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NOTES

Comparison of Midsummer Survival and Growth of Age-0 Hatchery Coho Salmon Held in Pools and Riffles

LANCE M. KRUZIC*[1] AND DENNIS L. SCARNECCHIA

Department of Fish and Wildlife Resources, University of Idaho, Moscow, Idaho 83844-1136, USA

BRETT B. ROPER[2]

U.S. Forest Service, Tiller Ranger District, Tiller, Oregon 97484, USA

Abstract.—Habitat use studies have shown that juvenile coho salmon *Oncorhynchus kisutch* select pools over riffles. However, stream alterations have caused pool habitat to be lost or degraded throughout the Pacific Northwest. This study compared the growth and survival of age-0 coho salmon in riffles and pools in four streams in the South Umpqua River basin, Oregon. Hatchery coho salmon were stocked in block-netted riffles and pools. At the end of the study, the fish were recovered in order to measure their growth and survival in each habitat type. The survival of coho salmon was significantly higher ($P < 0.01$) in pools (67%) than in riffles (27%). This variation in survival was related primarily to water depth. The growth of coho salmon did not differ significantly ($P > 0.05$) between pools and riffles. The condition factor of the coho salmon was significantly ($P < 0.05$) lower at the end of the experiment but did not differ between fish in pools and riffles ($P > 0.05$). The results of this study suggest that land management activities that reduce pool habitat may also reduce juvenile coho salmon survival or rearing capacity in small streams.

Coho salmon *Oncorhynchus kisutch* typically rear in streams their first year of life (Sandercock 1991). Many habitat use studies have shown that pools are essential for rearing juvenile coho salmon (Stein et al. 1972; Bisson et al. 1988b; Bugert et al. 1991; Kruzic 1998).

Human activities have reduced or altered stream habitat throughout the Pacific Northwest (Hicks et al. 1991; McIntosh 1992; Dose and Roper 1994). Activities such as dam construction or emplacing road culverts that offer inadequate fish passage have direct effects on salmonid production (Beechie et al. 1994). However, other land management activities, such as extensive timber harvesting and road building, can also affect the quantity and quality of stream habitat (for a review, see Meehan 1991). Such activities have been shown to alter stream flow (Harr and Coffin 1992) and to increase debris torrents (Hicks et al. 1991) and sedimentation (Chamberlin et al. 1991). This results in streams with less woody debris and reduced pool volume (Bisson and Sedell 1984). Many streams in the Pacific Northwest are now much shallower, less complex, and have more riffle habitat than they did a century ago (Chamberlin et al. 1991; Hicks et al. 1991; Fausch and Northcote 1992; Dose and Roper 1994; McIntosh et al. 1994). This change in stream habitat has significant implications for juvenile coho salmon.

More information is needed on how such stream habitat alterations affect the growth and survival of juvenile coho salmon. Previous studies have focused on observing coho salmon growth and production in stream reaches or in specific habitat types naturally selected by the fish (Carl 1983; Dolloff 1987; Bisson et al. 1988a). More recent studies have shown water depth and habitat complexity to be important to coho salmon survival (Lonzarich and Quinn 1995). However, we found no studies comparing the survival and growth of coho salmon forced to occupy certain habitat types (e.g., riffles), such as might occur after major habitat degradation that reduces pool habitat.

The objective of this study was to determine if juvenile coho salmon survival and growth in small streams depended on whether the fish occupied a pool or a riffle. The null hypothesis was that survival and growth rates were equal in pools and riffles.

* Corresponding author: lance.kruzic@noaa.gov

[1] Present address: National Marine Fisheries Service, 525 Northeast Oregon Street, Suite 510, Portland, Oregon 97232, USA.

[2] Present address: U.S. Forest Service, Idaho Panhandle National Forest, 3815 Schreiber Way, Coeur d'Alene, ID 83815, USA.

