Characteristics of Coarse Woody Debris for Several Coastal Streams of Southeast Alaska, USA[1]

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Coarse woody debris (>0.2 m in diameter and 1.5 m long) was measured along five undisturbed low-gradient stream reaches; volume, decay class, and horizontal orientation in relation to channel flow of first-, second-, third-, and fourth-order coastal streams were determined. Debris was also classified into four influence zones based on stream hydraulics and fish habitat. Average debris length, diameter, and volume per piece increased with stream size. Eighty percent of debris volume of the first-order and the smaller second-order streams was suspended above or lying outside the bankfull channel, while less than 40% was similarly positioned in the fourth-order stream. Approximately one-third of all debris was oriented perpendicular to stream flow, regardless of stream size. First-, second-, and third-order streams had a higher proportion of recent debris in the channel than the fourth-order stream (≥19 vs. 8%), most new debris being attributable to a major 1984 windstorm. Tree blowdown had a major influence on debris distribution along the smaller stream reaches. Debris jams and accumulations in the largest stream were formed from floated debris. These characterizations are useful for evaluating the distribution and amount of woody debris associated with land-management activities.

Les débris forestiers grossiers (> 0,2 cm de diamètre et 1,5 m de longueur) de cinq tronçons, non touchés par l'homme, de cours d'eau à pente faible ont été mesurés. Leur volume, classe de décomposition et orientation horizontale par rapport au sens d'écoulement de cours d'eau de premier, deuxième, troisième et quatrième ordres ont été déterminés. Les débris ont aussi été classés suivant quatre zones définies par leurs caractéristiques hydrauliques et le type d'habitat qu'elles offrent aux poissons. La longueur, le diamètre et le volume moyens des morceaux augmentaient en raison directe de la taille des cours d'eau. En volume, 80% des débris des cours d'eau de premier ordre et de ceux, plus petits, de deuxième ordre était suspendu au-dessus du chenal de débordement où reposait à côté de ce dernier. Ce pourcentage était inférieur à 40% dans le cas des cours d'eau de quatrième ordre. Environ un tiers de tous les débris était orienté perpendiculairement au courant, quelle que soit la taille des cours d'eau. La proportion de débris récents dans le chenal des cours d'eau de premier, deuxième et troisième ordres était supérieure à celle observée dans les cours d'eau de quatrième ordre (≥19% contre 8%). La plupart des nouveaux débris était dû à un coup de vent violent survenu en 1984. Les arbres déracinés ont eu un effet important sur la distribution des débris le long des plus petits cours d'eau. Les embâcles et les accumulations de morceaux de bois dans les plus gros cours d'eau étaient attribuables aux débris de flottage. Ce genre d'étude s'avère utile pour évaluer la distribution et les quantités de débris forestiers attribuables aux activités d'aménagement du territoire.

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Coarse woody debris (CWD) is an important component of salmonid fish habitat in streams throughout the Pacific Northwest (Bisson et al. 1987). It helps retain organic and inorganic particulate matter that is important for stream stability and biological productivity (Bilby 1984; Speaker et al. 1984). Coarse woody debris also provides structure and hydraulic roughness and can significantly influence habitat for fish and other aquatic organisms (Beschta and Platts 1986). Microhabitats of low-velocity water created by woody debris can be temporary refuges during high stream flow, while during low flow, debris may provide cover and reduce predation (Bustard and Narver 1975; Reiser and Bjornn 1979; Tschaplinski and Hartman 1983).

Coarse woody debris may locally deflect flows, thereby altering stream-bank stability, and floatable debris may damage structures such as culverts or bridges. Debris can also block fish migration (Helmers 1966) and decrease feeding efficiency by blocking out light (Wilzback and Hall 1985). However, its removal to improve fish migration (or for other purposes) has usually been associated with reduced salmonid production (Dolloff 1983; Murphy et al. 1986). Although there is general agreement in recent literature that CWD in streams benefits salmonid production (Harmon et al. 1986), the optimum amount, size, and placement for various streams and fish species have not been specified.

