Effects of an increase in large wood on abundance and survival of juvenile salmonids (*Oncorhynchus* spp.) in an Oregon coastal stream

Steven L. Johnson, Jeffrey D. Rodgers, Mario F. Solazzi, and Thomas E. Nickelson

Abstract: We examined the effect of an increase in large wood on the summer population size, smolt abundance, and freshwater survival of steelhead (*Oncorhynchus mykiss*), coastal cutthroat trout (*Oncorhynchus clarki clarki*), and coho salmon (*Oncorhynchus kisutch*). We examined these parameters for five brood years prior to the addition of wood and five brood years after in Tenmile Creek, a direct ocean tributary on the Oregon coast. Over the same time frame, a nearby reference stream, Cummins Creek, was also sampled for the same parameters. The input of large wood into Tenmile Creek resulted from a planned habitat restoration project in 1996 and an unplanned addition of wood from a winter storm the same year. Steelhead smolt abundance, steelhead freshwater survival, and coho salmon freshwater survival increased in Tenmile Creek after the input of large wood. Steelhead age-0+ summer populations and steelhead smolt populations increased in the reference stream, although steelhead freshwater survival did not. Coho salmon populations remained unchanged in the reference stream. Our results illustrate the potential shortcomings of the before-after-control-impact study design under field conditions and the potential for misinterpreting results had we employed a more modest sampling plan.

Résumé : Nous avons examiné les effets d'une augmentation des débris ligneux de grande taille sur la densité de la population en été, sur l'abondance des saumoneaux et sur la survie en eau douce chez la truite arc-en-ciel anadrome (*Oncorhynchus mykiss*), la truite fardée côtière (*Oncorhynchus clarki clarki*) et le saumon coho (*Oncorhynchus kisutch*). Nous avons suivi ces variables chez cinq cohortes annuelles de reproduction avant l'addition du bois et chez cinq cohortes après l'addition dans Tenmile Creek, un tributaire direct de l'océan sur la côte d'Oregon. Pendant la même période, nous avons mesuré les mêmes variables dans un cours d'eau témoin adjacent, Cummins Creek. L'addition de débris ligneux de grande taille résulte d'un projet planifié de restauration de l'habitat en 1996 et d'un apport imprévu de bois lors d'une tempête d'hiver la même année. L'abondance des saumoneaux de truites arc-en-ciel anadromes, la survie en eau douce des truites arc-en-ciel et la survie en eau douce des saumons coho ont augmenté à Tenmile Creek après l'addition de débris de bois de grande taille. Chez la truite arc-en-ciel anadrome du cours d'eau témoin, les populations d'été des poissons d'âge 0+ et les populations de saumoneaux ont augmenté, mais non la survie en eau douce. Les populations de saumons coho n'ont pas varié dans le cours d'eau témoin. Nos résultats illustrent les limites potentielles du plan d'expérience avant-après, témoin-impact dans les conditions de terrain et démontrent qu'il aurait été possible de mal interpréter nos résultats, si nous avions utilisé un plan d'expérience plus simple.

[Traduit par la Rédaction]

Introduction

In recent years, the role of large wood in streams of the Pacific Northwest has received considerable review (Harmon et al. 1986; Pearsons et al. 1992; Roni et al. 2002). Studies have documented the importance of large wood within the stream channel to slow bedload movement, deposit and sort gravels, scour pools, and increased nutrients through salmon carcass retention (Swanson et al. 1976; Cederholm and Peterson 1985; Ralph et al. 1994). Pools with large and complex accumulations of wood often show higher densities of rearing juvenile salmonids, particularly in winter, when storms routinely cause flooding in coastal streams (Bustard and Narver 1975; Nickelson et al. 1992*a*, 1992*b*). As our understanding of stream hydrology and habitat requirements of juvenile salmonids has improved, objectives and techniques for instream restoration have also evolved. However, few studies have quantified the changes in fish production resulting from freshwater restoration activities, and recent reviews have called for additional research (Smokorowski et al. 1998; Roni et al. 2002). Most studies have relied on estimates of fish numbers only near the restoration sites (Nickelson et al. 1992*b*; House 1996; Roni and Quinn 2001). While these types of studies are helpful in understanding the habitat requirements or preferences for the species in question, they were not designed to

Received 23 January 2004. Accepted 18 November 2004. Published on the NRC Research Press Web site at http://cjfas.nrc.ca on 23 March 2005.
J17936

S.L. Johnson.[1] Oregon Department of Fish and Wildlife, 2040 SE Marine Science Drive, Newport, OR 97365, USA.
J.D. Rodgers, M.F. Solazzi, and T.E. Nickelson. Oregon Department of Fish and Wildlife, 28655 Hwy 34, Corvallis, OR 97333, USA.

[1] Corresponding author (e-mail: johnsonst@fsl.orst.edu).

doi: 10.1139/F04-222

determine the total change in fish abundance in the entire stream.

Reeves et al. (1997) examined summer rearing populations and spring migrant populations of smolts of coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) from an entire stream before and after trees and boulders were added. Although steelhead smolt populations tended to be higher in post-treatment years, they observed no significant change in average population size. Solazzi et al. (2000) reported increased summer rearing populations, spring smolt populations, and overwinter survival of juvenile coho in two headwater streams of coastal Oregon after increasing the winter habitat compared with two nearby reference streams, where the habitat was not modified. They also observed increased spring migrants of age-1+ steelhead in the treatment streams after the habitat was modified.

In this paper, we examine the juvenile steelhead, coastal cutthroat trout (*Oncorhynchus clarki clarki*), and coho salmon populations from an Oregon coastal stream before and after a substantial input of large wood to the stream channel. Using an approach similar to that of Solazzi et al. (2000), we again examined the juvenile salmonid summer rearing populations and smolt populations for a treatment stream and a nearby reference stream; however, the treatment and reference streams examined in the present study are relatively small coastal watersheds and empty directly into the ocean. This allowed us to estimate summer rearing abundance and abundance of spring migrants for the entire watersheds. These streams support large populations of steelhead and coastal cutthroat trout, with coho salmon populations playing a smaller role. The instream restoration activities involved placing of whole trees in the active channel to create a series of large jams throughout the upper half of the treatment stream. The objective was to create numerous areas of large wood accumulations rather than creating specific pool types.

In February of 1996, an unplanned addition of large wood entered the main channel of the treatment stream during a large storm event. Natural debris jams were created from wood entering via debris slides from adjacent tributaries and from trees uprooted from the riparian area along the main channel. Because the flood impacts occurred in the same year as the planned in-stream restoration work (1996), the pretreatment and post-treatment design was unchanged. We redefined our evaluation to the broader question of how a sudden increase in large wood affects juvenile salmonid production and survival within a watershed. Thus, treatment effect refers to wood input into the watershed, some of which entered naturally through the February 1996 storm and some of which was placed into the stream channel as part of the restoration project in October 1996.

To determine changes in juvenile fish populations in the two streams, we estimated the summer rearing population for 10 years and the ocean migrant population for 12 years. Additional years of smolt trapping were required to determine the smolt production and freshwater survival of the age-0+ steelhead sampled in the ninth and tenth years of summer sampling. We hope that results from this type of long-term evaluation will provide fishery managers with a better understanding of the relationship between instream habitat and the freshwater production of juvenile salmonids.

Methods

Study area

Tenmile and Cummins creeks enter the Pacific Ocean on the central Oregon coast (Fig. 1). For our study, Tenmile Creek was the treatment stream and Cummins Creek was the reference stream. Because of the confining hillslope typography and the relatively high gradient of the watersheds, no estuary is present on either stream. The Tenmile Creek watershed encompasses approximately 60.7 km^2 and is located between the Cummins Creek and Rock Creek wilderness areas of the Siuslaw National Forest. The mainstem of Tenmile Creek is about 25.5 km in length. Two large tributaries, South Fork Tenmile Creek (3 km) and Wildcat Creek (2.1 km), also account for a significant amount of habitat within the watershed. The Tenmile Creek watershed consists almost entirely of the Yachats basalt formation (characteristic of the small coastal streams in the vicinity of Cape Perpetua), although Tyee sandstone (characteristic of most streams on the central Oregon coast) also exists at the extreme upper portion of the watershed (Baldwin 1992). The Cummins Creek watershed encompasses approximately 24.6 km^2 and enters the Pacific Ocean approximately 8 km north of the mouth of Tenmile Creek. Cummins Creek is approximately 11 km in length. The entire Cummins Creek drainage runs through the Yachats basalt formation.

