*North American Journal of Fisheries Management* 28:970–978, 2008

DOI: 10.1577/M07-085.1

[Article]

# Adult Coho Salmon and Steelhead Use of Boulder Weirs in Southwest Oregon Streams

PHIL RONI*

*National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Environmental Conservation Division, Watershed Program, 2725 Montlake Boulevard East, Seattle, Washington 98112, USA*

DAN VAN SLYKE

*Bureau of Land Management, Coos Bay District, 1300 Airport Lane, North Bend, Oregon 97459, USA*

BRUCE A. MILLER

*Oregon Department of Fish and Wildlife, 63538 Boat Basin Drive, Charleston, Oregon 97420, USA*

JOSEPH L. EBERSOLE

*U.S. Environmental Protection Agency, Western Ecology Division, National Health and Environmental Effects Research Laboratory, Office of Research and Development, 200 Southwest 35th Street, Corvallis, Oregon 97333, USA*

GEORGE PESS

*National Oceanic and Atmospheric Administration,National Marine Fisheries Service, Northwest Fisheries Science Center, Environmental Conservation Division, Watershed Program, 2725 Montlake Boulevard East, Seattle, Washington 98112, USA*

*Abstract*.—The placement of log and boulder structures in streams is a common and often effective technique for improving juvenile salmonid rearing habitat and increasing fish densities. Less frequently examined has been the use of these structures by adult salmonids. In 2004, spawner densities and redd counts of coho salmon *Oncorhynchus kisutch* in seven Oregon streams were compared between 10 reach pairs: reaches with artificially placed boulder weir structures (treatment) and reaches without weirs (control). In addition, based on annual spawner survey data collected from 2001 to 2005, redd density of steelhead *O. mykiss* and spawner and redd densities of coho salmon were examined to assess differences among main-stem reaches with boulder weirs, main-stem reaches without weirs, and tributary reaches without weirs throughout one basin (West Fork of the Smith River [WFS]). Numbers of coho salmon spawners and peak redd counts were significantly higher ($P \leq 0.05$) in treatment reaches than in control reaches in the first study. In contrast, no differences existed in coho salmon spawner counts or steelhead redd counts among reaches within WFS. Coho salmon redd densities differed significantly among the three reach types in WFS; redd densities in tributary reaches were higher than those in main-stem reaches either with or without boulder weirs. Both spawner density and redd density were positively correlated with percent gravel. Results from these two related studies suggest that the placement of boulder weirs in bedrock channels leads to localized increases in spawner abundance, although other factors (e.g., amount of spawning area or gravel) appear to influence coho salmon and steelhead spawner abundance and redd construction at a watershed scale. This also suggests that gravel sources are an important factor to consider when placing boulder weirs or other instream structures designed to improve spawning habitat.

One of the stated goals of many habitat enhancement projects in salmon and trout streams is to improve spawning habitat and increase spawner numbers. However, evaluations of adult salmonid response to enhancement structures in streams have been limited to (1) a handful of short-term studies demonstrating adult salmonid spawning in gravel accumulated at structures (Avery 1996; House 1996; Gortz 1998) and (2) observations of redds or adult spawning near enhancement sites (Moreau 1984; Crispin et al. 1993; Iversen et al. 1993; House 1996). For example, Gortz (1998) found three times as many redds of brown trout *Salmo trutta* in restored versus unrestored reaches of the River Esrom, Denmark, but found low numbers of fry, which indicated that the spawning was not successful. In one of the only comprehensive examinations of spawning habitat creation, House (1996) reported a 2.5-fold

* Corresponding author: phil.roni@noaa.gov

Received May 15, 2007; accepted December 13, 2007
Published online June 16, 2008

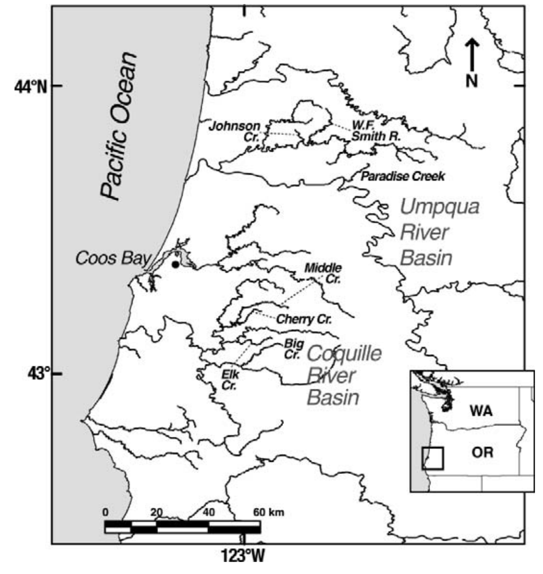



FIGURE 1.—Map of southwest Oregon, indicating locations of seven study sites used for an extensive study of salmonid spawner and redd densities after boulder weir placement; one of these sites (West Fork of the Smith River) was also used for an intensive study.

