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TIMBER MANAGEMENT/FISH MANAGEMENT PRODUCTIVITY

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SALMONID POPULATIONS IN STREAMS IN CLEARCUT VS. OLD-GROWTH FORESTS OF WESTERN WASHINGTON

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ABSTRACT

Cutthroat trout (*Salmo clarki*), juvenile steelhead trout (*S. gairdneri*), and juvenile coho salmon (*Oncorhynchus kisutch*) were sampled during the low-flow period of summer to compare population biomasses in western Washington streams flowing through old-growth forests with those in areas recently clearcut. In paired logged and unlogged sites, total salmonid biomasses averaged 1.5 times greater after logging than in adjacent unlogged sections. Among all sites (paired plus unpaired locations), total salmonid biomasses were 2.0 times greater, on average, in clearcuttings. Streams in logged watersheds contained higher percentages of age-0+ steelhead and age-0+ cutthroat trout, and lower percentages of age-0+ coho salmon and age-I+ and -2+ cutthroat, compared to streams in old-growth forests. Shifts in species and age composition were related to habitat changes that resulted from timber harvesting and debris removal from the channels. Large, stable organic debris declined and unstable debris increased after passage o: forest practices legislation that mandated immediate debris removal following logging. Pool volumes decreased and riffle volumes increased after streambank disturbances and channel clearance, although the frequency (number per km) of both pools and riffles was lower in streams flowing through clearcut sites. Riffles in streams that underwent extensive debris removal were elongated and in many cases extended through former pool locations. Increases in the proportional abundance of underyearling steelhead and cutthroat trout after clearcutting is possibly explained by the preference of these fishes for riffle habitat, while the relative decline of coho and older cutthroat may have resulted from the loss of pool volume and large, stable debris for cover.

INTRODUCTION

Studies of the impacts of logging on salmon and trout in streams of the Pacific Northwest have yielded conflicting results. Hall and Lantz (1974, 1975) found that cutthroat trout populations in the Alsea watershed of western Oregon declined after clearcutting and slash burning the adjacent forest. More recently, Murphy and Hall (1981) and Murphy *et al.* (1981) concluded that for streams in the Oregon Cascade Range, increased food production resulting from forest canopy removal masked or overrode the effects of sedimentation attributable to logging and led to higher levels of trout production. Elevated levels of algae and invertebrates caused by clearcutting have also been documented for streams in southeast Alaska by Weber (1981). Other studies published within the last decade (Burns 1972; Narver 1972; Aho 1976; Chapman and Knudsen 1980; Osborn 1980) have cited instances of increased salmonid carrying capacity in streams where the vegetative canopy had been reduced. These results have led to speculation that temporary increases in productivity can be expected after logging, provided that major disruptions to the stream channel do not occur.

The objective of our study was to extend the comparison of clearcut and old-growth watersheds to a number of drainages in western Washington to determine whether salmonid biomasses were consistently elevated in recently logged areas. We examined fish populations from both the southwest Washington Coast Range and the west slope of the Cascade Range. Biomass per unit area, age structure, and species composition of the salmonid communities were determined during the summer low-flow period. The surveys also included measurements of pool and riffle volume and frequency, and counts of the number of pieces of large woody debris within the channels. Results from this study are compared to those of other small-to-intermediate-sized watersheds (≤ 3,000) ha) in the Douglas fir region.

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STUDY AREA

A total of 25 stream sites were sampled, including 13 sites in unlogged forests (>75 yrs) and 12 sites in recent clearcuttings (1-11 yrs) (Fig. 1, Table 1). Among these were nine adjacent forested and clearcut pairs, and seven sites that represented only one condition. Riparian zones along old-growth forested streams were dominated by Douglas fir, western hemlock, and western red cedar. Buffer strips were not left along any streams in the logged sites, except for occasional non-merchantable timber such as small red alder and vine maple. In a few streams that had been logged more than six years previously, dense stands of red alder had begun to grow in the riparian zones. These trees, however, provided less than 10 percent shading to the channels. Streamside logging procedures were typical of those practiced in western Washington. Most trees were felled, bucked, and yarded away from the streams, but some trees entered the channels and were bucked in place. Wherever large amounts of logging slash occurred, this material was removed by hand to above the estimated high-water margin of the channel. Logging slash removal from streams was more thorough in watersheds logged after 1976, when the Washington Forest Practices Act took effect.

