Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams

M.F. Solazzi, T.E. Nickelson, S.L. Johnson, and J.D. Rodgers

Abstract: We used a BACI (before–after–control–impact) experimental design to examine the effects of increasing winter habitat on the abundance of downstream migrant salmonids. Two reference streams and two treatment streams were selected in the Alsea and Nestucca basins of Oregon. Population parameters for juvenile coho salmon (*Oncorhynchus kisutch*), age-0 trout (*Oncorhynchus* spp.), steelhead (*Oncorhynchus mykiss*), and coastal cutthroat trout (*Oncorhynchus clarki*) were estimated each year for 8 years in each stream. Stream habitat was modified to increase the quality and quantity of winter habitat during the summers of 1990 (Nestucca Basin) and 1991 (Alsea Basin). Complex habitat was constructed by adding large woody debris to newly created alcoves and dammed pools. Numbers of coho salmon summer juveniles and smolts increased in the treatment streams relative to the control streams during the posttreatment period. Overwinter survival of juvenile coho salmon also increased significantly in both treatment streams posttreatment. Summer trout populations in the treatment streams did not change, but downstream migrant numbers the following spring did increase. These increases suggest that winter habitat was limiting abundance of all three species.

Résumé : On a utilisé la méthode expérimentale CAA (comparaison avant–après) pour examiner les effets de l'extension des habitats d'hiver sur l'abondance des salmonidés en dévalaison. On a choisi deux cours d'eau de référence et deux cours d'eau expérimentaux dans les bassins de l'Alsea et de la Nestucca, en Oregon. On a estimé les paramètres de population du saumon coho (*Oncorhynchus kisutch*) juvénile, de truites (*Oncorhynchus* spp.) d'âge 0, du saumon arc-en-ciel (*O. mykiss*) et de la truite fardée côtière (*O. clarki*) chaque année pendant huit ans dans chacun des cours d'eau. Pendant les étés 1990 (bassin de la Nestucca) et 1991 (bassin de l'Alsea), l'habitat lotique a été modifié pour augmenter la qualité et la quantité des habitats d'hiver. On a construit un habitat complexe en ajoutant de gros débris ligneux dans des fosses latérales et des retenues artificielles nouvellement créées. Le nombre de juvéniles d'été et de smolts de coho dans les cours d'eau expérimentaux a augmenté par rapport à celui des cours d'eau de référence après l'aménagement. La survie hivernale des cohos juvéniles a aussi augmenté considérablement dans les deux cours d'eau après l'aménagement. Au cours du premier été, la population de truites dans les cours d'eau expérimentaux n'a pas changé, tandis que le nombre de migrateurs en dévalaison a augmenté au printemps suivant. Ces augmentations semblent indiquer que l'habitat d'hiver limite l'abondance chez ces trois espèces de poissons.

[Traduit par la Rédaction]

Introduction

Recent declines in abundance of coho salmon (*Oncorhynchus kisutch*) populations in Oregon coastal streams have resulted in increased recognition of the need for quantitative assessments of the effectiveness of methods used to restore habitat for juvenile salmon and trout (*Oncorhynchus* spp.). Various methods to improve freshwater habitat have been practiced in trout fishery management for several decades (Hubbs et al. 1932; Tarzwell 1937; Shetter et al. 1949). More recently, some of these techniques have been modified for Pacific salmon and trout (House and Boehne 1985; Nickelson et al. 1992*b*; Beechie et al. 1994).

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A review of the literature reveals a lack of quantitative information on whether habitat restoration affects the freshwater production of anadromous salmonid populations. Smokorowski et al. (1998) concluded that documentation of habitat projects was generally poor and that success was often measured by evaluating the desired changes in habitat without determining biological benefit. When evaluations of instream habitat restoration projects have examined the impacts on fish populations, the studies have usually focused only on estimating the number of fish rearing in the vicinity of the restoration project (Nickelson et al. 1992*b*; House 1996). They generally have not included reference streams or reaches with which to compare changes in fish abundance in the treated area. As a result, it is difficult to determine if changes in fish abundance near the restoration project represent an actual increase in production due to the effects of the habitat project or a redistribution of fish. Also, most past studies were completed during the summer low-flow period (Crispin et al. 1993; House 1996), leaving unresolved the question of survival during winter rearing prior to ocean migration.

Results of salmonid habitat restoration projects have been mixed. For example, Scruton et al. (1997) evaluated a variety of habitat projects aimed at increasing the production of Atlantic salmon (*Salmo salar*) in Newfoundland, Canada. These authors concluded that "Generally, the projects evaluated have been successful in increasing salmonid abundance and (or) production." Cederholm et al. (1997), comparing coho salmon and age-1 steelhead (*Oncorhynchus mykiss*) abundance from treatment and reference reaches in Washington, found that coho salmon smolt abundance, but not steelhead, increased significantly following the addition of large wood. An evaluation of a spawning habitat rehabilitation project on the Merced River, California (Kondolf et al. 1996), showed that the project failed to consider the erosion and transport potential. Consequently, the gravel placements were quickly transported downstream. These conflicting results coupled with the growing interest in the use of habitat modification techniques by federal, state, and private organizations underscore the need for careful evaluations of habitat enhancement projects.

We present the results of an experiment designed to evaluate the effects of habitat restoration projects on coho salmon smolt abundance in two coastal Oregon streams. The intent of the habitat modification was to increase the amount and complexity of winter habitat, which has been suggested to limit coho salmon populations in Oregon (Nickelson et al. 1992*a*). This experiment was originally designed to examine changes in abundance of coho salmon smolts. However, we collected information on two sympatric but less abundant species, steelhead and coastal cutthroat trout (*Oncorhynchus clarki*), as well.