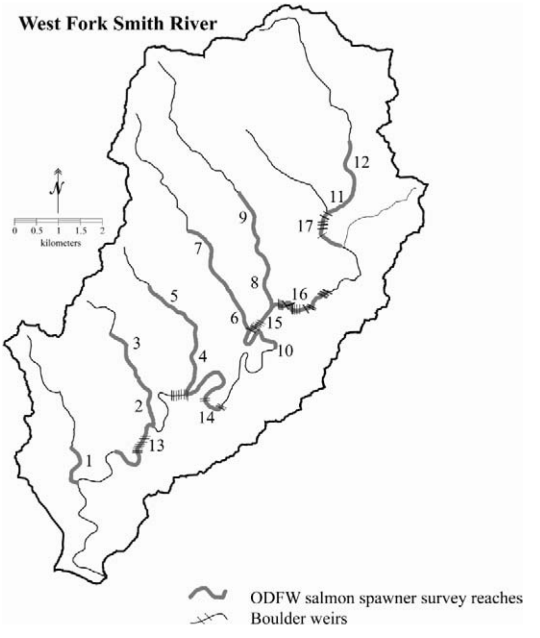



FIGURE 2.—Map of the West Fork of the Smith River (WFS) watershed, Oregon, showing reaches where coho salmon and steelhead spawner surveys were conducted by the Oregon Department of Fish and Wildlife (ODFW) and locations of boulder weir reaches used in an intensive study of adult response to weir placement. Spawner survey reach codes are defined in Table 3.

increase in spawner abundance of coho salmon *Oncorhynchus kisutch* after placement of rock-filled gabions in a 1.7-km reach of East Fork Lobster Creek, Oregon. These studies of limited scope emphasize the need for more-comprehensive reach- and watershed-scale evaluation of adult salmonid response to placement of instream structures (Roni et al. 2005).

Placement of boulder weirs is a particularly common method for improving bedrock or incised channels in western North America and western Europe and is often used to improve spawning habitat (Roni et al. 2005). These structures are generally designed to mimic large woody debris and boulder accumulations that naturally occurred in these streams prior to intensive land and river management. Boulder weirs have also been demonstrated to improve habitat and lead to increased juvenile salmonid abundance (Roni et al. 2005, 2006). Comprehensive study of adult salmon use of reaches or watersheds treated with boulder weirs has not yet occurred. To address this need, we conducted two studies to examine whether placement of boulder weirs influenced the distribution of salmonid spawning activity. The first study examined coho salmon redd and spawner numbers in reaches with and without boulder weirs in several watersheds (extensive study). The second study determined the redd density of steelhead *O. mykiss* and the spawner and redd densities of coho salmon within a single intensively surveyed watershed (intensive study).

## Methods

*Site description*.—All streams were located in southwest Oregon (Figures 1, 2) and had a similar legacy of splash damming (a method for driving logs downstream), stream cleaning (removal of logs from the channel), and other forestry activities that resulted in highly uniform, incised, bedrock-dominated channels with few boulders and low levels of woody debris. Tributaries to the West Fork of the Smith River (WFS) and other streams that did not have a legacy of splash damming had higher levels of woody debris, natural boulder accumulations, and less exposed bedrock. Thus, habitat in the reaches we surveyed had been greatly modified by historical forest practices, and salmonid production in these streams was generally limited by a lack of adequate spawning gravels and a lack of rearing habitat. Geology at most sites was composed of sandstone and siltstone, except sites at Cherry and South Fork Elk creeks, which were predominantly mudstone and sandstone (Niem and Niem 1990). Rainfall within watersheds was between

TABLE 1.—Summary of study designs used for intensive and extensive evaluations of coho salmon and steelhead use of boulder weirs in southwest Oregon streams. Abundance of coho salmon was estimated using the area-under-the-curve method.

| Characteristics | Intensive study | Extensive study |
|---|---|---|
| Watersheds examined | 1 | 7 |
| Reaches examined | 17 | 10 paired reaches |
| Reach length(s) | 0.8–2.5 km | 200 m |
| Reach stratification | Tributary, main stem with weirs, main stem without weirs | Treatment and control |
| Species examined | Adult coho salmon and steelhead | Adult coho salmon |
| Variables | Peak redd count (coho salmon), abundance (coho salmon), total redd count (steelhead), percent gravel, coho salmon redd distance from weirs | Coho salmon abundance, peak redd count |
| Analysis | Analysis of variance, regression | Paired *t*-test |

127 and 254 cm/year depending upon location and elevation. Riparian forests at study sites were dominated by deciduous trees, including red alder *Alnus rubra* and bigleaf maple *Acer macrophyllum*, as well as California laurel *Umbellularia californica* at sites in the Coquille River basin. Conifers, such as western redcedar *Thuja plicata*, Douglas-fir *Pseudotsuga menziesii*, and western hemlock *Tsuga heterophylla*, dominated upland areas in these basins and were also found at lower densities adjacent to streams. Land use was predominantly commercial forest; forests in most watersheds were largely composed of young (<25 years) to moderate-age (25–80 years) stands. Substrate in all reaches was dominated by bedrock except that pockets of gravel and sand were found in association with weirs and other channel obstructions in treatment reaches and tributaries of the WFS that had not been splash dammed. Bank-full width in study reaches ranged from 8 to 21 m (average = 12 m). More-detailed information on study sites and their physical habitat characteristics is given by Roni et al. (2006) and Ebersole et al. (2006).

