

## Effects of Wood Placement on Movements of Trout and Juvenile Coho Salmon in Natural and Artificial Stream Channels

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**Abstract.**—We monitored the movements of marked juvenile coho salmon *Oncorhynchus kisutch*, steelhead *O. mykiss*, and cutthroat trout *O. clarki* in a stream reach that had been “restored” with placed wood and a reference reach with no wood placement and tracked the growth and movements of individually marked coho salmon among habitats in artificial channels with and without woody debris. Monthly surveys in Shuwah Creek, Washington, indicated that few (0–33%) of the marked trout or coho salmon moved between the restored and reference reaches. However, a rapid decline in both marked and unmarked fish in late fall and the increasing proportion of unmarked fish indicated considerable migration to and from the study reaches. In the artificial channels, fewer fish moved in the simple (with no wood) channel than in the complex (with wood) channel (22% versus 37%), and the mean distance moved was shorter in the complex channel (4.4 versus 6.7 habitat units). In the simple channel, the fish that moved grew faster than those that did not. Movement may facilitate increased growth in stream reaches with little woody debris, and the placement of woody debris may lead to less frequent and shorter movements.

Populations of many fish species have been reduced by a combination of factors, including overfishing and degradation of habitat. Habitat modification has frequently been undertaken in an effort to restore fish populations or facilitate fishing in both freshwater and marine environments. In some cases, the structures are explicitly designed to concentrate fish and thus increase fishing success; an example is the “fish aggregating devices” (FADs) used to attract tuna (Holland et al. 1990; Higashi 1994). In other cases, such as with artificial reefs in freshwater and coastal marine areas, the structures clearly function in more than one way (Bassett 1994; Lindberge 1997; Bohnsack et al. 1997; Kelch et al. 1999). Artificial reefs are quickly colonized by adult fish, suggesting that there is movement among habitats even though many of the species in question are assumed to spend all or almost all of their time in very restricted home ranges (e.g., rockfishes; Matthews 1990a, 1990b). The structures may also provide refuge and increase the survival of recruits, and so benefit the population as a whole (Lindberge 1997). It is difficult to determine whether structures attract fish or in-

crease survival (or both), yet answering this question is important for evaluation of such structures.

The enhancement and restoration of stream habitat for salmonid fishes through the instream placement of structures and large woody debris (LWD) has increased dramatically in western North America in recent years. Numerous studies have documented increased density of resident and anadromous salmonids after instream habitat enhancement or restoration techniques (e.g., Hunt 1976; House and Boehne 1985; Binns 1994; House 1996; Cederholm et al. 1997). This change is consistent with observations that the density of juvenile salmonids varies with habitat and specifically that coho salmon *Oncorhynchus kisutch* tend to occupy pools that have woody debris (Bisson et al. 1982).

Studies relating salmonid density to variation in habitat quality (either natural or postrestoration) generally assume that the fish have small home ranges and seldom move between treated (restored or enhanced) and unaltered stream reaches or between natural reaches that vary in quality. The assumption of restricted movement is primarily based on studies prior to 1990, which indicated that juvenile and adult salmonids had limited home ranges and rarely moved far except for spawning migrations or emigration to the sea (reviewed by Gowan et al. 1994). Gowan et al. (1994) demon-

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strated that most studies of the movement of stream fishes were unlikely to detect movement and that movements of several hundred meters over the course of a week or even a day are common among juvenile and adult resident salmonids. Riley et al. (1992), Riley and Fausch (1995) and Gowan and Fausch (1996) reported that most of the increase in trout abundance in high-elevation Colorado streams enhanced with log structures was due to immigration. Other studies indirectly suggest that movement may play a role in increased fish abundance following habitat manipulations. Angermeier and Karr (1984) reported increased abundance of warmwater fishes in response to short-term habitat manipulations, which was clearly due to immigration. Hamilton (1989) found a twofold increase in the abundance of juvenile steelhead *O. mykiss* in a stream reach treated with boulders, while steelhead densities in a nearby reference reach declined by one-half.