Our experimental design combined a preproject and postproject evaluation with a treatment and reference stream approach. This allowed us to account for changes in the number of migrants produced in a given length of stream that could be due to factors other than the experimental treatment. We monitored the summer population size and estimated the number of spring migrants produced each year for 8 years in each of four study streams. This type of quantitative evaluation is critical for fishery managers trying to determine if artificial habitat manipulation projects are a viable tool for restoring salmonid habitat.

Materials and methods

Study area

Our paired study streams were of similar size and located largely on land managed by the U.S. Bureau of Land Management (Fig. 1). One pair was in the Alsea Basin, East Fork Lobster Creek and Upper Lobster Creek, and the other was in the Nestucca Basin, East Creek and Moon Creek. Upper Lobster Creek and East Creek were designated treatment streams. Study reaches established on each of the four streams ranged from a downstream smolt trap site to the upper limits of coho salmon distribution. Physical characteristics of these stream reaches are shown in Table 1. Both the Nestucca and Alsea basins receive between 150 and 250 cm of rain each year. Typical summer water temperatures ranges between 11 and 17°C and winter temperatures occasionally drop to as low as 4°C. Aquatic species present in the study streams included coho salmon, steelhead, coastal cutthroat trout, sculpins (*Cottus* spp.), Pacific lamprey (*Lampetra tridentata*), and giant salamanders (*Dicamptodon tenebrosus*). The riparian vegetation consists of an overstory of red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllium*), western redcedar (*Thuja plicata*), Douglas-fir (*Pseudotsuga menziesii*), and western hemlock (*Tsuga heterophylla*) as well as an understory of salmonberry (*Rubus spectabilis*), salal (*Gaultheria shallon*), vine maple (*Acer circinatum*), and sword fern (*Polystichum munitum*).

Summer and winter habitat surveys

During August and September of each year, we used Hankin and Reeves' (1988) methodology to estimate the amount of available habitat within the study reach of each stream. We classified habitat using the methods of Bisson et al. (1982), as modified by Nickelson et al. (1992*a*). Surface area for each habitat unit in each stream was visually estimated, and every tenth unit was measured to calibrate the visual estimates.

Habitat surveys were also conducted during winter. These surveys were completed in December and January during winter base flows. During the pretreatment period, surveys were completed twice in the Alsea study streams and once in the Nestucca study streams. During the posttreatment period, surveys were completed twice in all four streams.

Estimating summer fish populations

A combination of snorkeling and electrofishing was used during August and September of each year to estimate the number of juvenile coho salmon, age-0+ trout, steelhead and cutthroat trout (<90 mm combined), and yearling and older (≥90 mm) steelhead and cutthroat trout (designated age 1+). In pool habitats, divers counted the number of each species in every third pool. This value was then adjusted by a calibration factor derived from electrofishing population estimates in a subset of these snorkeled pools (Hankin and Reeves 1988). To determine the number of fish rearing in glide, riffle, and rapid habitats, we estimated the average fish density for a subset of each habitat type by electrofishing. For each habitat type, we then multiplied this average density by the surface area of the habitat type in the entire stream reach above the trap (Hankin 1984).

For the electrofishing sampling, we estimated the number of each species and age group using either a mark–recapture estimate (Chapman 1951) or a removal estimate with two or more passes (Seber and LeCren 1967). Mark–recapture estimates were generally used only in pool habitat characterized by a high degree of wood complexity or that presented special sampling problems where removal estimation methods have been shown to be less accurate (Rodgers et al. 1992). Every habitat unit was blocked by seines on both ends and then sampled using 1000-V DC backpack electrofishers. Specific protocols for sampling intensity were established to control the size of the confidence interval derived from the population estimate and to prevent exposing the fish to unnecessary repeated electrofishing. In each study stream each summer, we generally sampled 10 pools for snorkel calibrations and 10 glides and 10 riffles or rapids for electrofishing expansion.

Estimating the number of downstream migrants

We estimated the number of downstream-migrating coho salmon, steelhead, and cutthroat trout in each stream each spring for 8 years using modified incline plane traps (McLemore et al. 1989). Sampling began by the first week in March and continued until we no longer captured fish, usually by 1 June. Traps generally operated 24 h per day. Captured fish were removed daily from the trap, anesthetized with buffered MS 222, and measured. Population estimates were made for coho salmon ≥60 mm. Scale samples collected from coho salmon migrants ≥60 mm in 1991 and 1992 revealed that this size-class averaged 98% age-1+ fish and 2% age-2+ fish. Juvenile coho salmon in Oregon typically spend about a year in freshwater before migrating to the ocean as smolts during their second spring (Moring and Lantz 1975; Bradford et al. 1997).

Fig. 1. Location of the four study streams in the Alsea and Nestucca basins, Oregon.

