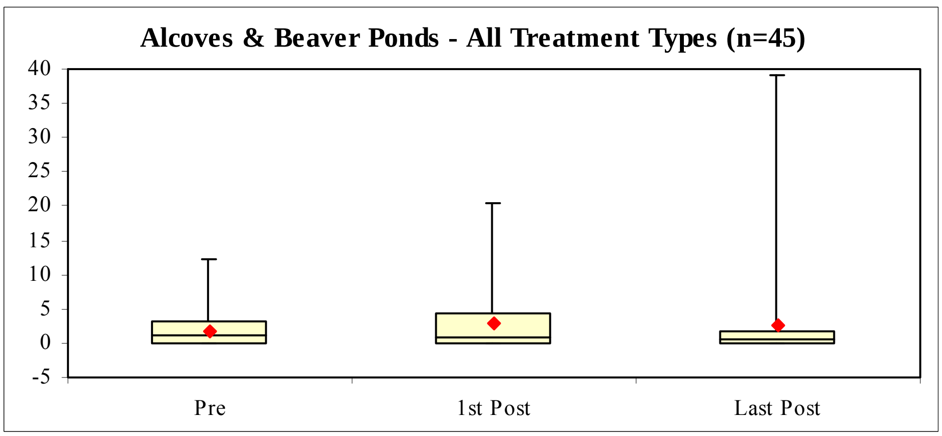

Figure 6. Comparison of percent alcoves and beaver ponds from pre-treatment to the first and last post treatment surveys of all treated streams (n=45).

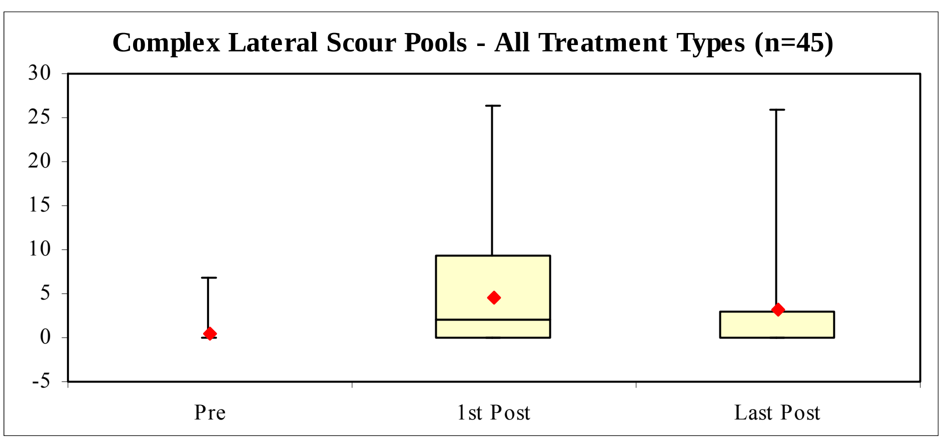

Figure 7. Comparison of percent complex lateral scour pools from pre-treatment to the first and last treatment surveys of all treated streams (n=45).

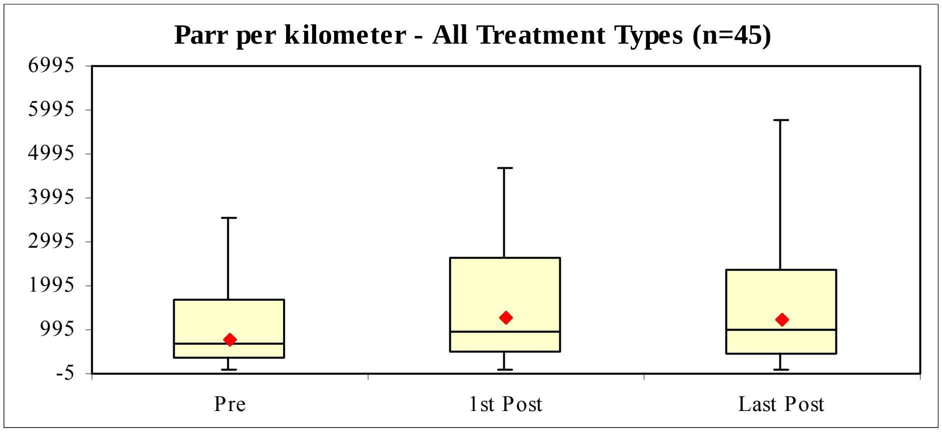

Figure 8. Comparison of parr per kilometer from pre-treatment to the first and last post treatment surveys of all treated streams (n=45).

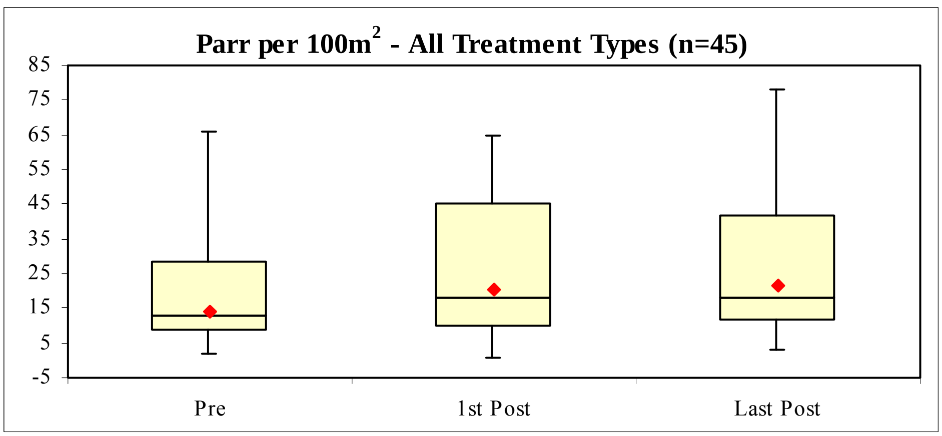

Figure 9. Comparison of parr per 100 square meters from pre-treatment to the first and last post treatment surveys of all treated streams (n=45).

DISCUSSION

Effect of season on survey results

The season, winter or summer, had a significant effect on the values of several of the stream variables. However, treatment effects were consistent when comparisons were made across pre-, 1-year post, and 6-year post survey using either the winter or the summer data. That is, the summer surveys provided results consistent with winter data in the pre-post comparisons. We selected to report the findings from the winter data sets because winter habitat is more important for juvenile coho. The primary difference between seasons was an observed decrease in the relative surface area of pools, measured as a percent of the total wetted channel area, and a decrease in the number of deep pools during in the summer compared to the winter, consistent with low base flow in the summer. Other variables such as substrate and large wood were not significantly different between seasons. Secondary channels, particularly small, old channels, were more visible in the winter due to less foliage on deciduous trees and shrubs, but the surface area and percent secondary channel estimates remained relatively similar between winter and summer. These results are consistent with that observed by Romer et al. (2008). The consistency of observations and paired comparisons allow us to reduce the surveys to one season while meeting our monitoring objectives.