*Study design and methods*.—We examined differences in coho salmon spawner density, coho salmon peak redd density, and steelhead redd density in areas with and without artificial boulder weirs using two different approaches: (1) an extensive evaluation of a number of paired treatment reaches (receiving boulder weirs) and control reaches in several watersheds and (2) an intensive evaluation of spawner and redd densities within one watershed that contained several reaches with and without boulder weirs (intensive study). Below, we provide the details of each study (see Table 1 for a summary).

*Extensive study*.—To examine coho salmon response to boulder weir placement across watersheds, we conducted coho salmon spawner surveys from October 27, 2004, to February 2, 2005, in 10 pairs of treatment and control reaches distributed in seven different streams in the lower Umpqua and Coquille River basins (Figure 1). Each treatment or control reach was 200 m long (>10 bank-full widths). Treatment was defined as the artificial placement of boulders and boulder weirs within the active stream channel. The control reach was a nearby reach (at least 200 m away) that was similar to the treatment site (prior to treatment) but had not been improved through placement of boulder weirs. The weirs were seminatural structures composed of many large boulders (>50 cm in diameter); although the boulder weirs spanned the channel, they were not solid structures and they allowed for upstream and downstream fish passage (Figure 3). In streams with multiple treatment and control reaches (Middle and Paradise creeks and WFS), treatment–control reach pairs were located two or more stream kilometers apart. Paired treatment–control reaches within a stream were of similar slope, width, riparian vegetation, discharge, and length. Stream gradient of study reaches ranged from 1% to 3%, and the gradients of paired treatment and control reaches were within 1% of each other. Elevation of study sites ranged from about 75 to 150 m. The number of boulder weirs (spanning the entire channel) in treatment reaches ranged from two to eight, and project age at sampling ranged from 1 to 20 years. Roni et al. (2006) examined physical habitat variables and juvenile fish abundance in the same study reaches and found that coho salmon, steelhead, and cutthroat trout abundance, pool area, large woody debris abundance, and boulder abundance were all higher in treatment reaches (those with boulder weirs) than in control reaches, although considerable variation in response existed among sites.

Coho salmon spawner and redd surveys were conducted using the Oregon Department of Fish and Wildlife (ODFW) salmon spawner survey protocol (ODFW 2003). This included periodic surveys approximately every 7–10 d between October 19 and January 26. A minimum of five surveys were conducted at each survey reach. Total number of coho salmon spawners was calculated from periodic surveys using estimates

FIGURE 3.—Photographs of a control (unimproved) reach (top panel) and a treatment reach to which a boulder weir was added (bottom panel); both reaches were part of an intensive study of adult salmonid response to weir placement in the West Fork of the Smith River, Oregon.

of area under the curve (AUC; Beidler and Nickelson 1980; Hilborn et al. 1999). The AUC method calculates total spawner numbers based on the mean number of adults seen in two consecutive surveys multiplied by the length of that period in days (typically 7–10 d). These values are then summed for the entire duration of the survey period, and the result is divided by the average residence time of adult coho salmon on spawning grounds (11.3 d; Beidler and Nickelson 1980). We used peak redd counts from coho salmon spawner surveys as an index of redd numbers. We used a paired $t$-test to compare spawner and redd data between paired treatment and control reaches.

*Intensive study*.—To examine spawner use of reaches with and without boulder weirs throughout a single watershed, we obtained coho salmon and steelhead spawner and redd survey data collected in WFS by ODFW from 2001 to 2005. These data were used to examine coho salmon spawner and redd densities and steelhead redd density in main-stem reaches with boulder weirs, main-stem reaches without boulder weirs, and tributaries (Figure 2). No boulder weirs exist in any of the tributary reaches. Surveyed reach lengths ranged from 1.1 to 2.5 km, but the length of a given reach was the same among years.

Similar to the extensive study sites, coho salmon spawner and redd surveys and steelhead redd surveys at intensive sites followed the protocol of ODFW (2003). Total coho salmon spawner numbers were estimated using AUC methods and peak redd counts (Beidler and Nickelson 1980; Hilborn et al. 1999). Because steelhead redd numbers were lower and surveys were less frequent than those for coho salmon, we used the total redd number from all surveys conducted within the same season (year) rather than peak counts to calculate steelhead redd numbers for a reach. For each survey reach and year, spawner or redd density was calculated by dividing the observed number by reach length. These values were then averaged across the 5-year period to provide one number for each metric (coho salmon spawners, coho salmon redds, and steelhead redds) within each reach.