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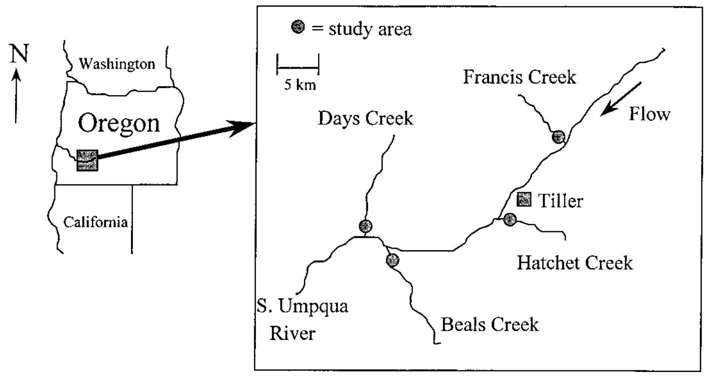

FIGURE 1.—The locations of the four study streams within the South Umpqua River basin, southwestern Oregon.

Study Sites

The study was conducted on the lower 1 km of four different tributaries to the South Umpqua River, Oregon (Figure 1). Elevations ranged from 247 m to more than 396 m. Historically, the dominant upland vegetation in these basins was Douglas fir *Pseudotsuga menziesii.* Riparian areas contained maple *Acer* spp., alder *Alnus* spp., and blackberry *Rubus* spp. All streams in the study areas except Beals Creek had nearly 100% riparian canopy closure. The riparian area of Beals Creek was less well developed than that of the other streams, and much of the study area had little or no canopy cover.

Mean stream temperature differed among the streams throughout the study period. Beals Creek and Days Creek, the lower elevation streams, were warmer than Francis Creek and Hatchet Creek. Mean daily stream temperature during the study period was 15.9°C (range, 11.4–19.6°C) for Francis Creek, 16.9°C (12.5–21.1°C) for Beals Creek and 17.7°C (12.9–22.7°C) for Days Creek, respectively. Based on occasional daily spot temperature measurements, Hatchet Creek was the coolest of the four streams (mean, 14.9°C), though no continuous data were available for this stream. Mean stream wetted widths in the study areas of Francis, Hatchet, Days, and Beals creeks were 2.6 m, 3.0 m, 3.8 m, and 2.1 m, respectively.

Fish typically found in all streams were coho salmon, steelhead *O. mykiss,* speckled dace *Rhinichthys osculus,* sculpin *Cottus* spp., and cutthroat trout *O. clarki.* Redside shiners *Richardsonius balteatus* were common in Days Creek.

Methods

A randomized-block experimental design (Ott 1993) was used to evaluate the effect of habitat type on age-0 coho salmon survival and growth. The habitat types (treatments) were classified as pools or riffles following Hankin and Reeves (1988). Each treatment was replicated three times in each of the four streams (designated as the block in the experimental design) for a total of 24 experimental units. Experimental units were designated by randomly starting with a pool or riffle then proceeding upstream, designating every other pool and riffle within each of the streams.

Once the habitat units had been designated, block nets (4.76-mm mesh) were installed. Based on juvenile coho salmon food preferences (Nielsen 1990) and the size of invertebrates in the streams (Kruzic 1998), the mesh size should not have impeded aquatic invertebrate drift. Working upstream to downstream, the uppermost block net was placed perpendicular to the channel. Approximately 25–30 cm of net was buried 15 cm deep into the substrate and covered with sand, gravel, and small cobbles. Steel rebar 9 mm in diameter was hammered into the substrate along the block net every 1 m to anchor and hold the net out of the water column. Each end of the block net was anchored at the streambank with large rocks. Once the upstream net was installed, the 20-m^2 area immediately below the net was sampled with a gasoline powered Smith-Root 15A backpack electrofisher (three passes) in an effort to remove all vertebrates. After electrofishing, the downstream net was installed. The block-netted areas averaged 78% (range 30% to 100%) of the entire riffle or pool. Based on the microhabitat characteristics measured in the block-netted areas (Table 1), these areas should not have favored a particular forage behavior class of juvenile coho salmon (Nielsen 1992). Electrofished animals were placed back into the stream outside the study area because the be-

TABLE 1.—Habitat characteristics of the pools and riffles of the four study streams. Values are means, with standard errors in parentheses.

