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Diversity of Juvenile Anadromous Salmonid Assemblages in Coastal Oregon Basins with Different Levels of Timber Harvest

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Abstract. -We examined the relationships of timber harvest, stream habitat complexity, and diversity of juvenile anadromous salmonid assemblages in 14 small- to intermediate-sized basins in coastal Oregon between 1985 and 1989. Diversity (the inverse of a species dominance index) of assemblages in streams in basins with low harvest levels (<25% of the basin area harvested) was greater than in streams in basins with high harvest levels (>25% of the basin area harvested) ($P = 0.02$). Assemblages in basins with high levels of harvest were more dominated by a single species than were assemblages in basins with low harvest. Percent of basin harvested was more strongly associated with assemblage diversity ($P = 0.07$) than were basin area ($P = 0.90$) or gradient ($P = 0.22$) when the influence of the other two factors was controlled. Habitat features were compared between three pairs of streams. Streams in basins with low timber harvest had more complex habitat, as manifested by more large pieces of wood per 100 m ($P < 0.01$). We conclude that a community and basin-level perspective is necessary to fully assess the effects of timber harvest and other human activities on stream fish.

Alteration of ecological processes and environmental conditions may affect several levels of ecological organization. Individual and population responses may vary with the magnitude and duration of the impact, species-specific requirements (Kelly and Harwell 1990; Yount and Niemi 1990), and the presence of refugia (Sedell et al. 1990). Because of variability in responses by individuals and populations, members of a community are unlikely to exhibit a uniform response to a disturbance or an environmental alteration. The effect of disturbance on communities depends, in part, on the combined effect on both individuals and populations as well as on the extent to which processes that influence the structure and composition of communities are altered (e.g., Reeves et al. 1987; Baltz et al. 1982).

A primary factor influencing the diversity of stream fish communities is habitat complexity (Gorman and Karr 1978; Schlosser 1982; Angermeier and Karr 1984). More diverse habitats support more diverse communities. Habitat diversity can also mediate biotic interactions such as competition (Kalleberg 1958; Hartman 1965) and predation (Crowder and Cooper 1982; Schlosser 1988).

Simplification of fish habitat in streams may be a primary consequence of timber harvest (Bisson and Sedell 1984; Hicks et al. 199 1). Consequences of simplification include a decrease in the range and variety of hydraulic conditions (Kaufmann 1987) and reductions in structural elements (Bisson et al. 1987), frequency of habitat units, and diversity of substrates (Sullivan et al. 1987). Ef-

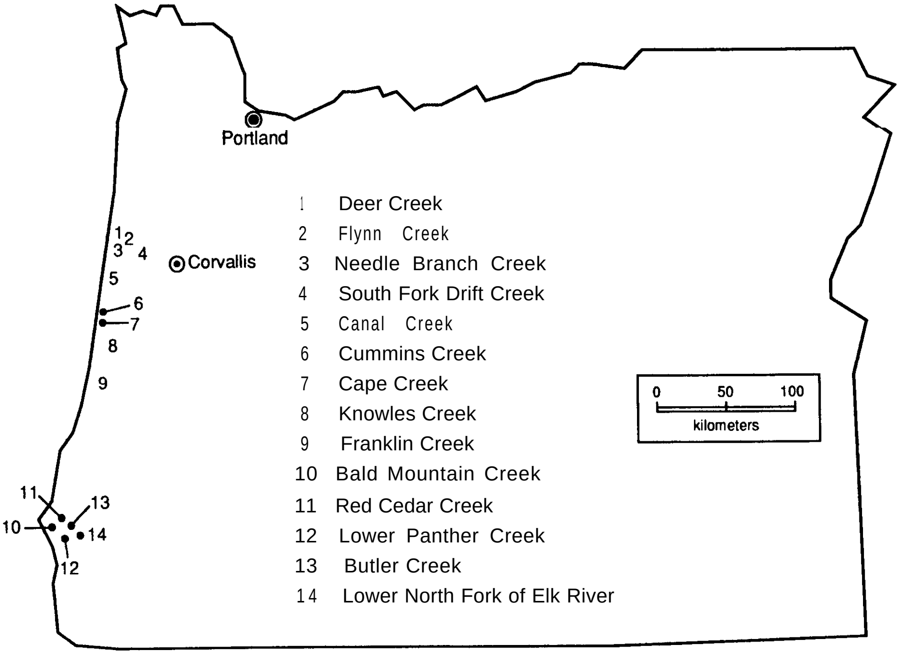

FIGURE 1 -- Location of study streams.

fects of timber harvest on fish have generally been considered in terms of a single species (e.g., Bums 1972; Murphy et al. 1986; Holtby 1988) or by examining densities of salmonids as a generic group (e.g., Hawkins et al. 1983). Little consideration has been given to effects of timber harvest and associated activities on fish from an assemblage or community perspective.