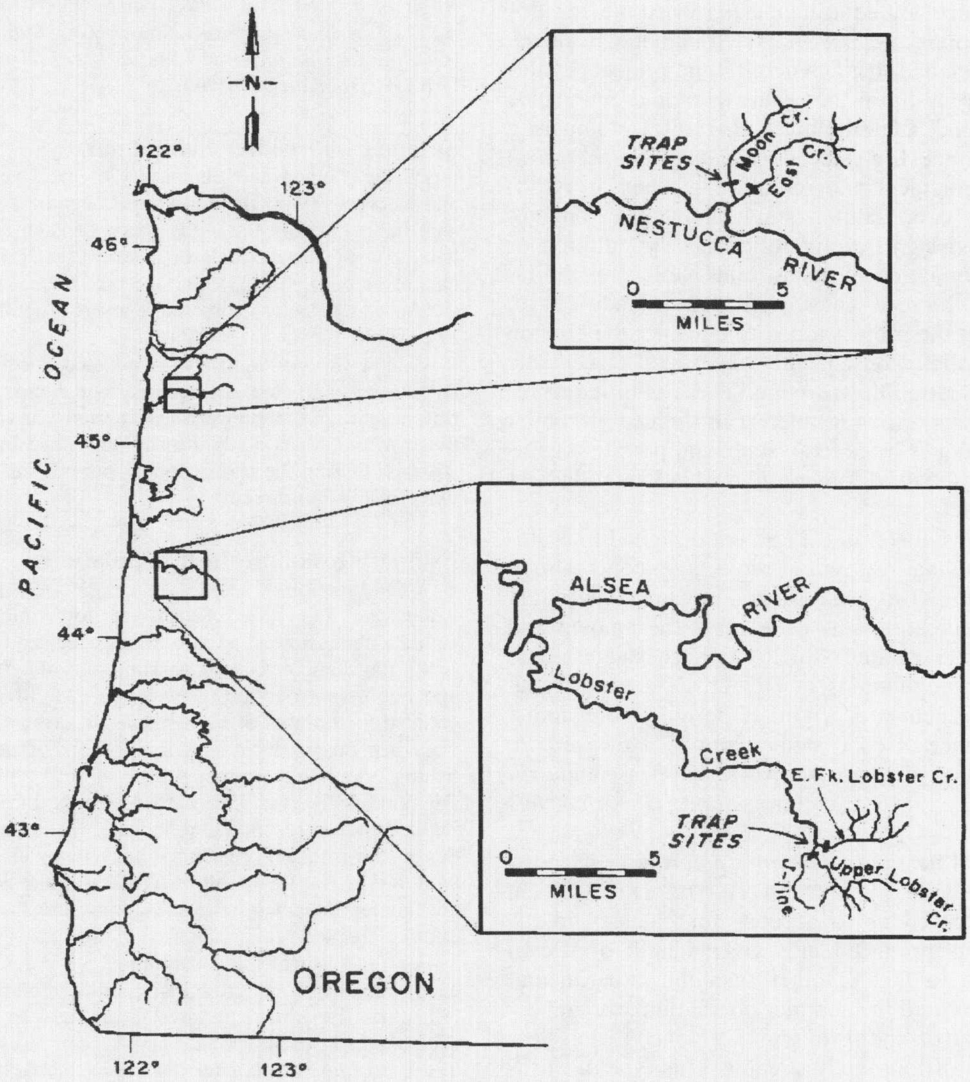


Table 1. Physical characteristics of the four study streams above the smolt traps.

Stream	Basin area (km^2)	Stream length (km)	Mean summer wetted width (m)	Average gradient (%)
Alsea Basin				
East Fork Lobster Creek	14.2	3.5	3.5	4.0
Upper Lobster Creek	12.4	4.7	3.2	2.6
Nestucca Basin				
Moon Creek	13.2	3.8	3.6	1.8
East Creek	17.5	5.0	4.0	2.4

Thus, our estimates of the number of coho salmon migrants ≥60 mm encompasses the smolt population. We made population estimates for steelhead and cutthroat trout migrants ≥90 mm. Scale analyses and length–frequency histograms indicated that fish of this size were age 1+ and older.

To estimate trap efficiency, up to 25 fish from each species were removed from the trap each day, given a caudal fin notch mark, and released into an area of quiet water 50–100 m above the trap site. Weekly trap efficiency estimates were calculated by dividing the number of marked fish recaptured by the number of marked fish released.

For coho salmon, the total number of unmarked fish captured was divided by the estimated trap efficiency to estimate the number of fish passing the trap site each week. Weekly estimates were summed to estimate the total number of fish passing the trap site each spring. Overwinter survival rates for coho salmon were calculated by dividing the estimate of the total number of coho salmon migrating past the trap site each season by the summer population estimate.

We did not attempt to calculate weekly estimates of the number of trout passing the trap because of the low numbers of migrants captured. A population estimate for trout was usually calculated by dividing the total number of trout captured during the trapping season by the seasonal estimate of trap efficiency.

Habitat modification

The habitat modification was completed during the summer of 1990 in East Creek (Nestucca Basin) and during the summer of 1991 in Upper Lobster Creek (Alsea Basin). Work on both streams was funded and constructed by the U.S. Bureau of Land Management in consultation with the Oregon Department of Fish and Wildlife. Total installation cost was about US$80 000. A track hoe was used to place full-spanning logs into the stream channel (to create large dam pools) and to excavate off-channel rearing ponds (alcoves). Erosion cloth and chain-link fence were attached to the upstream side of most full-spanning logs to reduce undercutting. Most of the large logs were anchored to the substrate with rebar. Large wood was added to each dam pool to act as scour agents. Rootwads and smaller trees were added to increase habitat complexity within the pools.

Sites for alcove construction were selected by using natural springs or seeps whenever possible. Full-spanning logs were generally placed immediately below the mouth of the alcove to insure that water flooded the entrance. Alders were uprooted and added to the alcoves to provide cover. We created 23 dam pools and eight alcoves in Upper Lobster Creek along a 3.2-km reach. Twenty-nine dam pools and 13 alcoves were constructed in East Creek along a 2.4-km reach. The constructed pools averaged 160 m^2 in surface area compared with an average of about 50 m^2 for natural pools.

Study design and analysis

The study was designed to assess changes in habitat and fish population parameters in a treatment stream by using a reference stream to account for changes due to factors other than the treatment. This approach has been referred to as a BACI (before–after–control–impact) design by Stewart-Oaten et al. (1986), who recommended it to address the problem of pseudoreplication often encountered in ecological impact studies (Hurlbert 1984). For each habitat or fish population parameter, we (*i*) calculated the ratio of treatment to reference each year, (*ii*) estimated the mean ratios for the pretreatment and posttreatment periods, and (*iii*) used a t test to compare the means. For coho salmon, our null hypothesis was that the ratio during the posttreatment period was not greater than the ratio during the pretreatment period because the habitat modification was expected to increase coho salmon populations. Thus, a one-tailed test was employed. For trout, our null hypothesis was that the posttreatment ratio was not different from the pretreatment ratio because the possible effects of habitat modification were unknown. Therefore, a two-tailed test was used. In each case, a logarithmic transformation of the ratios was used to equalize variances.