Large-scale movements (i.e., at the reach or watershed scale) of juvenile anadromous salmonids in streams often occur in fall as the fish relocate to off-channel habitat (e.g., Bustard and Narver 1975a, 1975b; Peterson 1982; Tschapinski and Hartman 1983; Cederholm and Scarlett 1984) and during seaward migration in spring (reviewed by Northcote 1992; McCormick et al. 1998). However, it is unclear how common movement is during the summer. Heggenes et al. (1991) and Harvey et al. (1999) found that most age-1+ cutthroat trout *O. clarki* in small coastal streams moved less than 50 m throughout the year. However, Kahler (1999) demonstrated that over the course of a summer approximately 50% of the juvenile coho salmon, cutthroat trout, and steelhead in three streams moved from their original tagging location. Most movements were about 5 habitat units (30–50 m), but a few fish moved more than 100 m. It is important to evaluate the extent of movement and the ways in which it might affect assessment of population level benefits from habitat restoration.

It has generally been assumed that not only do few fish move but that the movers are less fit than those that remain. Large size and territorial possession provide great advantages in competition for space (Rhodes and Quinn 1998 and references therein). Dominant juvenile salmonids may force smaller conspecifics to move to other habitats or suboptimal feeding areas (Chapman 1962; Nielsen 1992), and it seems reasonable to assume that movers would grow more slowly than residents. However, Kahler (1999) found that fish that moved had higher subsequent growth rates than those that did

not move. Fish in poor habitat (small, shallow pools) tended to move to higher-quality habitat, whereas fish in higher-quality habitat stayed despite high densities that reduced growth. Harvey et al. (1999) found that adult coastal cutthroat trout in habitats lacking LWD moved more frequently than those in habitats with LWD, but we know of no study that explicitly examined the movements of juvenile anadromous fish in response to the artificial placement of LWD or other instream structures.

In this study we examined the movements of juvenile coho salmon, steelhead, and cutthroat trout during fall and winter in a natural stream channel, testing the hypothesis that few fish would move between the unrestored (reference) and restored (treatment) reaches against the predicted alternative that fish would tend to move from the lower-quality to the higher-quality habitat. We also examined the movement patterns and growth of juvenile coho salmon in artificial channels with and without woody debris, testing the hypothesis that the frequency of movement is independent of habitat quality, fish size, and growth against the predicted alternatives that smaller fish would tend to move and grow more slowly than residents.

## Methods

**Movements in Shuwah Creek.**—Juvenile coho salmon, cutthroat trout, and steelhead were given group-specific photonic tags (pigment injected into the dorsal fin; Kahler 1999) in two reaches of Shuwah Creek, Washington, to determine the level of movement among treatment (artificial LWD placement) and reference (no LWD placement) stream reaches. The study section of Shuwah Creek was a small (6.5 m bankfull width), low-gradient (slope = 1.5%), forced-pool riffle channel (Montgomery and Buffington 1997) near Forks, Washington. A restoration project, including the placement of log structures within the bankfull channel, was conducted on approximately 500 m of Shuwah Creek in the summer of 1996. We selected two 90-m reaches within the creek, one at the upper end of the restored stream reach and one approximately 100 m farther upstream in an unrestored or reference reach. There were 35 and 47 pieces of large woody debris (>10 cm in diameter and > 2 m long) in the reference and treatment reaches, respectively, in September 1998. Much of the LWD in the reference reach was on the channel margins and was not actively creating pools. The treatment (restored) reach that we sampled included a total of 7 log habitat structures (i.e. deflectors, log

weirs, and cover structures) and had more pool area than the reference reach (80% versus 56% in September 1998). Besides coho salmon, cutthroat trout, and steelhead, the reaches contained torrent sculpin *Cottus rhotheus*, reticulate sculpin *C. perplexus*, and larval Pacific lamprey *Entosphenus tridentatus* (also known as *Lampetra tridentata*).

Salmonids were captured from September 6 to 8, 1998, by means of three-removal electrofishing; they were then anesthetized and the dorsal fin of each fish was given a red or blue mark depending upon whether it was captured in the treatment (red) or reference (blue) stream reach. Each fish was then returned to the habitat unit (e.g., pool or riffle) where it had been captured. A total of 114 coho salmon, cutthroat trout, steelhead, and trout fry not distinguishable to species were marked in the restored reach and 71 in the reference reach. Complications with the tagging equipment prevented the marking of 31 fish captured in the restored reach and 7 in the reference reach. The total numbers of trout and coho salmon captured were identical to multiple-removal abundance estimates using the technique of Carle and Strub (1978), and capture probability during three-pass electrofishing exceeded 0.73.