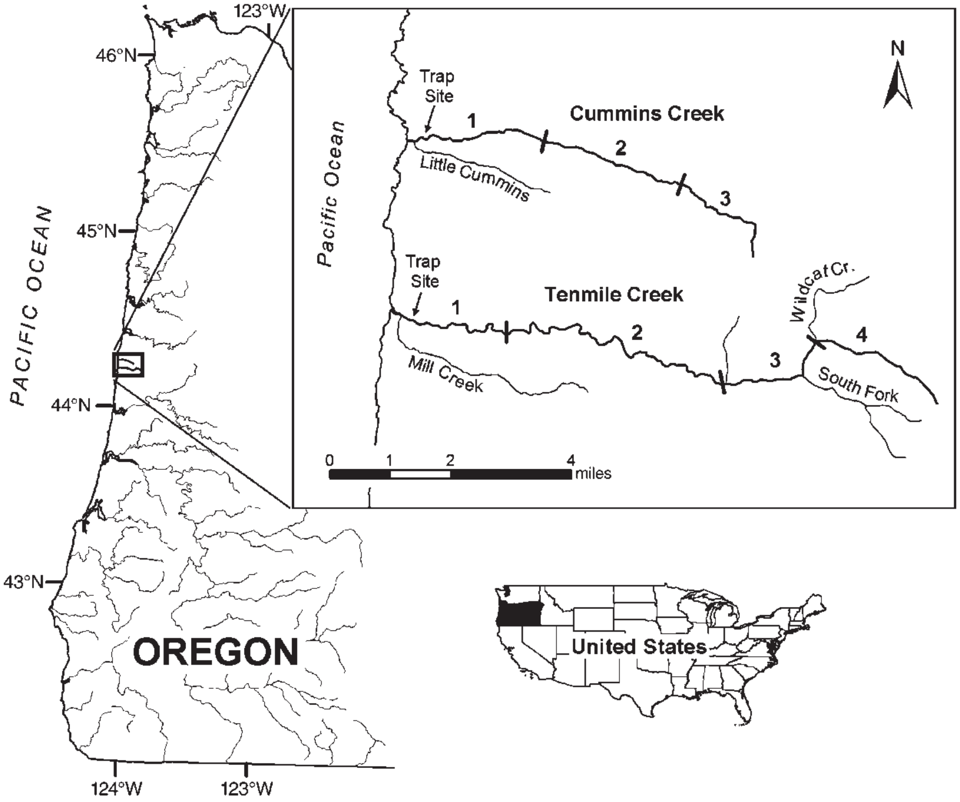
The climate of the two watersheds is Pacific maritime characterized by wet winters and dry summers. Precipitation, primarily rain, ranges between 180 and 230 cm·year^{-1} (Loy 1976). Summer air temperatures range between 20 and 25 °C. Although winter air temperatures occasionally drop below freezing, most winter days range between 5 and 15 °C. Maximum summer water temperatures in both Tenmile and Cummins creeks reach 18 °C in late July and early August and drop to 4 °C at times during the winter.

The overstory riparian vegetation of both watersheds is a mixture of coniferous trees (Sitka spruce (*Picea sitchensis*), western redcedar (*Thuja plicata*), Douglas-fir (*Pseudotsuga menziesii*), and western hemlock (*Tsuga heterophylla*)) and hardwood trees (red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllium*)). The understory consists primarily of salmonberry (*Rubus spectabilis*), salal (*Gaultheria shallon*), vine maple (*Acer circinatum*), and sword fern (*Polystichum munitum*).

Records indicate that Tenmile and Cummins creeks have consistently produced steelhead, cutthroat trout, and coho salmon. Chinook salmon (*Oncorhynchus tshawytscha)* spawn and rear in Tenmile Creek each year, although they are infrequently found in Cummins Creek. Chum salmon (*Oncorhynchus keta*) are found in Tenmile Creek in some years but were not observed in Cummins Creek during the study. We also observed Pacific lamprey (*Lampetra tridentata*), western brook lamprey (*Lampetra richardsoni*), eulachon (*Thaleichthys pacificus*), four species of sculpin (*Cottus asper*, *Cottus aleuticus*, *Cottus gulosus*, and *Cottus perplexus*), pacific giant salamanders (*Dicamptodon tenebrosus*), and tailed frogs (*Ascaphus truei*) in each basin.

To characterize fish rearing distribution and physical habitat within each watershed, we established four contiguous sampling reaches in the mainstem of Tenmile Creek and two sampling reaches in the largest tributaries, South Fork

Fig. 1. Location of Tenmile Creek (treatment) and Cummins Creek (reference) on the central Oregon coast, United States. Numbers along channels refer to stream reaches. 1 mile = 1.609 km.



Tenmile and Wildcat creeks. In Cummins Creek, we established three contiguous sampling reaches (Fig. 1). Reach breaks corresponded to major changes in gradient and valley floor conformation. The lower reaches of each stream are broad valleys with constraining terraces, while upper stream reaches exhibit narrow valley characteristics. Channel morphology of all reaches is primarily constrained by alternating terraces and hillslopes. The surveys in each watershed represent the entire spawning and rearing distribution for salmon and the majority of habitat used by steelhead. Smaller tributaries account for a significant but undetermined amount of spawning and rearing habitat for cutthroat trout within each basin. Physical characteristics of the study reaches are provided in Table 1.

Description of habitat modification

Watershed restoration work in the Tenmile basin began in the summer of 1996 as a cooperative project with the US Forest Service (Siuslaw Forest) and local landowners. The US Forest Service decommissioned approximately 19 km of roads in the watershed, removing culverts and fill to decrease future landslides. Riparian areas were planted with approximately 2000 young conifer trees along approximately 1.6 km of stream. Some streamside riparian areas dominated by hardwood were thinned to increase the growth of existing conifers. In October of 1996, a Chinook helicopter using a hydraulic grappling hook attached to a 90-m cable transported 241 large conifer trees to the stream channel. About 200 of the trees (30–35 m length, 75 cm butt diameter) were felled on adjacent ridges and placed within the stream channel with limbs attached. The remaining trees were removed from two debris torrent deposits adjacent to Tenmile Creek. These trees often had rootwads attached but were generally shorter in length (15–20 m) than the felled trees. The trees were placed predominately in the upper half of the watershed. Eighty-eight trees were placed in the upper half of Reach 2, 133 trees were placed throughout Reach 3, and 20 trees were placed in the lower half of Reach 4. Most placements consisted of three to eight large trees to produce accumulations of large wood and were located near the upper or lower entrances of old side channels or in natural bends where large debris would logically accumulate. Trees were not cabled or attached, although they were sometimes wedged between existing live trees in the riparian area to increase stability. Two numbered aluminum tags were attached to each habitat tree to allow us to identify trees in post-restoration surveys.

Several months prior to the instream tree placement work in the upper watershed, a large storm caused additional large wood to enter the main channel of Tenmile Creek. The amount of large wood deposited by the storm was similar to the amount placed by the restoration work; however, wood deposited by flooding was confined primarily to the lower half of the watershed, while the trees flown in as part of the restoration work were concentrated in the upper half of the basin. This same storm also caused new wood to enter the Cummins Creek watershed. Much of this wood debris was deposited in the upper portion of the basin above most

Table 1. Physical characteristics of Tenmile and Cummins creeks.

Stream	Stream length (km)	Mean summer wetted width (m)	Mean active channel width (m)	Average gradient (%)
Tenmile (60.7 m^2)[a]				
Mainstem Reach 1	3.7	9.6	23.1	1.0
Mainstem Reach 2	8.8	9.2	26.3	1.1
Mainstem Reach 3	3.7	6.8	17.4	1.9
Mainstem Reach 4	3.2	4.2	10.3	4.1
South Fork	3.0	4.1	8.5	5.3
Wildcat	2.1	4.1	9.0	4.5
Cummins (24.6 m^2)[a]				
Mainstem Reach 1	4.3	6.1	11.5	1.7
Mainstem Reach 2	4.6	5.1	9.0	2.5
Mainstem Reach 3	1.8	3.4	4.3	5.1

[a] Basin area.

salmon and steelhead spawning and rearing areas (on average only 5% of the steelhead and <1% of the coho summer populations were found in this area).

Habitat surveys

During August and September, we used the Hankin and Reeves (1988) methodology to estimate the amount of available summer habitat. We conducted summer habitat surveys in Tenmile Creek in 1991, 1993, and 1995–2000. In Cummins Creek, we conducted habitat surveys in 1991, 1992, 1994, and 1995–2000. We also conducted winter habitat surveys in Tenmile Creek in 1993 and 1997 and in Cummins Creek in 1991 and 1997. Habitat was classified using the methods of Bisson et al. (1982) as modified by Nickelson et al. (1992*a*). Surface area for each habitat unit was visually estimated, and every tenth unit was measured to calibrate the visual estimates. We classified the substrate in each habitat unit (Moore et al. 1997) and measured the maximum depth of each pool. We counted the number of pieces of wood (≥ 3 m in length and ≥ 15 cm in diameter) in the active channel once during the pretreatment period (1993) and once during the post-treatment period (1999). Key pieces of wood were defined as pieces ≥ 12 m in length and ≥ 60 cm in diameter (Moore et al. 1997).