Reaches were categorized as tributary reaches, main-stem reaches with boulder weirs, and main-stem reaches without boulder weirs, and the three categories were compared using single-factor analysis of variance (ANOVA). Tukey's multiple comparison tests were used to determine which categories differed. Because of differences in bank-full and wetted widths between main-stem and tributary reaches in WFS, spawner and redd densities per unit area were used instead of raw counts to compare differences among reach types. In addition, during fall 2005, ODFW recorded the distance from the nearest boulder weir for all coho salmon redds that were located within 10 m of a weir. For all other redds not associated with a boulder weir, the location was recorded to the nearest 50 m. We examined these data graphically to determine the typical redd distance from boulder weirs within treated reaches. Finally, estimates of wetted area (reach length $\times$ average wetted width) were obtained from ODFW habitat surveys conducted in 2002 (Coon and Beaver Creek reaches only) and 2005 (all other reaches; see Moore et al. [1997] for description of habitat survey methods). Percent gravel represents a visual estimate of the percentage of substrate that was composed of gravel within a habitat unit or reach. An ANOVA was used to compare percent gravel among intensive reaches, and we used simple linear regression to examine whether percent gravel was correlated with spawner and redd densities within WFS.

TABLE 2.—Coho salmon peak redd counts and estimated coho salmon spawner numbers (area under the curve) for treatment reaches (those receiving boulder weirs) and control reaches within extensive study streams of southwest Oregon (WFS = West Fork of the Smith River; NA = not available). All survey reaches were 200 m in length; surveys were conducted from October 2004 to February 2005. Deflectors are boulder weirs that did not span the entire channel.

| Stream | Number of boulder weirs or deflectors | Redd count | | Spawners | |
|---|---|---|---|---|---|
| | | Treatment | Control | Treatment | Control |
| Big Creek | 3 | 2 | 2 | 11 | 7 |
| Cherry Creek | 7 | 1 | 0 | 6 | 3 |
| South Fork Elk Creek | 4 | 6 | 1 | 9 | 5 |
| Paradise Creek, lower | 7 | 13 | 2 | 13 | 1 |
| Paradise Creek, upper | 4 | 0 | 4 | 4 | 4 |
| Middle Creek, lower | 4 | 4 | 0 | 7 | 0 |
| Middle Creek, upper | 2 | 2 | 1 | 4 | 2 |
| WFS, Crane reach | 4 | 9 | 2 | NA | NA |
| WFS, Beaver reach | 8 | 9 | 5 | NA | NA |
| WFS, upper reach | 3 | 3 | 3 | NA | NA |

## Results

Coho salmon peak redd counts and spawner abundance in the extensive study were significantly higher in treatment reaches than in paired control reaches (average difference = 2.9 redds and 4.6 spawners; $P \leq 0.05$; Table 2). No significant relationship was detected between the number of boulder weirs within a reach and the difference in treatment and control peak coho salmon redd counts (regression: $P = 0.65$) or spawner abundances ($P = 0.54$).

In the intensive study of WFS, coho salmon spawner density and steelhead redd density among reaches were not significantly different among tributary reaches and main-stem reaches with or without boulder weirs ($P > 0.15$). However, coho salmon redd density was significantly different among the three reach types ($P < 0.01$; Table 3). Multiple comparisons indicated that the coho salmon peak redd count was higher in tributaries than in main-stem reaches ($P = 0.02$) but did not differ between main-stem reaches with boulder

TABLE 3.—Estimates of mean adult coho salmon spawner abundance (estimated by the area under the curve [AUC]), peak coho salmon redd count, and total steelhead redd count in West Fork of the Smith River (WFS) basin, 2001–2005. Reach codes correspond to reach locations shown in Figure 2.