Previous studies of the effects of timber harvest have been focused at relatively small spatial scales, generally confined to stream reaches less than 100 m (e.g., Murphy et al. 1981; Hawkins et al. 1983; Carlson et al. 1990). Streams are tightly coupled systems; downstream areas are greatly influenced by events upstream (Vannote et al. 1980). Therefore, to understand fully the effects of timber harvest and other human activities on fish communities, a broader spatial context such as the basin or subbasin scale may be required. The few large-scale fish studies that have been conducted-the Alsea Watershed Study in Oregon (Hall et al. 1987) and the study on Carnation Creek in British Columbia (Holtby 1988; Scrivener and Brownlee 1989) -have focused on the effects on species separately. They have not considered community level aspects.

In this paper we (1) examine the relation between the diversity of juvenile anadromous salmonid assemblages and the level of timber harvest and associated activities in coastal Oregon streams in basins of small to intermediate size, and (2) compare features of habitat diversity in selected pairs of streams in basins with differing levels of timber harvest.

Methods

Study area. -All study basins were in central and southern Oregon, within 40 km of the coast (Figure 1). South-coast streams were subbasins of Elk River. Basins differed in size, gradient, and percent of area that had been subjected to timber harvest (Table 1). The majority of each basin is on public land except for Knowles Creek, which is largely in private ownership. Timber harvest was the sole or primary land management activity in each basin. Douglas fir *Pseudotsuga menziesii* and red alder *Alnus rubra* were the dominant plant species in all basins.

Fourteen streams, seven in basins with low levels and seven in basins with high levels of timber harvest, were sampled throughout the distribution of juvenile anadromous fish. Basins with low logging levels had 25% or less of the watershed area harvested. Basins with high logging levels had more than 25% of the basin harvested. The 25% level of harvest within a basin is used as a threshold for watershed-level cumulative-effects analysis in some national forests and has been demonstrated

TABLE 1.-Management history, location, sampling date, and features of study basins.

Basin	Oregon location	Rock type	Year surveyed	Basin area (hectares)	Gradient (%)	Length sampled (km)	% harvested
Upper Flynn Creek	Central	Sandstone	1988	200	0.6	1.5	0
Red Cedar Creek	South	Sandstone	1985	695	0.8	2	0
South Fork Drift Creek	Central	Sandstone	1988	210	0.8	1.5	0
Cummins Creek	Central	Basalt	1987	2,410	2.0	9	1
Lower North Fork Elk River	South	Sandstone	1985	2,450	1.3		
Lower Panther Creek	South	Sandstone	1985	2,350	1.3	4	6
Franklin Creek	Central	Sandstone	1989	1,840	1.2	4	15
Bald Mountain Creek	South	Sandstone	1985	2,750	2.5	7	30
Butler Creek	South	Sandstone	1985	1,770	0.6	4	30
Canal Creek	Central	Sandstone	1985	3,590	0.8	7	42
Deer Creek	Central	Sandstone	1988	300	0.6	2.2	50
Cape Creek	Central	Basalt	1987	3,300	2.0	7.5	78
Knowles Creek	Central	Sandstone	1989	5,200	0.6	10	80
Needle Branch Creek	Central	Sandstone	1988	70	1.4	1	100

to have ecological effects on vegetation patterns (Franklin and Forman 1987; Li et al., in press). We considered percent of basin harvested to be a measure of the intensity of the potential effect on the stream resulting from all facets of timber harvest activities, including road building, actual timber harvest, and site preparation after harvest.

Basins with low levels of harvest or effects from other activities are rare because of the extensive amounts of timber harvesting and other land management activities in coastal Oregon. Those selected are a substantial proportion of the population of basins with low harvest levels. Basins with high harvest levels were selected because of their geographic proximity and similar nature (i.e., size and gradient) to low-harvest streams.

Physical habitat. — Habitat units were classified as pools, riffles, glides, or side channels (Bisson et al. 1982). Length and mean width of each unit were determined following the methodology outlined in Hankin and Reeves (1988). Pieces of wood at least 30 cm in mean diameter and at least 3 m long were counted in each habitat unit.