Due to the presumed importance of winter habitat to coho salmon survival, we focused on changes in winter habitat. These parameters included the surface area of coho salmon winter rearing habitat (i.e., slow-water habitat), the surface area of fast-water habitat, and total surface area. Winter rearing habitat was defined as the combined area of alcoves, dammed pools, and beaver ponds. The restoration modifications were designed to increase this habitat type. Fast-water habitat, the combined area of cascades, rapids, riffles, and glides, was expected to decrease because habitat modification tended to convert fast water to slow water (i.e., winter rearing habitat). The statistical analysis of winter habitat was only possible for the Alsea study streams because the Nestucca study streams had only one winter habitat survey during the pretreatment period.

The parameters used to assess changes in coho salmon populations were summer population, overwinter survival rate, and estimated numbers of smolts. For trout populations, we analyzed summer populations of age-0+ trout, age-1+ steelhead, and age-1+ cutthroat trout and numbers of downstream-migrating steelhead and cutthroat trout. We did not compare overwinter survival rate for trout because the populations contained multiple year-classes.

Potentially, the first effects of the habitat modification should have been on overwinter survival during the winter following construction. This would have occurred following summer rearing of the 1989 brood coho salmon in the Nestucca study streams and the 1990 brood coho salmon in the Alsea study streams. The organization of the pre–post comparisons of the habitat and population parameters is described in Table 2.

Results

Habitat

The amount of winter rearing habitat in Upper Lobster Creek (Alsea treatment) was significantly greater (one-tailed t test: $p = 0.025$) following habitat modification relative to that in East Fork Lobster Creek (Alsea reference). The average area of winter rearing habitat increased by about 700% in the treatment stream, whereas it decreased by about 30% in the reference stream (Fig. 2). The average area of fast-water habitat decreased by about 5000 m^2 (30%) in the treatment stream, while that in the reference stream remained about the same (Fig. 2). However, the decrease was not significant (one-tailed t test: $p = 0.16$).

Average area of winter rearing habitat in East Creek (Nestucca treatment) following habitat modification increased 13 times over that in the previous year (Fig. 2). During the same years, winter rearing habitat in Moon Creek (Nestucca reference) remained about the same. Fastwater habitat in the treatment stream decreased by about 6000 m^2 after the habitat modification, whereas it remained relatively constant in the reference stream (Fig. 2).

Total surface area during winter remained relatively constant in both reference streams (Fig. 2). The range of values represented only about 10% of the total area. Total surface area of the Alsea treatment was not changed significantly by the habitat modification (two-tailed t test: $p = 0.47$), most of which occurred within the stream channel. In the Nestucca treatment stream, total surface area increased by about 25% the first winter following habitat modification because of extensive construction of off-channel alcoves (Fig. 2). The area decreased somewhat the next winter when channel changes isolated some of these alcoves.

Fish populations

Following habitat modification, summer populations of juvenile coho salmon in the Alsea treatment stream increased relative to populations in the reference stream (one-tailed t test: $p = 0.02$). Mean summer population in the treatment stream increased by 50% in the posttreatment period compared with the pretreatment period, while the mean population in the reference stream decreased by 25% (Fig. 3). Mean summer populations of coho salmon in both of the Nestucca study streams were lower during the posttreatment period than during the pretreatment period (Fig. 2). However, because the populations in the treatment stream declined to a lesser degree (20%) than did those in the reference stream (50%), the ratio between the two increased (one-tailed t test: $p = 0.01$).

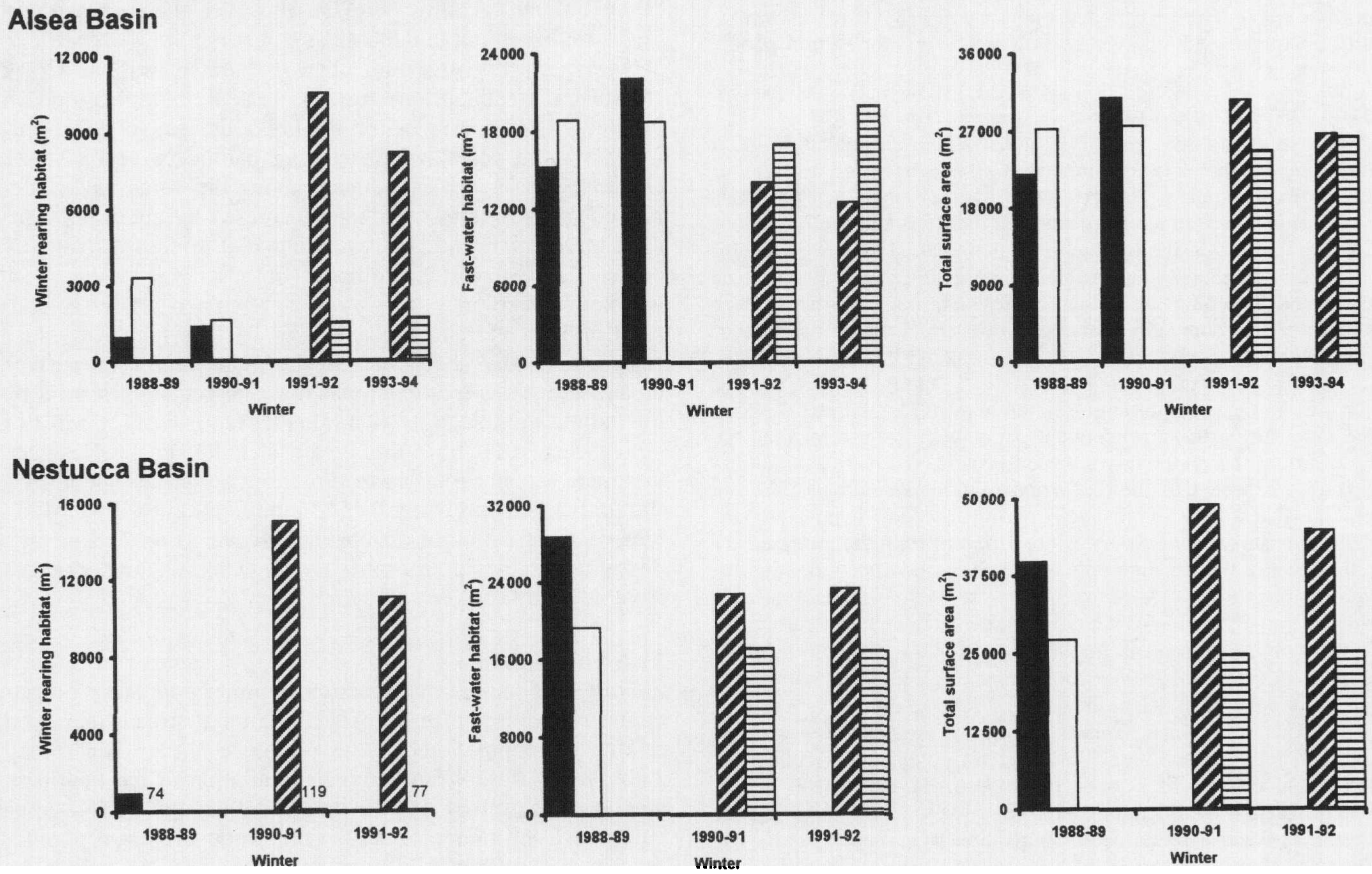
The number of coho salmon smolts in the treatment streams after habitat modification increased relative to the number of coho salmon migrants in the reference streams (one-tailed t test: Alsea, $p = 0.024$; Nestucca, $p = 0.005$).