| Reach code | Stream or reach | Physical habitat: Number of boulder weirs | Physical habitat: Reach length (km) | Physical habitat: Wetted width (m) | Physical habitat: Percent gravel | Coho salmon: AUC | Coho salmon: Peak redds | Total steelhead redds |
|---|---|---|---|---|---|---|---|---|
| | **WFS tributaries** | | | | | | | |
| 1 | Coon Creek 1 | 0 | 1.11 | 3.8 | 28 | 49.5 | 18.7 | 4.7 |
| 2 | Crane Creek 1 | 0 | 1.15 | 4.6 | 21 | 23.0 | 16.5 | 2.2 |
| 3 | Crane Creek 2 | 0 | 1.54 | 4.6 | 27 | 30.8 | 20.1 | 2.1 |
| 4 | Moore Creek 1 | 0 | 1.33 | 4.2 | 44 | 58.9 | 21.8 | 8.7 |
| 5 | Moore Creek 2 | 0 | 1.99 | 3.9 | 40 | 53.9 | 19.4 | 3.7 |
| 6 | Beaver Creek 1 | 0 | 1.17 | 5.9 | 39 | 54.9 | 20.9 | 7.7 |
| 7 | Beaver Creek 2 | 0 | 2.11 | 4.1 | 26 | 37.6 | 16.5 | 2.5 |
| 8 | Gold Creek 1 | 0 | 1.26 | 7.9 | 23 | 38.6 | 19.0 | 5.9 |
| 9 | Gold Creek 2 | 0 | 1.86 | 5.7 | 21 | 38.4 | 15.5 | 8.2 |
| | Mean | | 1.50 | 4.5 | 30 | 42.8 | 18.7 | 5.1 |
| | **WFS reaches without weirs** | | | | | | | |
| 10 | WFS tributary to Beaver Creek | 0 | 1.56 | 11.8 | 15 | 41.7 | 8.3 | 6.7 |
| 11 | WFS section 4 | 0 | 1.36 | 6.3 | 27 | 49.9 | 13.7 | 16.7 |
| 12 | WFS section 5 | 0 | 1.92 | 5.3 | 17 | 17.2 | 9.9 | 11.9 |
| | Mean | | 1.61 | 7.8 | 20 | 36.3 | 10.6 | 11.8 |
| | **WFS main-stem reaches with weirs** | | | | | | | |
| 13 | WFS tributary to Crane Creek | 8 | 1.71 | 16.9 | 26 | 30.4 | 11.3 | 10.5 |
| 14 | WFS Moore Creek to tributary | 5 | 2.5 | 13.1 | 9 | 31.2 | 5.6 | 10.4 |
| 15 | WFS Beaver Creek to Gold Creek | 8 | 0.84 | 13.8 | 30 | 82.6 | 20.2 | 13.0 |
| 16 | WFS Gold Creek to left tributary | 17 | 1.78 | 11.1 | 33 | 59.0 | 17.3 | 25.2 |
| 17 | WFS last bridge | 7 | 1.12 | 8.3 | 36 | 56.6 | 19.3 | 20.7 |
| | Mean | 9 | 1.59 | 12.6 | 27 | 52.0 | 14.7 | 16.0 |

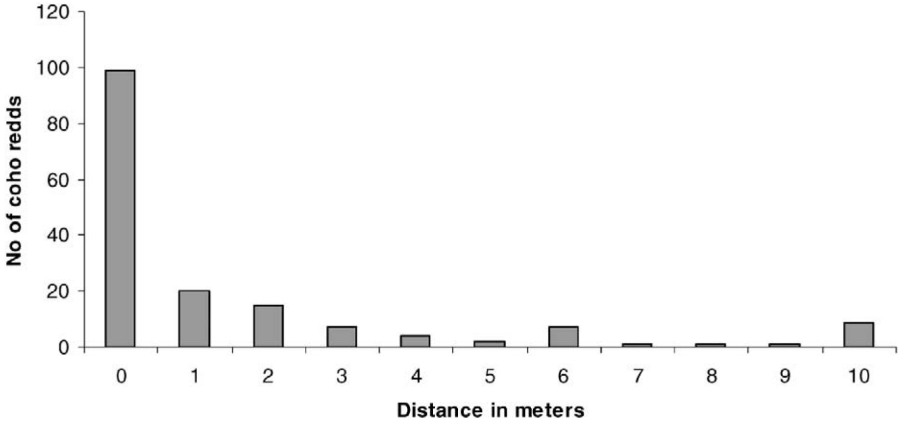


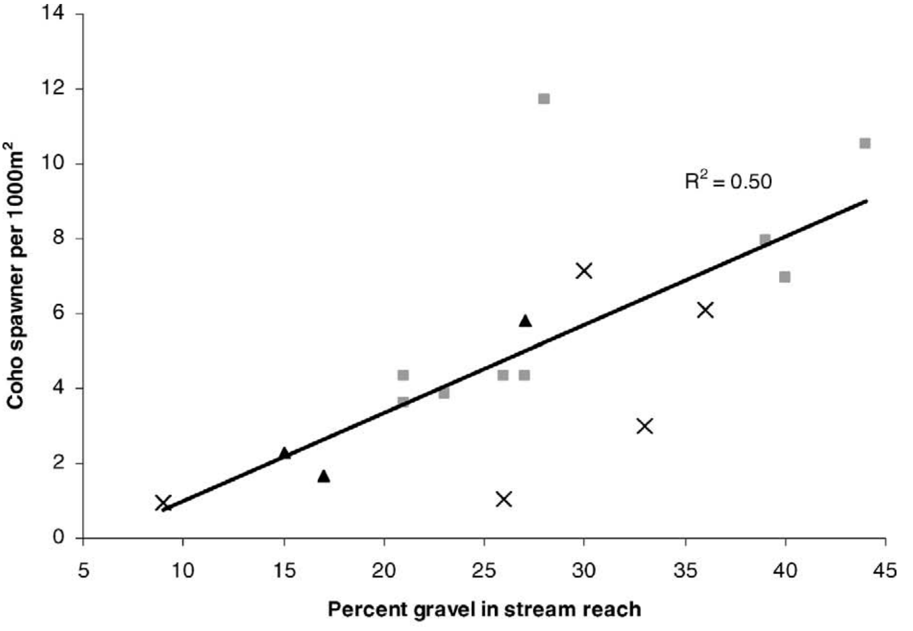

FIGURE 4.—Distance (m) between coho salmon redds and faces of boulder weirs that were added to the main-stem West Fork of the Smith River, Oregon; redds were surveyed in 2005. Among all surveyed treatment reaches, 166 of the 384 redds were located within 10 m of a weir (163 were immediately upstream; 3 were downstream).