Characteristic	Francis	Hatchet	Days	Beals
Pools				
Depth (m)	0.19 (0.018)	0.14 (0.010)	0.15 (0.011)	0.13 (0.011)
Substrate (m)	0.05 (0.004)	0.02 (0.005)	0.01 (0.002)	0.02 (0.003)
Velocity (m/s)	0.08 (0.014)	0.07 (0.013)	0.08 (0.009)	0.04 (0.007)
Riffles				
Depth (m)	0.07 (0.005)	0.06 (0.004)	0.09 (0.004)	0.05 (0.005)
Substrate (m)	0.06 (0.004)	0.04 (0.007)	0.03 (0.004)	0.03 (0.002)
Velocity (m/s)	0.16 (0.018)	0.17 (0.024)	0.18 (0.021)	0.14 (0.016)

havior, growth, and survival of the study fish could be altered by the presence of another species (Resetarits 1995; Harvey and Nakamoto 1996). Excluding all the electrofished animals reduced the potential confounding effects from other fish species and provided the most standardized baseline for evaluating the influence of habitat type on coho salmon survival and growth, especially in the South Umpqua River basin where fish densities differ significantly within and among habitat types and streams (Roper 1995; Kruzic 1998). Chicken wire (2.5-cm mesh) was placed above the uppermost block net of each stream to catch debris.

Age-0 coho salmon (mean length 82.3 mm, mean weight 7.2 g) were obtained from the Oregon Department of Fish and Wildlife's Butte Falls Hatchery (South Umpqua River basin parent stock) and stocked at 1.0 fish/m^2 (20 fish per pool or riffle) into the block-netted areas on July 17, 1996. We used hatchery coho salmon because sufficient numbers of wild coho salmon could not easily have been collected for the study. Using hatchery fish, which were raised under identical conditions, also reduced the potential biases associated with using wild coho salmon, which would have been collected predominately from pools. The density of the coho salmon was slightly higher than that typically found in streams of the upper South Umpqua River basin (Roper 1995), but it represented an intermediate value in the density range reported in Pacific Northwest streams (Chapman 1962; Bisson et al. 1988a; Nielsen 1992; Rodgers et al. 1992). We stocked both riffles and pools at the same density per unit of area in order to evaluate the effect of habitat type. Because juvenile coho salmon do not typically position themselves directly above conspecifics in the water column in the South Umpqua River basin (L. M. Kruzic, personal observation), stocking pools and riffles at the same density would provide the same amount of usable area (Sullivan 1986). All fish were anesthetized in 0.05 g/L tricaine methanesulfonate (MS-222; trade name Fintrol) and individually measured to the nearest millimeter of fork length (FL) and weighed to the nearest 0.1 g before being stocked. All of the 20 surplus fish that were put into a live well in one stream and retained for 2 d survived.

During the first week after the fish were stocked, the block nets were checked daily to remove debris and ascertain fish mortalities. After the first week, the block nets were checked every two to 4 d. Fish were held in the block-netted areas until August 19–21, 1996, or slightly more than one month, at which time the enclosed areas were again sampled with electrofishing (three passes) to recover the stocked coho salmon. Fish were enumerated and measured again for length and weight. Because of the different dates on which the fish were collected, all lengths and weights were standardized to 35 d.

The pools and riffles in between the block-netted units and upstream and downstream of the study area were also electrofished in an attempt to recover hatchery coho salmon that might have escaped from the block nets. Based on the movement patterns of age-0 coho salmon in the South Umpqua River basin (Kruzic 1998), the areas sampled should have been sufficient to recapture fish that escaped. Hatchery coho salmon could be distinguished from wild coho salmon because they were 10–30 mm longer, exhibited greater condition factor, and did not have well-defined parr marks. No hatchery coho salmon were recovered outside the block-netted areas, so it was assumed that all fish not recovered died within the block netted area or were lost to predation.

Twenty randomly selected measurements of depth, substrate size, and mean water velocity were obtained in each of the block-net areas to quantify the habitat conditions (Table 1). Depth was measured to the nearest 0.01 m, and substrate size was determined by averaging three measurements of the intermediate-length axis of the piece of substrate. Mean depth was calculated by averaging all depth measurements, and maximum depth was the maximum depth recorded at the random locations. Mean velocity was obtained with a Price-type ''mini'' flowmeter placed at 0.6 the total depth of the water column.