Table 2. Analytical layout of the habitat and population parameters.

		Alsea study streams comparisons		Nestucca study streams comparisons	
Parameter	First data collected	Pretreatment	Posttreatment	Pretreatment	Posttreatment
Winter physical habitat	Winter 1988–1989	Winter 1988–1989 Winter 1990–1991	Winter 1991–1992 Winter 1993–1994	Winter 1988–1989	Winter 1990–1991 Winter 1991–1992
Coho salmon summer population	Summer 1988	1987–1990	1991–1993	1987–1989	1990–1993
Coho salmon overwinter survival	Winter 1988–1989	1987–1989	1990–1993	1987–1988	1989–1993
Coho salmon smolts	Spring 1988	1986–1989	1990–1993	1986–1988	1989–1993
Trout summer populations	Summer 1988	1987–1990[a]	1991–1993[a]	1987–1989	1990–1993
Steelhead migrants	Spring 1988	1986–1989[a]	1990–1993[a]	1986–1988	1989–1993
Cutthroat trout migrants	Spring 1988	1986–1989[a]	1990–1993[a]	1986–1988	1989–1993

Note: For habitat comparisons, years represent calendar years. For population comparisons, years represent brood years.
[a]For consistency, brood year designations are based on coho salmon smolts. Thus, brood year 1987 would have a summer population estimated in 1988 and a migrant population in spring 1989, regardless of trout age.

Fig. 2. Surface area of winter rearing habitat, fast-water habitat, and total habitat in the treatment and reference streams in the Alsea and Nestucca basins, pretreatment and posttreatment. Winter rearing habitat areas in the Nestucca reference stream were too small to display on the graph and are therefore shown as numeric values. Solid bars, treatment pre; open bars, reference pre; diagonally hatched bars, treatment post; horizontally hatched bars, reference post.