weirs and those without boulder weirs ($P = 0.90$). Small, nonsignificant ($P = 0.27$) differences in percent gravel were observed among reaches (Table 3). Analysis of coho salmon redd location data from WFS indicated that 43% of observed redds (166 of 384) were located within 10 m of a boulder weir. Of those redds, more than 80% were within 3 m upstream of a boulder weir (Figure 4); only three redds were located immediately downstream of a weir. Coho salmon spawner abundance and redd density were positively correlated with percent gravel ($P < 0.03$), which explained 50% of the variation in spawner density and 35% of the variation in redd density (Figure 5). Steelhead redd density was also positively correlated with percent gravel, but only 24% of variation was explained (steelhead redd density = [0.235 × percent gravel] − 1.34; $r^2 = 0.24$, $P = 0.48$).

## Discussion

The observed differences in coho salmon spawner and redd densities between treatment and control reaches in our extensive study indicates that placement of boulder weirs provides local improvements in spawning conditions and spawner use. Such improvements are probably accomplished through accumulation of well-oxygenated gravel immediately upstream of a weir, which has been documented in previous studies (e.g., House and Boehne 1985; Klassen and Northcote 1988; House 1996). We did not quantify the gravel area or volume at specific boulder weirs, but gravel accumulations upstream of most weirs appeared to be generally much deeper than other gravel accumulations in the main-stem channel. In the absence of weirs or other channel obstructions, the channels were dominated by bedrock interspersed with small, unstable pockets of gravel. The relationship among gravel, boulder weirs, and spawners is supported by the positive relationships between the three salmonid metrics and percent gravel at intensive sites (WFS). Our results are consistent with less-intensive and extensive studies by Overton et al. (1984), House and Boehne (1985), Crispin et al. (1993), and House (1996), who reported accumulation of gravel upstream of boulder weirs and gabion structures and use of these areas by spawning salmon.

Given that (1) boulder weirs and other instream structures trap gravel and (2) the area downstream of a weir is typically a deep pool, it is not surprising that much of the spawning within improved reaches was immediately upstream of the weirs. Similar to our results, House and Boehne (1985) reported that most spawning occurred within 6 m of structures in an Oregon stream; those authors indicated that 51% of observed redds were associated with placed wood or boulder structures. The lack of a significant difference in percent gravel between WFS reaches with and without boulder weirs is somewhat surprising, as other studies have reported increases in spawning gravel not only at weir sites but also at a reach scale. For example, House and Boehne (1985) reported increases in gravel accumulation of more than 25% in a 1-km reach of East Fork Lobster Creek. Although differences in percent gravel in our study were not significant, it should be noted that on average, percent gravel in reaches with boulder weirs was intermediate between percent gravel values in tributaries and main-stem reaches without boulder weirs. The lack of a significant difference in WFS might be attributable to weirs only influencing spawning habitat immediately upstream; alternatively, it is possible that more-accurate annual