Monthly night snorkel surveys were conducted from October 1998 through April 1999 to count tagged and untagged fish in the two reaches. Because juvenile coho salmon, cutthroat trout, and steelhead in western Washington streams become nocturnal when temperatures drop below approximately 9°C, night snorkeling provides abundance estimates that are similar to those of multiple-removal electrofishing during winter (Roni and Fayram 2000). One diver with a halogen dive light entered the habitat from the downstream end and slowly moved upstream, stopping occasionally to relay the number, approximate size, mark (tag color), and species of fish observed to a second individual on the bank. Water temperature, underwater visibility, and flow were measured prior to snorkeling (Table 1). Underwater visibility was measured using a horizontal Secchi disk. Snorkel surveys were initiated 1 h after sunset and only conducted on nights with cloud cover or no visible moonlight to assure similarity in light levels.

The numbers of marked and unmarked fish were compared between the two reaches over the 8-month sampling period. Most of the trout observed were cutthroat trout, but we could not reliably distinguish juvenile cutthroat trout from steelhead during snorkel surveys. Therefore, we refer to these species collectively as trout throughout our

TABLE 1.—Water temperature, underwater visibility, and discharge at Shuwah Creek during the initial tagging (September) and monthly snorkel surveys. Visibility was not recorded in the initial survey.

Month	Temperature (°C)	Visibility (m)	Discharge (m <sup>3</sup> /s)
Sep	13.0		0.01
Oct	8.5	3.0	0.07
Nov	8.4	3.0	0.38
Dec	7.1	2.0	0.40
Jan	6.5	2.5	0.53
Feb	5.8	3.0	0.66
Mar	6.7	3.0	0.16
Apr	7.1	2.5	0.05

analysis. Regression and analysis of covariance (ANCOVA) were used to examine the relationship between survey date and abundance within and between stream reaches. Two sample *t*-tests were used to examine the difference in length between fish in the treatment and reference reaches during September, when accurate length measurements were available.

*Movements in artificial channels.*—Experiments were conducted in a seminatural outdoor stream system (45 × 6 m, 3% grade) at the National Marine Fisheries Service's Manchester Field Station near Manchester, Washington (Berejikian et al. 2000). The stream system was divided evenly down the middle into two separate, identical channels (A and B) by a wooden wall 1 m high, and each channel was further divided into 8 individual habitats units 5 m long × 3 m wide (A1–8 and B1–8; Figure 1). Well water was supplied at 80 L/min and was recirculated at a flow of 0.05 m<sup>3</sup>/s (0.025 m<sup>3</sup>/s in each channel). Wooden weirs 15 cm high created hydraulic drops between units within each channel. Previous unpublished experiments with coho salmon fry and parr indicated that these weirs were not a barrier to fish movements. Each habitat unit contained equal amounts of gravel 3–5 cm in diameter, which was graded to form shallow plunge pools. Depths were standardized between habitats to 30 cm at the upstream end and 10 cm at the midpoint and decreased gradually to 2 cm at the downstream end. The exception was the lowermost habitats in each channel (A8 and B8), where water backed up against the screens and depths were 40 cm at the upstream end and 30 cm at the downstream end. Screens could be placed between each unit to allow for sampling of individual habitats and permanent screens were installed at the upstream and downstream end of both channels to prevent emigration out of the channels.