We were unable to find in the literature or to develop a satisfactory single measure or index of habitat diversity and complexity applicable to our study basins. Pieces of large wood and number of pools were considered to be indicators of habitat complexity (Sullivan et al. 1987; Bisson et al. 1987) and were therefore analyzed separately.

Comparison of numbers of pieces of wood per 100 m and habitat units (pools) per 100 m were made between paired segments of Franklin Creek (low harvest) and Knowles Creek (high harvest), Upper Flynn Creek (low harvest) and Deer Creek (high harvest), and Lower North Fork of Elk River (low harvest) and Butler Creek (high harvest). Segments ranged in length from 1 to 2.6 km and were sampled in the same year. These pairs were selected to reduce variation between streams associated with size, rock types, gradient, and geographic location. Because Knowles Creek was larger than Franklin Creek, a segment of Knowles Creek with a basin area equal to the size of the Franklin Creek watershed was used in the comparison. Pieces of wood per 100 m and pools per 100 m were compared by a two-sample t-test.

Salmonid assemblages. -The assemblage of juvenile anadromous salmonids was sampled once in each stream between 1985 and 1989 (Table 1). Sampling occurred between mid-July and early September. All fish were from naturally reproducing populations; no hatchery supplementation occurred in any stream during the study period. Fish numbers were estimated by 1 or 2 divers between 0900 and 1600 hours. The senior author and one individual made most of the counts. Divers entered a habitat unit at the downstream end and proceeded slowly upstream along the midline of the unit, identifying and counting juvenile anadromous salmonids. Species and numbers of fish were recorded on a plexiglass slate that had had its surfaces roughened with sandpaper. In units requiring two divers, the estimated number of fish in the unit was the sum of the diver counts. Species identified and counted were chinook salmon *Oncorhynchus tshawytscha,* coho salmon 0. *kisutch,* 1-year-old and older steelhead 0. *mykiss,* and 1-year-old and older cutthroat trout *0. clarki.* Sculpins *Cottus* spp. either were the only other fish

TABLE 2.-Number of wood pieces and number of pools per 100 m of stream in paired coastal Oregon basins with low (≤25%) or high (>25%) levels of timber harvest.

Basin	Level of harvest	Wood pieces[a] per 100 m			Pools per 100 m		
		Mean (SD)	t (df)	*P*	Mean (SD)	t (df)	*P*
Franklin Creek	Low	12.1 (8.7)	13.4 (50)	<0.01	9.5 (3.4)	1.9 (50)	0.07
Knowles Creek	High	3.4 (2.9)			8.6 (3.0)		
Upper Flynn Creek	Low	11.2 (5.4)	3.6 (36)	co.01	16.3 (5.0)	4.9 (36)	co.01
Deer Creek	High	5.6 (4.2)			9.8 (3.3)		
Lower North Fork Elk River	Low	6.2 (3.9)	4.6 (19)	co.01	4.6 (1.0)	1.1 (19)	0.28
Butler Creek	High	0.5 (0.7)			4.0 (2.0)		

[a] Minimum size of wood pieces was 0.3 m in diameter and 3 m in length.

or were the predominant nonsalmonid found in each stream.

Because of poor underwater visibility in Knowles Creek, the population estimate was made by electrofishing with a portable battery-powered backpack electroshocker. Boundaries of habitat units were blocked with nets and the unit was shocked beginning at the downstream end. Passes were made until there was a 75% reduction in the number of fish of each type captured on successive passes. The Moran-Zippan equal-effort removal estimator (Seber 1982) was used to generate the population estimates for individual habitat units.

Habitat units sampled for fish numbers were selected systematically. In each stream, 20-25% of pools, 10% of riffles, 1 O-l 5% of glides, and 50-100% of side channels were sampled. The total number of fish of each species was estimated for each habitat type. Estimated numbers in each habitat type were summed to derive the estimated total population for the basin (Hankin and Reeves 1988). Because diver counts were not calibrated (as per Hankin and Reeves 1988), population estimates presented are relative estimates. Based on previous experience, we assumed divers observed the same fraction of each species in each basin.