The study sites encompassed a variety of geological conditions. The most common condition was characterized by highly dissected valleys possessing weathered volcanic rock and deep, fine-textured soils. This group included the Grays River tributaries, Summers Creek (Kalama River drainage), Otter Creek (Tilton River drainage), and the Chehalis River tributaries. A second condition was characterized by hard, resistant volcanic rock and predominantly shallow, stony soils; included in this group were Wolf Creek (Kalama River drainage), Ware Creek (Deschutes River drainage) and Jessie Creek (Tilton River drainage). Fall River (Willapa Bay drainage) flowed over marine sandstone deposits, while the Hoh River watershed was characterized by wide glaciated valleys, hard sedimentary rock, and shallow, stony soils.

Streams in valley walls were steep (≥ 4% gradient), usually with small drainage areas, while streams in valley floors possessed a shallower gradient (4%) and tended to have large drainage areas. Study streams ranged from third- to fifth-order channels.

TABLE 1. Characteristics of the study streams

Stream	Condition	Drainage (ha)	Gradient (%)	Forest Age (yr)	Physiographic Province
Grays River					
Tributary 12	Forested	101	5	330	Coast Range
	Clearcut	108	6	2	Coast Range
Tributary 13	Forested	189	7	330	Coast Range
	Clearcut	205	7	2	Coast Range
Tributary 21	Forested	277	6	330	Coast Range
	Clearcut	324	3	2	Coast Range
Kalama River					
Summers Creek	Forested	1109	5	75	Cascade Range
	Clearcut	961	5	5	Cascade Range
Wildhorse Creek	Forested	702	4	114	Cascade Range
Wolf Creek	Clearcut	715	8	11	Cascade Range
Tilton River					
Jessie Creek	Forested	487	8	113	Cascade Range
Otter Creek	Forested	454	8	118	Cascade Range
Willapa Bay					
Fall River	Forested	3039	1	75	Coast Range
	Clearcut	3025	1	7	Coast Range
Chehalis River					
Salmon Creek	Forested	877	3	120	Coast Range
	Clearcut	456	4	1	Coast Range
Newaukum River	Forested	2057	1	130	Cascade Range
	Clearcut	2018	2	5	Cascade Range
Mack Creek	Clearcut	252	5	3	Coast Range
Thrash Creek	Clearcut	1063	3	8	Coast Range
Deschutes River					
Ware Creek	Forested	280	8	130	Cascade Range
	Clearcut	285	8	6	Cascade Range
Mainstem/W. Fk.	Forested	866	4	130	Cascade Range
	Clearcut	740	5	5	Cascade Range
Hoh River					
Unnamed Trib.	Forested	275	7	275	Coast Range