Restoration effectiveness

The short-term changes of restoration projects were notable within one year of treatment. The density of wood pieces, key wood pieces, and wood volume increased significantly in comparisons of pre-treatment and post treatment surveys. This is due largely to the direct addition of large wood to create complex structures, and may also be attributed to an increase in natural wood recruited by the new structures. A significant increase in the percentage of complex pools (pools with at least $20m^3$ of wood) is also a direct result of the placement of large wood structures. Although there was no immediate increase in the density of pools or secondary channel area, the restoration structures did create increased habitat capacity for juvenile salmonids. The density of parr per square meter and per kilometer increased significantly within the first year of treatment as a result of the complex pools.

The long-term effects of restoration projects were more extensive than the short-term changes. Large wood structures and wood/boulder placements changed the composition of the substrate sorting sand, silt, and fine organic matter in pools and increased the percentage of gravel in riffle units. A decrease in the percent bedrock in all habitat units reflects the ability of large wood and boulders to retain gravel and cobble, increasing the roughness of the streambed. The amount of exposed bedrock was slightly, but consistently lower six years after the sites were treated.

An overall long-term increase in the density of large wood pieces and wood volume can be attributed not only to the direct addition of large wood treatments, but also to the accumulation of natural wood over an extended period of time. Streams treated with wood only and combinations of wood and boulders were successful in accumulating natural wood. Groups of individual wood pieces are placed in the stream to span the active channel width, interlocking in a manner that lends itself to trapping natural wood and debris floating downstream. The structures were capable of creating large debris jams and were more effective than the boulder only treatment. The boulder only structure did not trap naturally recruited wood. The boulder only treatment of Esmond Creek (Lower) in the Siuslaw River basin retained gravel, but lost wood volume, wood pieces, and gravel over a six year period.

The wood structures had a significant effect on pool structure and amount. While more complex pools and surface area were observed, the residual pool depth did not change and the frequency of deep pools decreased. We suspect that the wood structures did an effective job of trapping sediment which slightly, but significantly ($p=0.03$)

reduced the number of pools deeper than one meter. The abundance of bedrock in many of these sites also prevented pools from scouring.

We suggest that favorable changes in substrate, and amount, type and complexity of pools, improved the habitat for juvenile and adult salmon. We cannot directly assess the biological response in terms of fish density or survival, but the Habitat Limiting Factors Model and other literature indicate a significant improvement in rearing capacity during the summer and winter (Nickelson 1992, Cederholm et al 1997).

It is not possible to set up an unbiased paired control-treatment experiment because restoration sites are selected as the most appropriate places for treatment, which based on the geomorphic template, may have a higher intrinsic potential than nearby sites. However, the geographic scope and variety of sites in this evaluation permits broad based conclusions about the effectiveness of the projects.

This is the first extensive study of before-after effects of restoration treatments over a broad geographic scale. Previous studies of the WORSP projects (e.g. Jacobsen et al. 2007) reported retention and recruitment of large wood, but few other changes were significant. Here, we demonstrated an increase in surface area of pools and sorting of substrate within the project areas in the majority of the projects. Of the 46 projects evaluated over a 6-year period, only 8 (17%) were considered to have “failed”, losing large wood or pool area. Another 15 projects (30%) increased the amount of large wood, but generally did not experience other change. For 24 (53%) of the projects however, wood was maintained, additional pool area was created, gravel accumulated, and rearing capacity for juvenile coho increased. These projects, distributed throughout the coast and lower Columbia basins and including both large wood and wood/boulder projects, we considered successful six years following treatment. While 6 years may be marginally “long term,” this study is a first attempt to quantify change in habitat following restoration more than 6 years after treatment.

We were unable to sort out geomorphic or watershed factors that contributed to the success, or lack of, of the projects. Some of the most successful projects were those that included large complex wood jams, or that had beavers move into the project area and build dams. All of the projects were placed in appropriate geomorphic settings and within the distribution of coho, maximizing the effectiveness of restoring fish habitat. We expect that the projects have started to improve fish habitat at the population and ESU scales. The WOSRP and OWEB large wood projects treated 750 km of stream from 1995-2007 in western Oregon, of which 550 km were within the distribution of coho. If half of the projects are successful (as defined above), up to two percent of coho habitat in the Coast Coho ESU has been significantly improved. While limited relative to the kilometers of stream potentially inhabited by coho, the impact is more pronounced given the projects were placed within the stream reaches most productive for overwintering juvenile coho.

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APPENDIX A

Appendix A-1. Projects with paired summer-winter pre-treatment and 1-year post treatment surveys (n=103).

Basin	Stream	GCG	Site No.	Treatment Year	Active Channel Width (m)	Kilometers Treated	Treatment Type
				1999			
Necanicum	Mail Creek	NC	48		7.5	0.5	Wood
Nestucca	Baxter Creek	NC	2		6.2	0.7	Wood
Wilson	Devils Lake Fk Wilson R.	NC	27		8.4	0.8	Wood
Alsea	Little Lobster Creek	MC	43		10.1	0.4	Wood
Alsea	Seeley Creek #2	MC	60		8.1	0.6	Wood
Siletz	Long Prairie Creek (Upper)	MC	47		6.0	0.6	Wood
Siuslaw	Dogwood Creek	MC	28		7.6	0.5	Wood
Yaquina	Deer Creek #2	MC	23		8.0	0.5	Wood
Yaquina	Salmon Creek	MC	58		7.0	0.4	Wood
				2000			
Miami	Peterson Creek	NC	54		7.6	0.7	Wood
Necanicum	Beerman Creek	NC	6		7.1	0.5	Wood
Necanicum	Johnson Creek	NC	38		5.1	0.5	Wood
Nehalem	Coal Creek	NC	16		6.7	0.5	Wood
Nestucca	Farmer Creek	NC	30		5.3	0.5	Wood
Wilson	Cedar Creek	NC	13		15.1	0.4	Wood
Alsea	Cherry Creek	MC	15		6.9	0.5	Wood
Alsea	Honeygrove Creek	MC	35		9.2	0.5	Wood
Siletz	Little Rock Creek	MC	44		5.9	0.5	Wood
Siletz	Long Prairie Creek (Lower)	MC	46		9.0	0.5	Wood
Siuslaw	Camp Creek	MC	11		5.5	0.6	Wood
Yaquina	Bales Creek	MC	1		8.5	0.5	Wood
Coquille	Bear Creek	MS	4		6.8	0.5	Wood
Coquille	Rasler Creek	MS	55		4.9	0.4	Wood
Umpqua	Byron Creek	UMP	10		4.6	0.5	Wood/Boulders
Umpqua	Charlotte Creek	UMP	14		10.2	0.5	Wood
Umpqua	Lane Creek	UMP	41		4.1	0.5	Wood/Boulders
Umpqua	Wood Creek	UMP	65		4.4	0.5	Wood
Chetco	Jack Creek	SC	36		10.5	1.6	Wood
Hunter	Little SF Hunter Creek	SC	45		10.1	0.5	Wood
Clackamas	Golf Creek	LC	33		2.7	0.5	Wood
Molalla	Canyon Creek	LC	12		6.1	0.5	Wood
South Santiam	Roaring River Tributary	W	56		5.4	0.5	Wood
				2001			
Nehalem	North Fork Wolf Creek	NC	95		10.5	0.7	Wood
Yaquina	Feagles Creek	MC	31		9.5	0.6	Wood/Culvert
Yaquina	Wolf Creek	MC	108		6.5	0.5	Wood
Millicoma	Fish Creek	MS	32		6.3	0.8	Wood
Smith	Salmonberry Creek	UMP	99		4.7	0.5	Wood
South Umpqua	Starvout Creek	UMP	151		5.7	0.5	Wood
Clatskanie	Buck Creek	LC	73		7.1	0.5	Wood
MF Willamette	Anthony Creek	W	67		8.9	0.6	Wood
Molalla	Deadhorse Creek	W	78		13.1	0.6	Wood/Boulders
South Santiam	SF Crabtree Creek	W	101		11.3	0.5	Wood
				2002			
Nestucca	Bays Creek	NC	3		9.5	0.5	Wood
Wilson	Devils Lake Fk Wilson R. Upper	NC	133		7.8	0.5	Wood
Alsea	Bummer Creek	MC	9		8.4	0.6	Wood
Alsea	Crab Creek	MC	20		10.4	0.6	Wood
Coquille	Bear Creek	MS	125		9.3	0.9	Wood