Wood cover in the form of denuded Douglas firs

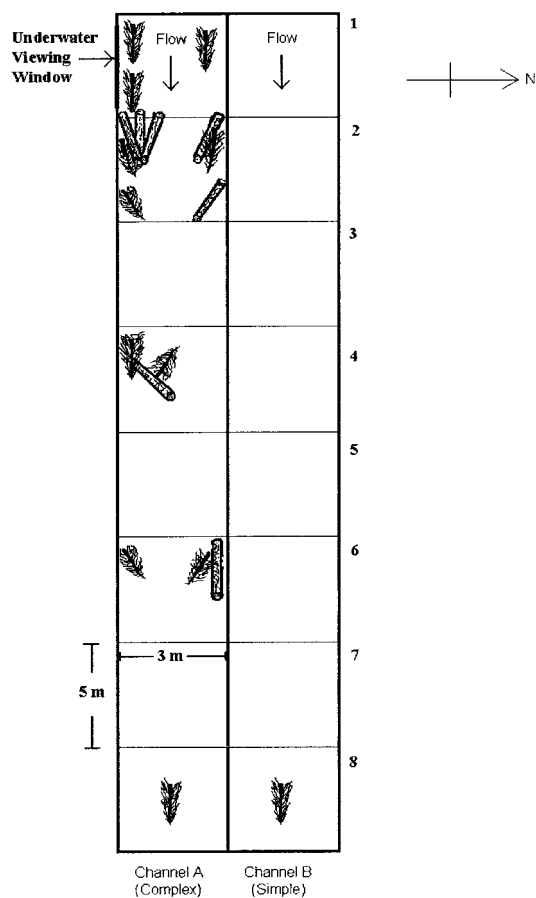


FIGURE 1.—Diagram of the artificial stream at the National Marine Fisheries Service's Manchester Field Station that was used to study the differences in size, growth rate, and movement of coho salmon in complex and simple channels.

*Pseudotsuga menziesii* 1.8 m long (commercially farmed Christmas trees) and red alder *Alnus rubra* logs (1.2 m long  $\times$  15 cm in diameter) was placed in habitat units 1, 2, 4, and 6 in channel A (Figure 1). Additionally, a single Douglas fir was placed in habitat units A8 and B8 because of high fish densities in those units and to minimize avian predation. Wood was placed in an orientation similar to that found in many stream habitat enhancement projects (Figure 1). Water temperatures ranged from 8.1°C to 15°C during the study. Abundant production of aquatic insects ( $>16,500$  chironomids/m<sup>2</sup>) within the stream channel made it unnecessary to feed the fish over the course of the study.

Altogether, 506 juvenile coho salmon were obtained from the Washington Department of Fish

and Wildlife's Minter Creek Hatchery and placed into the experimental channel on April 21, 1999. Thirty coho salmon were placed in each unit, and the remaining 26 fish were split equally between units A1 (complex) and B1 (simple). The fish were allowed to acclimate and move freely within channels for 2 weeks. On May 5 the fish were recaptured, anesthetized, implanted with passive integrated transponder (PIT) tags, measured, weighed, and released into the habitat in which they were captured. The fish were then sampled three times (May 19, June 2, and June 16) to determine their location and size. Screens were placed between habitat units to prevent movement, and then fish were captured by making five passes through each habitat with a 6-mm-mesh stick seine. All wood was temporarily removed from a habitat prior to sampling and replaced shortly after sampling. Fish were anesthetized with tricaine methanesulfonate (MS-222) and their length, weight, and PIT tag number recorded. To minimize handling, fish were not weighed on May 19 and June 2.

Only those fish that were recovered on the last sampling date (June 16) were used in our analysis of length, weight, and growth, and only fish for which we had records for at least 3 of the 4 weeks were included in the movement analysis. A "holder" was defined as a fish that was captured in the same habitat on all sampling dates; a "mover" was defined as a fish that was recovered at least once in a habitat other than the one in which it was found on May 5 (i.e., its original tagging location). Length-weight relationships between holders and movers were compared using ANCOVA, and analysis of variance (ANOVA) was used to examine differences in length, weight, growth rate (length on May 5 minus length on June 15) between movers and holders and between channels. A chi-square test was used to compare the proportions of movers and holders between the two channels.

## Results

### Movements in Shuwah Creek

Little movement was observed between the reference and treatment reaches in Shuwah Creek from September through April (Figure 2). Although the total number of marked fish in the two reaches differed (78 and 114 in the reference and treatment reaches, respectively), similar numbers of marked fish were observed in the reference (5–29 fish) and treatment (5–24 fish) reaches from November to April. From 0 to 4