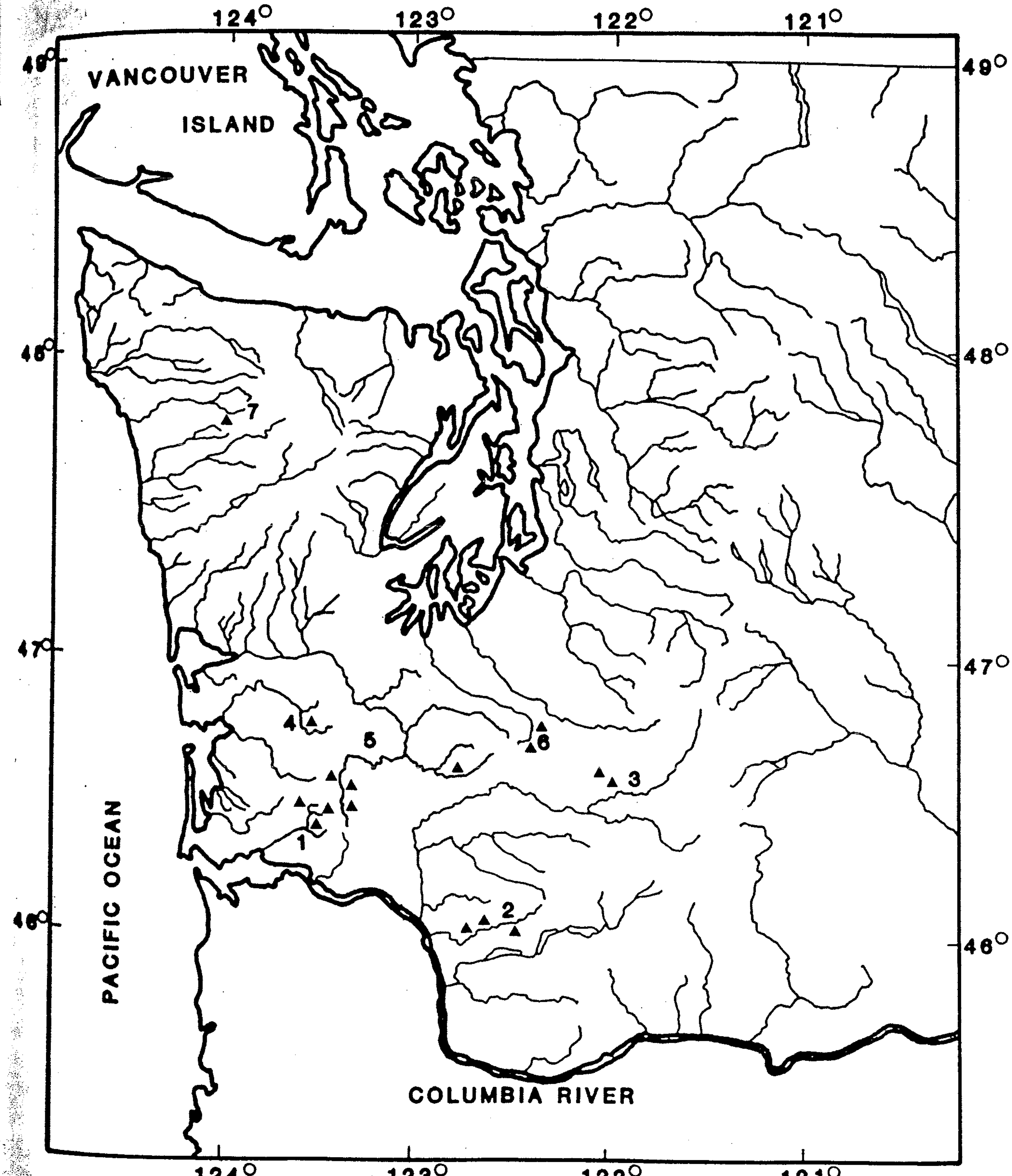

Figure 1. Location of study streams in western Washington: (1) Grays River, (2) Kalama River, (3) Tilton River, (4) Fall River (Willapa Bay drainage), (5) Chehalis River, (6) Deschutes River, and (7) Hoh River.

METHODS

Fish populations were sampled with a pulsed-DC portable fish shocker. Samples were taken during 1978-1979 at Grays River, Kalama River, and Tilton River by isolating 40- to 200-m stream reaches with blocking nets and performing two passes with the shocker. Samples in 1980-81 (all other sites) were obtained by isolating individual habitats and performing three passes with the shocker. Population estimates for the 1978-79 period employed the method of Seber and LeCren (1967), while estimates for the 1980-81 period used a modified removal summation method (Carle and Strub 1978) that corrected for small samples. Although the two techniques differed slightly, population estimates obtained during both periods were similar and are believed to be comparable. All of the study streams were located on privately owned timberland, and, to our knowledge, none had received significant sport fishing pressure.

Following capture, salmonids were anesthetized and measured to the nearest millimeter. Weights were estimated from length-weight regressions that had been established from subsamples. For the three salmonid species encountered during the study, the length-weight regressions were:

cutthroat trout	$w = (1.056 \times 10^{-5})\ L^{2.98}$	(1)
steelhead trout	$v = (1.797 \times 10^{-5})\ L^{2.88}$	(2)
coho salmon	$w = (1.611 \times 10^{-5})\ L^{2.91}$	(3)

where w = blotted wet weight (g) and L = fork length (mm). Age determinations were based on samples of scales from various size-classes of fish.