The response variables used in the analysis were survival, growth, and condition factor (Resetarits 1995). Survival was the proportion of fish recovered at the end of the experiment. Growth was measured as the change in length and weight from the beginning to the end of the experiment. The change in condition factor was calculated using the equation $K = (W/L^3) \times 10^5$, where K is condition factor, W is weight in grams, and L is fork length in millimeters. Production estimates were computed according to the formula $P = GB$, where G is the difference in the logarithmic weights of fish from the beginning to the end of the experiment and B is the mean biomass of the fish (Bisson et al. 1988a). Mean biomass was calculated as the mean of the product of weight and the number of fish at the start and end of the experiment. Means for each response variable in every experimental unit (24 total) were calculated and these formed the units of analysis.

Response variables were analyzed using multivariate analysis of variance (MANOVA) and standard ANOVA. Survival and the change in length, weight, and condition factor were the response variables used in the MANOVA (Resetarits 1995). Each of the response variables was then analyzed individually by means of two-way ANOVA with habitat type and stream as the independent variables. Multiple comparisons were conducted using the Scheffé method (Ott 1993). Multiple regression was used to evaluate the relationship between the habitat characteristics measured in each of the experimental units and the survival of the coho salmon. The length-frequency distribution of fish before and after the experiment was analyzed using chi-square goodness-of-fit (Ott 1993). An α of 0.05 was used to determine the significance of each test result.

Results

Twenty-one of the 24 block-netted areas maintained their integrity during the study period. Two of the block-netted areas were not secured properly, and water passed over the block net within the first few days. The other block-net failure was due to a poor anchoring location, namely, a rock wall. In each of these three areas, 20–30 additional fish (i.e., dace, redside shiner, age-0 steelhead, and sculpin) were electroshocked at the end of the study, thus confirming fish passage by the block nets. These three areas were not used in the analysis.

In the remaining 21 block-netted areas, evidence suggests that passage by the block nets was low. Few if any additional fish were found within the individual block-netted areas at the end of the study. Altogether, there were less than five fish (primarily dace and sculpin) measuring less than 50 mm FL. No hatchery coho salmon were recovered while electrofishing upstream or downstream of the block-netted areas.

The survival, growth, and condition factor of the coho salmon varied significantly, depending on the habitat and stream the fish occupied (MANOVA, Wilks' λ: $P < 0.01$). Habitat type and stream appeared to interact in determining the survival, growth, and condition of the coho salmon ($P < 0.01$).

Survival

Coho salmon survival was significantly higher in pools than in riffles (ANOVA: $P < 0.01$; Figure 2a). The mean survival for all streams combined was 27% in riffles (range, 0–70%) and 67% in pools (15–100%). There were no significant differences in coho salmon survival among the four streams (ANOVA: $P = 0.09$; Figure 2a) and no significant interaction between stream and habitat type (ANOVA: $P = 0.08$). During the study, 11 fish were found dead in riffles and no fish were found dead in the pools. Ten of the 11 documented mortalities were found within 4 d of stocking.

Of the habitat characteristics examined (substrate size, average velocity, and water depth), water depth was the only variable exhibiting a significant relationship with coho salmon survival ($P < 0.01$; the estimated equation was survival rate $= -0.2 + 4.87 \times$ depth $+ 1.35 \times$ substrate $+ 0.53 \times$ velocity, with $R^2 = 0.51$). In both riffles and pools, the highest rates of survival were observed in the deepest habitats. Within-stream variation in survival also appeared to be related to pool depth. In Beals Creek, the mean depth of the pool that had the lowest fish survival (15%) was 0.11 m (maximum depth, 0.16 m), whereas the mean depth of the pool with the highest fish survival (85%) was 0.15 m (maximum depth, 0.27 m). Average water velocity and substrate size were not significantly related to survival ($P > 0.60$).