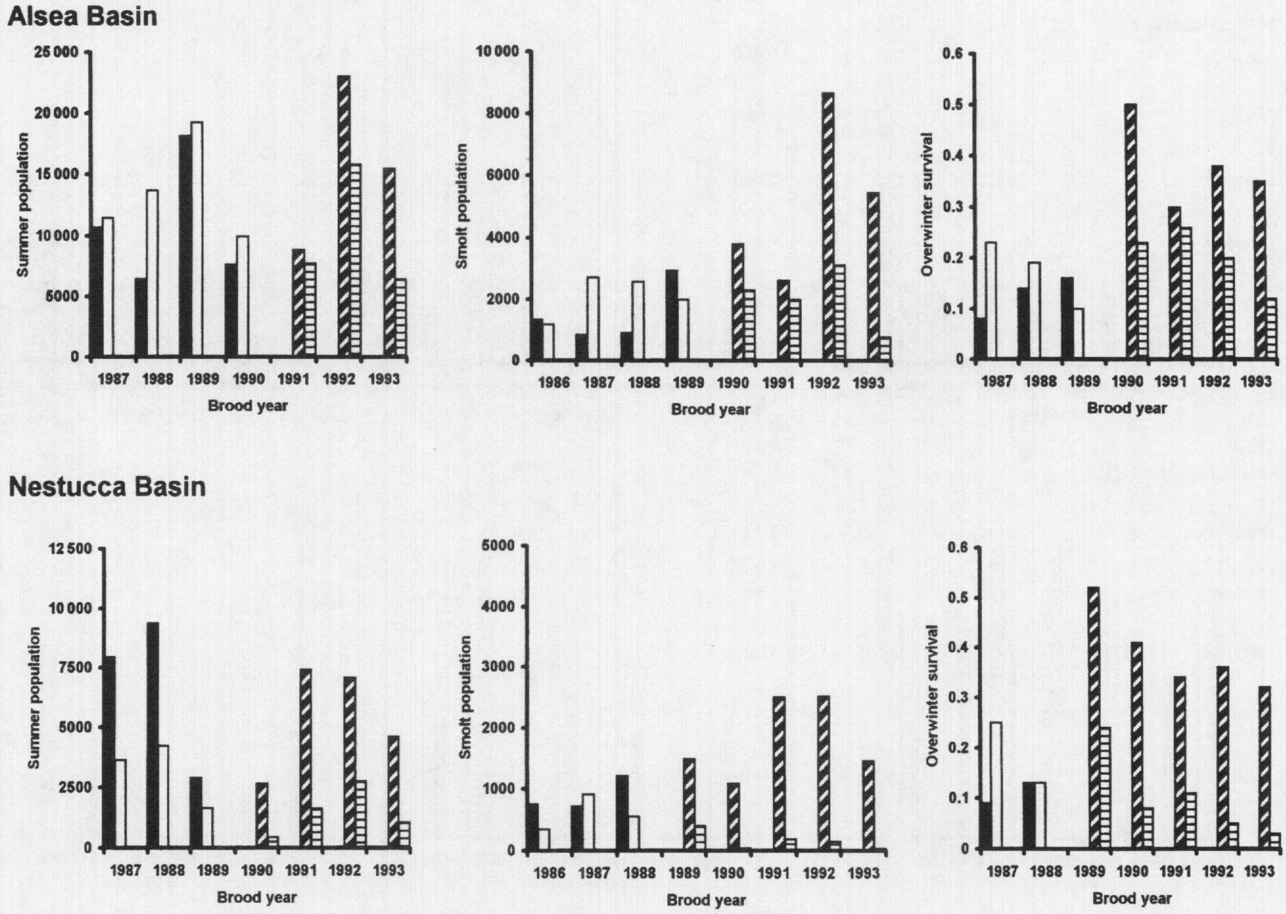


Mean number of coho salmon smolts increased by over 200% in the Alsea treatment stream, while the mean for the reference stream remained the same (Fig. 3). Similarly, the mean number of coho salmon migrants in the Nestucca treatment stream doubled, whereas the mean in the reference stream decreased by 75% (Fig. 3).

Overwinter survival of coho salmon also increased in both treatment streams after habitat modification relative to survival in the reference streams (one-tailed t test: Alsea, p = 0.04; Nestucca, p = 0.007). Survival in the Alsea treatment stream increased from a pretreatment mean of 0.13 to a posttreatment mean of 0.38 (Fig. 3). Mean survival in the reference stream increased slightly from 0.17 to 0.20 (Fig. 3). In the Nestucca treatment stream, mean overwinter survival increased 250% from 0.11 to 0.39, whereas in the reference stream, survival fell from a mean of 0.19 to a mean of 0.10 (Fig. 3).

Summer populations of trout did not change significantly in the treatment streams following habitat modification relative to populations in the reference streams in either the

Fig. 3. Coho salmon summer populations, spring migrants, and overwinter survival for the treatment and reference streams in the Alsea and Nestucca basins, pretreatment and posttreatment. Solid bars, treatment pre; open bars, reference pre; diagonally hatched bars, treatment post; horizontally hatched bars, reference post.



Alsea (two-tailed t test: 0+ trout, $p = 0.78$; 1+ steelhead, $p = 0.26$; 1+ cutthroat, $p = 0.20$) or the Nestucca (two-tailed t test: 0+ trout, $p = 0.62$; 1+ steelhead, $p = 0.63$; 1+ cutthroat, $p = 0.33$). Populations of age-0+ trout and age-1+ steelhead in the Alsea study streams had similar levels of abundance and variability, whereas age-1+ cutthroat trout were more variable (Fig. 4). The opposite tended to be the case in Nestucca study streams, where the age-0+ trout and age-1+ steelhead populations tended to be more variable than the cutthroat trout populations (Fig. 4). Because of the interannual variability in these populations, the power of these tests was low.

Following habitat modification, migrant populations of steelhead increased in the two treatment streams relative to the reference streams (two-tailed t test: Alsea, $p = 0.005$; Nestucca, $p = 0.037$). The mean number of steelhead migrants increased by over 800% in the Alsea treatment stream, whereas the mean number of steelhead migrants in reference stream increased by 65% (Fig. 5). Similarly, in the Nestucca treatment stream, steelhead migrants increased by about 400%, while in the reference stream, they declined by about 40% (Fig. 5).