Habitat conditions in the study streams were characterized by drawing maps of selected reaches to scale. The mapping technique was similar to the debris mapping technique of Swanson *et al.* (1976) and identified individual riffle and pool habitats, and also showed bottom contours, which facilitated estimates of habitat volume. During 1979, the abundance of large organic debris was recorded in the study sites as well as in the 44 additional stream sites, most of which were located in the southwest Washington Coast Range. All pieces of wood debris > 10-cm diameter in the exposed channel were recorded, and were divided into those greater than, and less than, 3 m long. Streams in which debris was surveyed were classified as either old-growth, streams logged prior to the 1976 Washington Forest Practices Act, or streams logged after 1976.

RESULTS

Total salmonid biomasses were significantly greater in streams in logged sites than in streams in old-growth forests (Table 2). Among the paired sites, which were believed to yield the most valid comparison, average salmonid biomass was 1.5 times greater in streams in clearcuts than those in forested sites ($p < 0.05$, paired *t*-test). Among all sites (paired plus unpaired), biomass in streams in clearcuts was 2.0 times greater than in streams in old-growth forests ($P < 0.05$, analysis of variance, data transformed $\ln[x + 1]$), but there were highly significant ($P < 0.01$) differences among sample streams. No differences existed between average biomasses in streams in the Coast Range vs. streams in the Cascade Range; however, Chehalis River populations exhibited greater biomasses in streams in both forested and logged watersheds than did populations in the other river systems.

Average total salmonid densities among paired sites were similar (Table 2), but, for all sites, average density in streams in clearcuts exceeded that of streams in old-growth forests by 1.6 times. However, this difference was not significant due to high inter-site variation. The overall effects of clearcutting on salmonid communities were more strongly expressed in biomass differences than in density differences.

Shifts in the composition of species and age-groups also took place following logging (Table 3). Population structure was compared in streams having (1) cutthroat trout only, (2) cutthroat and steelhead, and (3) cutthroat, steelhead, and coho. Where cutthroat was the only salmonid, age structure shifted in streams in logged sites to favor age-0+ fish, with a corresponding proportional (but not absolute) decline in the numbers of age-1+ and 2+ fish. Where both cutthroat and steelhead were present, cutthroat dominated streams in the old-growth sites, while steelhead dominated streams in the clearcut sites. Where cutthroat, steelhead, and coho occurred together, cutthroat were very infrequent and were represented by only age-1+ and 2+ individuals. The proportion of underyearling steelhead increased in streams in clearcuts, but underyearling coho exhibited proportional density reductions there compared to streams in old-growth forests.

The proportional reduction of age-0+ coho and age-1+ and 2+ cutthroat in the logged watersheds was probably related to habitat alteration. Underyearling coho, and yearling and older cutthroat and steelhead, prefer pool habitats (Fig. 2; see also Hartman 1965; Lister and Genoe 1970; Griffith 1972; Allee 1974; Bustard and Narver 1975a, 1975b; Nickelson and Hafele 1978; Cleugh *et al.* 1979), particularly those associated with abundant cover. In our study streams, only underyearling steelhead and cutthroat showed a preference for riffles. On the average, pools were less frequent in streams in logged

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TABLE 2. Total salmonid biomass and density in the study streams

Stream		Biomass (g/m²)		Density (no./m²	
		Forested	Clearcut	Forested	Clea
Grays River					
Tributary 12		0.75	0.98	0.10	1.
Tributary 13		1.46	1.14	0.08	0.
Tributary 21		1.03	1.53	0.10	0.
Kaluma River					
Summers Creek		1.23	3.15	0.10	0.
Wildhorse Creek		1.15	no data	0.06	nc
Wolf Creek		no data	3.51	no data	0.
Tilton River					
Jessie Creek		1.85	no data	0.12	nc
Otter Creek		1.74	no data	0.12	nc
Willapa Bay					
Fall River		1.59	0.91	0.60	0.
Chehalis River					
Salmon Creek		5.22	9.62	0.80	0.
Newaukum River		2.51	2.69	0.27	0.
Mack Creek		no data	6.13	no data	0.
Thrash Creek		no data	7.33	no data	1.
Deschutes River					
Ware Creek		1.60	2.71	0.45	0.
Mainstem/W. Fork		1.53	2.72	0.16	0.
Hoh River					
Unnamed Trib		2.05	no data	0.66	no
Totals					
Paired sites	$\bar{x}$	1.88	2.83	0.30	0.
	SE	0.42	0.85	0.09	0.
All sites	$\bar{x}$	1.82	3.54	0.28	0.
	SE	0.30	0.76	0.02	0.