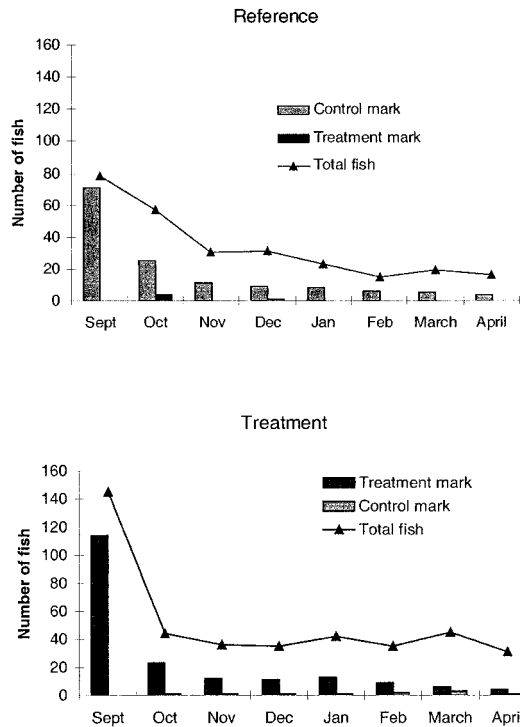


FIGURE 2.—Number of marked coho salmon, cutthroat trout, and steelhead observed in the reference and treatment reaches of Shuwah Creek from October 1998 through April 1999, together with the total number of fish observed in each reach. The presence of control (reference) fish in the treatment reach or treatment fish in the reference reach indicates movement between reaches. The September counts are the total number of fish captured by electrofishing during the tagging process; the counts for all other months are from snorkel surveys.

treatment marked fish (0–14% of marked fish present) were observed in the reference reach during monthly snorkel surveys (October to April), and from 1 to 3 reference marked fish (4–33% of marked fish present) were observed in the treatment reach. The percentage of fish observed during monthly snorkel surveys that had marks generally declined with time in both reaches (Table 2). The number of fish observed in the treatment reach ranged from 36 to 145 and was consistently higher than the total number in the reference reach (15–78 fish; Figure 2). Total monthly fish counts were nearly significantly different between reaches (paired *t*-test;  $P = 0.06$ ), but not when coho salmon and trout were examined separately ( $P = 0.17$  and  $0.26$  for coho salmon and trout, respectively).

Despite the small number of tagged fish that

TABLE 2.—Percentage of fish with marks observed in the reference and treatment reaches of Shuwah Creek during monthly surveys from September 1998 to April 1999.

Reach	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Reference	91	51	37	26	35	40	26	31
Treatment	79	55	36	34	33	31	20	16

moved between reaches, the appearance of untagged fish indicated considerable movement. The proportion of marked fish in the reference reach decreased from 91% (71 fish) in September to 31% (5 fish) in April. Similarly, the proportion of marked fish in the treatment reach decreased from 79% (114 fish) to 16% (5 fish) over the same period (Table 2). Juvenile salmonid abundance decreased dramatically in October in the treatment reach. The total number of fish remained relatively constant throughout the winter (December to April), particularly in the treatment reach; numbers decreased gradually over the winter in the reference reach. Regression analysis indicated that the relationship between survey date (month) and fish abundance was significant for the reference reach ( $P < 0.01$ ,  $r^2 = 0.78$ ) but not for the treatment reach ( $P = 0.11$ ,  $r^2 = 0.37$ ). However, the differences between the slopes and elevations of these equations were not significant (ANCOVA;  $P > 0.15$ ). When examined by species, a significant decline over time was observed for both coho salmon ( $P < 0.01$ ,  $r^2 = 0.91$ ) and trout ( $P = 0.04$ ,  $r^2 = 0.55$ ) in the reference reach; in the treatment reach, there was a significant decline for coho salmon ( $P = 0.04$ ,  $r^2 = 0.54$ ) but not for trout ( $P = 0.46$ ; Figure 3). No significant difference existed in the survey date–abundance regression equations between reaches for coho salmon (ANCOVA;  $P > 0.20$ ) or trout ( $P > 0.15$ ).

In September, the coho salmon ranged from 60 to 130 mm in length and the trout from 47 to 187 mm. The fish were significantly smaller in the reference reach than in the treatment reach (73.5 mm versus 77.6 mm for coho salmon [ $P = 0.02$ ], 90.8 mm versus 105.3 mm for trout [ $P = 0.04$ ]). Fish lengths from October through April were based on visual snorkel estimates and no analysis was performed on these data.