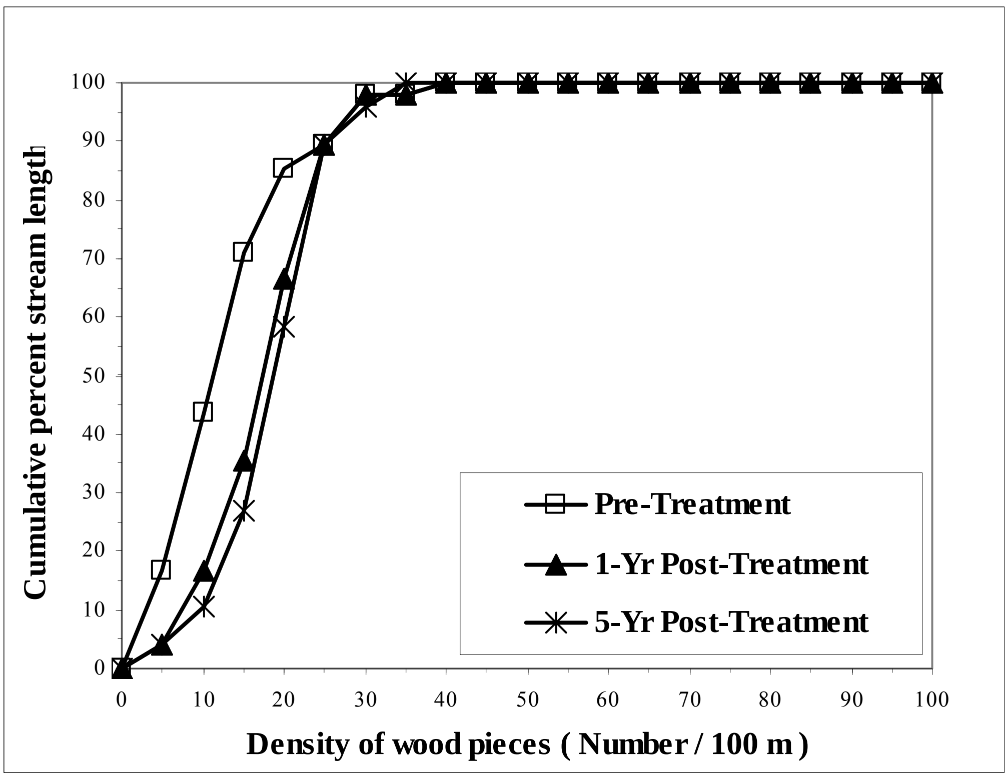
Basin	Stream	GCG	Site No.	Treatment Year	Active Channel Width (m)	Kilometers Treated	Treatment Type
Coquille	Myrtle Creek	MS	144		19.7	0.5	Wood/Boulders
Elk	Cedar Creek	SC	128		4.2	0.5	Wood/Boulders
Euchre	Pea Creek	SC	145		3.5	0.5	Wood
				2002			
Floras	Swanson Creek	SC	148		3.8	0.7	Wood/Culvert
Pistol	Deep Creek (Phase 1)	SC	132		9.9	0.5	Wood
Rogue	Edson Creek (Lower)	SC	135		5.3	0.5	Wood
Clackamas	Foster Creek	LC	86		4.0	0.7	Wood
Clackamas	NF Eagle Creek	LC	157		14.8	0.6	Wood
				2004			
Siletz	Long Prairie Creek	MC	222		6.7	2.4	Wood
Siuslaw	Eames Creek	MC	177		7.0	0.5	Wood
Siuslaw	Nelson Creek	MC	210		7.3	0.5	Wood
Yaquina	Sugarbowl Creek	MC	223		3.1	1.4	Wood/Culvert
Smith	Big Creek (Phase 2)	UMP	241		7.6	2.2	Wood/Boulders
Smith	Big Creek Tributary A	UMP	242		5.5	1.6	Wood/Boulders
Smith	Big Creek Tributary C	UMP	244		5.3	0.9	Wood/Boulders
Rogue	Rogue River Tributary C	SC	240		4.4	0.5	Culvert
				2005			
Necanicum	Square Creek	NC	256		5.8	0.5	Wood
Trask	Cruiser Creek	NC	272		9.7	1.7	Wood/Boulders
Trask	Cruiser Creek Tributary	NC	273		6.8	1.0	Wood/Boulders
Trask EF	Steampot Creek	NC	237		6.6	0.6	Wood
Wilson	SF Wilson River Tributary	NC	258		5.9	0.7	Wood
Alsea	Deer Creek	MC	301		6.1	2.0	Wood
Siuslaw	Haight Creek	MC	224		6.2	2.4	Wood
Yaquina	Cougar Creek	MC	305		4.0	1.5	Wood
Yaquina	Big Elk Creek	MC	307		6.6	1.2	Wood
Millicoma	Elk Creek	MS	285		11.7	2.2	Wood
Brush Creek	Brush Creek Tributary	SC	239		9.0	0.6	Wood
Molalla	Russell Creek	W	298		31.2	0.6	Culvert
				2006			
Wilson	Elliott Creek	NC	337		8.8	1.3	Wood
Wilson	Game Hog Creek	NC	297		8.6	0.7	Wood
Siletz	Long Prairie Creek	MC	335		8.8	0.5	Wood
Siletz	Sams Creek	MC	334		14.9	0.6	Wood
Millicoma	Elk Creek (Phase 2)	MS	325		12.6	2.9	Wood
				2007			
Necanicum	Hawley Creek	NC	371		5.2	0.7	Wood/Culvert
Necanicum	Necanicum River	NC	370		8.0	1.0	Wood
Nestucca	Bear Creek (Lower)	NC	364		5.6	0.6	Wood
Nestucca	Bear Creek (Upper)	NC	365		5.4	0.4	Wood
Nestucca	Swab Creek	NC	368		3.6	1.4	Wood/Culvert
Nestucca	Wolfe Creek	NC	367		6.2	3.0	Wood/Culvert
Tillamook	Munson Creek	NC	342		6.7	1.8	Wood
Tillamook	Munson Creek Tributary A	NC	343		4.1	0.8	Wood
Tillamook	Munson Creek Tributary B	NC	344		3.7	0.5	Wood
Alsea	Lobster Creek	MC	374		14.0	1.6	Wood
Alsea	Preacher Creek	MC	375		10.5	3.0	Wood
Beaver Creek	Elkhorn Creek	MC	373		7.9	2.3	Wood
EF Coquille	Karl Creek	MS	356		10.4	0.8	Wood
Umpqua	Paradise Creek (Site 2)	UMP	352		10.8	1.5	Wood
Tualatin	WF Dairy Creek	W	363		4.0	1.0	Wood/Culvert