TABLE 3. Comparison of species and age-group composition in forested and clearcut streams. Means are follc standard errors (in parentheses)

Community composition	Condition	No. of sites	Percent of total salmonid density					
			Cutthroat			Steelhead		Co
			0+	1+	2+	0+	1+	0
Cutthroat only	Forested	8	31(10)	54(8)	15(3)			
	Clearcut	8	58(5)	32(4)	10(2)			
Cutthroat, steelhead	Forested	2	14(6)	25(15)	20(6)	33(5)	10(3)	
	Clearcut	3	4(4)	19(11)	10(4)	45(22)	21(13)	
Cutthroat, steelhead, coho	Forested	2	0(0)	3(1)	2(1)	64(4)	7(4)	2
	Clearcut	2	0(0)	1(0)	1(0)	74(20)	7(5)	2

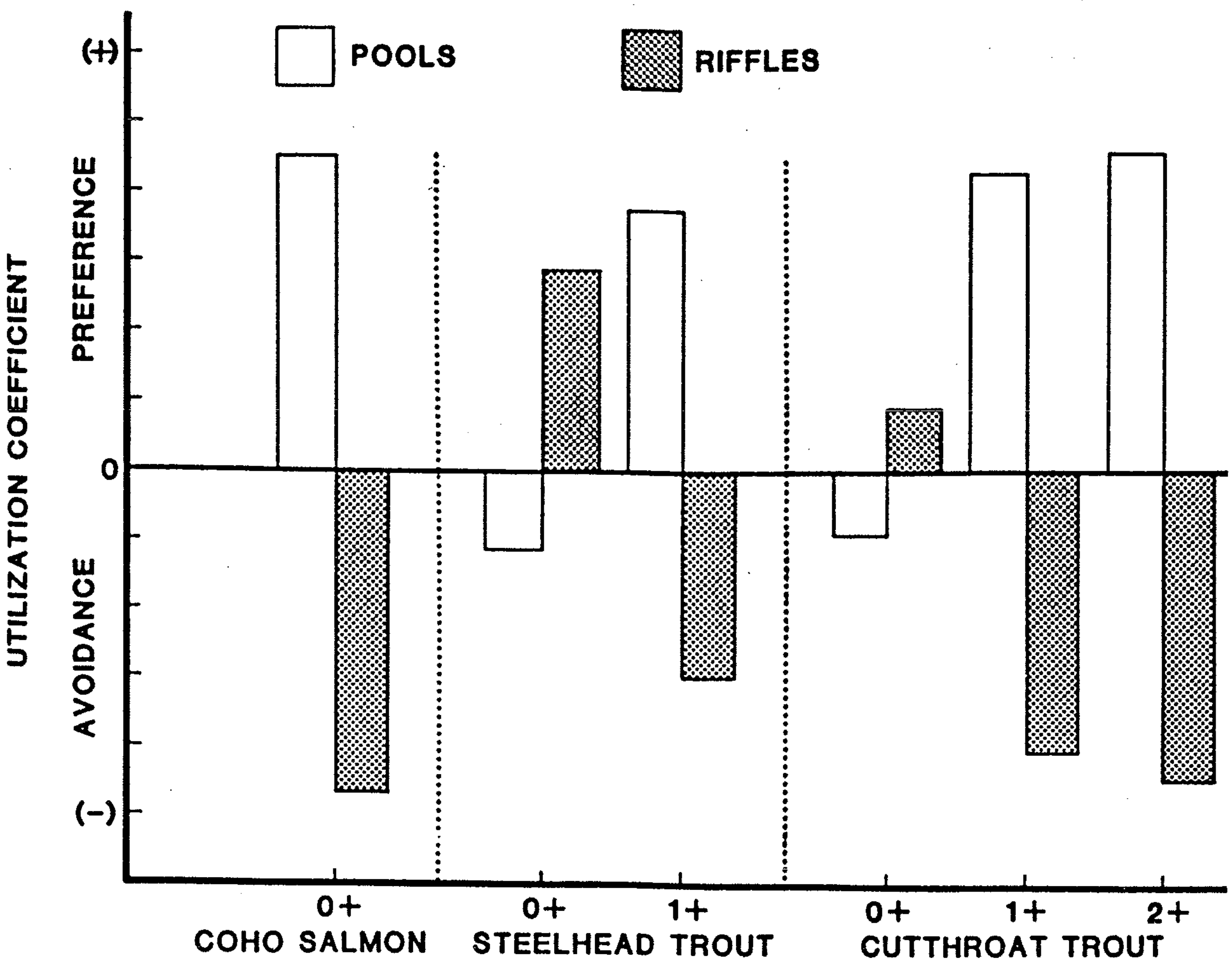

Figure 2. Relative habitat preferences of salmonids, as determined from samples taken during 1980-81. The formula used to calculate the habitat utilization coefficient was as follows:

$$\text{Utilization}^* = \frac{\textit{habitat specific density - average total density}}{\textit{average total density}} \quad (4)$$

where: habitat specific density = average density in the habitat type of interest

average total density = average density over the entire stream reach, all habitats combined

*values range from -1 to + infinity.

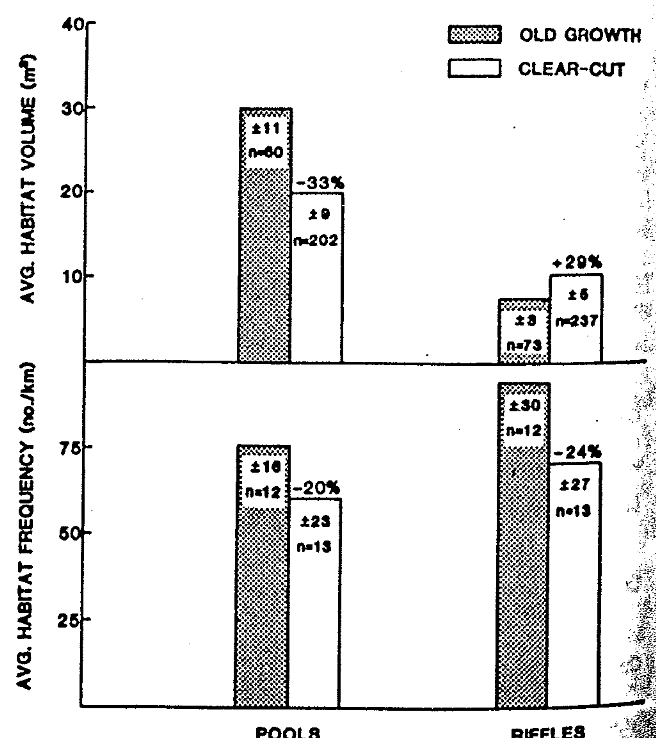

Figure 3. Comparison of volumes and frequencies of pools and riffles in streams in old-growth forests with streams in recently clearcut areas. Ninety five pecent confidence limits and sample sizes are indicated within each bar.

