

Varied Effects of Clear-cut Logging on Predators and Their Habitat in Small Streams of the Cascade Mountains, Oregon¹

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Assemblages of aquatic vertebrate and insect predators were inventoried in streams in old-growth and logged coniferous forests in the western Cascades of Oregon to assess effects of clear-cut logging on stream communities. Effects associated with logging depended on stream size, gradient, and time after harvest. Clear-cut sections where the stream was still exposed to sunlight (5-17 yr after logging) generally had greater biomass, density, and species richness of predators than old-growth (>450-yr-old) forested sections. Increases were greatest in small (first-order), high gradient (10-16%) streams, where clear-cut sites had both greater periphyton production and coarser streambed sediment than old-growth sites of similar size and gradient. Effects on predators were mixed in larger, lower gradient streams, where clear-cut sites showed accumulation of sediment and relatively small increases in periphyton production. Second-growth logged sections (12-35 yr after logging), reshaded by deciduous forest canopy, had lower biomass of trout and fewer predator taxa than old-growth sites.

Key words: trout, salamanders, insects, logging, sediment, periphyton, watershed management

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Un inventaire des groupements de vertébrés aquatiques et d'insectes prédateurs dans des cours d'eau de forêts de conifères âgés ou soumis à l'exploitation forestière dans les Cascades occidentales de l'Orégon, ont permis d'évaluer les effets de l'abattage à blanc sur ces communautés. Les effets de l'exploitation forestière dépendent de la taille et du gradient du cours d'eau, et de la période qui suit la récolte. Les sections d'abattage à blanc dans lesquelles les cours d'eau sont encore exposés à la lumière solaire (5-17 ans après abattage) ont généralement une biomasse, une densité et une diversité d'espèces de prédateurs supérieures à celles des sections de bois âgés (>450 ans). Les augmentations sont les plus grandes dans les petits cours d'eau (de premier ordre) à gradient élevé (10-16%), où les sites d'abattage à blanc sont caractérisés par une plus grande production de périphton et un lit à sédiment plus grossier que les sites de même étendue et de même gradient de bois âgés. Les effets sur les prédateurs sont mixtes dans les grands cours d'eau à faible gradient, où il y a accumulation de sédiments et augmentations relativement faibles de production de périphton. Les sections de seconde croissance (12-35 ans après exploitation), ombragées de nouveau par un canapé de forêt caducue, ont une biomasse de truites moins abondante et un nombre moindre de taxa de prédateurs que les sites de bois âgés.

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A primary concern of resource managers in the Pacific Northwest is that logging and road construction in mountainous

terrain may have adverse impacts on aquatic resources. Clear-cut logging can have multiple effects on both physical and trophic conditions in small streams by introducing sediment and logging debris, altering streamflow and temperature regime, increasing nutrient concentrations, altering forms and amounts of organic detritus, and changing rates of aquatic primary production (Gibbons and Salo 1973). Previous studies of logging impacts in the Oregon Coast Range showed substantial declines in cutthroat trout (*Salmo clarki*) popula-

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tions following clear-cutting (Hall and Lantz 1969; Moring and Lantz 1974, 1975). In the western Cascades, however, Aho (1976) found greater abundance of cutthroat trout in a stream flowing through a small clear-cut than in an adjacent upstream section in undisturbed forest. Considering the contradictory results of these studies, we investigated logging impacts in the McKenzie River drainage in the western Cascades to test the generality of Aho's finding and to identify the cause of higher biomass in the clear-cut.

We chose to study effects on predators because the predator functional group (Cummins 1974) derives energy from all lower trophic levels and may integrate total trophic response of the system. By studying predator assemblages we could assess logging impacts on salmonids and their potential competitors, and on the productivity of the stream ecosystem.

We assessed logging impacts by comparing logged and forested sections of streams over a range of stream size and gradient. Because no data were available on prelogging conditions, we assumed that on the average no difference existed between sites before logging. The advantage of this approach is the ability to infer how impacts depend on watershed characteristics, allowing prediction of impacts in similar watersheds given information about stream size and gradient (Hall et al. 1978). Logging impacts will vary, however, among watersheds in different geologic and climatic provinces. Results from this study should be applicable to other first- to third-order streams in areas with moist climate, steep, heavily forested topography, and volcanic parent material.