#### Movements in Artificial Channels

Of the 506 juvenile coho salmon released in the artificial channels, 466 (93%) were recaptured approximately 2 months later. Recovery rates were not significantly different between the simple and



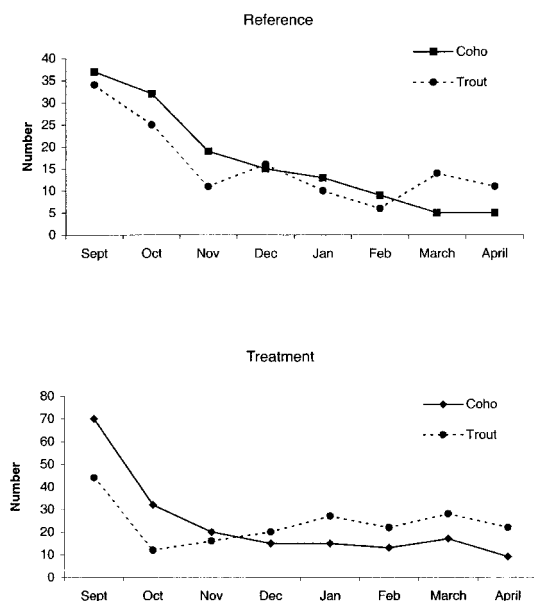


FIGURE 3.—Total number of trout and coho salmon observed in monthly surveys of the reference and treatment reaches of Shuwah Creek from September 1998 through April 1999. The September counts are the total number of fish captured by electrofishing during the tagging process; the counts for all other months are from snorkel surveys.

complex channels (98% and 86%, respectively;  $P = 0.98$ ). A larger proportion of the fish moved in the complex channel than in the simple channel (37% versus 22%; chi-square test,  $P < 0.01$ ; Table 3). However, of the fish that moved, a greater proportion moved only once (rather than several times) in the complex channel ( $P = 0.01$ ; Table 3). The net direction of movement (upstream versus downstream) was similar between the two channels; 34% and 43% of the movement was upstream in the simple and complex channels, respectively ( $P = 0.98$ ; Table 3).

No difference in length, weight, or growth was detected between the movers and holders in the complex channel (ANOVA;  $P > 0.30$ ). However, in the simple channel movers were longer ( $P = 0.04$ ) and heavier ( $P < 0.01$ ) and grew more rapidly ( $P < 0.01$ ) than holders. Length-weight relationships between holders and movers were similar in the complex channel (ANCOVA;  $P = 0.91$ ) but differed in the simple channel ( $P < 0.01$ ; Table 4), with movers being heavier for a given length. The fish moved farther in the simple than in the complex channel (6.7 versus 4.4 habitat units;  $t$ -test,  $P < 0.01$ ), but there was no relationship between length or weight and distance moved

TABLE 3.—Percentages of (1) fish moving, (2) number of moves, and (3) movements in a particular direction in experimental channels with (complex) and without (simple) woody debris. Equal direction movement indicates that the fish moved an equal number of habitats upstream and downstream over the course of the study.

Movement indicator	Channel A (complex)	Channel B (simple)
Fish moving (%)	37	22
Number of moves		
One	75	51
Two	18	38
Three	7	11
Direction		
Upstream	43	34
Downstream	48	40
Equal	9	26

(ANOVA;  $P = 0.94$ ) or frequency of movement ( $P > 0.35$ ) in either channel. The distribution of fish differed between the simple and complex channels; more fish were found in the upstream habitats of the complex channel (where wood was present) than in the corresponding habitats of the simple channel. However, in both channels most of the fish were found in the most downstream habitats (Figure 4).

### Discussion

Gowan et al. (1994) suggested that the movements of salmonids may in part account for the increased density observed at instream restoration projects. In contrast, Reeves and Roelofs (1982) indicated that it was unlikely that LWD placement or other habitat structure would concentrate fish in treated stream reaches, as juvenile salmonids would disperse to those habitats vacated by others. The results of our tagging

TABLE 4.—Mean lengths, weights, and growth of juvenile coho salmon moving or holding in complex and simple artificial channels. Length and weight were measured at the end of the experiment.