Reiser and Bjornn (1979) and Sullivan et al. (1987) have suggested that the natural or pristine configuration of CWD in

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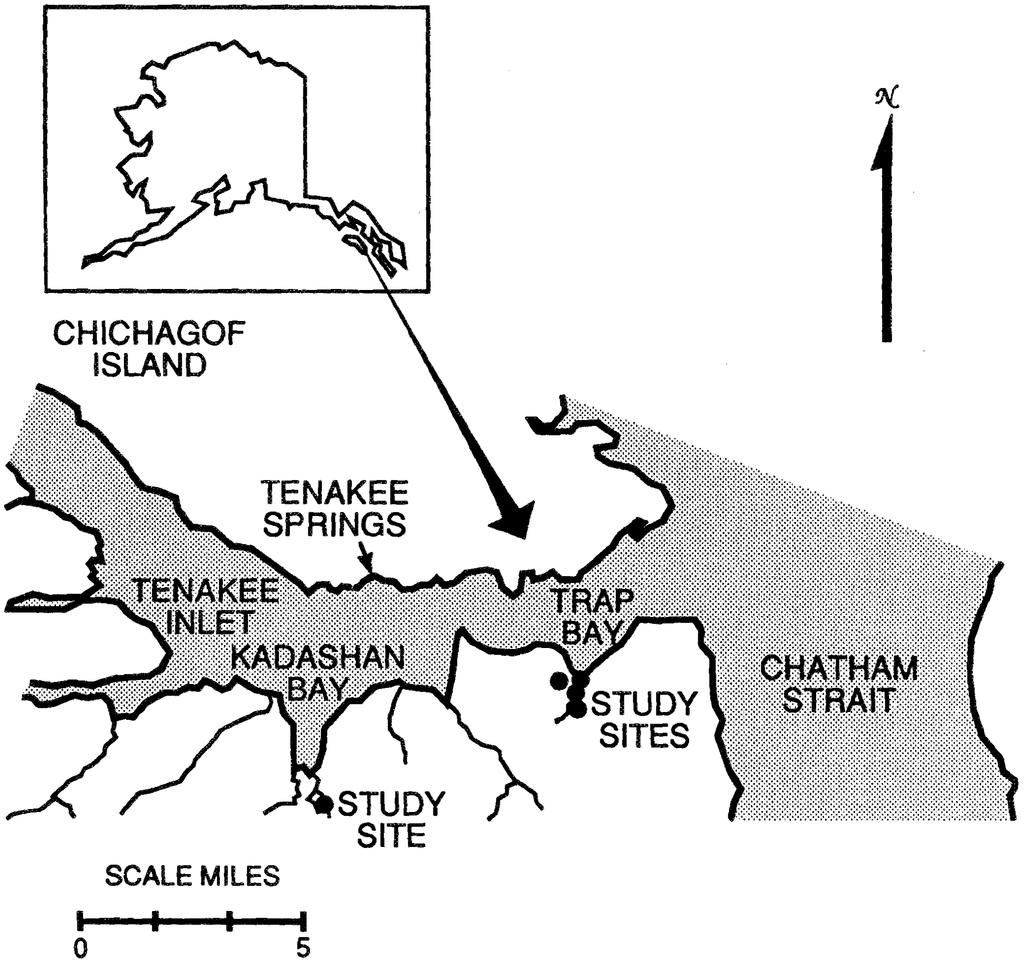

FIG. 1. Location of study streams.

and along streams is desirable because it represents a component of stream habitat to which fish have adapted. Resource managers have often added CWD to streams in an attempt to enhance fish habitat, or have manipulated riparian zones in an attempt to simulate natural conditions, but data on the size and spatial distribution of debris in undisturbed stream systems is largely lacking.

The volume of CWD per unit length or area of stream channel has been used as an index of "stream health" in many studies (Bisson et al. 1987). However, volume measurements seldom differentiate whether CWD is predominantly in a stream, above it, or alongside it. Many studies measure all CWD within a fixed distance from the center of the stream (Andrus et al. 1988). With that technique, a larger proportion of terrestrial CWD will be measured on small streams than on large streams.

This study was undertaken to assess CWD (i.e. pieces greater than 0.2 m in diameter and 1.5 m long) in undisturbed low-gradient stream reaches in southeastern Alaska. We were specifically interested in evaluating the extent to which debris volume, piece characteristics, and spatial distribution varied with stream size.