Materials and Methods

Study sites were located in or near the H. J. Andrews Experimental Forest in the western Cascade Mountains in Oregon (Fig. 1). The steep terrain ranges 400–1600 m in elevation and is heavily forested with Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*). Volcanic parent material underlies soils ranging from shallow and stony to deep clay loam (Rothacher et al. 1967). A maritime climate with about 240 cm precipitation prevails. Above 800 m elevation, snow may accumulate during winter. Lower elevations receive mostly rain. Streams are generally steep and dominated by boulders and large woody debris. Streamflow responds quickly to storms and may be 5000 times greater during winter storms than during summer base flow (Harr 1976).

Streams in old-growth forests were sampled to characterize natural variation for comparison with logged areas. Old-growth sites were undisturbed by logging, except that in some cases clear-cuts were located 1–2 km upstream. Logged areas had been clear-cut without buffer strips and later burned. We divided logged sites into two groups according to their vegetation: clear-cut sites (5–17 yr after logging) where streams were still mostly unshaded by vegetation, and second-growth sites (12–35 yr after logging) that were heavily shaded by deciduous vegetation. We compared old-growth and clear-cut sites to detect early effects of logging. To detect logging impacts that may vary with stream size or gradient, we compared nine pairs of adjacent clear-cut and old-growth sites on streams of different size (first- to third-order, Strahler 1957) and gradient (2–16%). We examined temporal succes-

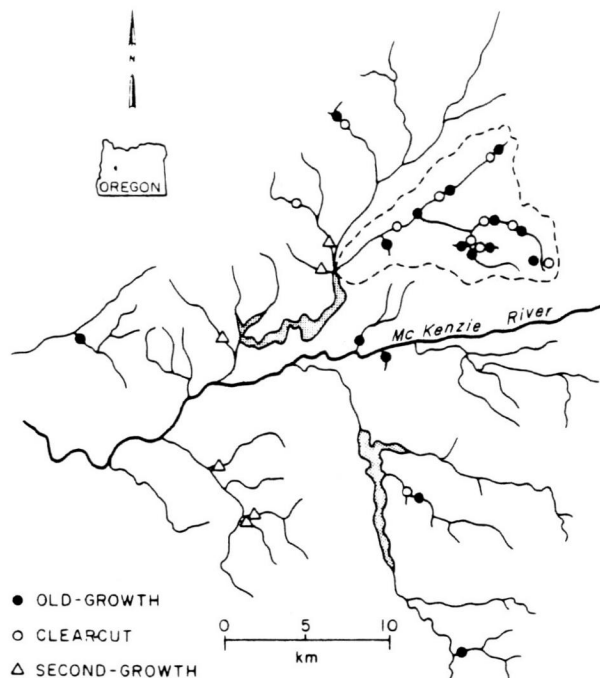


FIG. 1. Locations of the 33 study sites. The H. J. Andrews Experimental Forest is outlined; Blue River and Cougar reservoirs are shaded.

sion after logging by comparing clear-cut and second-growth sites.

Old-growth and clear-cut sites were selected to provide a wide range of drainage area, width, depth, gradient, and elevation (Table 1). Second-growth sites were lower in elevation than other sites because of the historical pattern of logging. Clear-cut sites were mostly exposed to direct sunlight, second-growth sites were densely shaded by deciduous vegetation, and old-growth areas were partially exposed to sunlight because of fallen trees.

For each study site we subjectively classified stream habitat as riffle or pool according to whether stream surface was turbulent or not. During summer low flow, we estimated proportions of these habitats by lateral transects at 2-m intervals for a 30-m length of stream. Quality of pools as habitat for trout was rated by the method of Duff and Cooper (1976).

Size composition of sediment was quantified by visually estimating proportion of streambed surface that was sand-gravel (<3 cm diam) within 0.25-m² quadrats. Density of large crevices (>25 cm³) in the streambed was determined within the same quadrats. Means of 20 quadrat samples, five each in the middle and at the edge of pools and riffles, provided ratings for sediment composition and crevice density for each site.

Volume of large wood debris (>10 cm diam) in the active channel at each site was scaled. The volume of each piece of debris was calculated from the formula:

$$\text{Volume} = (D_1^2 + D_2^2) \cdot \text{length} \cdot \frac{\pi}{8}$$

TABLE 1. Range of physical characteristics of the 15 old-growth, 10 clear-cut, and 6 second-growth sites.