Estimating summer fish populations

Estimates of the number of age-0+ steelhead and age-0+ coho salmon rearing in each stream reach were made each year during August and early September. Stream reach population estimates were combined to obtain an abundance estimate for the entire stream.

To estimate the number of fish rearing in pool habitat within each reach, divers counted the number of each species in every third pool. We electrofished in at least five pools in each stream reach to calibrate and adjust the diver counts. The mean of the adjusted values was then multiplied by the total number of pools in the reach (Hankin and Reeves 1988). Because snorkel estimates are impractical in shallow habitat, we estimated the mean density of each species for a subset of glide, riffle, and rapid habitats by electrofishing. For each habitat type, we then multiplied this mean density by the surface area of this habitat type in the entire stream reach (Hankin 1984). We generally sampled at least 10 of each shallow-water habitat (riffles, rapids, and glides) in each stream reach to estimate densities in these habitat types.

For the electrofishing sampling, we estimated the number of each species in each sample unit 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 in pool habitat with high wood complexity or with 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 sampled for juvenile salmonids using 1000-V direct current backpack electrofishers. Criteria 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.

Estimating the number of downstream migrants

We estimated the number of downstream-migrating juvenile steelhead, cutthroat trout, and coho salmon in each stream each spring for 12 years using rotating screw traps. In each stream, traps were located near the stream mouth, just before the stream emptied into the Pacific Ocean. Traps were operated from the first week in March until catches diminished to low levels in mid- to late June. Traps operated continuously and were normally checked and cleared of fish and debris once a day, although traps often required constant attention during storm events. Fish were anesthetized with tricaine methanesulfonate (MS 222) and enumerated by species and size class. A sample of 25 lengths was taken on each size group of each species each week. Coho salmon were identified as fry or smolts (≥ 80 mm). Trout fry (< 60 mm) were not differentiated to the species level. Additional size classes were 60–89, 90–119, and ≥ 120 mm for steelhead and 60–89, 90–119, 120–159, and ≥ 160 mm for cutthroat trout. Only fish in the largest size class for each species showed signs of smoltification (silvering, loss of condition). Therefore, we defined these fish as smolts in our analyses.

To estimate trap efficiency, we daily marked up to 25 fish of each species and size group with either a small clip on their caudal fin (fish < 90 mm) or an injection of dye at the base of the ventral fin using a Panjet injector (Wright Health Group Ltd., Dundee, Scotland) (fish ≥ 90 mm). Marked fish were released at dusk approximately 200 m upstream of the traps. For each species and size group, weekly trap efficiency estimates were calculated by dividing the number of marked fish recaptured by the number of marked fish released. The total number of unmarked fish captured during the week was then divided by the weekly trap efficiency to estimate the total number of fish of each species migrating past the trap during the week. Weekly estimates were summed to estimate the total number of migrants of each species passing the trap each spring.

Estimating age composition of juvenile salmonids

Each year, scale samples were taken on juvenile steelhead during the summer rearing period and spring migration period to determine age composition. In the summer (August), scale samples were taken from 20 fish per 1-cm size interval. During the spring migration period (March–June), scale samples were taken from 10 fish per 1-cm size interval each month. For each sampling period, the age composition of each 1-cm size interval was applied to the length frequency of the population to determine the age composition of the entire population. This information was then used to partition each calendar year's population estimate into the appropriate brood years for subsequent analysis. For example, each calendar year, the steelhead smolt population was composed of smolts from three different brood years (age-1+, age-2+, and age-3+ smolts). To determine the number of steelhead smolts from a particular brood year (1992, for example), we added the age-1+ smolts from the spring of 1993, the age-2+ smolts from the spring of 1994, and the age-3+ smolts from 1995.

Study design and analysis

We designed the study using a before-after-control-impact (BACI) design suggested by Stewart-Oaten et al. (1986) to assess changes in habitat and fish parameters, a design that we had employed in an earlier study (Solazzi et al. 2000). However, after examining the data, it became evident that the pairing of the treatment and reference streams was not appropriate for this data set. This approach assumes that the reference stream will "track" the treatment stream. A change in this tracking relationship after the treatment impact provides evidence for an effect. In this study, the reference stream did not track well with the treatment stream. The rearing density and overall population size of age-0+ steelhead populations in the treatment stream remained at a high and constant level throughout the study. Alternatively, the populations of age-0+ steelhead in the reference stream were low relative to the available habitat in the first years of the study but increased steadily over time, presumably from increased numbers of spawning adult steelhead. Such differences in trends over time between treatment and reference violate the assumptions inherent in the BACI analysis and therefore may result in misleading significance (Stewart-Oaten et al. 1986; Smith et al. 1993). Additionally, in one year of the study, no age-0+ coho salmon were observed in the reference stream, which creates an additional problem if the ratio of treatment to control is used for analysis (Smith et al. 1993).

Because of these difficulties, we analyzed the data separately for each stream. For each habitat and fish population parameter, we used a *t* test to compare the means for the pretreatment and post-treatment periods. For each fish parameter, our null hypothesis was that the post-treatment mean was not different from the pretreatment mean; thus, we used a two-tailed test for each comparison. We excluded broods from each analysis that would have spent part of their lives in pretreatment years and part in post-treatment years (transition years). For consistency, brood year was designated as the year of age-0+ rearing for both steelhead and coho salmon. For habitat parameters, our null hypothesis was the post-treatment period was not greater than the pretreatment period because we expected the addition of large wood to create more pool habitat. Thus, we used a one-tailed test for these comparisons. The layout for the analysis for each species and life history stage and habitat attribute is provided in Table 2.

For steelhead and coho salmon, we determined whether age-0+ summer abundance, spring smolt abundance, or freshwater survival changed between the pretreatment and post-treatment periods for the 1991–2000 broods. Because we did not have accurate estimates of the number of adult spawners for each brood year, we defined freshwater survival as the percentage of age-0+ fish that survived to smolt. We did not analyze freshwater survival for coho salmon in Cummins Creek because in four of the 10 brood years, the summer population was so low that reliable estimates of survival could not be made. This also occurred in the 1998 survival estimate of coho salmon in Tenmile Creek, and we removed that brood from the analysis of freshwater survival.

For cutthroat trout, we determined whether the spring sea-run smolt abundance changed between the pretreatment and post-treatment periods. We analyzed the cutthroat trout smolt data by calendar year, rather than by brood year, because we found it difficult to age many of the upper year-class cutthroat by scale analysis. Unlike steelhead and salmon in these streams, not all of the cutthroat trout migrate to the ocean. Estimates of sea-run cutthroat smolts are therefore not a complete estimate of year-class strength. Scale analysis did suggest that most sea-run cutthroat smolts migrated to the ocean after 3 years of freshwater residence, although some age-2 and age-4 migrants were also observed.

Results

Habitat

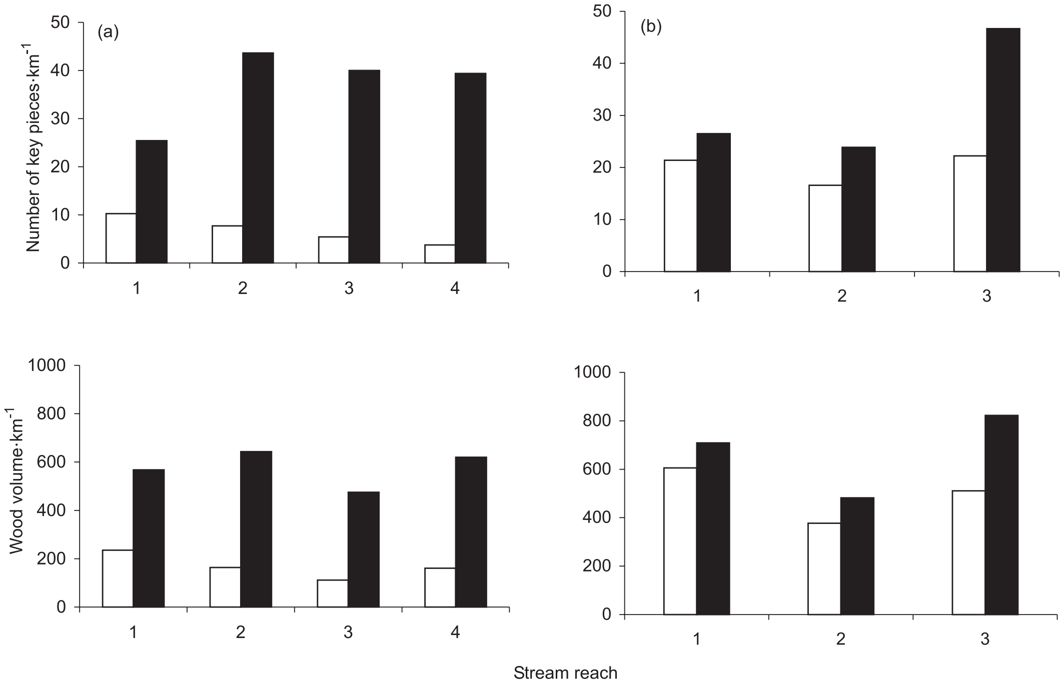
In Tenmile Creek (treatment stream), the number of key pieces of wood (wood pieces ≥12 m in length and ≥ 60 cm diameter) increased from 7.1 pieces·km^{-1} in the pretreatment count done in 1993 to 38.8 pieces·km^{-1} in the post-treatment count completed in 1999. The increase was observed in all four reaches in the mainstem of Tenmile Creek, where the number of key pieces increased 2.5 times in Reach 1, 5.7 times in Reach 2, 7.4 times in Reach 3, and 10.4 times in Reach 4 (Fig. 2). Placement of large trees during habitat restoration work accounted for all of the increase in large wood in Reach 3, while the storm-induced input of wood accounted for the additional large wood in Reach 1. The in-