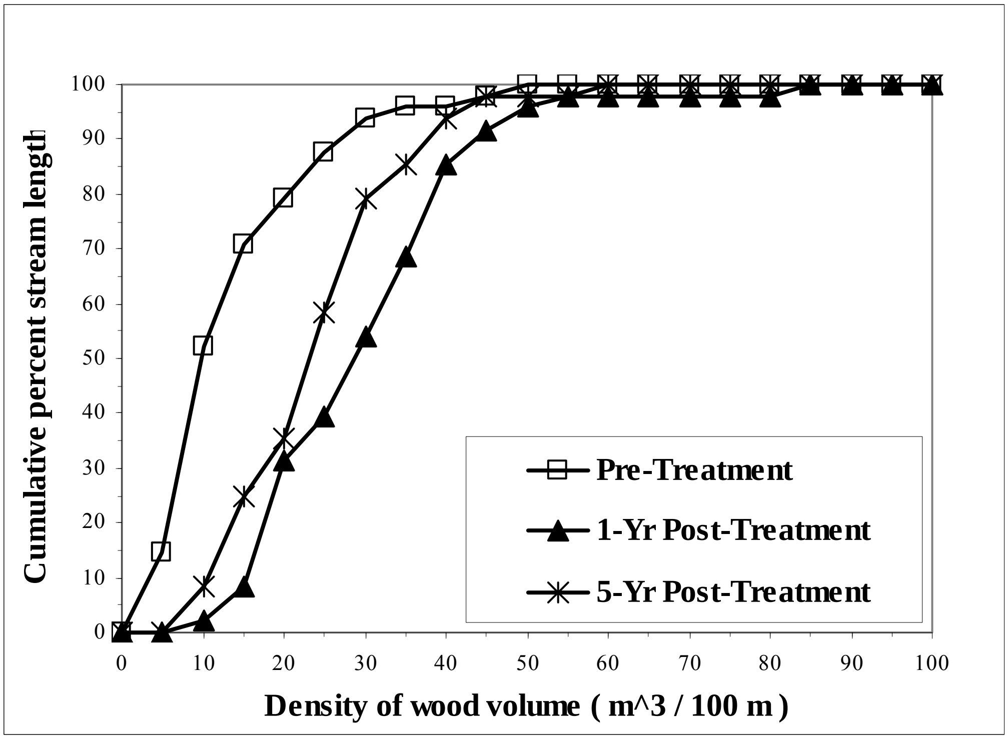
Appendix A-2. Projects with paired summer-winter pre-treatment, 1-year post and 6- or 7-year post treatment surveys (n=46).

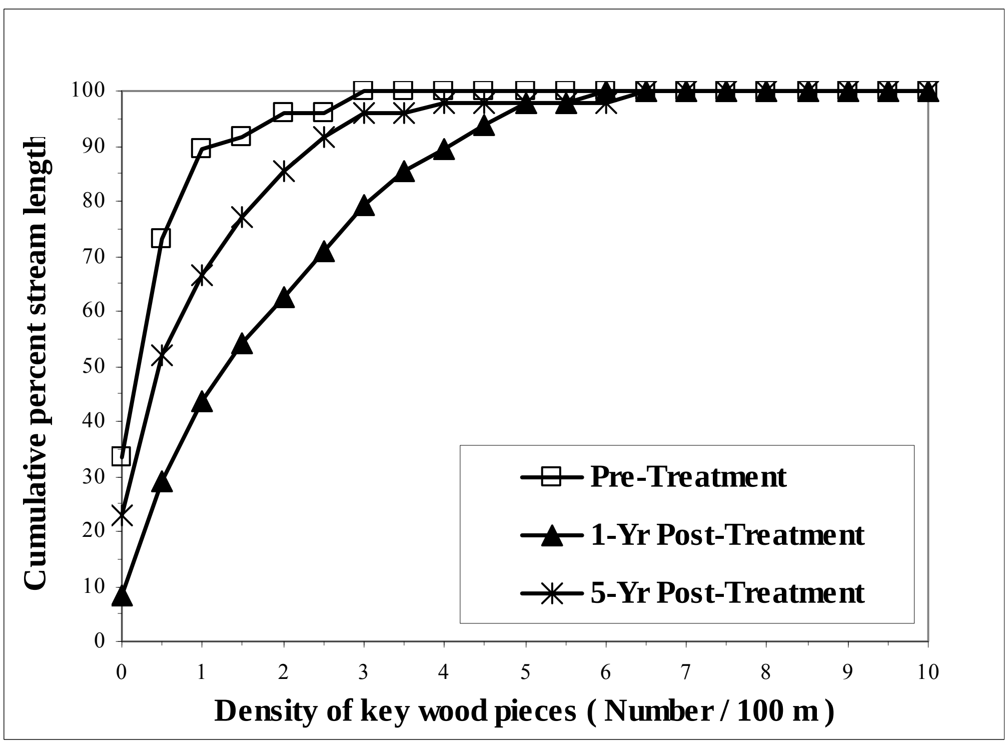
Basin	Stream	GCG	Site No.	Treatment Year	Active Channel Width (m)	Kilometers Treated	Treatment Type
				1999			
Necanicum	Mail Creek	NC	48		7.5	0.5	Wood
Nestucca	Baxter Creek	NC	2		6.2	0.7	Wood
Wilson	Devils Lake Fk Wilson R.	NC	27		8.4	0.8	Wood
Alsea	Little Lobster Creek	MC	43		10.1	0.4	Wood
Alsea	Seeley Creek #2	MC	60		8.1	0.6	Wood
Siletz	Long Prairie Creek (Upper)	MC	47		6.0	0.6	Wood
Siuslaw	Dogwood Creek	MC	28		7.6	0.5	Wood
Yaquina	Deer Creek #2	MC	23		8.0	0.5	Wood
Yaquina	Salmon Creek	MC	58		7.0	0.4	Wood
				2000			
Miami	Peterson Creek	NC	54		7.6	0.7	Wood
Necanicum	Beerman Creek	NC	6		7.1	0.5	Wood
Necanicum	Johnson Creek	NC	38		5.1	0.5	Wood
Nehalem	Coal Creek	NC	16		6.7	0.5	Wood
Nestucca	Farmer Creek	NC	30		5.3	0.5	Wood
Wilson	Cedar Creek	NC	13		15.1	0.4	Wood
Alsea	Cherry Creek	MC	15		6.9	0.5	Wood
Alsea	Honeygrove Creek	MC	35		9.2	0.5	Wood
Siletz	Little Rock Creek	MC	44		5.9	0.5	Wood
Siletz	Long Prairie Creek (Lower)	MC	46		9.0	0.5	Wood
Siuslaw	Camp Creek	MC	11		5.5	0.6	Wood
Yaquina	Bales Creek	MC	1		8.5	0.5	Wood
Coquille	Rasler Creek	MS	55		4.9	0.4	Wood
Umpqua	Charlotte Creek	UMP	14		10.2	0.5	Wood
Umpqua	Lane Creek	UMP	41		4.1	0.5	Wood/Boulders
Umpqua	Wood Creek	UMP	65		4.4	0.5	Wood
Hunter	Little SF Hunter Creek	SC	45		10.1	0.5	Wood
Clackamas	Golf Creek	LC	33		2.7	0.5	Wood
Molalla	Canyon Creek	LC	12		6.1	0.5	Wood
South Santiam	Roaring River Tributary	W	56		5.4	0.5	Wood
				2001			
Nehalem	North Fork Wolf Creek	NC	95		10.5	0.7	Wood
Yaquina	Feagles Creek	MC	31		9.5	0.6	Wood/Culvert
Yaquina	Wolf Creek	MC	108		6.5	0.5	Wood
Millicoma	Fish Creek	MS	32		6.3	0.8	Wood
Millicoma	WF Millicoma River #1 (Upper)	MS	64		11.4	0.5	Wood/Boulders
Smith	Salmonberry Creek	UMP	99		4.7	0.5	Wood
South Umpqua	Starvout Creek	UMP	151		5.7	0.5	Wood
Clatskanie	Buck Creek	LC	73		7.1	0.5	Wood
				2002			
Wilson	Devils Lake Fk Wilson R. Upper	NC	133		7.8	0.5	Wood
Siuslaw	Esmond Creek (Lower)	MC	137		13.0	0.5	Boulders
Siuslaw	Oxbow Creek	MC	53		6.8	0.5	Wood
Coquille	Myrtle Creek	MS	144		19.7	0.5	Wood/Boulders
North Umpqua	Clover Creek	UMP	130		5.3	0.5	Wood/Bldr/Culvert
Smith	Clabber Creek	UMP	77		5.6	0.5	Wood
Smith	Panther Creek	UMP	96		8.4	0.5	Wood
South Umpqua	Catching Creek	UMP	127		6.5	0.5	Wood
Umpqua	Weatherley Creek	UMP	150		11.3	0.5	Wood/Boulders