Two attributes of biotic diversity, species richness and dominance, are generally considered in community studies. We only examined dominance, however. We did not consider species richness because we could not definitively identify the reason for the absence of a species in some basins, particularly those with high harvest levels. We believed that any consideration of species richness could be biased. We used the Berger-Parker index, $d = N_{\max}/N$, where $N_{\max}$ is the number of individuals of the most abundant species and N is the total number of individuals in the assemblage, to measure dominance (Berger and Parker 1970). This index is independent of number of species but is influenced by sample size (Magurran 1988). We expressed diversity as $1/d$ so that higher values were associated with higher diversity (Magurran 1988).

A two-sample t-test was used to compare diversity of the assemblages in the two categories of basins. Partial correlation analysis was used to evaluate the relation between assemblage diversity and level of timber harvest while the influences of basin size and gradient were controlled.

Densities of fish in the two categories of streams were compared with a two-sample t-test. In comparing mean density of individual species, streams that did not have any fish of a given species were excluded from the analysis. This was done so as not to bias the analysis by including streams where a particular species may not occur naturally.

Results

Physical Habitat

Stream habitats in basins with low timber harvest levels were more diverse than habitats in basins with high levels of harvest. In the paired comparisons, streams in low-harvest basins had significantly more pieces of wood per 100 m — 2-12 times more- than streams in high-harvest basins (Table 2). Streams in low-harvest basins also had 10-47% more pools per 100 m than did streams in high-harvest basins; the difference in pool frequency was highly significant in one comparison, moderately significant in another, and not significant in the third.

Salmonid Assemblages

Salmonid assemblages in basins with high harvest levels were dominated by a single species more often than were assemblages in low-harvest basins (Table 3). As a consequence, juvenile anadromous

TABLE 3. - Species composition and diversity of juvenile anadromous salmonid assemblages in coastal Oregon basins with low and high levels of timber harvest.

	Species composition				
Basin or statistic	≥1-year-old steelhead (%)	≥1-year-old cutthroat trout (%)	Coho salmon (%)	Chinook salmon (%)	Diversity[a]
		Low harvest level (≤ 25%)			
Upper Flynn Creek	0	4.7	95.3	0	1.05
South Fork Drift Creek	2.9	4.0	93.1	0	1.07
Franklin Creek	12.5	2.3	85.1	0	1.18
Red Cedar Creek	61.2	0	38.8	0	1.63
Lower North Fork Elk River	59.0	3.2	27.2	10.7	1.69
Cummins Creek	35.5	4.8	62.7	0	1.59
Lower Panther Creek	47.5	0.1	48.4	5.3	2.07
Mean					1.470
Variance					0.381
		High **harvest level** (> 25%)			
Needle Branch Creek	0	0.9	99.1	0	1.01
Deer Creek	0	1.8	98.2	0	1.02
Canal Creek	2.3	0.3	97.3	0	1.03
Knowles Creek	2.1	2.1	95.1	0	1.05
Bald Mountain Creek	91.7	8.3	0	0	1.09
Butler Creek	93.1	3.6	0	3.2	1.09
Cape Creek	15.9	1.2	82.8	0	1.21
Mean					1.068
Variance					0.068

[a] Inverse of dominance index (1/*d*).

salmonid assemblages were significantly more diverse in low-harvest basins (1/d = 1.47 ± 0.381) than in those with high harvest (1/d = 1.07 ± 0.068; t = 2.745, df = 12, P = 0.02). This pattern held when basins were stratified by rock type, size, and geographic location (Figure 2).

Percent of basin harvested was the variable most highly associated with assemblage diversity. The