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

	Data collection period		
Parameter	Pretreatment years	Transition years	Post-treatment years
Physical habitat			
Summer			
Tenmile Creek	1991, 1993, 1995	1996	1997–2000
Cummins Creek	1991, 1992, 1994–1995	1996	1997–2000
Winter			
Tenmile Creek	1993		1997
Cummins Creek	1991		1997
Steelhead age-0+ summer population	1991–1995	1996	1997–2000
Steelhead smolt population	1991–1994	1995–1996	1997–2000
Steelhead freshwater survival	1991–1994	1995–1996	1997–2000
Coho salmon summer population	1991–1995	1996	1997–2000
Coho salmon smolt population	1991–1995	1996	1997–2000
Coho salmon freshwater survival	1991–1995	1996	1997, 1999–2000
Cutthroat smolt population	1992–1995	1996–1997	1998–2001

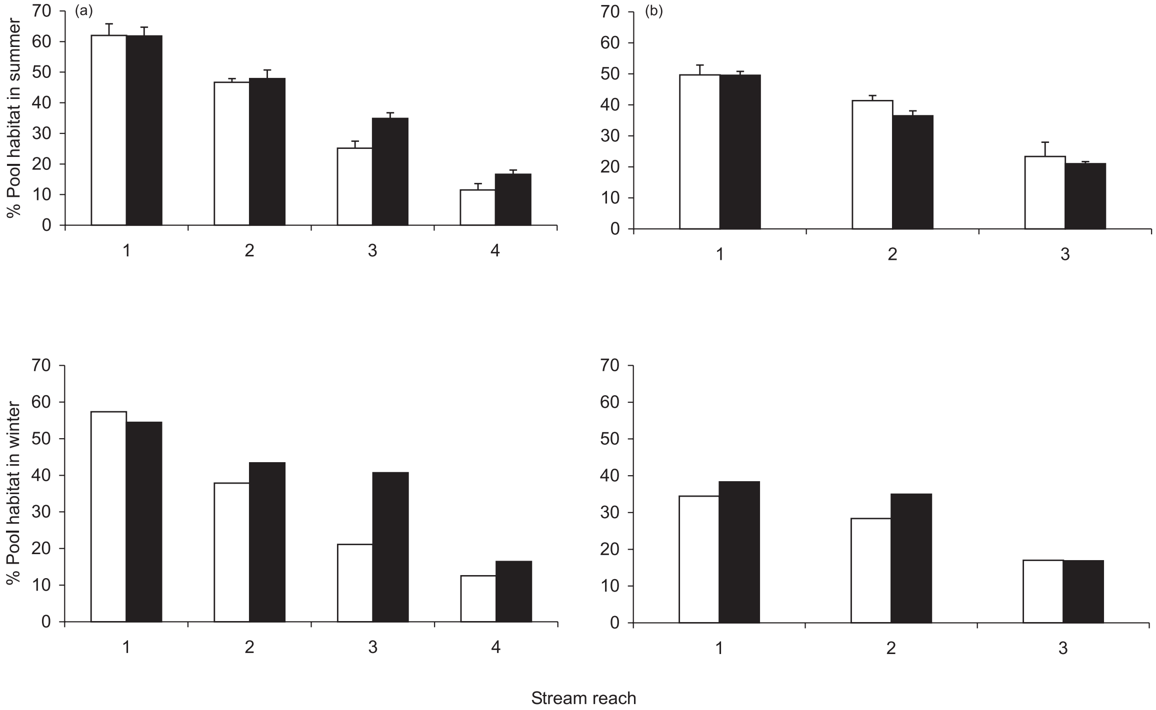
Note: Transition years for fish populations refer to years that were not used in the analyses because juveniles spent a portion of their freshwater rearing in both pretreatment and post-treatment years. For habitat comparisons and cutthroat trout (*Oncorhynchus clarki clarki*) population comparisons, years refer to calendar year. For steelhead (*Oncorhynchus mykiss*) and coho (*Oncorhynchus kisutch*) salmon population comparisons, years refer to brood years. For consistency, brood year is based on the year of age-0+ summer rearing for both steelhead and coho salmon. Total count of wood pieces was completed once in the pretreatment years (1993) and once in the post-treatment years (1999).

Fig. 2. Comparison of the number of key pieces of large wood (pieces 12 m in length and 60 cm in diameter) and the total volume (m^3) of wood in (*a*) Tenmile Creek (treatment) and (*b*) Cummins Creek (reference) before (1993) and after (1999) wood input in 1996. Increases in wood in Tenmile Creek resulted from a February 1996 storm event and an October 1996 instream habitat restoration project. Increases in wood in Cummins Creek resulted only from the February 1996 storm. Open bars represent pretreatment years and solid bars represent post-treatment years.



crease in Reach 2 and Reach 4 resulted from both the restoration trees and the flood impacts. In Cummins Creek (reference stream), key pieces of wood increased from 19.5 pieces·km^{-1} before the February 1996 storm event (1993 survey) to 28.9 pieces·km^{-1} after the storm (1999 survey). However, most of this increase was in the upper watershed (Reach 3), above most of the spawning and rearing of anadromous fish (Fig. 2). Estimates of total volume of wood (≥ 3 m in length and ≥ 15 cm in diameter) also increased throughout the mainstem of Tenmile Creek during the post-treatment period (167–593 m^3). Estimates of total volume of wood in Cummins Creek showed a smaller increase (494–

Fig. 3. Comparison of the mean percentage of summer and winter pool surface area (pool surface area/total wetted surface area) in (*a*) Tenmile Creek (treatment) and (*b*) Cummins Creek (reference) before and after wood input in 1996. Increases in wood in Tenmile Creek resulted from a February 1996 storm event and an October 1996 instream habitat restoration project. Increases in wood in Cummins Creek resulted only from the February 1996 storm. Open bars represent pretreatment years and solid bars represent post-treatment years. For summer habitat, error bars indicate standard error. Winter habitat was surveyed only once in each period; thus, no error bars are provided.



633 m^3), observed primarily in the upper portion of the watershed (Fig. 2).

In the upper portion of Tenmile Creek, the percentage of summer wetted surface area classified as pool habitat increased during the post-treatment phase of the study (Reach 3, one-tailed *t* test: $p = 0.010$; Reach 4, $p = 0.040$), while Reach 1 and Reach 2 showed no change ($p = 0.48$ and $p = 0.37$, respectively) (Fig. 3). More of the summer surface area of pool habitat in Tenmile Creek was associated with deep pools (maximum depth ≥ 1 m) in the post-treatment period. In Reach 3, where most of the habitat restoration trees were placed in the stream channel, the percentage of pool habitat associated with pools ≥ 1 m deep increased from an average of 21% in the pretreatment years to an average of 36% in the post-treatment years (one-tailed *t* test: $p = 0.046$). The reference stream, Cummins Creek, did not show a change in the percentage of summer stream surface area classified as pool habitat between pretreatment and post-treatment years.

Winter habitat surveys were completed once in the pretreatment period and once in the post-treatment period during periods of comparable flows. These surveys indicate that total surface area of mainstem winter habitat increased in Reach 3 of Tenmile Creek following treatment (Fig. 4), and much of this increase was associated with pool habitat (Fig. 3). In Cummins Creek, winter habitat surveys did not show an increase in the surface area of total habitat or pool habitat. We also observed an increase in side-channel habitat in Reach 2 and Reach 3 in Tenmile Creek after treatment, while side-channel habitat in Cummins Creek remained relatively constant (Fig. 4).