Study-Site Characteristics

The five streams evaluated in this study are on Chichagof Island in southeast Alaska approximately 115 km southwest of Juneau (Fig. 1); all flow into the Tenakee Inlet. Four of them, Trap Creek, Bambi Creek, Beach Creek, and East Fork Trap Creek, join together and flow into Trap Bay. These streams drain a glacial cirque that is bounded by serrated ridges and a horn peak at the southern end. They have been the subject of previous research on fish populations (Bryant 1984), bedload transport (Campbell and Sidle 1985; Estep and Beschta 1985), riparian vegetation (Sidle 1986), and slope stability (Sidle and Swanston 1982). The fifth and largest stream, the Kadashan River, flows into Kadashan Bay 16 km to the west, draining a much broader glacial valley.

Sitka spruce (*Picea sitchensis*), westen hemlock (*Tsuga heterophylla*), and red alder (*Alnus rubra*) are the overstory tree species (Table 1). Tree basal-area varies from 11–15 m^2/ha along the five streams, alder comprising less than 16% basal area except along the Kadashan River. The number of trees per hectare greater than 0.2 m in diameter at breast height ranges from 55 to 98. A dense understory is dominated by devil's club (*Oplopanax horridum*). Skunk cabbage (*Lysichitum americanum*), blueberry and huckleberry (*Vaccinium* spp.), and salmonberry (*Rubus spectabilis*) are also present.

Coho (*Oncorhynchus kisutch*), pink salmon (*Oncorhynchus gorbuscha*), and Dolly Varden char (*Salvelinus malma*) use the Trap Bay streams (Bryant 1984); those species, plus steelhead trout (*Oncorhynchus mykiss*), and chum salmon *Oncorhynchus keta*) use the Kadashan River drainage.

TABLE 1. Characteristics of the five study streams.

Characteristic	Beach Creek	Upper Bambi Creek	Est Fork Trap Creek	Trap Creek	Kadashan River	Average
Stream order	1	2	2	3	4	—
Watershed[a]						
Area (km^2)	0.72	1.53	5.0	11.4	55.4	—
Elevation (m)						
Minimum	5	5	20	10	15	—
Maximum	615	630	1180	1180	810	—
Stream[a]						
Summer flow[b] (m^3/s)	0.02	0.04	0.30	0.49	1.16	—
2-year peakflow (m^3/s)	1.5	3.0	7.4	13.3	57.8	—
Gradient (%)	1.6	2.3	2.5	1.1	0.8	—
Average low-flow depth (m)	0.24	0.15	0.49	0.58	0.85	—
Average bankfull width (m)	4.9	4.6	8.8	12.8	25.9	—
Study reach						
Length (m)	335	338	457	1530	915	—
Measurement spacing[c] (m)	0.9	0.9	1.5	1.5	3.0	—
Streamside overstory						
Mean number stems/ha	56	77	55	98	62	70
Total basal area (m^2/ha)	15	12	12	15	11	13
Percentage of total basal area						
Red alder	10	16	0	11	25	12
Sitka spruce	59	39	46	55	62	52
Western hemlock	31	45	54	34	13	36

[a] Watershed and stream characteristics were determined for the downstream end of study reaches.

[b] Calculated discharges were based on precipitation and watershed area from Water Resources Atlas for Alaska (USDA Forest Service 1978).

[c] Distance between measurement locations along stream thalweg.

The study reaches on the first-, third-, fourth-, and two second-order streams each had an average gradient of 1.7% (±0.7%) and varied from 335 to 1 530 m in length (Table 1). In all cases they exceeded 35 times the bankfull channel width. Bed material of the reaches consists predominantly of gravel-sized sediment; bedrock or boulder outcrops are uncommon. Average annual precipitation in the area is approximately 165 cm (Sidle and Swanston 1982).

Methods

Along each reach, individual pieces of CWD were characterized by species, volume, location-orientation along the channel, decay class, and grouping. Large-end diameter, average diameter, and length of each piece was measured. Assuming cylindrical shapes, we calculated CWD volumes (m^3) as length $\times$ π $\times$ (average diameter/2)^2 (Hogan 1987).