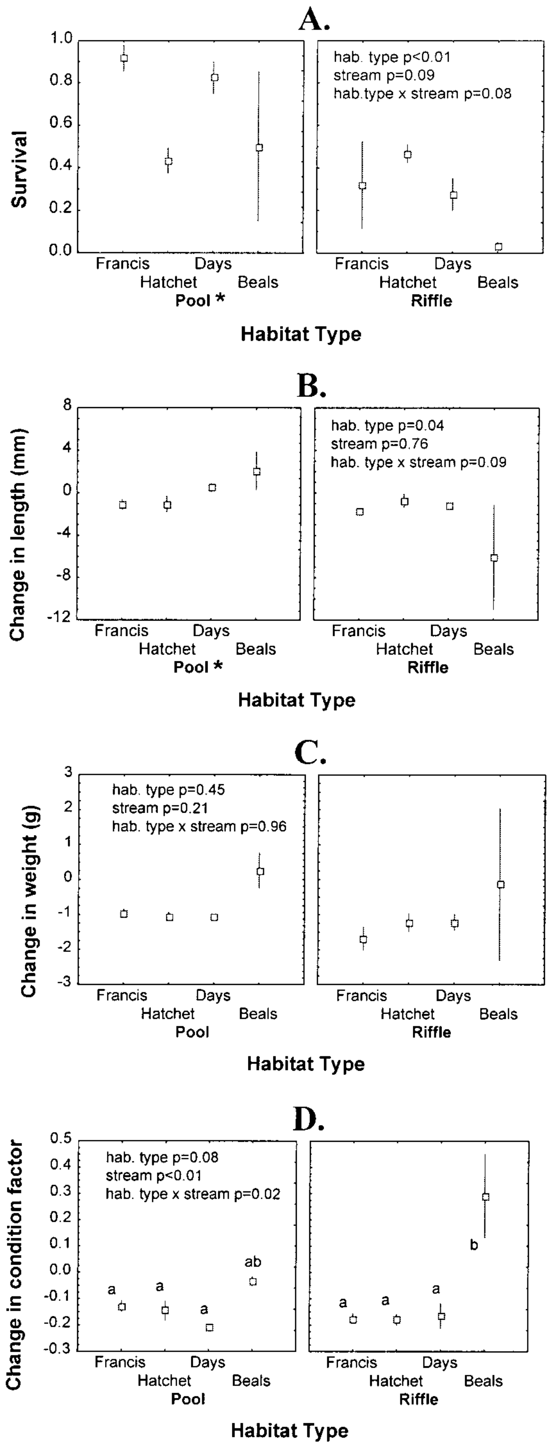

FIGURE 2.—Responses of coho salmon in terms of survival, change in mean length, change in weight, and change in condition factor by habitat type (pool or riffle) in Francis, Hatchet, Days, and Beals creeks. Means (±SE) are reported. Asterisks indicate a significantly

Growth

At the start of the experiment, the length and weight of the coho salmon stocked into pools were not significantly different from those of the fish stocked into riffles (ANOVA: $P = 0.39$). Fish lengths did not change significantly over the course of the study (ANOVA: $P = 0.11$): the mean length of coho salmon stocked into pools increased less than 1 mm, while that of fish stocked into riffles decreased 2 mm (Figure 2b). However, the difference between the changes in length experienced by the two groups of fish was significant (ANOVA: $P = 0.04$). On average, the fish weighed less at the end of the experiment than when they were stocked, but the weight changes were not found to be related to habitat type or stream (ANOVA: $P > 0.20$; Figure 2c). Because the mean weight of fish decreased in both pools and riffles, production (g/m^2) was negative. The length-frequency distributions of the two groups of coho salmon were not statistically different at the beginning and end of the experiment ($\chi^2 < 2.0$; df $= 6$; $P > 0.05$).

Condition Factor

The condition factor of fish stocked into pools was not significantly different from that of fish stocked into riffles at the start of the experiment (ANOVA: $P = 0.96$). On average, the condition factor decreased throughout the study for all fish (ANOVA: $P < 0.05$), but no significant differences were found between the change experienced by fish occupying riffles and that experienced by fish occupying pools (ANOVA: $P = 0.08$; Figure 2d). However, the condition factor did change depending on the stream where the fish were stocked (ANOVA: $P < 0.01$). The fish stocked into the riffles of Beals Creek constituted the only group for which condition factor increased throughout the study period (Figure 2d). The change in these fishes' condition factor was significantly greater (ANOVA: $P < 0.02$) than it was for all other groups, except for fish stocked into the pools of Beals Creek (Figure 2d).