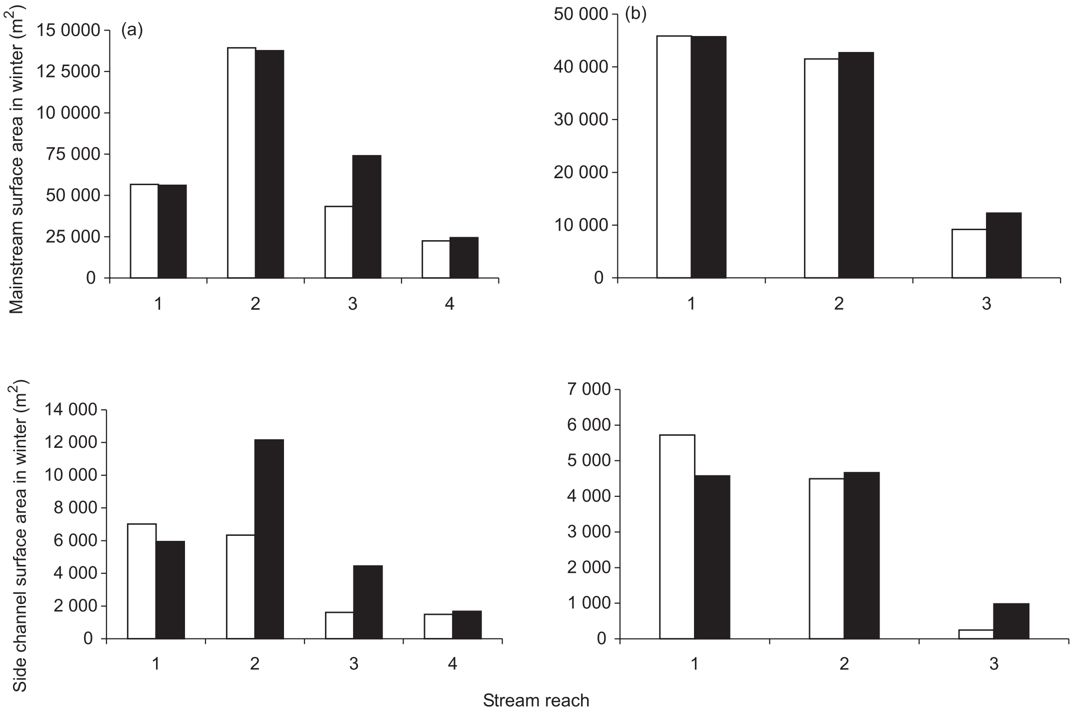
Changes in substrate composition were not detectable at the reach level for either stream during the course of the study. Major changes in substrate composition were observed, however, at individual wood jams (both natural and restoration sites) as gravels were deposited above and below the jams during high-water events.

Fish populations

Steelhead

The summer population size of age-0+ steelhead in the treatment stream (Tenmile Creek) did not change significantly between pretreatment and post-treatment years ($p = 0.946$) (Fig. 5). In the reference stream (Cummins Creek), there was a significant increase in the age-0+ steelhead summer rearing populations from the pretreatment to the post-treatment period ($p = 0.001$) (Fig. 5). Estimates of steelhead smolt abundance in the spring increased significantly in both Tenmile Creek ($p = 0.016$) and Cummins Creek ($p = 0.035$) between the pretreatment and post-treatment years (Fig. 5). Freshwater survival increased significantly in Tenmile Creek from the pretreatment to the post-treatment years ($p = 0.011$) but did not change significantly in Cummins Creek ($p = 0.18$) (Fig. 5).

Fig. 4. Comparison of winter wetted surface area of mainstem and side-channel habitat in (*a*) Tenmile Creek (treatment) and (*b*) Cummins Creek (reference) before and after wood input in 1996. Pretreatment winter habitat surveys (open bars) were completed in the winter of 1991–1992 in Cummins Creek and 1993–1994 in Tenmile Creek. Post-treatment winter habitat surveys (solid bars) were completed in both streams in the winter of 1997–1998.



Cutthroat trout

The number of searun cutthroat smolts migrating to the ocean in the spring increased significantly in both Tenmile Creek ($p = 0.0015$) and Cummins Creek ($p = 0.0075$) (Fig. 6) between pretreatment and post-treatment periods. No estimates of age-0+ population or of freshwater survival were made for cutthroat trout.

Coho salmon

There was no significant change in the summer rearing populations of age-0+ coho salmon in Tenmile Creek ($p = 0.080$) or Cummins Creek ($p = 0.324$) between pretreatment and post-treatment years. There was also no significant change in the number of coho salmon smolts leaving Tenmile Creek ($p = 0.496$) or Cummins Creek ($p = 0.791$) between pretreatment and post-treatment years (Fig. 7). However, juvenile coho salmon did show a significant ($p = 0.005$) increase in freshwater survival in Tenmile Creek (Fig. 7). Coho salmon freshwater survival was not calculated for Cummins Creek because low summer population sizes in several years made it difficult to accurately determine the percentage that survived.

Discussion

The addition of wood to Tenmile Creek by the February 1996 storm event and the October 1996 habitat restoration activities increased the number of large key pieces of wood to levels observed in the reference stream, Cummins Creek. This resulted in an increase in the percentage of surface area of pool habitat and pool depth in the upper two reaches of Tenmile Creek. Winter side-channel habitat also increased in Reach 2 and Reach 3 of Tenmile Creek after the input of large wood. A similar response to the physical habitat of other Pacific Northwest streams has been observed after the addition of large wood (Crispin et al. 1993; Reeves et al. 1997; Solazzi et al. 2000).

Our results suggest that these habitat changes resulted in significantly higher survival for juvenile steelhead and coho salmon in Tenmile Creek in the post-treatment period. The increased survival resulted in steelhead smolt abundance that averaged 2.5 times higher in the post-treatment period than in the pretreatment period. In the reference stream, Cummins Creek, the post-treatment steelhead smolt abundance averaged 1.6 times higher than in pretreatment years but resulted from an increasing population size of age-0+ steelhead in the stream over the 10-year period rather than an increase in freshwater survival, as was observed in Tenmile Creek.

Results from other studies examining the effect of increased instream structure on juvenile steelhead have been inconclusive. The addition of boulders and placement of rock-filled gabions in an Oregon coastal stream led to an increase in the summer rearing population of juvenile steelhead (House and Boehne 1985), but no increase was observed in age-0+ or age-1+ steelhead populations after the addition of large wood to a Washington stream (Cederholm et al. 1997). In Washington and Oregon streams, steelhead and cutthroat populations did not change near large woody debris placement projects compared with control reaches during the summer but increased during the winter (Roni and Quinn 2001). However, these studies measured steelhead population size at the reach level and did not attempt to estimate

Fig. 5. Age-0+ steelhead (*Oncorhynchus mykiss*) summer rearing populations, spring smolt population, and freshwater survival for the 1991–2000 brood years in (*a*) Tenmile Creek (treatment) and (*b*) Cummins Creek (reference). Freshwater survival is defined as the percentage of age-0+ steelhead that survive to smolt. Open bars represent pretreatment brood years, hatched bars represent transition brood years, and solid bars represent post-treatment brood years.