Characteristic	Old-growth	Clear-cut	Second-growth
Drainage area (ha)	30-1680	50-1790	100-980
Mean width (m)	1-6	1-6	1-4
Mean depth (cm)	4-26	4-21	5-14
Channel gradient (%)	2-18	2-13	1-13
Elevation (m)	400-1200	400-1200	300-500
Canopy shade (%) ^a	40-95	5-40	80-100

^aVisually estimated.

where D is the diameter of either end.

Algal accumulation was measured during September by placing two clay tiles in riffle areas in the paired clear-cut and old-growth sites. After 1 mo, tiles were removed and chlorophyll *a* was measured (Wetzel and Westlake 1969).

Prior to sampling we selected a group of predator taxa whose abundance we would quantify. The selected group included all fishes, salamanders, and the following invertebrates: Setipalpia (Plecoptera), Odonata, Megaloptera, larval Coleoptera, and most *Rhyacophila* (Trichoptera). Although not all inclusive, this group of taxa should be a representative sample of the predator functional group. Predatory Diptera and terrestrial predators that prey in streams (e.g. *Natria*, *Cinclus*) were not sampled.

Population size of vertebrates was estimated from July to October 1976 once in each of 31 sites by mark-recapture and removal methods (Robson and Regier 1971). Vertebrates in a 30-m section of stream were collected with an electroshocker, anesthetized, measured, marked with a toe clip or finclip, and released within the site. We usually attempted recapture 1 wk after marking. Salamanders and sculpins from several sites were frozen and later weighed to provide length-weight regressions. A regression for trout was obtained from Aho (1976). Trout and sculpins were separated into two size-classes, less than 70 mm in length (age 0) and larger. Biomass (g wet wt/m²) was estimated separately by size-class.

To sample predatory insects, we held a square-framed net (33 cm wide, mesh 0.33 mm) perpendicular to streamflow while agitating 0.16 m² of substrate in front of the net to a depth of 10 cm. In pool habitat we agitated an equal area of substrate while directing current through the net by hand. Insects were picked from samples in the field, preserved in alcohol, and later identified, counted, and measured under a microscope. We calculated regressions for converting length to dry weight. Biomass (mg dry wt/m²) and density (no./m²) in pool and riffle habitats were estimated by the mean of three samples from each habitat type. For simplicity, we used species richness (total number of taxa collected) as a single measure of species diversity. Sixteen sites were sampled once for predatory insects in August and September 1976 and 12 sites were sampled in December after an extended period of unusually low streamflow. Paired sites were sampled within 1 d of each other. We combined data from these periods for analysis.

Data were analyzed with nonparametric statistical methods. To correlate differences between paired clear-cut and old-growth sites with the size and gradient of the streams, we calculated the percentage difference

$$\Delta\% = (CC - OG) / OG \cdot 100$$

where CC = the value from the clear-cut site and OG = the value from the old-growth complement. This difference measure has a possible range of -100 (CC = 0, OG > 0) to positive infinity (CC > 0, OG = 0). For data analysis we considered all values of positive infinity to be equal.

Results

EFFECTS ON PREDATORS

Ten vertebrate and 27 insect taxa were collected from the study sites. In biomass and frequency of occurrence, the dominant vertebrate was the Pacific giant salamander *Dicamptodon ensatus*, which made up as much as 99% of total predator biomass in some sites. The cutthroat trout was also common, although usually absent from first-order streams. Several species of sculpin (*Cottus* spp.) were abundant in some streams that were less than 7% gradient. A small number of Olympic salamanders (*Rhyacotriton olympicus*) were collected from first-order sites and dace (*Rhinichthys osculus* and *R. cataractae*) occurred in some of the third-order streams. Dominant predatory insects included the stoneflies *Calineuria californica* and *Alloperla* spp. Both were abundant in most sites, with *Calineuria* occurring primarily in riffles, and *Alloperla* mainly in pools. Most predator taxa were uncommon. Of the 37 taxa, 27 were found in less than one-third of the study sites, and only three were found in every site. A complete list of predator taxa is given in Murphy (1979).

Diversity and biomass of predatory insects were greater in clear-cut than in old-growth sites (Table 2). Species richness and total biomass of predatory insects averaged 28 and 88% greater, respectively, in clear-cut than in old-growth sites. Because of large variation, however, insect density and vertebrate species richness, biomass, and density did not differ significantly between clear-cut and old-growth. Among paired sites mean biomass of the 10 most common taxa, including salamanders, trout, and insects, ranged from 5 to 523% greater in clear-cut than in old-growth sites. The greater biomass in clear-cut sites was statistically significant for trout ($P < 0.01$) and three of eight insect taxa ($P < 0.01$, 0.02, 0.02 Wilcoxon matched-pairs test). Much of the variation in logging effects was related to differences among stream microhabitats, habitat requirements of individual species, and size and gradient of the study streams.