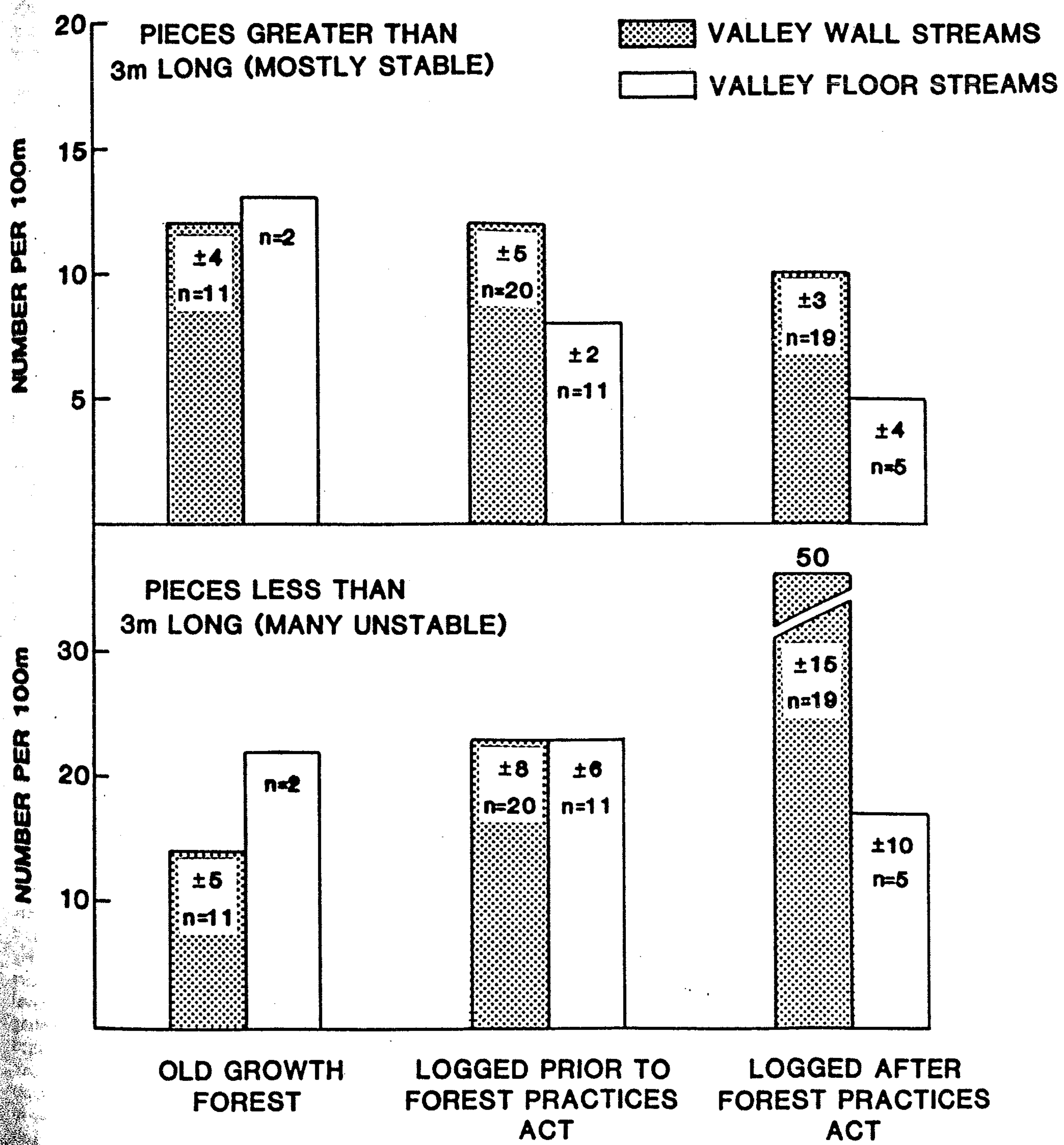

Figure 4. Abundance of large organic debris (>10-cm diameter) in the study streams. Ninety five percent confidence limits and sample sizes are indicated within each bar.

sites, and they were smaller (Figure 3), although variation because of stream size prevented the differences between old-growth and clearcut sites from being statistically significant. Riffles also tended to be less frequent, but, unlike pools, they became more elongated and were observed to extend through areas that formerly held pools.

Large, stable woody debris declined in streams in clearcut sites compared to that in streams in old-growth forested sites. Reductions in the stable wood component were most apparent in valley floor streams that were logged and cleaned after passage of forest practices legislation that mandated immediate debris removal (Figure 4). The frequency of unstable (< 3-m) debris, however, sharply increased in valley wall streams wh watersheds were logged after the Forest Practices A apparently as the result of re-entrainment during fresh of short chunks that had been bucked in the channel a placed on the stream bank. These short pieces were oft found clumped together in debris dams with a lo sediment terrace and associated riffle upstrea Although the amount of wood present in a given chan within a clearcut site was highly variable, the gene trend was toward a less-even spacing of debris, sporad accumulations in dams, and reduced frequency of lon stable pieces that provided cover and contributed to po formation.