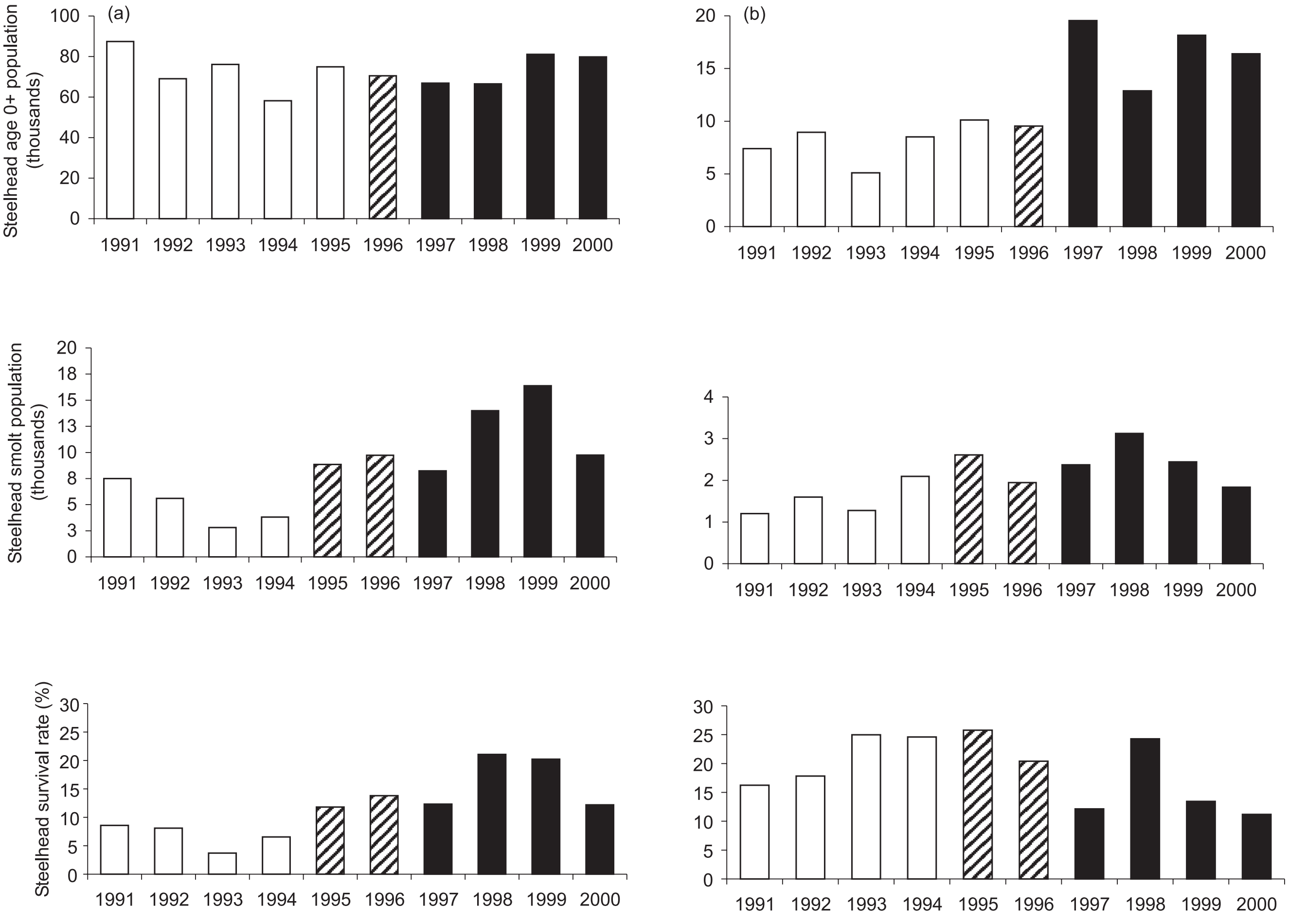
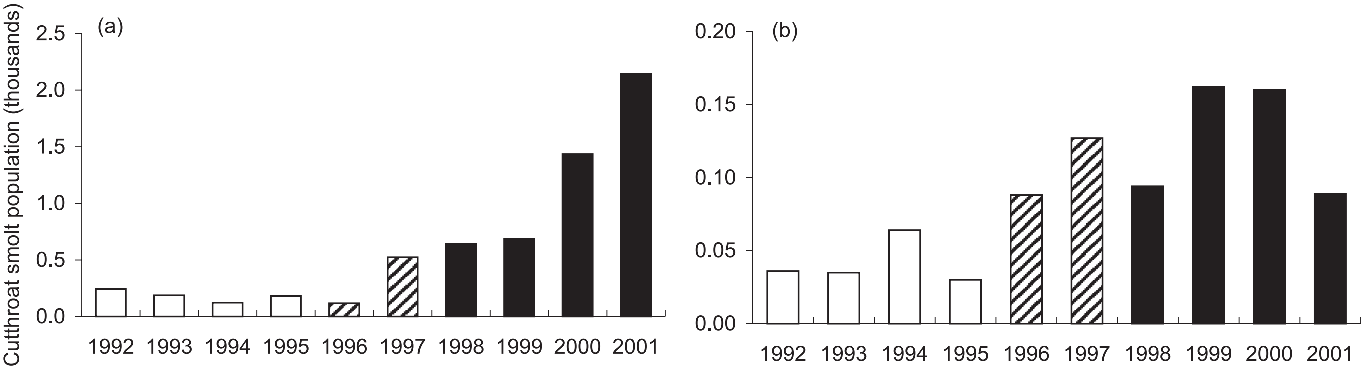
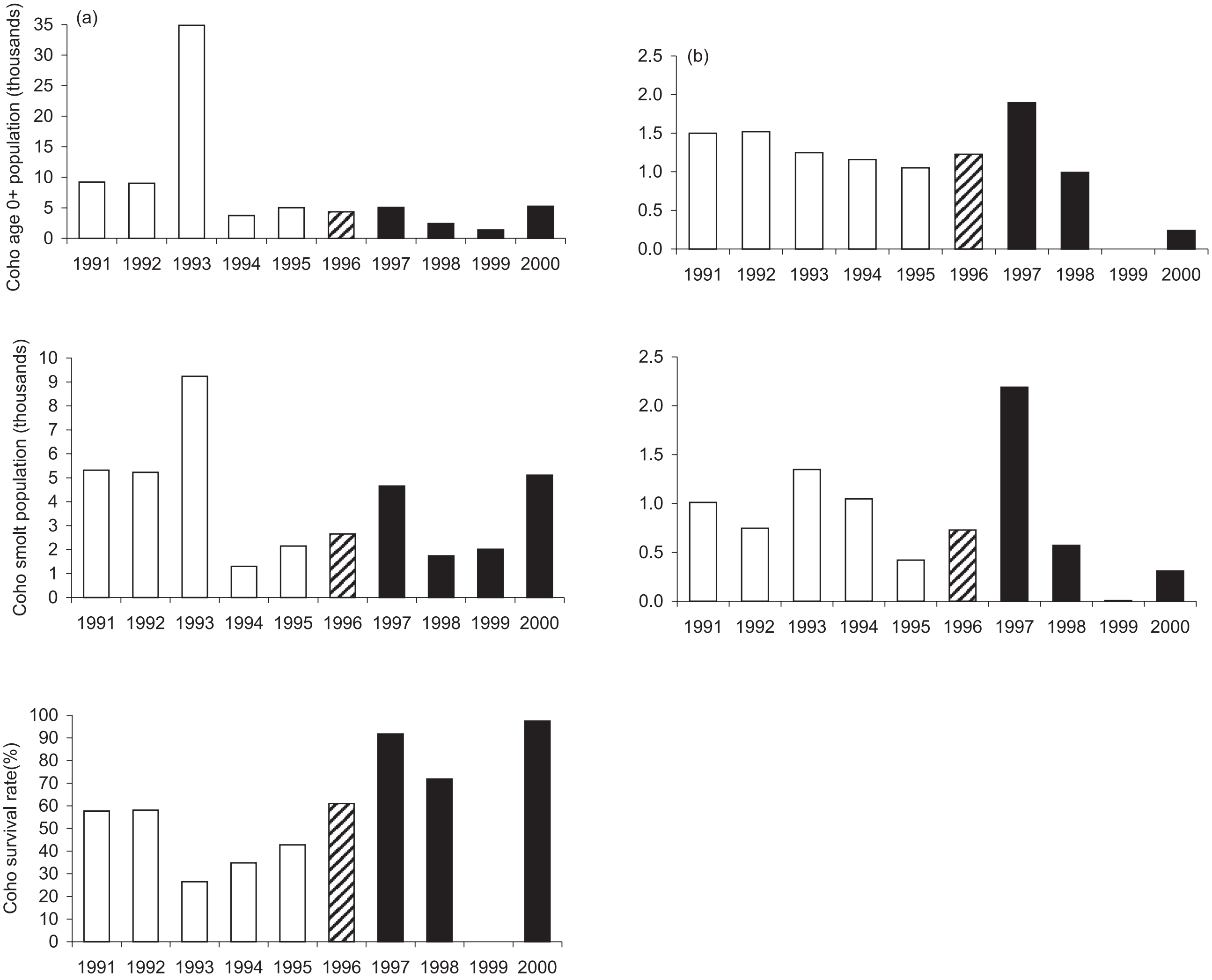


Fig. 6. Sea-run cutthroat trout (*Oncorhynchus clarki clarki*) spring migrant populations for (*a*) Tenmile Creek (treatment) and (*b*) Cummins Creek (reference) for calendar years 1992–2001. Cutthroat smolts are defined as fish 160 mm. Open bars represent pretreatment years, hatched bars represent transition years, and solid bars represent post-treatment years.



smolt abundance for the entire stream. Solazzi et al. (2000) did not observe an increase in the abundance of juvenile steelhead in the summer in two Oregon coastal streams after habitat restoration activities but did observe an increase in the number of spring migrant steelhead (> 90 mm). However, most of these migrants were not smolts on their ocean migration but age-1+ fish moving downstream for another year of rearing. Reeves et al. (1997) observed a 28% increase in the mean number of steelhead smolts leaving Fish Creek (Clackamas River, Oregon) after habitat restoration, al-

Fig. 7. Age-0+ coho salmon (*Oncorhynchus kisutch*) summer rearing populations and spring migrant populations for the 1991–2000 brood years in (*a*) Tenmile Creek (treatment) and (*b*) Cummins Creek (reference). Freshwater survival is also shown for Tenmile Creek. Freshwater survival is defined as the percentage of age-0+ coho salmon that survive to smolt. Open bars represent pretreatment brood years, hatched bars represent transition brood years, and solid bars represent post-treatment brood years.



though the increase was statistically insignificant because of the variation in the annual number of migrants both before and after treatment.

Abundance of steelhead smolts is inherently difficult to measure in many coastal streams because many juvenile steelhead leave their natal streams after 1 year of rearing and spend another year of rearing in larger streams. Therefore, if study streams are selected in smaller tributaries in the upper portions of a watershed, a complete estimate of steelhead smolt production is not possible. Because Tenmile and Cummins creeks are both direct ocean tributaries, we avoided this problem by placing our smolt traps near the stream mouths, where the streams entered the Pacific Ocean.