Logging had different effects on pool and riffle assem-

TABLE 2. Species richness, biomass, and density of predators in old-growth and clear-cut sites.

Assemblage characteristic	Old-growth		Clear-cut	
	Mean	Range	Mean	Range
	<i>Insects</i>			
Number of taxa	8.3	6-14	10.6 ^a	6-13
Biomass (mg dry wt/m ²)	210.5	47.0-555.0	395.3 ^a	119.0-724.0
Density (no./m ²)	117.6	52.0-304.0	167.5	58.0-335.0
	<i>Vertebrates</i>			
Number of taxa	2.3	1-5	2.0	1-3
Biomass (g wet wt/m ²)	17.5	6.5-33.2	23.1	6.7-51.4
Density (no./m ²)	2.2	0.5-3.5	2.0	0.9-6.0

^aDifference significant, $P < 0.01$, Mann-Whitney U test, $n = 13$ for insects and 15 for vertebrates in old-growth sites, and $n = 10$ in clear-cut sites for both taxa.

TABLE 3. Comparison of total density (no./m²) of predatory insects in paired clear-cut (CC) and old-growth (OG, control) sites, listed in order of increasing stream gradient.

Site pair ^a	Gradient (%)	Pools			Riffles		
		CC	OG (control)	$\Delta\%$ ^b	CC	OG (control)	$\Delta\%$
CO	2.5	30	54	-44	124	106	17
LO	4.0	456	476	-4	214	132	62
MR	4.0	68	128	-47	116	114	2
LL	6.0	c	c		c	c	
LS	9.0	134	188	-29	66	114	-42
MA	9.5	160	176	-9	110	42	162
WA	11.0	274	126	117	312	158	97
MC	12.0	178	184	-3	156	40	290
AR	15.5	250	124	102	154	168	-8
Rank correlations with stream gradient				0.78 ^d	0.19		

^aFor identification of site pairs refer to Murphy (1979).

^bPercentage difference = $(CC - OG)/OG \cdot 100$.

^cInsects not sampled.

^d $P < 0.05$.

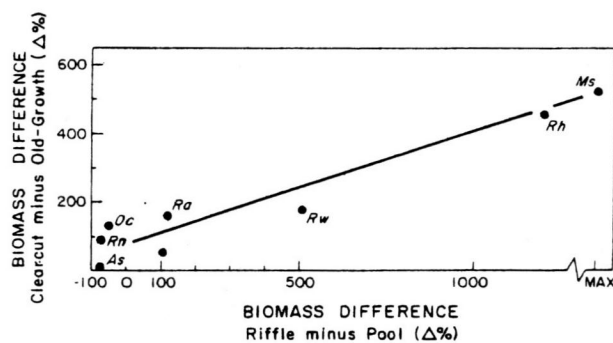


FIG. 2. Difference in mean biomass of the eight most common insect taxa (collected from >10 sites) between the 16 paired clear-cut and old-growth sites in relation to difference in mean biomass for the same taxa between riffle and pool habitats in all study sites. Taxa are indicated as As = *Alloperla* spp., Cc = *Calineuria californica*, Ms = *Megarcys* sp., Oc = *Orohermes crepusculus*, Ra = *Rhyacophila acropedes*, Rh = *R. hyalinata*, Rn = *R. narvae*, Rw = *R. williametta*. The line was fitted by inspection ($r_s = 0.93$, $P < 0.01$).

blages of insects (Table 3). Steeper streams exhibited greater increases or smaller decreases in density of insects in pools than did lower gradient streams. Effects on riffle assemblages, however, were not significantly correlated with stream gradient. Density in riffles showed increases in most cases (median $\Delta\% = 39.5$, $P < 0.05$, Wilcoxon matched-pairs test), whereas density in pools showed more declines than increases associated with clear-cutting (median $\Delta\% = -6.5$).

Individual taxa also showed different effects related to their habitat. Taxa that were concentrated in riffles showed greater increases associated with clear-cutting than those concentrated in pools (Fig. 2). For example, *Megarcys* sp., restricted to riffle habitat, showed the greatest increase associated with clear-cutting, whereas *Alloperla* spp., concentrated in pools, showed the smallest increase. Clear-cutting thus increased abundance of taxa that inhabited riffles more than those that inhabited pools.