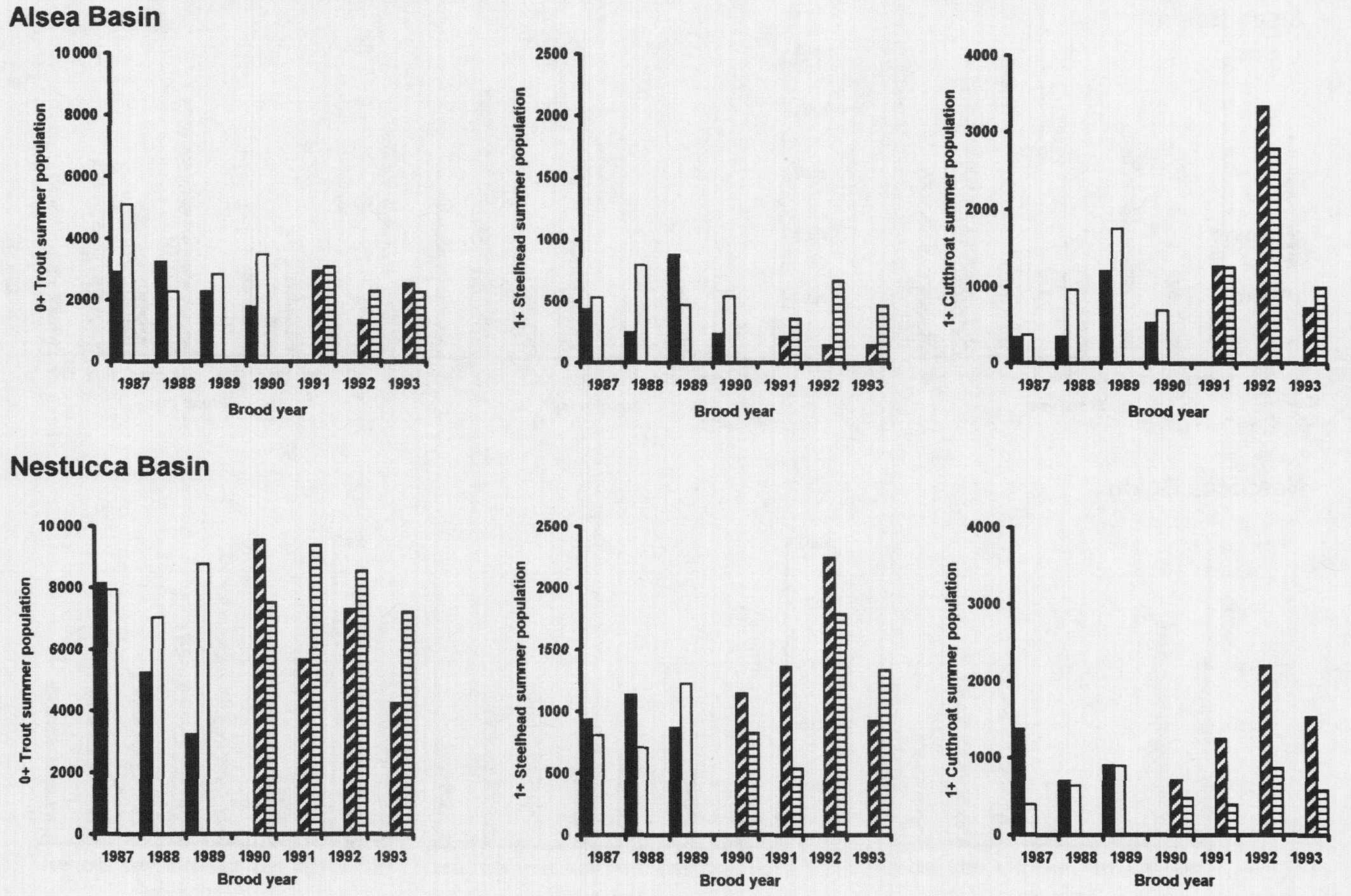
Cutthroat trout migrants increased in both of the Alsea study streams during the posttreatment period (Fig. 5). Although there was about a fivefold increase in cutthroat trout migrants in the treatment stream and a doubling of migrants in the reference stream (Fig. 5), the difference was not significant (two-tailed t test: $p = 0.25$). Following habitat modification, the number of migrants in the Nestucca treatment stream increased relative to that in the reference stream (two-tailed t test: $p = 0.024$). Cutthroat trout migrants in the treatment stream increased by 275%, whereas migrants in the reference stream decreased by 75% (Fig. 5).

Discussion

Habitat modification in two Oregon coastal streams resulted in increased winter rearing habitat for anadromous salmonids. The increases in winter rearing habitat resulted from a combination of improvement of marginal in-channel habitats and the creation of new off-channel habitats. The creation of slow-water habitat and the addition of large quantities of wood to the stream were critical elements of the habitat modification.

The increase in winter habitat resulted in increased coho salmon smolt abundance. In the summers following habitat modification, there were significantly more juveniles in the treatment streams compared with the reference streams. However, our study demonstrates that overwinter survival was the key to the increased smolt abundance. In the Alsea treatment stream, the summer juvenile population increased by about 50%; however, the overwinter survival increased

Fig. 4. Summer populations of 0+ trout and 1+ steelhead and cutthroat trout in the treatment and reference streams in the Alsea and Nestucca basins, pretreatment and posttreatment. Solid bars, treatment pre; open bars, reference pre; diagonally hatched bars, treatment post; horizontally hatched bars, reference post.



300% after habitat modification. Likewise, the Nestucca treatment stream produced twice as many coho salmon smolts despite a 20% decrease in summer juveniles; overwinter survival increased approximately 3.5 times. The alcoves and complex dammed pools constructed in these two streams provided the coho salmon with refuge from the high-velocity conditions that characterize most Oregon coastal streams during winter. These results further support the conclusion of Nickelson et al. (1992*a*) that winter habitat limits production of coho salmon smolts in many Oregon coastal streams.