We designated four "influence zones" for the stream reaches on the basis of habitat and hydraulic considerations (Fig. 2). Portions of CWD in Zone 1 provide local cover for fish and other aquatic organisms during most of the year, when streams are at low flow. When flows increase during rainfall or snowmelt, CWD in Zones 1 and 2 deflects flows and can cause local scour and fill, affecting the general roughness of a stream. The volume of wood in Zone 3 is a potential source of debris to the channel. Although it does not yet affect a stream hydraulically, it will probably do so in the future. The volume in Zone 4 is another potential source of CWD and, in some cases, its mass and configuration in the terrestrial zone anchor CWD in Zones 1 and 2.

The "influence zones" allow distinction of the volume that could influence fish habitat at low flow (Zone 1), affect stream roughness at high flow (Zones 1 and 2), or eventually enter the channel (Zones 3 and 4). The proportion of a given piece of CWD within each zone was estimated. Debris was measured if any portion was found in Zones 1, 2, or 3; CWD that lay entirely in Zone 4 was not measured (Robison 1988).

The horizontal orientation of each CWD piece was recorded as an angle (0°–180°) relative to the direction of flow (Fig. 3). Precise orientation was often difficult to ascertain because much of the CWD was irregularly shaped, partially decayed, broken, or partially buried in the bank or streambed.

Five decay classes were used to indicate the range from new debris to debris in advanced decay (Table 2). Each debris piece was also characterized as "grouped" (touching another piece) or "ungrouped," and it was noted whether the debris rootwad (if present) was in or out of the channel.

Results and Discussion

Volumes and Characteristics

Total CWD volume per 100 m of stream length increased with stream size while total CWD volume per unit bankfull area (i.e. $m^3/100\ m^2$) decreased (Table 3). Coarse woody debris volumes for Zones 1 and 2, expressed in either unit, increased

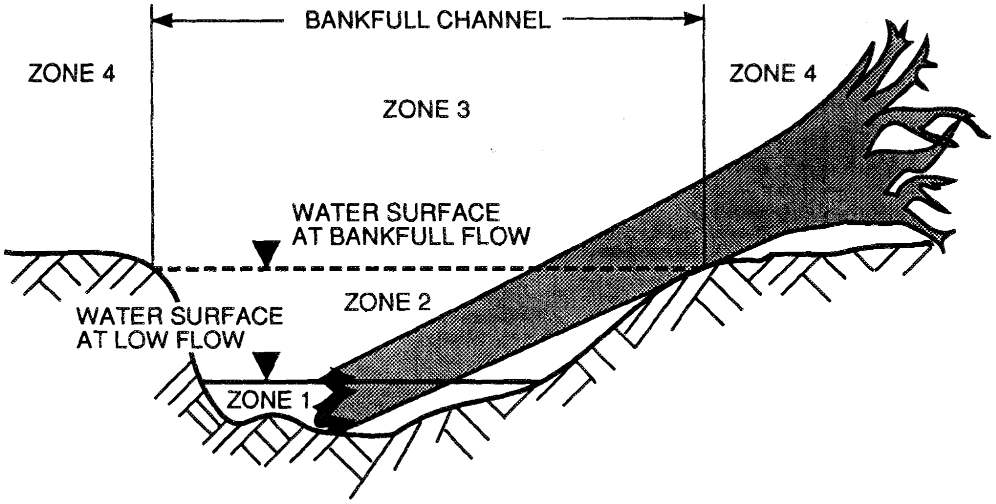

FIG. 2. Coarse woody debris "influence zones."