Effects of clear-cutting depended on stream gradient for salamanders but not for trout (Table 4). For salamanders the percentage difference in biomass between paired clear-cut and

TABLE 4. Biomass (g/m^2) of salamanders and trout in paired clear-cut and old-growth sites, listed in order of increasing stream gradient.

Site pair	Salamander			Trout		
	CC	OG (control)	$\Delta\%$	CC	OG (control)	$\Delta\%$
CO	8.5	16.8	-49.4	7.7	5.6	37.5
LO	0.4	3.5	-88.6	7.7	2.8	175.0
MR	0.2	1.8	-88.9	4.5	3.3	36.4
LL	12.5	14.3	-12.6	7.7	5.7	35.1
LS	24.6	24.3	1.2	0.4	0.0	a
MA	20.1	14.4	39.6	6.3	2.4	162.5
WA	43.8	16.6	163.9	2.8	2.6	7.7
MC	51.4	26.1	96.9	0.0	0.0	a
AR	13.7	10.5	30.5	0.0	0.0	a

^aTrout absent from site; $\Delta\%$ not calculated.

TABLE 5. Comparison of chlorophyll accumulation on artificial substrates and proportion of pool area in paired clear-cut and old-growth sites. Differences in these variables were correlated with stream drainage area.

Site pair	Drainage area (km^2)	Chlorophyll <i>a</i> (mg/m^2)			Pool area (%)		
		CC	OG (control)	$\Delta\%$	CC	OG (control)	$\Delta\%$
MC	0.3	2.8	0.0	a	2	53	-96
AR	0.8	1.2	0.0	a	26	46	-43
LS	1.0	29.9	2.8	968	38	78	-51
MA	4.4	36.6	20.1	82	21	46	-54
LL	7.8	16.3	6.7	143	53	50	6
CO	11.4	11.7	4.5	160	52	65	-20
MR	12.4	14.8	5.2	185	38	57	-33
WA	15.0	b	b		54	30	80
LO	16.8	7.0	11.3	-38	32	41	-22

^aChlorophyll below level of detection in old-growth; $\Delta\%$ maximum.

^bChlorophyll accumulation not measured.

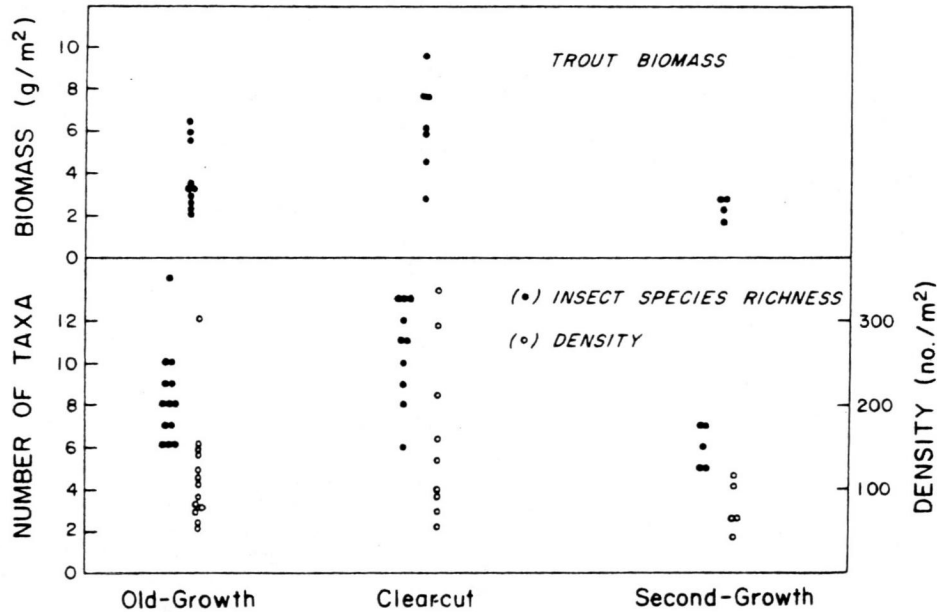


FIG. 3. Biomass of trout and species richness and mean density of predatory insects in old-growth, clear-cut, and second-growth sites. Second-growth sites had lower trout biomass than old-growth ($P < 0.05$) or clear-cut sites ($P < 0.005$), lower insect species richness than old-growth ($P < 0.025$) or clear-cut sites ($P < 0.005$), and lower insect density than clear-cut sites ($P < 0.05$). Mann-Whitney U test).

old-growth sites was significantly correlated with stream-gradient ($r_s = 0.83$, $P < 0.01$) and closely tracked the percentage difference in density of substrate crevices ($r_s = 0.78$, $P < 0.05$). In streams steeper than 9% gradient salamander biomass was greater in clear-cut than in old-growth sites, but the difference reversed in lower gradient streams. Trout biomass, however, was greater in clear-cut than in old-growth sections in all pairs of sites where trout occurred. The difference in trout biomass was not related to channel gradient or sediment concentration.