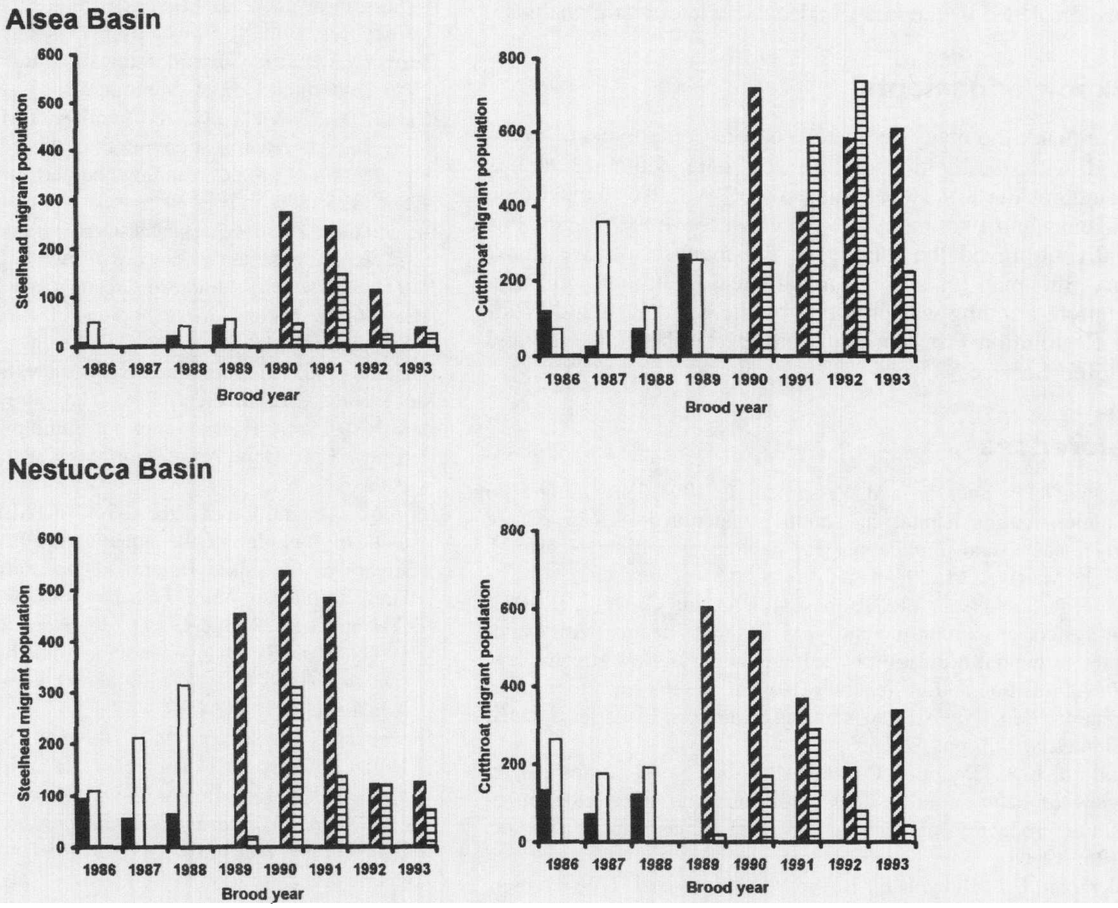
Because the habitat modification in our study streams was targeted at coho salmon, the question arises as to possible impacts on other salmonids, such as trout, which might prefer different habitat (Bisson et al. 1982). Cederholm et al. (1997) examined this question for the addition of large wood to a stream. Except for a decrease in age-0 steelhead at one treatment site during spring, they found no changes in age-0 or age-1 steelhead during spring, autumn, or winter following treatment. The one exception may have been an artifact of the difficulty of estimating abundance of very small fish. House and Boehne (1985) reported that abundance of trout fry, steelhead parr, and cutthroat trout parr increased during summer as a result of placing boulders and rock-filled gabions in East Fork Lobster Creek. The results suggest no negative impacts of habitat enhancement on trout populations. However, neither of these studies examined steelhead or cutthroat trout migrants.

We found increases in steelhead migrants in both treatment streams and increases in cutthroat trout migrants in one treatment stream following creation of winter habitat for coho salmon. Changes in summer populations were not detectable. This implies that, like coho salmon, overwinter survival of trout was increased by the habitat modification. Habitat modification that creates complex slow-water habitat appears to benefit not only coho salmon but steelhead and cutthroat trout as well.

The increases in population size for all three salmonid species were probably due to the increase in habitat that had a combination of depth, velocity, and cover sufficient to provide an increase in winter refuge or rearing space. In species such as coho salmon, steelhead, and cutthroat trout, which have evolved in sympatry, the ability to partition the available habitat to minimize competition has been documented (Facey and Grossman 1992). In our study, the increase in habitat complexity was sufficient to increase the abundance of all three species.

The inclusion of the reference streams was critical to the design of this study. Without the reference streams to help account for interannual variation, two of our conclusions would have been different. If we had looked only at the treatment streams, we would have concluded that summer

Fig. 5. Steelhead and cutthroat trout spring migrants for the treatment and reference streams in the Alsea and Nestucca basins, pretreatment and posttreatment. Solid bars, treatment pre; open bars, reference pre; diagonally hatched bars, treatment post; horizontally hatched bars, reference post.



populations did not differ between pretreatment and posttreatment. However, because summer populations in the reference streams decreased posttreatment, the relationship between populations in treatment streams and the reference streams changed significantly. Similarly, without knowing that cutthroat trout migrants increased in East Fork Lobster Creek posttreatment, we would have concluded that the treatment had resulted in an increase in cutthroat trout migrants in Upper Lobster Creek. It is therefore difficult to interpret the results of studies of the effects of habitat modification that do not include reference streams to account for the effects of factors other than the treatment.

Our study also provides insights into the construction details of habitat restoration. For example, when alcoves are constructed, we recommend that they only be located in areas where springs, seeps, or temporary streams can be incorporated. Water flowing through the alcoves helps control the accumulation of fine sediment that tends to block the entrance. Even so, periodic maintenance will probably be necessary in most cases to keep constructed alcove habitat available for winter use by juvenile salmonids. We also do not recommend that full-spanning structures be anchored to the substrate or incorporate the use of rebar, chain-link fence, or erosion cloth. When the channel moves or the structure fails, the nonnatural materials are left exposed in the stream channel and do not provide much in the way of habitat. Instead, we recommend that large wood be placed in the stream to establish itself in the channel as a function of natural processes.

We believe that the results of this study are specific to the particular type of habitat created (i.e., deep, complex dammed pools and excavated alcoves with large amounts of wood). They should not be interpreted as a general justification for all types of instream habitat restoration. This type of restoration project would be inappropriate and probably have little beneficial impact on salmonid migrant production if, for example, the stream was subject to extreme summer temperatures due to the lack of an adequate riparian area. In addition, these types of projects have substantial impact on the landscape (due to the use of heavy equipment and the large volumes of excavated material) and are only appropriate for unconstrained stream reaches with poor-quality habitat.

Although the restoration efforts that we describe were located relatively high in the drainage basins, we believe that even larger benefits could be derived from projects to increase the amount of available winter rearing areas in the lower reaches of coastal basins. These areas, where historically the largest numbers of juvenile coho salmon probably overwintered, are now used primarily for agricultural production. Many of the streams have been channelized and the sloughs and wetlands drained, resulting in large-scale reductions in potential overwinter rearing space (Lichatowich

1987). We do not recommend that this type of habitat restoration be used ubiquitously. There are, however, some key areas where it can give immediate help to salmonid populations threatened by the lack of adequate winter rearing habitat.

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