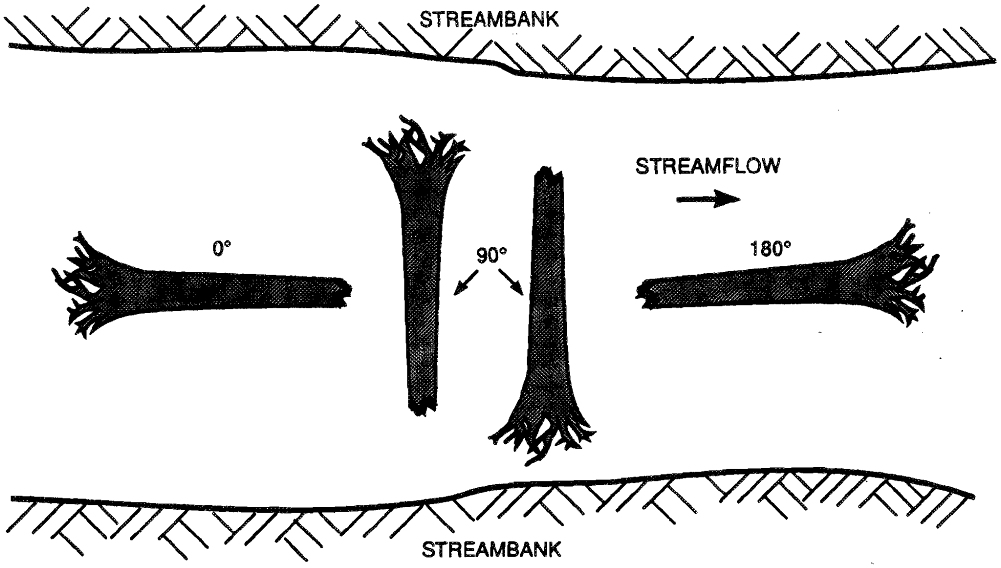

FIG. 3. Method for characterizing horizontal orientation of coarse woody debris in relation to the channel.

with stream size (Fig. 4). Further, the proportion of large CWD pieces within Zones 1 and 2 increased greatly with increasing stream size. For example, the percentage of those pieces with greater than 2 m^3 volume that were lying at least partly in Zones 1 and 2 increased from 10% in the smallest to 56% in the largest stream (Table 3). As stream size increases, larger pieces of CWD are an increasingly important component of the channel environment because they are more stable and less prone to being transported downstream.

The Zone 1 and 2 CWD in this study is similar in definition to the "effective inchannel debris" of Swanson et al. (1984), who found an average loading of 10.1 kg/m^2 for several study streams in southeast Alaska. If a density of 0.5 g/cm^3 is assumed, CWD loadings for Zone 1 and 2 range from 7 kg/m^2 in Beach Creek to 12.5 kg/m^2 in East Fork Trap Creek, which indicates that inchannel debris loadings of streams in both study areas were generally equivalent.

The proportion of CWD within zones changed markedly with stream size (Fig. 5). Approximately 80% of the debris volume in each of the two smallest streams was above or beside the stream (Zones 3 and 4), but in the largest stream, the percentage was less than 40%. There are several reasons for this. In the two smallest streams, average piece length (7.9 and 6.7 m) exceeded average bankfull width (4.9 and 4.6 m); thus, CWD pieces often lay on channel banks with much of their volume suspended above the water surface at bankfull flow. In the two larger and wider streams, trees were more likely to lie partially or entirely in the channel because of greater bankfull widths, which exceeded average piece lengths 1.8 to 3.1 times. As bankfull width increases, even large pieces of CWD can lie completely within Zones 1 and 2.

Approximately 24% of all CWD pieces had volume greater than 2 m^3 (Fig. 6). The number of such pieces ranged from 5.6/100 m of channel on Bambi Creek to 12.3/100 m on the Kadashan River. The average volume per piece for the Kadashan River was 55% greater than that on the other streams (Table 3), and the average length was 8.4 m in comparison to 7.2 m. These results are similar to those for other regions, including those in the northwestern (Bilby 1984) and northeastern United States (Likens and Bilby 1982).

The relatively large piece volumes associated with the Kadashan River may be due to its capacity to transport smaller CWD pieces downstream during high flows. Even with a greater potential for transport, the Kadashan River had 42 pieces/100 m

TABLE 2. A five-class system of evaluating decay of coniferous aquatic coarse woody debris, adapted from Maser and Trappe (1984).

Decay class	Bark	Twigs (3 cm; 1.18 in)	Texture	Shape	Wood color
I	Intact	Present	Intact	Round	Original color
II	Intact	Absent	Intact	Round	Original color
III	Trace	Absent	Smooth; some surface abrasion	Round	Origial color; darkening
IV	Absent	Absent	Abrasion; some holes and openings	Round to oval	Dark
V	Absent	Absent	Vesicular; many holes and openings	Irregular	Dark

TABLE 3. Characteristics of coarse woody debris (CWD) in and along the five study streams. In all instances, % = percentage of pieces, not percentage of volume.