Effects of clear-cutting changed with time after logging. Our old-growth, clear-cut, and second-growth sites form a chronological series ranging from before logging to about 35 yr after logging. The densely shaded, second-growth sites contained less trout biomass and fewer predatory insect taxa than either old-growth or clear-cut sites (Fig. 3). Density and biomass of predatory insects in second-growth sites were lower than in clear-cut sites but similar to density in old-growth sites.

EFFECTS ON HABITAT

Accumulation of chlorophyll *a* on tiles placed in the streams depended on stream size and density of the forest canopy (Table 5). For old-growth sites the amount of chlorophyll accumulated was directly related to stream width, drainage area, and percentage open canopy ($r_s = 0.83$, 0.68 , 0.67 , $P < 0.01$, 0.05 , 0.05 , respectively, $n = 8$). Chlorophyll accumulation in clear-cut sites was greater than in adjacent old-growth sites ($P < 0.05$, $n = 8$, Wilcoxon matched-pairs test), but the percentage difference decreased with stream width and drainage area ($r_s = -0.80$ and -0.76 , respectively, $P < 0.05$). Clear-cutting thus seemed to enhance periphyton production by removing forest canopy, but this effect was reduced in the larger streams that were naturally more open.

Volume of large organic debris in old-growth sites was inversely related to stream size, decreasing an order of magnitude from first- to third-order streams (Fig. 4). Debris was randomly distributed in first-order sites, but was aggregated at intervals of 20–50 m along the larger streams. Variance was greatest for mid-sized old-growth streams because of this larger scale heterogeneity. Reduced quantities of debris in the larger streams probably resulted from an increase in stream power and ability of streams to transport debris (Swanson et al. 1976; Anderson et al. 1978).

In small drainages, logged areas contained less woody debris than did old-growth sites (Fig. 4). In drainages larger than 4 km², large debris was lacking in every logged site except one that contained a log jam. Debris was either removed intentionally during logging or, where the stream was large, was destabilized by logging, and exported during floods.

Large organic debris played a key role in shaping channel morphology and retaining sediment, particularly in the smaller, higher gradient streams. Removal of debris reduced pool area and released trapped sediment. Old-growth sites averaged 47.3% pools, whereas logged sites averaged 35.2% pools, about a 25% decrease ($P < 0.05$, $n = 31$, Mann-Whitney *U* test). The difference in percentage pool area between paired clear-cut and old-growth site was significant-

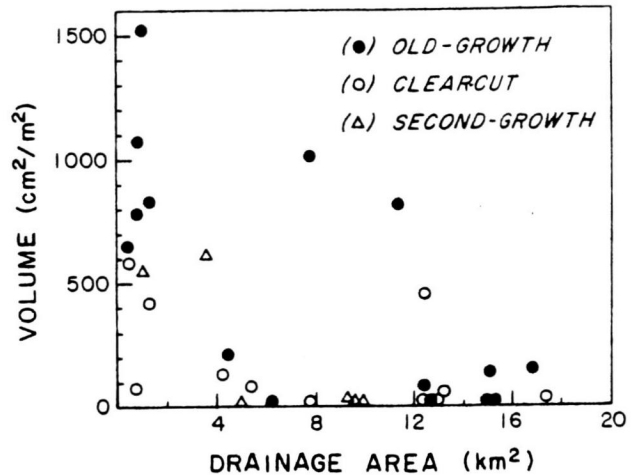


FIG. 4. Volume of large organic debris (>10 cm diam) in the active stream channel in relation to drainage area for old-growth, clear-cut, and second-growth sites.

ly correlated with stream drainage area ($r_s = 0.62$, $P < 0.05$, Table 5). The reduction in pool area was greatest in the smallest streams, where debris had its greatest influence on old-growth channel morphology. Quality of pools, as rated by the Duff and Cooper index, did not differ between paired clear-cut and old-growth sites.