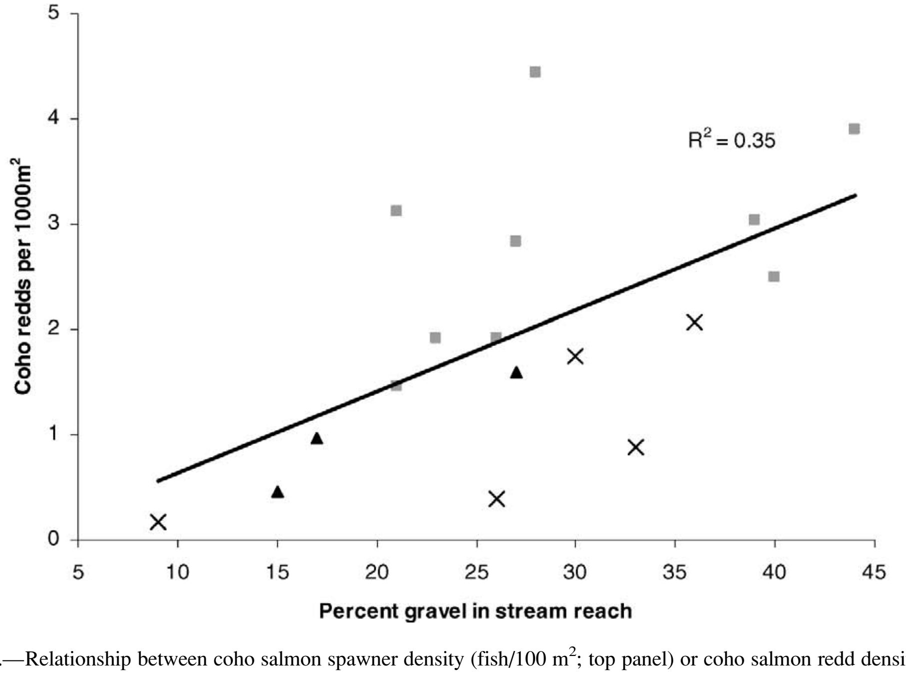




FIGURE 5.—Relationship between coho salmon spawner density (fish/100 m$^2$; top panel) or coho salmon redd density (redds/100 m$^2$; bottom panel) and percent gravel within intensively surveyed reaches of the West Fork of the Smith River, Oregon (squares = tributary reaches, $\times$-symbols = main-stem reaches with weirs, triangles = main-stem reaches without weirs). Regression equations are spawner density = [0.235 $\times$ percent gravel] − 1.34 ($r^2 = 0.50$; $P < 0.01$) and redd density = [0.0.077 $\times$ percent gravel] − 0.14 ($r^2 = 0.35$; $P = 0.01$).

volumetric gravel survey methods (rather than a single year of visual gravel area estimation) are needed to detect differences among reaches or at a watershed scale.

We did not examine whether the pools downstream of weirs provided important adult holding habitat; however, such areas are used extensively by juvenile fishes, and wood and boulder structures are known to produce increases in numbers of juvenile coho salmon and trout (e.g., House 1996; Roni and Quinn 2001; Roni et al. 2006). These findings suggest higher spawner use and higher survival to the parr stage in reaches with boulder weirs. Weir height and width and the distance between weirs also obviously influence the ability of these structures to trap gravel and provide high-quality spawning habitat (see House 1984, 1996; Moreau 1984; House and Boehne 1985). Thus, the optimal spacing and height of artificial instream structures and the needs of both juveniles and spawners should be considered when placing weirs and other instream structures.

Our intensive evaluation of spawner and redd abundance in WFS did not detect consistent differences among tributary or main-stem reaches for the two salmonid species. This result may simply reflect spawning preferences of coho salmon for small tributaries and steelhead for main-stem reaches or may indicate a number of other plausible explanations. The number of boulder weirs within treatment reaches of WFS was not high (Table 3); perhaps weir spacing was too wide or weir number was too low to induce a detectable change in spawner numbers at a watershed scale. Because of their location in the watershed, tributaries and headwaters of WFS naturally had more gravel or suitable spawning habitat than main-stem reaches. Because all stream reaches were less than 20 m in bank-full width, redds were probably equally visible in all reaches, whereas spawners might have been slightly more visible in tributaries than in main-stem reaches. In addition, the ODFW spawner survey data we examined were originally collected to monitor trends in spawner use of randomly selected reaches as well as the most productive reaches within the basin. Thus, reaches with and without boulder weirs were not paired, which may have reduced our ability to detect a change. We also did not have preproject data with which to examine basinwide spawner distribution prior to placement of boulder structures.

A number of factors can affect variability in adult salmon returns (e.g., ocean conditions, harvest, smolt numbers, and survival) and our ability to accurately enumerate spawners and redds in study reaches (e.g., flow and visibility). Moreover, previous studies have estimated that more than 10 years of data are needed to detect postrestoration increases in adult salmon numbers (Korman and Higgins 1997). The pairing of very similar treatment and control reaches in the extensive study may have been a more powerful design than simply categorizing reaches by weir presence or absence, as was done in the intensive study. Finally, it is often suggested that placement of instream structures leads to concentration of fish rather than increased production. This may have influenced results of our extensive study but is unlikely to be the case for our intensive study. Surveys conducted throughout most of WFS over a number of years showed little difference in coho salmon spawner or redd numbers between reaches with and without weirs. The lack of a consistent, basin-level response to boulder weir placement is probably attributable to a combination of the above factors.

In summary, our research supports previous short-term case studies reporting salmon and steelhead use of gravels trapped by instream structures; our work also suggests that boulder weirs can lead to increased spawner and redd densities. Combined with studies on juvenile fish response to boulder weir placement, our results indicate that both juvenile and adult fish respond positively to placement of these structures. The positive correlation between coho salmon spawner density and percent gravel indicates that spawner numbers can be increased by increasing gravel accumulations via placement of boulders, logs, or other structures that trap gravel. Our examination of WFS spawner data is also one of the few published attempts to evaluate adult salmon response to restoration at both reach and watershed scales. This work emphasizes the need for preproject data, longer-term monitoring of adult use of restored areas, and more-comprehensive, basinwide surveys for examining adult salmonid numbers and response to restoration at a watershed scale. When placing boulders or boulder weirs to create spawning habitat in streams with a limited gravel supply, fisheries managers should consider locating the weirs near gravel sources or constructing the weirs in a manner that will maximize their ability to retain gravel. Finally boulder weirs are artificial structures that can increase fish abundance but should not be seen as a substitute for restoring natural processes that create and maintain habitat.

## Acknowledgments

We thank Heather Lilienthal and Steve Hixson for assisting with spawner surveys and Roseburg Resources, Plum Creek, Lone Rock Timber, and other private land owners for access to sites on their lands. This work was funded by ODFW, U.S. Environmental Protection Agency (USEPA), National Oceanic and

Atmospheric Administration Fisheries, and Bureau of Land Management. It has been subjected to review by the National Health and Environmental Effects Research Laboratory's Western Ecology Division and approved for publication. Approval does not signify that the contents reflect the views of the USEPA. We also thank Barry Baldigo and three anonymous reviewers for helpful comments on earlier versions of this report. Reference to trade names does not imply endorsement by the U.S. Government.