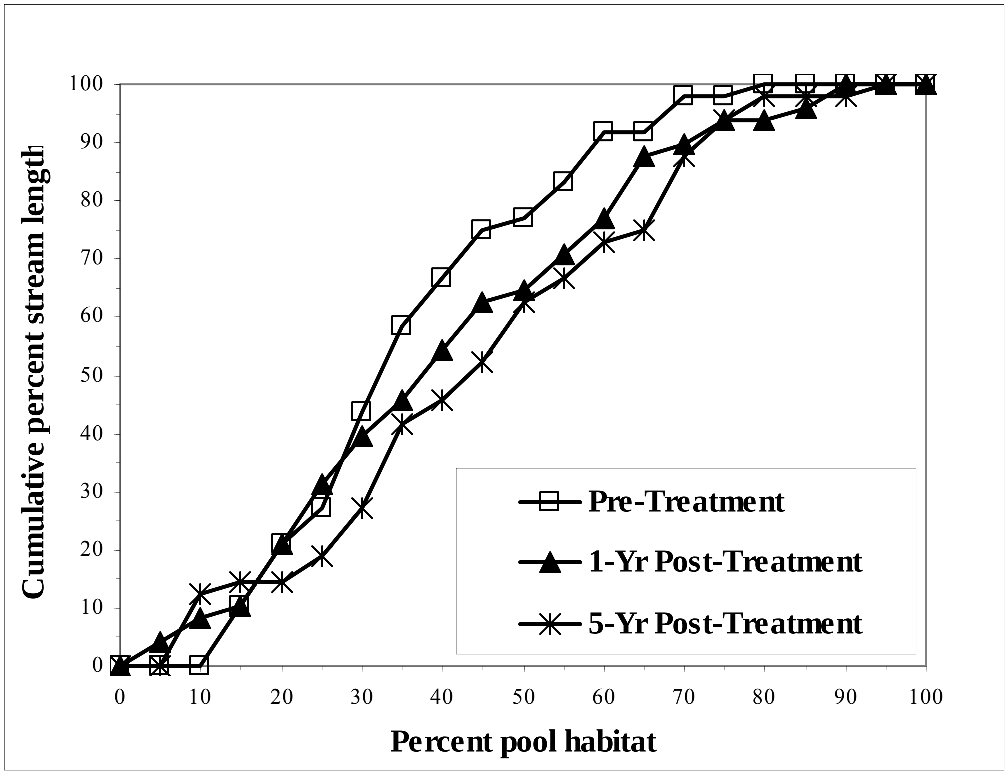
APPENDIX B

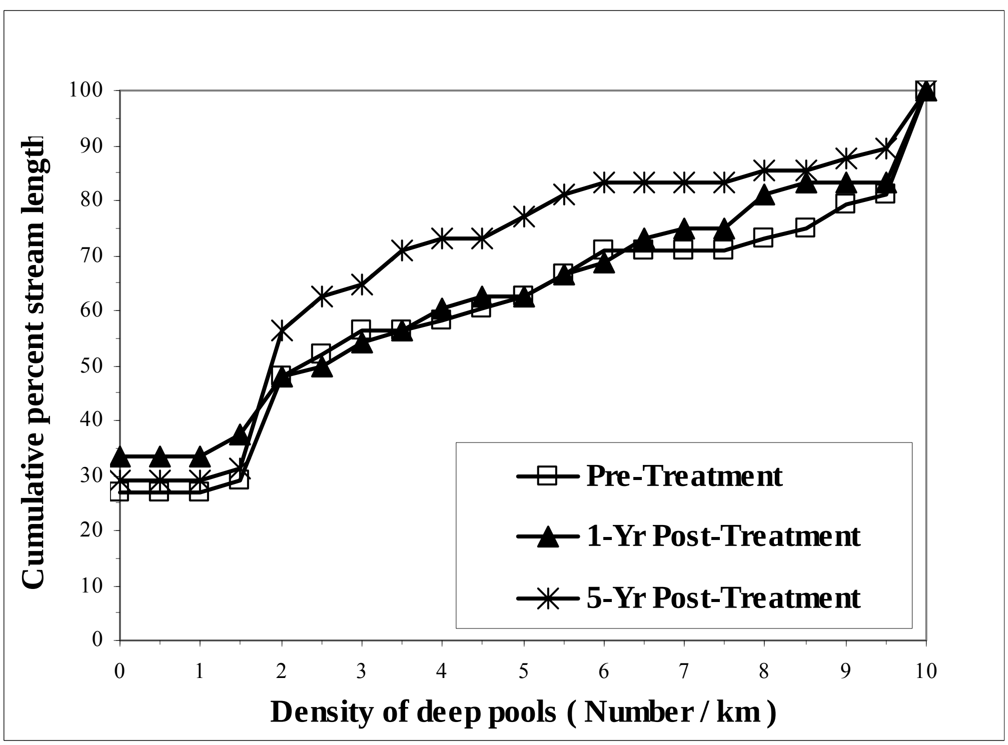
APPENDIX B-1: Winter habitat characterization of pre-, 1-year post, and 6-year post treatment surveys (n=46). Sites identified in Appendix A-2. The data for each habitat variable are standardized by length or percent so each site has an equal weight.