The amount of sand-gravel and density of crevices in logged sites were strongly correlated with channel gradient, but storage of fine sediment by organic debris in steep channels reduced these correlations for old-growth sites (Table 6). The net effect was that differences between paired sites in percent sand-gravel and crevices depended on stream gradient. The higher gradient clear-cut sites contained coarser sediment than similar old-growth sites, probably because fine sediment that was previously stored or introduced by logging had been exported. Logged sites on streams less than 4% gradient, however, had more fine sediment than adjacent old-growth sites, probably because sand and gravel introduced by logging accumulated in the lower gradient sites.

Discussion

Clear-cutting seemed to have its greatest effects on predators by altering aquatic primary production and streambed sediment composition. Opening the canopy increased primary production and, by energy transfer through the food web, probably increased consumer production generally. We did not measure prey availability, but Brocksen et al. (1968) demonstrated the direct effect of increased light on production of insects, snails, and fish in laboratory stream communities. Logging may either increase or decrease the amount of fine sediment in the streambed. Accumulated fine sediment reduces abundance of benthos (e.g. Cordone and Kelly 1961). By removing large woody debris from high gradient streams, logging may reduce the amount of sediment in the streambed, and in these cases benthos may increase.

These effects of clear-cutting depend on stream size and gradient. As streams widen, canopy opens naturally (Vannote

TABLE 6. Comparison of sediment characteristics among paired clear-cut and old-growth sites. Differences in these variables were correlated with stream gradient.

Site pair ^a	Gradient (%)	Sand-gravel %			Crevices (no./m ²)		
		CC	OG (control)	Δ%	CC	OG (control)	Δ%
CO	2.5	51	31	65	6.6	9.9	-33
LO	4.0	35	15	133	6.0	8.1	-26
MR	4.0	36	35	3	4.9	6.6	-26
LL	6.0	31	33	-6	7.3	10.9	-33
LS	9.0	15	37	-59	16.3	13.3	23
MA	9.5	9	12	-25	12.4	10.4	19
WA	11.0	1	19	-95	29.7	14.7	102
MC	12.0	19	30	-37	24.3	10.9	123
AR	15.5	16	28	-43	11.8	10.6	11
Rank correlations with stream gradient							
		-0.75 ^a	-0.30	-0.79 ^b	0.75 ^a	0.60 ^a	0.75 ^a

^aP < 0.05.^bP < 0.01.

et al. 1980); hence, canopy removal has a smaller effect on periphyton production. As gradient decreases, streams have lower competence to transport sediment. Thus, sediment introduced by logging may be exported from high gradient streams and accumulate in low gradient reaches. After clear-cutting, small, high gradient streams should show relatively large increases in primary production and sediment coarseness compared to larger, lower gradient streams. In our study, vertebrates and predatory insects appeared to respond to these differential effects with relatively large increases in biomass, density, and species diversity in the smaller, high gradient streams, and mixed changes in the larger, lower gradient streams.

Logging may have different effects in different stream microhabitats. Primary production is directly related to current velocity (McIntire 1966) and sediment deposition is inversely related to current velocity (Leopold et al. 1964). Thus the capacity for primary production should be greater for riffles than for pools, whereas sediment deposition should be more severe for pools than riffles. After clear-cutting, predators inhabiting riffles should receive more energy from increased primary production and suffer less from sedimentation than predators inhabiting pools. Because salamanders inhabit substrate crevices they should also be directly affected by shifts in sediment composition. The cutthroat trout, however, feeds on drifting organisms (Brocksen et al. 1968) and its production should be sensitive to changes in productivity of riffles. These relations may explain why pool insects and salamanders showed variable effects of logging depending on stream gradient, whereas riffle insects and trout showed increased abundance regardless of stream gradient.

Other effects were probably less important. Stream temperature may increase after clear-cutting (Brown 1971). However, our clear-cut sites had only 50–200 m exposed to sunlight upstream of our sample area. Temperature increases were probably small. In one of our pairs of sites, for example, Aho (1976) found weekly mean temperature ranged only 0.1–1.0°C higher in the clear-cut than in the adjacent old-growth section. Increases in temperature would be greater,

however, in very small or low gradient streams or where longer reaches are exposed (Brown 1971). Nutrient concentrations in streams in the study area increase after logging, but return to prelogging levels within 10–15 yr (Fredriksen, USFS, Forestry Sciences Lab, Corvallis, personal communication.) Increases in nutrients may also have contributed to greater productivity of clear-cut sites (Gregory 1980).