## References

Avery, E. L. 1996. Evaluations of sediment traps and artificial gravel riffles constructed to improve reproduction of trout in three Wisconsin streams. North American Journal of Fisheries Management 16:282–293.

Beidler, W. M., and T. E. Nickelson. 1980. An evaluation of the Oregon Department of Fish and Wildlife standard spawning survey system for coho salmon. Oregon Department of Fish and Wildlife, Information Reports (Fish) 80–9, Portland.

Crispin, V., R. House, and D. Roberts. 1993. Changes in instream habitat, large woody debris, and salmon habitat after the restructuring of a coastal Oregon stream. North American Journal of Fisheries Management 43:96–102.

Ebersole, J. L., P. J. Wigington, Jr., J. P. Baker, M. A. Cairns, and M. R. Church. 2006. Juvenile coho salmon growth and survival across stream network seasonal habitats. Transaction of the American Fisheries Society 135:1681–1697.

Gortz, P. 1998. Effects of stream restoration on the macroinvertebrate community in the River Esrom, Denmark. Aquatic Conservation: Marine and Freshwater Ecosystems 8(1):115–130.

Hilborn, R., B. G. Bue, and S. Sharr. 1999. Estimating spawning escapements from periodic counts: a comparison of methods. Canadian Journal of Fisheries and Aquatic Sciences 56:888–896.

House, R. 1984. Evaluation of improvement techniques for salmonid spawning. Pages 5–13 *in* T. J. Hassler, editor. Pacific Northwest Stream Habitat Management Workshop. American Fisheries Society, Humboldt Chapter, Humboldt State University, Arcata, California.

House, R. 1996. An evaluation of stream restoration structures in a coastal Oregon stream 1981–1993. North American Journal of Fisheries Management 16:272–281.

House, R. A., and P. L. Boehne. 1985. Evaluation of instream enhancement structures for salmonid spawning and rearing in a coastal Oregon stream. North American Journal of Fisheries Management 5:283–295.

Iversen, T. M., B. Kronvang, B. L. Madsen, P. Markmann, and M. B. Nielsen. 1993. Re-establishment of Danish streams: restoration and maintenance measures. Aquatic Conservation: Marine and Freshwater Ecosystems 3(2):73–92.

Klassen, H. D., and T. G. Northcote. 1988. Use of gabion weirs to improve spawning habitat for pink salmon in a small logged watershed. North American Journal of Fisheries Management 8:36–44.

Korman, J., and P. S. Higgins. 1997. Utility of escapement time series data for monitoring the response of salmon populations to habitat alteration. Canadian Journal of Fisheries and Aquatic Sciences 54:2058–2067.

Moore, K., K. Jones, and J. Dambacher. 1997. Methods for stream habitat surveys. Oregon Department of Fish and Wildlife, Information Report 97–4, Salem.

Moreau, J. K. 1984. Anadromous salmonid habitat enhancement by boulder placement in Hurdygurdy Creek, California. Pages 97–116 *in* T. J. Hassler, editor. Pacific Northwest Stream Habitat Management Workshop. American Fisheries Society, Humboldt Chapter, Humboldt State University, Arcata, California.

Niem, A. R., and W. A. Niem. 1990. Geology and oil, gas, and coal resources, southern Tyee basin, Southern Coast range, Oregon. Oregon Department of Geology and Mineral Industries, Open-File Report O-89–3, Portland.

ODFW (Oregon Department of Fish and Wildlife). 2003. Coastal salmon spawning survey procedure manual 2003. ODFW, Corvallis. Available: nrimp.dfw.state.or.us/crl/Reports/OASIS/05SSmanual.pdf. (May 2008)

Overton, K., W. Brock, J. Moreau, and J. Boberg. 1984. Restoration and enhancement program of anadromous fish habitat and populations on Six Rivers National Forest. Pages 158–168 *in* T. J. Hassler, editor. Proceedings: propagation, enhancement and rehabilitation of anadromous salmonid populations and habitat symposium. American Fisheries Society, Humboldt Chapter, Humboldt State University, Arcata, California.

Roni, P., K. Hanson, G. Pess, T. Beechie, M. Pollock, and D. Bartley. 2005. Habitat rehabilitation for inland fisheries: global review of effectiveness and guidance for restoration of freshwater ecosystems. FAO (Food and Agriculture Organization of the United Nations) Fisheries Biology Technical Paper 484.

Roni, P., G. Pess, T. Bennett, S. Morley, and K. Hanson. 2006. Rehabilitation of stream channels scoured to bedrock: the effects of boulder weir placement on aquatic habitat and biota in southwest Oregon, USA. River Research and Applications 22:967–980.

Roni, P., and T. P. Quinn. 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58:282–292.