Variable	Channel A (complex)	Channel B (simple)
<b>Movers</b>		
Mean length (mm)	87.5	89.9
Mean weight (g)	7.9	8.6
Growth (mm)	23.2	25.3
N	71	47
<b>Holders</b>		
Mean length (mm)	88.6	87.6
Mean weight (g)	8.1	7.7
Growth (mm)	24.1	22.5
N	120	141

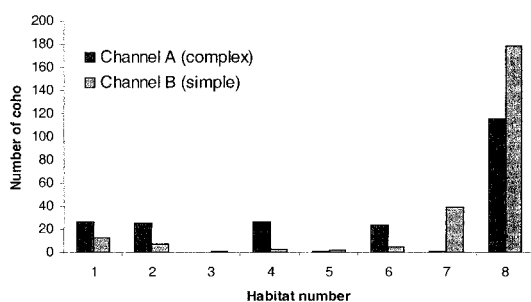


FIGURE 4.—Distribution of juvenile coho salmon in artificial channels with (complex) and without (simple) woody debris on June 15, 1999. Habitat numbers (x-axis) are in order from upstream to downstream. Habitat units 1, 2, 4, and 6 in channel A all contained woody debris; habitat unit 8 in both channels was deeper than the other units because a screen at the downstream end of each channel caused the water to pond.

study on Shuwah Creek were consistent with this latter conclusion, as few tagged fish moved between the restored and reference reaches. Thus, we did not reject our null hypothesis of limited exchange between the treatment (high-quality or complex habitat) and reference (low-quality or simple habitat) reaches. In addition, in artificial channels we found no difference in growth, but fish in the complex channel moved more frequently and shorter distances than those in the simple channel. Other factors, however, may contribute to the limited exchange that we observed between reaches in Shuwah Creek and the differences in movement between the two artificial channels; these include the loss of marks, mortality, emigration, and the spatial scale examined.

Kahler (1999) examined the summer movements of individually marked trout and coho salmon in Shuwah Creek from approximately 178 m downstream of our treatment reach to 120 m upstream of our reference reach. He found that few fish moved between the treatment and reference reaches or into areas above, between, or below the two reaches during summer (T. Kahler, unpublished data). Kahler (1999) found that on average fish moved 5 habitat units (approximately 35 m) and that few fish moved more than 100 m. Similar results have been reported in studies on resident rainbow trout *O. mykiss* and cutthroat trout (Heggenes et al. 1991; Northcote 1992; Matthews 1996). Our fall and winter results and Kahler's summer results both suggest limited movement (exchange) between treatment and reference reaches.

The total number of marked fish, however, decreased in both study sections of Shuwah Creek from October through December, and we interpret this as emigration. Juvenile coho salmon, cutthroat trout, and other anadromous salmonids make large-scale movements in the fall and winter following heavy rains (Cederholm and Scarlett 1984; Peterson 1982; Swales and Levings 1989; Shirvell 1994), and the rapid decrease in densities observed in Shuwah Creek during fall is consistent with these studies. Some overwinter mortality doubtless occurred (on the order of 50–75%; Quinn and Peterson 1996), contributing to the density decreases we observed. The decrease from September to October may be due in part to the fact that electrofishing was used to initially capture fish and estimate abundance in September while night snorkel counts were used during all other months. However, this would not explain declines from October to November. Moreover, Roni and Fayram (2000) reported that night snorkel estimates were similar to multiple-removal electrofishing estimates during fall and winter, when water temperature and fish densities are low. The percentage of unmarked fish also increased over the course of the winter. This might have resulted from mark degradation, but our experience indicates that the marks we used are readily visible for 9 months or more, and we noticed no deterioration of marks during the study. Therefore, we conclude that the increased proportion of unmarked fish resulted from both immigration of unmarked fish and emigration of marked fish and that the declines in abundance resulted from movement as well as mortality.

Coho salmon and trout were significantly larger in the treatment reach of Shuwah Creek at initial tagging despite their higher density. This is unusual because the length of juvenile coho salmon is known to be inversely related to density in natural streams (Fraser 1969; Roni and Quinn 2001). The difference in size may indicate that differences in habitat quality between the two reaches (i.e., differences in LWD and pool areas) influenced size in some way. High-quality areas might be occupied by larger fish because smaller ones are forced out, or such areas might permit higher growth rates.