Pool area was reduced in logged sections because of debris removal. This change in channel morphology, however, does not account for observed differences in abundance of predators, since clear-cut and second-growth sites had similar amounts of pool area but different amounts of biomass of trout and density of insects. In southwest Washington, Bisson and Sedell (unpublished data) suggest that debris removal may reduce habitat quality for large trout and favor smaller size-classes. Our data for paired clear-cut and old-growth sites did not show any consistent shifts in either pool quality or size structure of trout populations. A shift toward smaller trout, however, was observed in our lowest gradient sites that had small amounts of debris and few boulders whether these sites were logged or not. Debris may thus be more important in providing trout habitat in low gradient (<2%) streams where boulders are not abundant than in high gradient streams where boulders provide good pool habitat in the absence of debris.

Changes in stream ecosystems after clear-cutting depend on changes in the forest and the streambed. Most previous studies of logging impacts have concentrated on immediate effects occurring within 1 or 2 yr. We allowed for an initial period of adjustment and concentrated on effects from 5 to 35 yr to examine long-term effects on ecosystem productivity. In our study, clear-cutting seemed to cause an early increase in productivity. Elevated rates of production, however, seemed to decline within 10–20 yr after logging as riparian vegetation shaded the stream.

Effects on physical habitat may be longer lasting. Harvest rotations of less than 100 yr preclude recovery of prelogging levels of large organic debris in streams (Swanson and Lienkaemper 1978). Depositional zones in high gradient streams may thus be reduced for as long as present harvest

practices and rotation periods are applied. Sediment may accumulate in low gradient streams after logging, but detrimental effects may be masked at first by increased autotrophic production. As canopy recovers and the community shifts to a heterotrophic food base, any habitat degradation from sedimentation may be more evident.

Several studies corroborate the direct stimulus of canopy removal on productivity of stream ecosystems. In one of our pairs of sites in the H. J. Andrews Experimental Forest, the exposed, clear-cut section had about twice the annual primary production (Gregory 1980), four times the insect emergence (Grafius 1976), and three times the production of cutthroat trout (Aho 1976) compared with the adjacent old-growth section. Differences in trout production were due to greater growth and survival rates in the exposed section, not to movement between sites.

Removal of streambank vegetation from streams in Wisconsin increased biomass of brook trout, *Salvelinus fontinalis* (Hunt 1978). In northern California, Erman et al. (1977) found greater density of aquatic insects at sites logged without streamside buffer strips than in forested areas, and Burns (1972) found that logging increased carrying capacities for juvenile salmonids when channels were adequately protected and cleared. In southwest Washington, Bisson and Sedell (unpublished data) also found greater biomass of cutthroat trout in open sections of streams in clear-cuts than in adjacent forested sections.

Other studies have found varied effects of logging on salmonids. Narver (1972) compared logged and forested sections of two streams in British Columbia and found greater densities of salmonids in a clear-cut section than in a forested section in one stream, but the opposite result in the other stream. Warren et al. (1964) found no effect on trout production when canopy was removed from a small stream in the Willamette Valley. In the Oregon Coast Range, Moring and Lantz (1974, 1975) found mixed effects of logging without streamside buffers on biomass of coho salmon (*Oncorhynchus kisutch*), but consistent reductions in cutthroat trout populations. Thus clear-cutting may be a direct stimulus to secondary production in some regions if other detrimental effects, such as temperature increase, reduction in pool quality, or sedimentation, are not severe.

Differences in geomorphology and sediment load may explain differing impacts of logging on stream communities. Logging impacts on trout, for example, differ between the western Cascades and Coast Range in Oregon, perhaps because streams in the Coast Range are often lower gradient and carry more sediment than those in the western Cascades. High competence of small Cascade streams reduces local sedimentation from logging because introduced sediment is exported to reaches lower in the drainage network.

Potential logging impacts on predators and on the stream ecosystem in general must be viewed with a perspective for both the geomorphic setting and potential downstream effects. Disturbances in headwater regions often have effects downstream (e.g. Madej 1978). Sites of sediment export and deposition depend on the competence and capacity of the stream along its longitudinal profile (Leopold et al. 1964). Logging in the western Cascades appears to be accelerating sediment transport from small headwater streams to down-

stream reaches by accelerating erosion of hillslopes (Swanston and Swanson 1976) and by removing large woody debris from high gradient stream channels. Such shifts in sediment may favor productivity in the headwaters but depress it downstream where gradient is lower.

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