Discussion

Previous studies have shown the distribution and density of fish to be influenced by the habitat

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($P < 0.05$) higher response for a particular habitat type. Where interaction effects (habitat type × stream) occurred, means with different letters are significantly ($P < 0.05$) different.

characteristics of the stream (Bilby and Bisson 1987; Meehan 1991; Beechie et al. 1994). Sullivan (1986) showed that only a proportion of the available habitat is within a tolerable range for juvenile coho salmon, that range being defined by combinations of water depth, velocity, and substrate. Coho salmon were distributed in direct proportion to the amount of usable habitat (Sullivan 1986). Coho salmon select the relatively deep, slow-moving stream areas and avoid shallow, swift-water areas (Bisson et al. 1988b; Bugert and Bjornn 1991; Kruzic 1998). In this study, the higher survival of coho salmon in pools compared with riffles can be attributed to more suitable areas in the pools. The riffle habitat was much shallower and swifter than coho salmon would select naturally (Kruzic 1998). Consequently, fewer habitat areas in the riffles were usable by coho salmon. This was evident in the first few days of the experiment when all of the fish found dead were in the riffles. Coho salmon possess deep, laterally compressed bodies and large median fins that are advantageous for maneuvering in pools but less adapted for sustained swimming in riffles (Bisson et al. 1988b). Using pools rather than riffles has been shown to increase the total production of juvenile coho salmon (Bisson et al. 1988a).

Fish were exposed to greater predation risk in riffles because they typically resided in low-velocity water along the margins of the stream or against the downstream block net. These positions were generally very shallow and had little or no overhead cover, which probably exposed the fish to greater predation risk than they would have experienced in deeper water habitat (Lonzarich and Quinn 1995). Although predation was not directly observed during the study period, several known predators were observed in or near block-net areas, including the garter snake *Thamnophis* spp., belted kingfisher *Ceryle alcyon*, great blue heron *Ardea herodias,* and green-backed heron *Butorides striatus.* The common merganser *Mergus merganser,* river otter *Lutra canadensis,* raccoon *Procyon lotor,* and mink *Mustela vison* were also observed in nearby areas. Beals Creek had the lowest overall survival and exhibited the greatest signs of predation. On several occasions, garter snakes and herons were observed perched on the block nets, and belted kingfishers were seen in riparian trees. Spalding et al. (1995) documented successful attacks by belted kingfishers and green herons on coho salmon in experimental stream channels. The fish in the pools were more uniformly distributed, less conspicuous, and typically resided in the deepest areas of the pool, thus making them less vulnerable to predation.

Coho salmon survival in this study may have been lower in both habitat types than would be observed for wild coho salmon. The study fish were forced to occupy the area where they were stocked; in the wild, coho salmon can migrate from riffles to more suitable habitat, which would probably result in higher survival rates. Even though the fish densities used in this study were within the range typically found in the wild, the survival and growth of coho salmon might have been higher in both habitat types if lower densities were used. The hatchery fish used in the study were also not previously subjected to predation, which may have made them more vulnerable to predators (Healey and Reinhardt 1995). Previous predation pressure would have tended to reduce the hatchery fishes' aggressiveness and movement, thus making them less conspicuous to predators (Martel 1996).

We expected that the growth and condition factor of coho salmon occupying the pools would be significantly higher than those for the fish in the riffles. The similarity in condition factor of fish in the riffles and pools at the end of the study was probably related to food availability. If fish were able to find a suitable location within the riffle, they were able to take advantage of a relatively high food supply (Merritt and Cummins 1996), which would offset the cost of maintaining positions in less favorable habitat (Fausch 1984). This appeared to be the case with fish stocked into the riffles of Beals Creek. Even though these fish had the lowest survival, if they found a suitable location within the riffle they experienced favorable feeding conditions and consequently exhibited the greatest increase in condition factor (Figure 2d). Even though growth and condition factor did not differ between riffles and pools, the total coho salmon biomass was much higher in the pools at the end of the study.

In the Pacific Northwest, land management activities have adversely modified stream habitat by reducing pool depth or pool-forming features such as large woody debris (Bisson and Sedell 1984; Hicks et al. 1991; McIntosh 1992; Quinn and Peterson 1996). In the South Umpqua River River basin, streams are much shallower and wider than they were a century ago (Dose and Roper 1994). Because coho salmon typically rear in freshwater during their first year of life (Sandercock 1991), the loss of pool habitat may adversely affect their long-term population dynamics. The capacity of the habitat to support coho salmon is reduced in areas where pool habitat has been degraded, causing greater emigration rates and lower production for juvenile coho salmon in natal streams (Bilby and Bisson 1987; Fausch and Northcote 1992). Restoring complex pool habitat in small streams is essential to conserving and recovering many imperiled coho salmon stocks throughout the Pacific Northwest and California.

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