Smolt trapping in the spring showed significant increases in sea-run cutthroat migrants in both Tenmile and Cummins creeks in the post-treatment period of the study. Solazzi et al. (2000) reported finding no detectable differences in summer cutthroat numbers but observed increases in the number of migrants after restoration work on one of two Oregon coastal streams. Because we do not know the age-0+ population size of cutthroat trout in Tenmile and Cummins creeks, it is difficult to interpret the results of increased cutthroat smolt production during the post-treatment period. While habitat changes may have influenced cutthroat smolts in the post-treatment period in Tenmile Creek, more restrictive trout fishing regulations were placed on all Oregon coastal streams in the mid-1990s and could also be partially responsible for the increased number of sea-run cutthroat migrants that we observed.

No significant change in the coho salmon summer rearing population size or spring smolt abundance was observed in either stream during the study. Summer rearing densities of juvenile coho salmon in both Tenmile and Cummins creeks were low, generally <0.1 fish·m^2 pool surface area^{-1}. Rearing densities of age-0+ coho salmon in Oregon coastal streams with adequate adult spawning the previous winter usually average close to 1.5 fish·m^2 pool surface area^{-1} (Nickelson et al. 1992*a*). The low rearing densities measured in this study were likely the result of low adult spawner escapement to these and other Oregon coastal streams during the 1990s.

These results illustrate the problem of trying to evaluate effects of habitat restoration on anadromous fish populations in streams when population sizes are low. While the habitat changes may result in an increase in the potential rearing capacity, short-term studies (and this study was relatively long term) may not observe increases if fry abundance is insufficient to exploit all available habitat. In addition, when streams have low numbers of adult spawners, small changes in adult spawners can result in a large variation in juvenile abundance, regardless of habitat restoration activities. If population levels are low and freshwater survival is high because of adequate habitat and little density-dependent mortality, field sampling techniques may not be sensitive enough to detect changes in freshwater survival. This was particularly true in this study for coho salmon in Cummins Creek, where the confidence intervals associated with summer population estimates and spring smolt estimates of coho salmon often overlapped.

Although we observed a significant increase in the freshwater survival of juvenile coho salmon in Tenmile Creek, summer rearing densities were generally lower in the post-treatment period than in the pretreatment period, and less density-dependent mortality may have contributed to the observed increase in freshwater survival in the post-treatment period. In particular, the summer rearing population of age-0+ coho salmon for the 1993 brood in Tenmile Creek was much higher than in other years and was undoubtedly subjected to more density-dependent mortality during the winter. This may have biased the comparison of survival between pretreatment and post-treatment years.

Solazzi et al. (2000) observed increased freshwater survival of coho juveniles in East Creek (Nestucca River, Oregon) and Lobster Creek (Alsea River, Oregon) after instream restoration projects. Freshwater survival was higher in this study than observed in East and Lobster creeks, presumably because of the low rearing densities observed in Tenmile Creek. Others have also documented positive responses to juvenile coho populations after instream structure was added to Pacific Northwest streams (Nickelson et al. 1992*b*; Cederholm et al. 1997; Roni and Quinn 2001). However, Reeves et al. (1997) did not observe a change in summer rearing populations or smolt populations of coho salmon after restoration activities in Fish Creek (Clackamas River, Oregon).

This study was designed in an approach outlined by Stewart-Oaten et al. (1986), where we sampled multiple years before and after treatment (wood input) and also used an adjacent stream as a reference to isolate the impacts of the habitat modification on fish populations. Solazzi et al. (2000), using this study design, documented how results could be misinterpreted without the inclusion of a reference stream. In this study, using Cummins Creek as a reference stream had unexpected consequences that made interpretation of steelhead numbers using a standard BACI design inappropriate. Cummins Creek initially seemed like a good reference stream. Although smaller in size than Tenmile Creek, it was in close proximity, similar in geology, and had a similar history of fish management to the treatment stream. In addition, because the Cummins Creek watershed is designated as a wilderness area, we were assured that land use activities within the watershed would remain unchanged during the course of the study. Still, Cummins Creek eventually proved to be an inappropriate reference stream because the trend of age-0+ steelhead populations was different from what we observed in the treatment stream.

Ideally, both the treatment and reference streams would have an adequate number of adult spawners to seed the available rearing habitat with emerging fry each spring. This would ensure that the summer rearing populations and smolt populations reflect the production potential of the available habitat. It would also minimize the variation in density-dependent mortality between years and between treatment and reference streams. Large changes in density-dependent mortality can minimize our ability to determine if habitat changes result in changes in freshwater survival. If sufficient numbers of age-0+ juveniles do not occur to seed the available rearing habitat, the treatment stream and reference stream should at least show the same trend in the pretreatment period (Smith et al. 1993). In this study, however, the rearing densities of age-0+ steelhead were high and constant in the treatment stream (Tenmile Creek), while the rearing densities in the reference stream (Cummins Creek) were initially low and increased throughout the 10-year study. In Tenmile Creek, the rearing densities of age-0+ steelhead averaged 0.3 fish·m^{-2} in riffles and 0.4 fish·m^{-2} in pools. These densities are similar to those observed in other Oregon coastal streams with established steelhead populations (S.L. Johnson, unpublished data). At the beginning of the study, the rearing densities in the reference stream were substantially lower (0.1 fish·m^{-2} in riffles and 0.2 fish·m^{-2} in pools) but increased over the course of the study, presumably from an increase in adult spawners. Because of this difference in the initial seeding levels of fry between the two streams, the increases in smolt production exhibited by both streams occurred for different reasons. The steelhead smolt abundance in the reference stream increased because initial seeding of fry increased, resulting in more juveniles rearing in the stream and eventually more smolts migrating to the ocean. Survival of age-0+ steelhead to smolt (primarily age 2+), however, remained unchanged for the reference stream over the course of the study. In the treatment stream (Tenmile Creek), the age-0+ steelhead population size remained constant over time, but the smolt abundance increased because freshwater survival increased.

Our results illustrate the difficulty in obtaining definitive conclusions when trying to determine the effect of habitat changes on juvenile salmonid abundance. Various sampling designs have been proposed to assess ecological impacts. (Hicks et al. 1991; Osenberg et al. 1996; Roni et al. 2003). The BACI-type design seems to present a logical approach to evaluate the effect of habitat restoration projects on salmon populations and has been used successfully in the past (Solazzi et al. 2000). This approach allows for a direct comparison of fish abundance and survival in an entire stream before and after a treatment or impact. A successful evaluation, however, is difficult to achieve. Interannual variation in juvenile salmonid populations is often large because of changes in adult spawner abundance or environmental conditions. To understand this variation requires a study design with pretreatment and post-treatment periods of at least 4 or 5 years for each period to attain even a minimal sample size (Roni et al. 2003). In our study, we removed the middle two brood years from our comparisons of steelhead smolt abundance because these fish spent part of their freshwater residence in the pretreatment period and part in the post-treatment period. Thus, although we sampled steelhead populations for 10 brood years, we could only use eight years to compare pretreatment and post-treatment smolt abundance and survival. Maintaining continuity in funding, personnel, and methods is always a challenge with long-term studies. Unforeseen changes in land use activities, changes in fishing regulations, or large impacts from floods or droughts that affect treatment and reference streams disproportionately also complicate evaluation. Resource limitations have rarely allowed researchers to include true replication by sampling multiple treatment and reference watersheds simultaneously. Underwood (1996) argued convincingly that including multiple reference sites with a given treatment site would alleviate many of the problems associated with comparing a single treatment and reference as outlined by Stewart-Oaten et al. (1986). In future studies, this design would be an improvement if additional appropriate reference sites could be identified and adequate funding could be secured.

When many species are sampled as part of a BACI design, Smith et al. (1993) suggested dropping species from the analysis that do not show consistent trends between treatment and reference sites and concentrate the analysis on species that do show consistent trends. This solution is not suitable when sampling fish populations in the Pacific Northwest, where species diversity is naturally low and salmonid species are often the primary concern. In our situation, we felt that it was most appropriate to acknowledge that other factors complicated the direct comparison of treatment and reference streams and analyze the data separately for each stream.