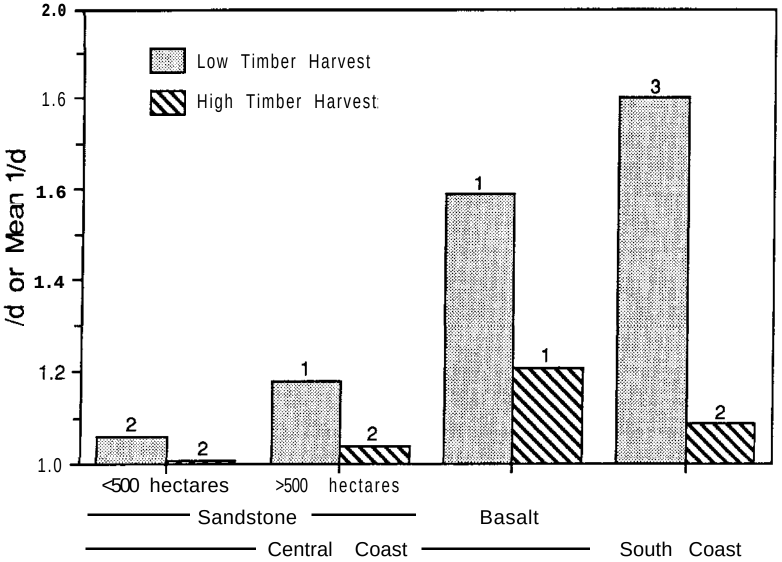

FIGURE 2. -Diversity of juvenile anadromous salmonid assemblages (1/*d*) in coastal Oregon streams of different size, rock type, and geographic location. Numbers above bars are numbers of basins.

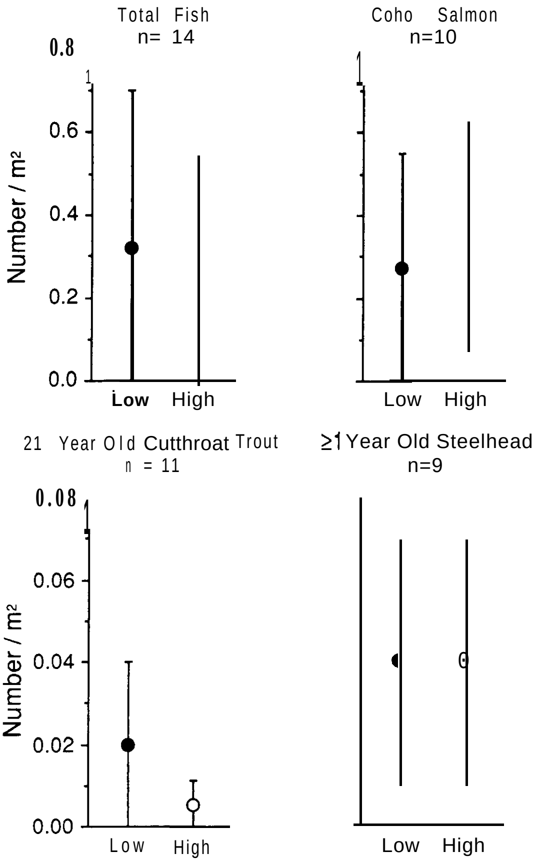

FIGURE 3. -Mean relative densities (±SDs) of juvenile anadromous salmonids in streams in coastal Oregon basins with low (≤ 25%) or high (> 25%) levels of timber harvest. Note differences in scale among groups.

partial correlation was -0.532, and it explained 29% of the observed variation after adjustments were made for the influences of basin area and gradient. This correlation was significant at P = 0.07. Basin area and gradient accounted for 1.5% and 14.4% of the variation in assemblage diversity, respectively, after adjustments were made for the influences of the other variables. Significance levels were P = 0.90 for area and P = 0.22 for gradient.

At the level of individual species or total fish, there were no differences in the mean densities between basins with different harvest levels. Mean total density and cutthroat trout density were higher in streams of low-harvest basins (Figure 3), but not significantly so (t = 0.222, df = 14, P = 0.82 for total density; t = 1.234, df = 11, P = 0.23 for cutthroat trout density). Likewise, mean densities of coho salmon (t = -0.368, df = 10, P = 0.72) and steelhead (t = -0.001, df = 9, P = 0.99) did not differ between harvest levels (Figure 3).

Discussion

Physical Habitat

Our results support the idea that wood is a primary element influencing habitat diversity and complexity in streams. Consequences of decreased amounts of wood include loss of cover and structural complexity (Bisson et al. 1987; Hicks 1990), decreased availability and abundance of habitat units (Grette 1985; Sullivan et al. 1987; Bilby and Ward 199 l), and reduced variety of current velocities and other hydraulic features (Kaufmann 1987). Habitat simplification, in turn, may influence the structure and composition of fish assemblages.

Salmonid Assemblages

The apparent response of juvenile anadromous salmonid assemblages to decreased habitat complexity was a decrease in assemblage diversity. Similar results were reported by Bisson and Sedell (1984) for Washington streams, by Hicks (1990) for coastal Oregon streams, and by Rutherford et al. (1987) for Oklahoma streams when they examined the effects of timber harvest on fish communities. Corn and Bury (1989) found that the diversity of amphibians was greater in streams in uncut forests than in streams in logged stands of the Oregon Coast Range. Similar patterns of decreased diversity of fish communities has been observed in streams altered by other anthropogenic activities such as agriculture (Schlosser 1982; Berkman and Rabini 1987) and urbanization (Leidy 1984; Scott et al. 1986).