DISCUSSION

The complex, interacting changes that result from logging include both positive and negative influences on salmon and trout production. Removal of the forest canopy allows more solar radiation to penetrate to the stream channel, causing temperature increases (Brown 1970) and elevated algal growth (Lyford and Gregory 1975). Both of these processes can increase fish production unless thermal change and algal accumulation become excessive, at which point production can be reduced (Bisson and Davis 1976). Similarly, physical habitat changes associated with logging activities may result in conditions that favor certain species or age-groups at the expense of others. For example, the removal of woody debris may facilitate the upstream migration of anadromous species, while at the same time releasing large quantities of stored sediment and organic material (Beschta 1979; Bilby and Likens 1980) and eliminating the structural features of the channel that result in pool formation (Swanson and Lienkaemper 1978; Bryant 1980).

Against this complex backdrop of causes and effects it is interesting that summer biomasses increased in most cases in the recently clearcut watersheds we studied. Among all sites, there was an average doubling of biomass in clearcut compared to old-growth forested watersheds; and within the paired sites, seven out of nine pairs were highest where logging had occurred. The magnitude of change (1.5-2x) approximated the increases observed in streams in logged areas of northern California and Oregon by Burns (1972), Aho (1976), and Murphy and Hall (1981).

Two different, but not mutually exclusive, hypotheses have been advanced to explain elevated carrying capacity of fish populations following stream-side timber removal. The "increased food" hypothesis was first suggested, but not confirmed, by Warren *et al.* (1964) and Hall and Lantz (1969). Recent support for this hypothesis has come from Murphy *et al.* (1981) and Weber (1981), who found higher densities of benthic invertebrates in streams where the timber canopy had been removed, and from Smith (1980), who noted reduced invertebrate and trout populations following stream-side afforestation. The "increased temperature" hypothesis advanced by Narver (1972) held that stream temperature elevations resulted in earlier emergency of fry, increased appetite, and a prolonged growing season. Recent evidence for this hypothesis has been provided by Osborn (1980) and t preliminary data from the Carnation Creek watersh study on Vancouver Island, British Columbia (Hartma 1981). In our view, both processes could have been acti together to promote the higher summer biomasses w found in streams in logged watersheds. Stream grave following canopy removal visually appeared to posse more periphyton, and spot checks of temperature showe that streams in clearcuts were often several degre (Celsius) higher than in adjacent forested reaches, whe the logged site was downstream from the forested site

Our finding that steelhead trout biomass, particularl of age-0+ fish, increased with logging-related habita alteration agrees with a study of Northern Californi streams by Burns (1972), who found that filling of poo with sediment resulted in expanded riffle areas. In th same study, Burns noted a reduction in the biomass o large trout and underyearling coho. Hartman (196 showed experimentally that steelhead actively defen territories in riffles but not those in pools; for coho, th opposite is true. Chapman and Knudsen (1980) have als suggested that increases in abundance of underyearlin trout may have been related to the decline in predato populations (i.e., older trout). Whatever the mechanism it seems clear from our observations, as well as fro other studies, that alterations of physical habitat that ar caused by cover removal and channel destabilization lea to a shift in species and age composition within th community, which enhances fish that are not dependen upon pools and cover but may not favor fish that strongl prefer these habitat features.

The conclusion that salmonid biomasses wer generally higher in streams in recent clearcuts mus therefore be tempered with the observation that carryin capacity increases were not shared equally among specie or age-groups. Regulations prescribing debris remova were enacted with the primary intent of preventin blockages to migration; however, some streams cleane since passage of stream-protection legislation now hav reduced quantities of large, stable debris that create pool and provide cover. A change of regulatory policies i light of recent evidence could, in certain instances, resul in forest management practices that would combine th benefits of canopy removal with the maintenance o adequate pools and cover, with the goal of enhancing al species and age-classes.

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