Murtaugh (2000) pointed out that large-scale ecological studies often have little or no replication, yet many of these studies have contributed to our understanding of ecological processes. In a recent review of the BACI design, Conquest (2000) concluded that sometimes the best interpretation could be accomplished by staring hard at good graphs and using process knowledge in one's arguments. In this study, even with the complications of incorporating these data into a typical BACI design, we did increase our understanding of how these fish populations reacted to the change in the amount of large wood input into the Tenmile Creek watershed. Our understanding of how steelhead freshwater survival changed in Tenmile Creek would not have been possible without the intensive sampling required to measure both the summer population size of age-0+ fish and their subsequent smolt abundance for each brood year. Had we chosen a less intensive approach, perhaps sampling at only one life history stage, resources could have been reallocated to include additional streams in the study design. However, we would not have gained the same insights into the changes in total population size and freshwater survival. For example, if we had only sampled the steelhead smolt populations migrating from the two streams each spring, we would have concluded that the Tenmile Creek steelhead population was unchanged relative to Cummins Creek (steelhead smolt production increased in both streams). Only by sampling both the summer rearing populations and the spring smolt populations were we able to understand what happened in these two streams over the course of this study.

Acknowledgements

We dedicate this paper to the memory of Greg Willmore, former US Forest Service biologist, whose enthusiasm and commitment to these watersheds helped launch this study. In a study of this duration, many have contributed to the successful completion of the project. We specifically thank Jack Sleeper and Paul Thomas of the Siuslaw National Forest, US Forest Service, for their commitment to the project. Many people worked on our sampling crews, often during inclement weather, to collect the fish population data. In particular, we acknowledge the multiple years of work that Stan VandeWetering, Ron Constable, Chris Romsos, Jim Brick, and Ward Batson contributed to the study. We also express our thanks to Paul Engelmeyer of the National Audubon Society and the many landowners of Tenmile Creek who allowed us access to their property. We also thank Mary Buckman, whose comments and criticisms improved the manuscript. Funding was provided by the Sport Fish and Wildlife Restoration Program (administered by the US Fish and Wildlife Service) and by the Siuslaw National Forest, US Forest Service.

References

Baldwin, E.M. 1992. Geology of Oregon. 4th ed. Kendall/Hunt Publishing Co., Debuque, Iowa.

Bisson, P.A., Nielson, J.L., Palmason, R.A., and Grove, L.E. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. *In* Acquisition and utilization of aquatic habitat inventory information. *Edited by* N.B. Armantrout. American Fisheries Society, Bethesda, Md. pp. 62–73.

Bustard, D.R., and Narver, D.W. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. **32**: 667–680.

Cederholm, C.J., and Peterson, N.P. 1985. The retention of coho salmon (*Oncorhynchus kisutch*) carcasses by organic debris in small streams. Can. J. Fish. Aquat. Sci. **42**: 1222–1225.

Cederholm, C.J., Bilby, R.E., Bisson, P.A., Bumstead, T.W., Fransen, B.R., Scarlett, W.J., and Ward, J.W. 1997. Response of juvenile coho salmon and steelhead to placement of large woody debris in a coastal Washington stream. N. Am. J. Fish. Manag. **17**: 947–963.

Chapman, D.G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample census. Univ. Calif. Publ. Stat. **1**: 131–160.

Conquest, L.L. 2000. Analysis and interpretation of ecological field data using BACI designs: discussion. J. Agric. Biol. Environ. Stat. **5**: 293–296.

Crispin, V., House, R., and Roberts, D. 1993. Changes in instream habitat, large woody debris, and salmon habitat after the restructuring of a coastal Oregon stream. N. Am. J. Fish. Manag. **13**: 96–102.

Hankin, D.G. 1984. Multistage sampling designs in fisheries research: applications in small streams. Can. J. Fish. Aquat. Sci. **41**: 1575–1591.

Hankin, D.G., and Reeves, G.H. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Can. J. Fish. Aquat. Sci. **45**: 834–844.

Harmon, M.E., Anderson, N.H., Franklin, J.F., Cline, S.P., Swanson, F.J., Aumen, N.G., Sollins, P., Sedell, J.R., Gregory, S.V., Lienkaemper, G.W., Lattion, J.D., Cromack, K., Jr., and Cummins, K.W. 1986. Ecology of course woody debris in temperate ecosystems. Adv. Ecol. Res. **15**: 133–302.

Hicks, B.J., Hall, J.D., Bisson, P.A., and Sedell, J.R. 1991. Responses of salmonids to habitat changes. *In* Influences of forest and rangeland management on salmonid fishes and their habitat. *Edited by* W.R. Meehan. Am. Fish. Soc. Spec. Publ. 19. pp. 483–518.

House, R.A. 1996. An evaluation of stream restoration structures in a coastal Oregon stream, 1981–1993. N. Am. J. Fish. Manag. **16**: 272–281.

House, R.A., and Boehne, P.L. 1985. Evaluation of instream enhancement structures for salmon spawning and rearing in a coastal Oregon stream. N. Am. J. Fish. Manag. **6**: 38–46.

Loy, W. 1976. Atlas of Oregon. 2nd ed. University of Oregon, Eugene, Oreg.

Moore, K., Jones, K., and Daumbacher, J.M. 1997. Methods for stream habitat surveys. Oreg. Dep. Fish Wild. Inf. Rep. (Fish). 97-4.

Murtaugh P.A. 2000. Paired intervention analysis in ecology. J. Agric. Biol. Environ. Stat. **5**: 280–292.

Nickelson, T.E., Rodgers, J.D., Johnson, S.L., and Solazzi, M.F. 1992*a*. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. **49**: 783–789.

Nickelson, T.E., Solazzi, M.F., Johnson, S.L., and Rodgers, J.D. 1992*b*. Effectiveness of selected stream improvement techniques to create suitable summer and winter rearing habitat for juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. **49**: 790–794.

Osenberg, C.W., Schmitt, R.J., Holbrook, S.J., Abu-Saba, K.E., and Flegal, A.R. 1996. Detection of environmental impacts. *In* Detecting ecological impacts. *Edited by* R.J. Schmitt and C.W. Osenberg. Academic Press, San Diego, Calif. pp. 83–108.

Pearsons, T.N., Li, H.W., and Lamberti, G.A. 1992. Influence of habitat complexity on resistance to flooding and resilience of stream fish assemblages. Trans. Am. Fish. Soc. **121**: 427–436.

Ralph, S.C., Poole, G.C., Conquest, L.L., and Naiman, R.J. 1994. Stream channel morphology and woody debris in logged and unlogged basins of western Washington. Can. J. Fish. Aquat. Sci. **51**: 37–51.

Reeves, G.H., Hohler, D.B., Hansen, B.E., Everest, F.H., Sedell, J.R., Hickman, T.L., and Shively, D. 1997. Fish habitat restoration in the Pacific Northwest: Fish Creek of Oregon. *In* Watershed restoration: principles and practices. *Edited by* J.E. Williams, C.A. Wood, and M.P. Dombeck. American Fisheries Society, Bethesda, Md. pp. 335–359.

Rodgers, J.D., Solazzi, M.F., Johnson, S.L., and Buckman, M.A. 1992. A comparison of three population estimation techniques to estimate juvenile coho salmon populations in small streams. N. Am. J. Fish. Manag. **12**: 79–86.

Roni, P., and Quinn, T.P. 2001. Density, and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Can. J. Fish. Aquat. Sci. **58**: 282–292.

Roni, P., Beechie, T.J., Bilby, R.E., Leonetti, F.E., Pollock, M.M., and Pess, G.R. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. N. Am. J. Fish. Manag. **22**: 1–20.

Roni, P., Liermann, M., and Steel, A. 2003. Monitoring and evaluating responses of salmonids and other fishes to instream restoration. *In* Restoration of Puget Sound rivers. *Edited by* D.R. Montgomery, S. Bolton, D.B. Booth, and L. Wall. University of Washington Press, Seattle, Wash. pp. 318–339.

Seber, G.A.F., and LeCren, E.D. 1967. Estimating population parameters from catches large relative to the population. J. Anim. Ecol. **36**: 631–643.

Smith, E.P., Orvos, D.R., and Cairns, J. 1993. Impact assessment using the before-after-control-impact (BACI) model: concerns and comments. Can. J. Fish. Aquat. Sci. **50**: 627–637.

Smokorowski, K.E., Withers, K.J., and Kelso, J.R.M. 1998. Does habitat creation contribute to management goals? An evaluation of literature documenting freshwater habitat rehabilitation or enhancement projects. Can. Tech. Rep. Fish. Aquat. Sci. No. 2249.

Solazzi, M.F., Nickelson, T.E., Johnson, S.L., and Rodgers, J.D. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Can. J. Fish. Aquat. Sci. **57**: 906–914.

Stewart-Oaten, A., Murdoch, W.W., and Parker, K.R. 1986. Environmental impact assessment: pseudoreplication in time? Ecology, **67**: 929–940.

Swanson, S.J., Lienkaemper, G.W., and Sedell, J.R. 1976. History, physical effects, and management implications of large organic debris in western Oregon streams. U.S. For. Serv Gen. Tech. Rep. PNW-56.

Underwood, A.J. 1996. On beyond BACI: sampling designs that might reliably detect environmental disturbances. *In* detecting ecological impacts. *Edited by* R.J. Schmitt and C.W. Osenberg. Academic Press, San Diego, Calif. pp. 151–175.