Differential Response

Species in the assemblages examined did not appear to respond to environmental alterations as a single unit. Rather, one species appeared to be affected positively or not at all while others were negatively affected. Numbers of coho salmon smolts leaving Carnation Creek, British Columbia, increased after timber harvest (Holtby 1988); concurrently steelhead and cutthroat trout smolt numbers declined (Hartman 1988), and survival of chum salmon *Oncorhynchus keta* decreased (Scrivener and Brownlee 1989). Gurtz and Wallace (1984) observed a differential response by benthic macroinvertebrates to clear-cut logging in a second-order stream. Examination of individual species or total fish responses may mask community-level effects.

Our findings suggest that the pattern of response by the species and assemblages examined was not consistent among basins, however. For example, Canal Creek had "good numbers" of cutthroat trout, steelhead, and coho salmon and a large population of spawning chum salmon in the mid to late 1950s (Oregon Fish Commission 1955), before major timber harvest activities began in the basin. Coho salmon were the dominant species in our survey and trout were only a small component of the community (Table 3). Chum salmon are no longer found in Canal Creek. In contrast, coho and chinook salmon were found in Bald Mountain Creek in the early 1960s, before major timber harvest activities began (U.S. Forest Service 1991). We observed trout but no salmon in 1985.

We believe the observed variability of species response to environmental alterations is related to the suitability of the habitat for the particular species. A major difference between Bald Mountain Creek and Canal Creek was gradient; mean gradients were 2.5 and 0.8%, respectively. Coho salmon are more suited to slower water and trout are more suited to faster water (Bisson et al. 1988). Loss of structure in higher-gradient streams may result in the loss of slow-water habitat and thus would be less favorable to coho salmon. Loss of higher-velocity areas associated with large wood in lower-gradient streams may result in conditions less suitable for cutthroat trout. Rutherford et al. (1987) attributed changes in fish communities in Oklahoma streams that had been subjected to timber harvest to the tolerance of species for environmental extremes; species with the greatest tolerances were able to maintain themselves better than were species with smaller tolerance ranges.

We do not know if the salmonid assemblages in the basins with high levels of timber harvest will recover to preharvest composition in the near future. Schwartz (1991) found that cutthroat trout populations in streams with coho salmon in clear-cut areas appeared not to have recovered up to 25 years after harvest. Recent work by Hicks (1990) and Bilby and Ward (1991) suggests that habitat is slow to recover to preharvest levels of complexity. Gurtz and Wallace (1984) hypothesized that stream biotas may not be able to recover from the effects of timber harvest. They believed that timber harvest has no analogue in the natural disturbance regime and, therefore, that organisms may not have evolved an appropriate response. Yount and Niemi (1990), modifying the definition of disturbance of Bender et al. (1984), classified timber harvest as a "press disturbance." This suggests that species will respond differentially to the disturbance and also that the system may not recover to predisturbance states.

Our results suggest that at the basin or subbasin scale, the level of timber harvest activities affect the structure and composition of assemblages of juvenile anadromous salmonids. Concerns about the effects of timber harvest activities have previously focused on a reach scale (e.g., Hawkins et al. 1983; Carlson et al. 1990). Such studies have shown no or negligible effects on fish. Because the effects of such activities may extend to downstream areas, a broader spatial context is needed to fully evaluate the extent and magnitude of the effects on fish and fish habitat.

We do not intend to imply from this study that habitat simplification resulting from timber harvest (or other land management activities) is the only factor responsible for the current depleted status of anadromous salmonid stocks in the Pacific Northwest. Other consequences of such activities may influence juvenile anadromous populations, such as increased sedimentation (Everest et al. 1987) and elevated water temperatures (Beschta et al. 1987). Undoubtedly, factors such as overexploitation in recreational and commercial fisheries, migration impediments, habitat destruction, and genetic alteration and disease introductions from hatchery practices (Nehlsen et al. 1991) also influence assemblage attributes directly or indirectly. The importance of each factor is unknown at present, but it probably varies greatly among watersheds and regions. Interactions of these factors will be difficult to interpret. Nevertheless, we believe the results from this study suggest that timber harvesting can cause basin-level habitat simplification and that such simplification can reduce the diversity of juvenile anadromous salmonid assemblages.

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