We found no difference in growth or size between movers and holders in the artificial channel with woody debris. Similarly, Spalding et al. (1995) found that varying levels of woody debris had little effect on the growth of juvenile coho

salmon but that density strongly affected growth in a seminatural channel system. However, movers were initially larger and grew faster than holders in the channel without woody debris, suggesting that some of the larger juvenile coho salmon may move to new habitats under poor habitat conditions. This result is consistent with Kahler's (1999) work but not with previous studies on juvenile salmonids (e.g., Chapman 1962; Nielsen 1992), which indicated or implied that movers are smaller and less fit than fish that maintain territories. For example, Nielsen (1992) examined the dominance hierarchies in juvenile coho salmon within individual habitats and found that "floaters" (fish that moved around an individual habitat) grew less than dominant fish. However, she examined dominance and movement within individual habitat units whereas we examined movement among habitats. Other studies have reported that although mobile salmonids are larger (Riley et al. 1992; Young 1994) they may be in poorer condition than those not moving (Naslund et al. 1993; Gowan and Fausch 1996). The difference in size between mobile and static juvenile coho salmon needs further investigation, especially if fish that move enjoy higher overwinter survival rates (Quinn and Peterson 1996).

The results in the artificial channels are consistent with those of Heggenes et al. (1991) and Kahler (1999); although many fish moved, most moved only once and only a few habitat units. The percentage of movers was higher in the complex channel, though fish moved less frequently and shorter distances in that channel (Table 3). This pattern suggests that the placement of wood (the only difference between the channels) resulted in occasional short-distance movements and that in the absence of structure fish moved more frequently in search of suitable habitat, forage, or lower levels of competition. Harvey et al. (1999) found that adult cutthroat trout that had been marked in habitats without woody debris or cover were more likely to move and moved farther than those tagged in habitat with woody debris. Similarly, Kahler (1999) indicated that during summer juvenile trout and coho salmon were more likely to move from shallow habitats lacking cover to deeper, more complex habitats. Matthews (1996) found that adult golden trout *O. aguabonita* in a meadow stream moved less frequently and longer distances in a degraded (cattle grazing) than restored (no grazing) stream reach, but did not report exchange

between nearby study reaches though little wood was present in her study reaches. The results from Shuwah Creek suggest that fish are less likely to move from complex habitat, as the decreases in trout and coho salmon abundance during fall and winter were more rapid in the reference reach than in the treatment reach. Coupled with the findings of other recent studies, our results from both natural and artificial channels suggest that trout and juvenile coho salmon move shorter distances in channels with abundant woody debris and that limited movement occurs between complex and simple habitats.

The majority of the coho salmon in our artificial channels congregated in the lowermost habitats, and some fish may have been attempting to emigrate. Wilzbach (1985) examined the emigration of cutthroat trout from artificial channels and found that it was higher at low food abundance and that cover influenced emigration only at high food levels. In contrast, Mesick (1988) found that reduced food levels resulted in little emigration of Apache trout *O. apache* and brown trout *Salmo trutta* from artificial channels regardless of the level of cover. Gianico and Healey (1998) found that change in flow rather than food was the factor that causes juvenile coho salmon to emigrate from experimental channels. In our study, emigration due to lack of food or change in flow was unlikely because food levels and growth were high and flow was held constant. Furthermore, the density of the coho salmon in our artificial channels was about 2.0 fish/m<sup>2</sup> throughout our study, which is high but not unusual for natural streams (Nickelson et al. 1992a, 1992b; Roni 2000). Spalding et al. (1995) found little emigration of juvenile coho salmon from artificial channels at higher densities than we examined. Lonzarich and Quinn (1995) found that depth was more important than structure in determining the distribution of coho salmon in artificial channels. For these reasons, we believe that the higher numbers of fish that we observed in the lower habitat units was due to the greater depth of these units rather than to attempts to emigrate from the channels.

Coupled with the results from previous studies, the two movement studies we conducted suggest that short-distance movements among individual (small-scale) habitats are common for juvenile coho salmon and juvenile and adult trout. Although little exchange may occur between nearby stream reaches with simple and



complex habitats (such as in Shuwah Creek), larger-scale movements make it difficult to determine the level of emigration from or movement between restored and unrestored stream reaches. Our results support the conclusions of Gowan et al. (1994) and Riley and Fausch (1995), suggesting that both large-scale and small-scale movement patterns should be considered when evaluating stream restoration and habitat utilization.

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