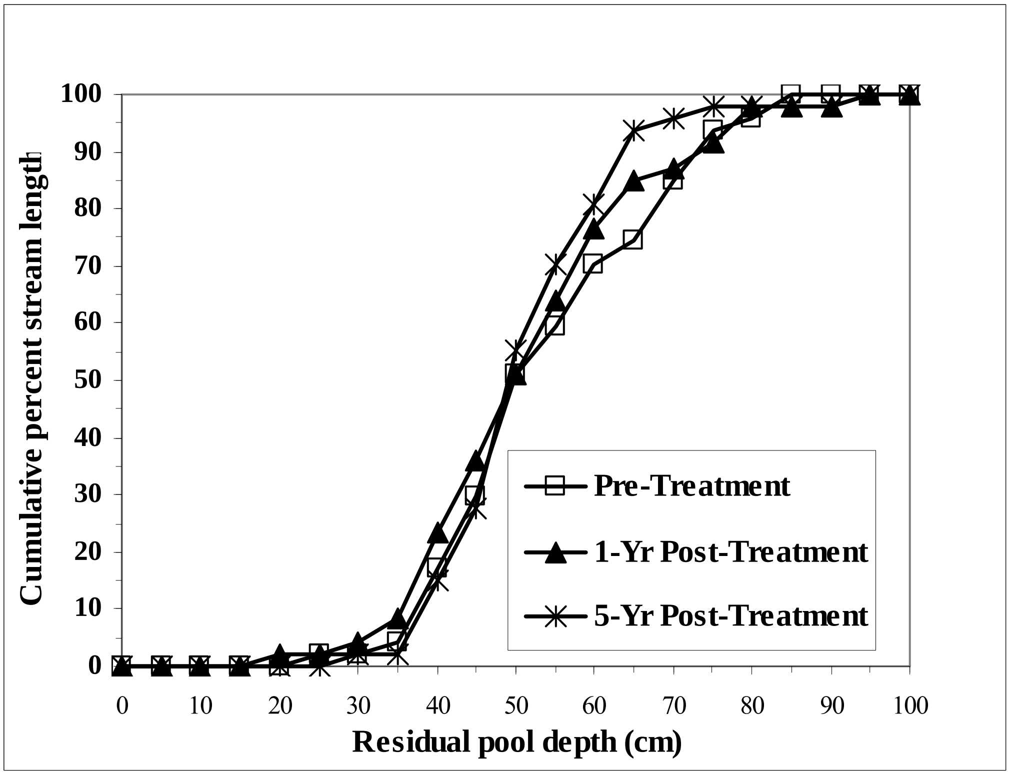


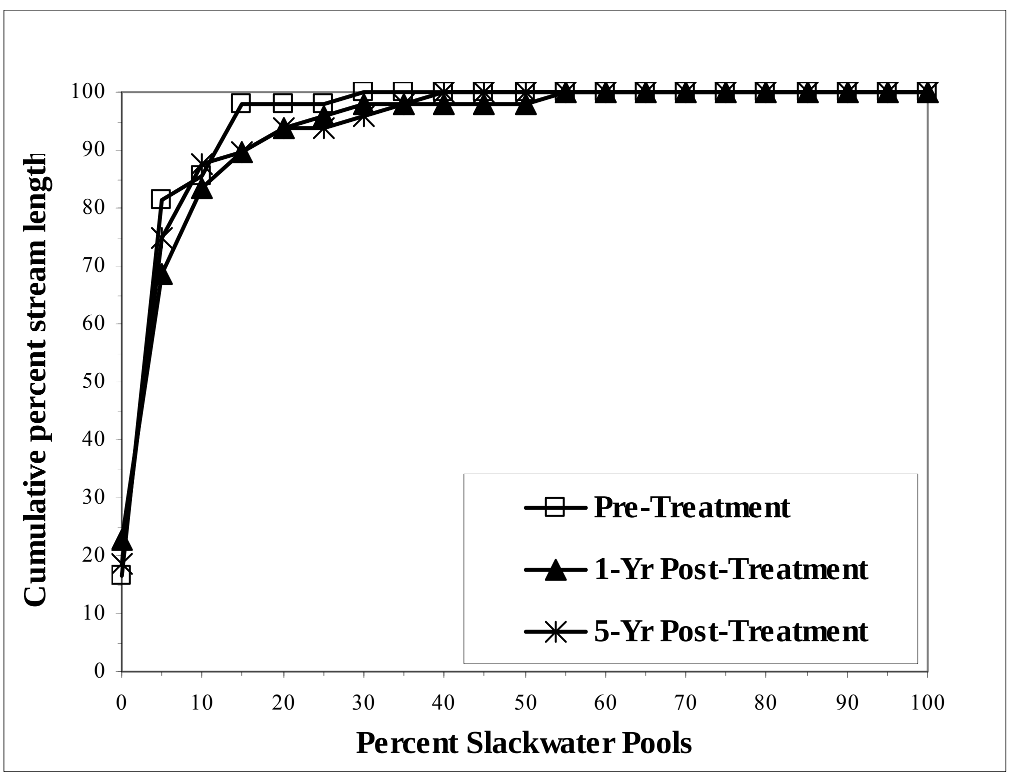

Cumulative percent stream length
Density of wood volume (m^3 / 100 m)
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment

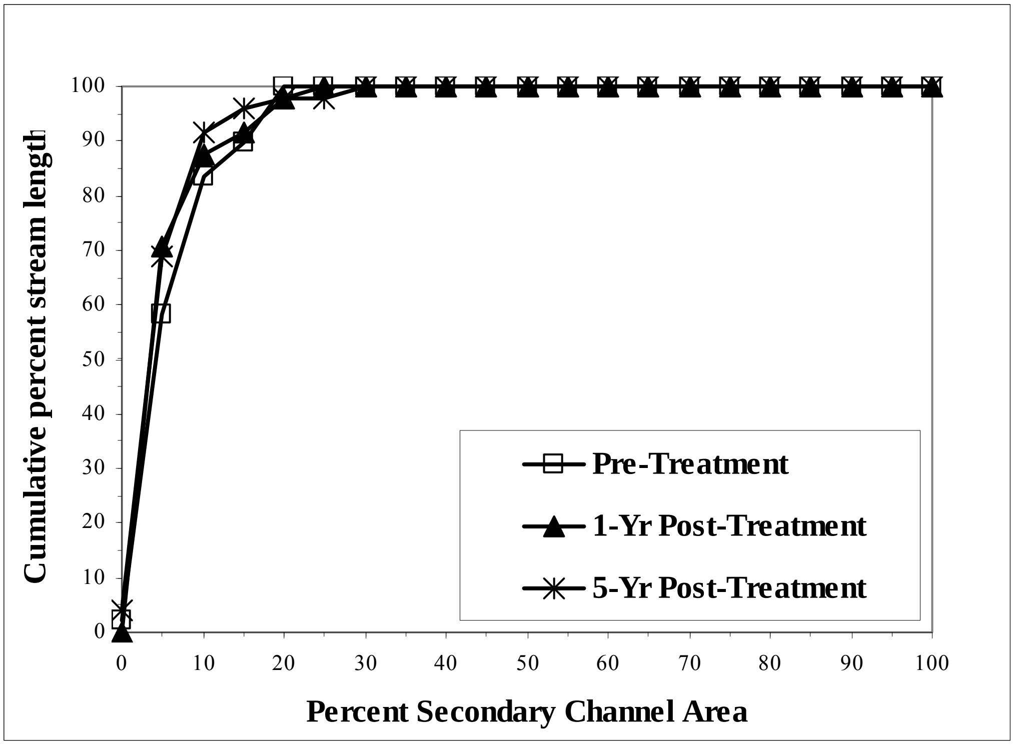

Cumulative percent stream length
Density of key wood pieces (Number / 100 m)
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment

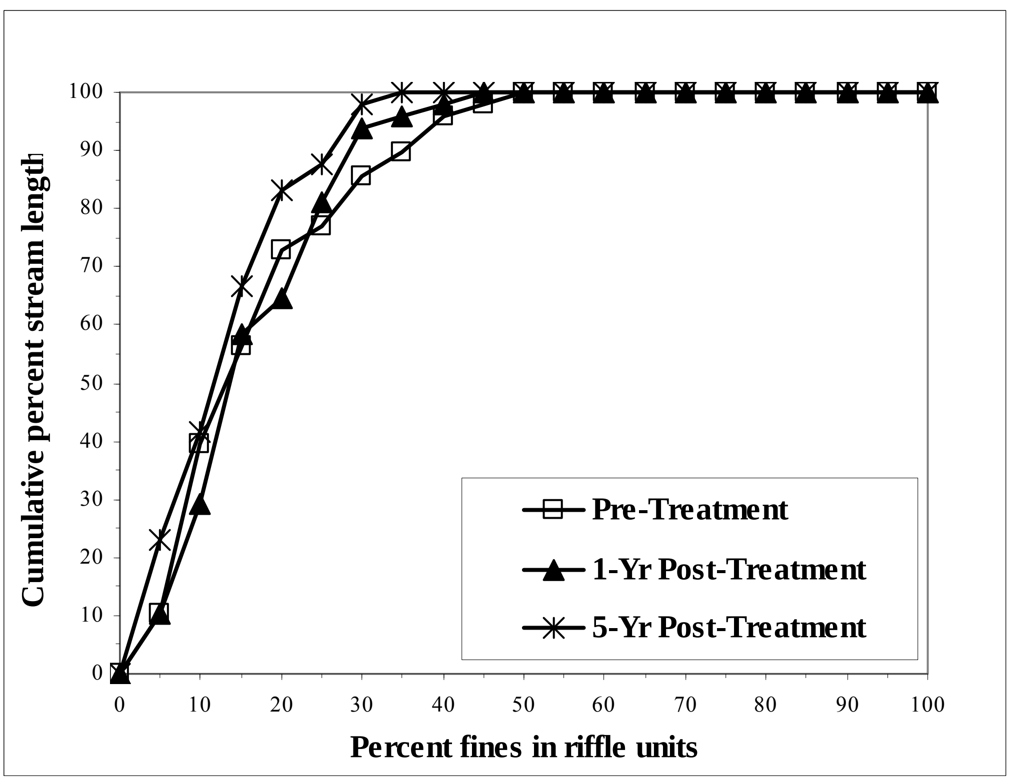

Cumulative percent stream length
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Percent pool habitat
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment

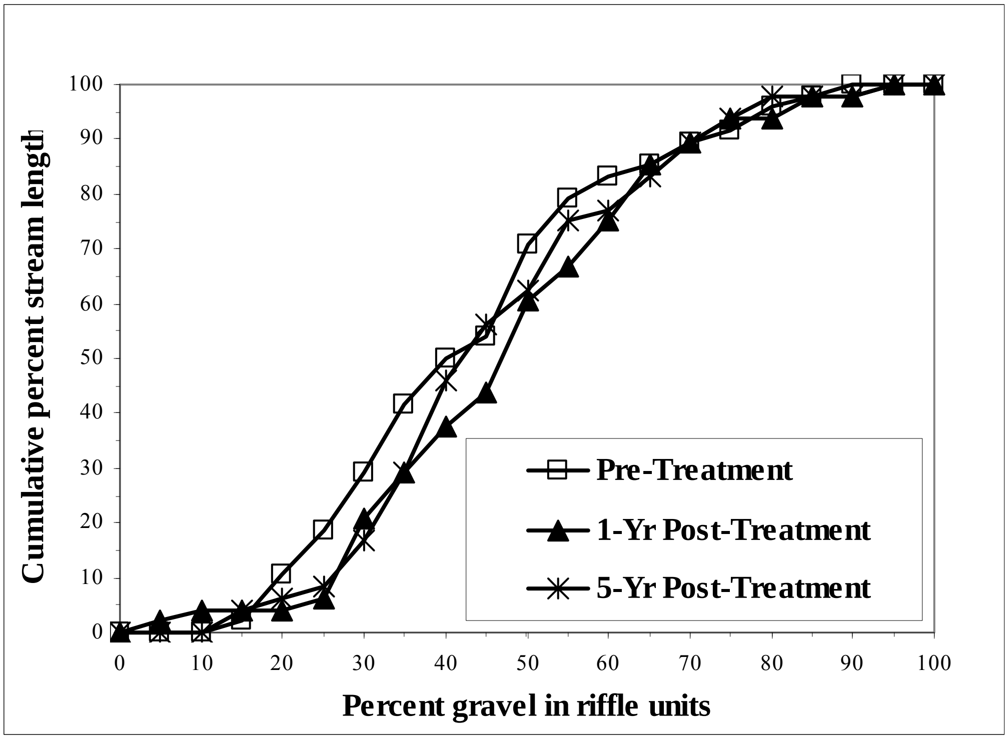

Cumulative percent stream length
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
Density of deep pools (Number / km)
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment

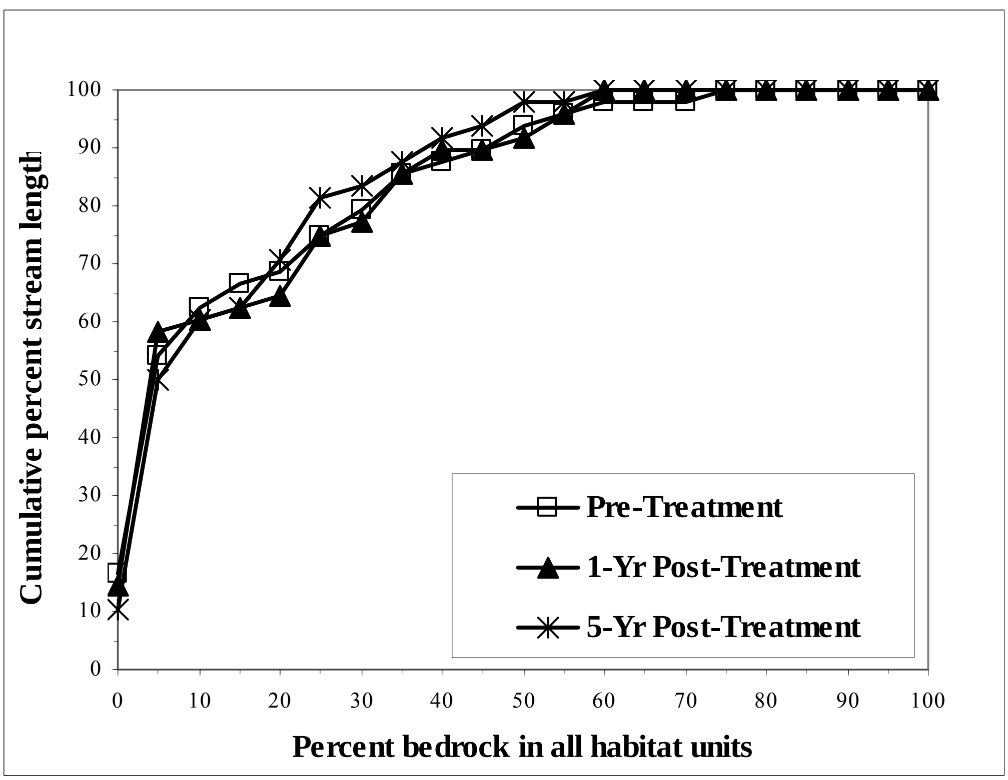

Cumulative percent stream length
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Residual pool depth (cm)
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment

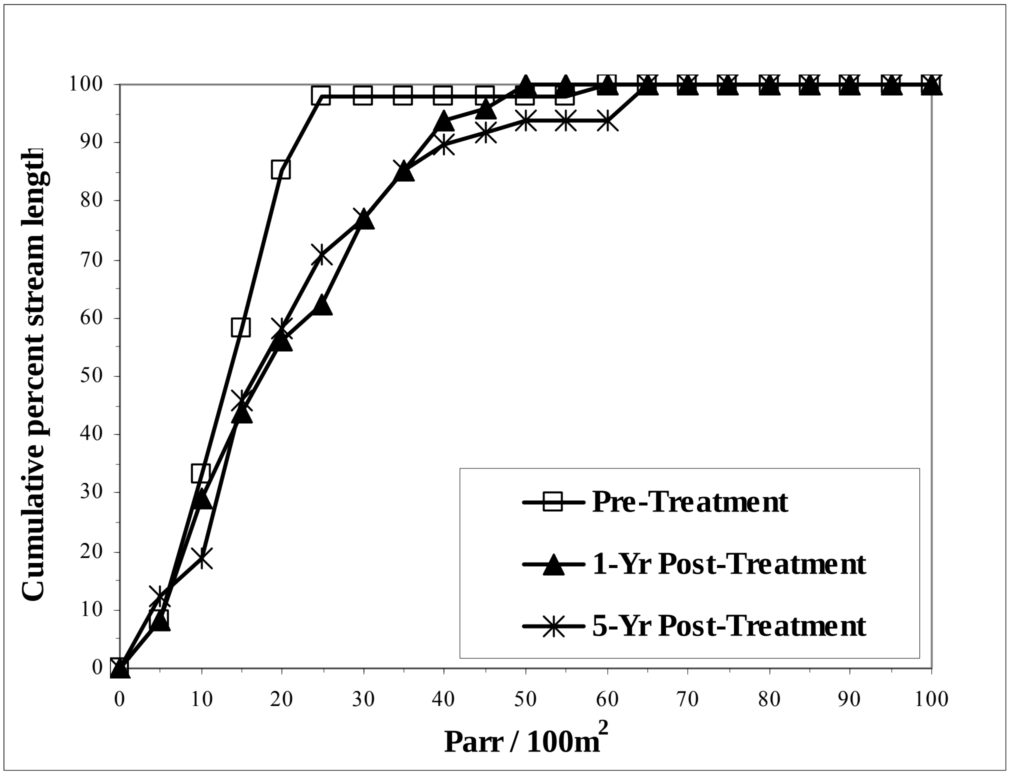

Cumulative percent stream length
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Percent Slackwater Pools
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment


Cumulative percent stream length
Percent Secondary Channel Area
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment

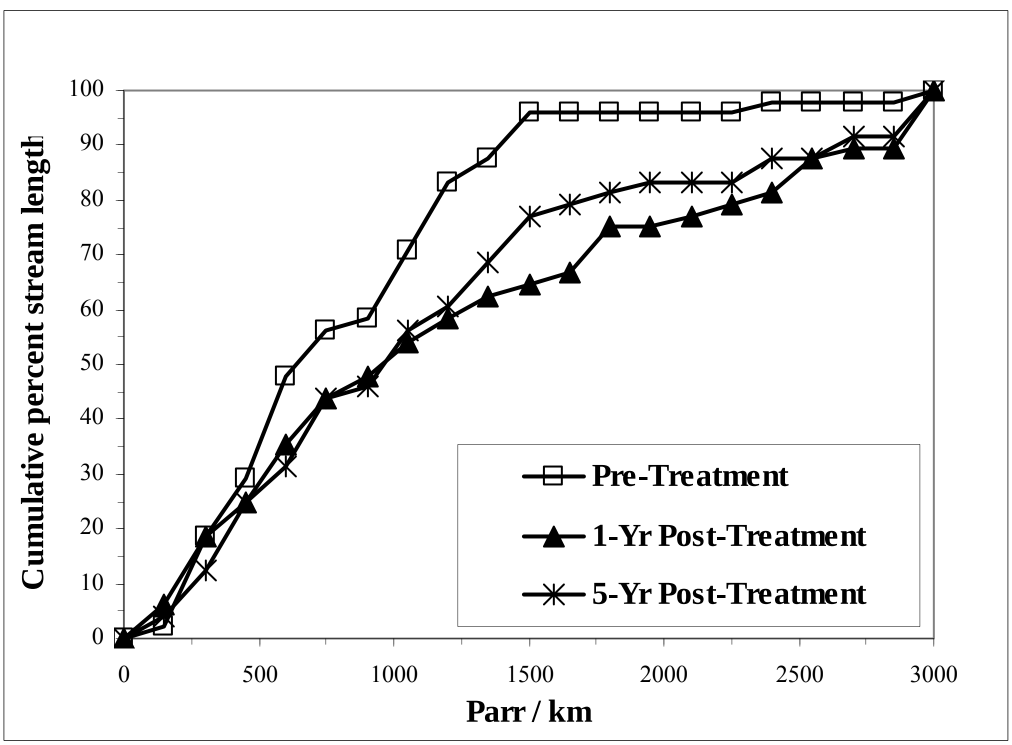

Cumulative percent stream length
Percent fines in riffle units
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment


Cumulative percent stream length
Percent gravel in riffle units
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment


Cumulative percent stream length
Percent bedrock in all habitat units
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment



Cumulative percent stream length
Parr / 100m²
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment
0
10
20
30
40
50
60
70
80
90
100



Cumulative percent stream length
Parr / km
Pre-Treatment
1-Yr Post-Treatment
5-Yr Post-Treatment
0
500
1000
1500
2000
2500
3000