	Stream					
CWD characteristic	Beach Creek	Upper Bambi Creek	East Fork Trap Creek	Trap Creek	Kadashan River	Average
Number pieces measured	83	85	188	514	303	—
Pieces/100 m stream length	25	25	41	34	42	33
Average length (m)	7.9	6.7	6.7	7.3	8.4	7.4
Average large diameter (m)	0.53	0.46	0.51	0.53	0.60	0.53
Volume/piece (m^3)	1.5	1.4	1.5	1.8	2.4	1.7
Volume/100 m stream length (m^3)						
All zones	37	36	60	57	100	58
Zones 1 and 2	7	7	22	24	62	24
Volume/100 m^2 bankfull area (m^3)						
All zones	7.6	7.9	6.7	4.3	3.9	6.1
Zones 1 and 2	1.4	1.6	2.5	1.9	2.4	2.0
Pieces >2 m^3 in zones 1 and 2 (%)	10	10	22	32	56	26
Rootwads in channel (%)	2	6	24	24	20	15
Number rootwads/ 100 m	0.6	1.5	9.8	8.2	8.4	7.1
Grouped (%)	67	58	52	68	72	63
Alder (%)	12	12	4	16	29	15
Decay class (%)						
I and II	30	19	22	24	8	21
III	23	34	27	27	34	29
IV and V	47	47	51	49	58	50

in comparison with only 25 pieces/100 m in the two smallest streams. Frequency of CWD per unit of stream length decreases with an increase in stream size (R. E. Bilby and J. W. Ward, Weyerhaeuser Co., Western Forestry Research Center, Centralia, WA 98531, USA, unpubl. data). The greater frequency of CWD associated with the Kadashan River may be due to relatively high rates of CWD entry. While trees blown over by high wind would fall primarily parallel to the prevailing wind direction, bank cutting may cause them to fall towards a stream. We observed that CWD recruitment due to bank erosion

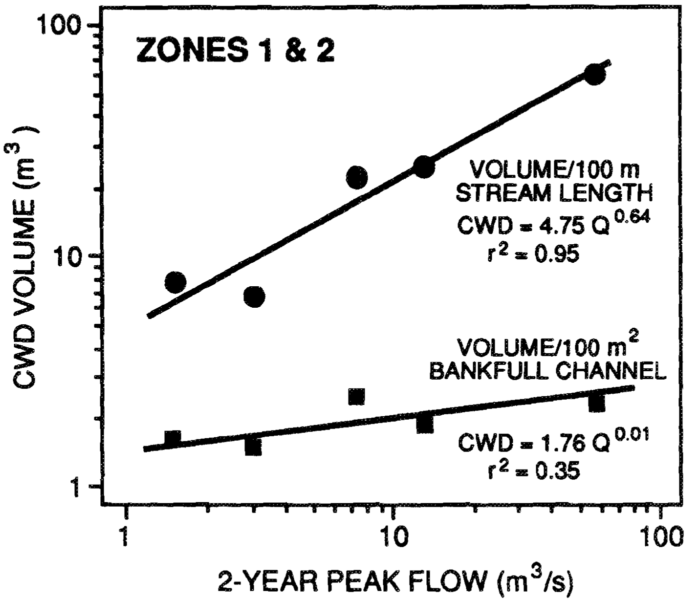

FIG. 4. Volume of coarse woody debris (CWD) in Zones 1 and 2 in relation to 2-yr peak flows of the five study streams.

was more common in the larger streams, which were more likely to meander and shift laterally during periods of high streamflow, thereby recruiting trees or snags. Also, the rootwads of trees falling into a stream because of streambank erosion were often at the channel edge, where larger streams could easily divert around them and incorporate them in the active channel. The relative proportion of rootwads in a channel may thus index the capacity of a stream to move laterally and recruit debris. The proportion of CWD with rootwads in the channel was only 4% for the two smallest streams but 23% for the three largest (Table 3). An average of only one rootwad per 100 m of stream channel was found for the two smallest streams in contrast to 9/100 m for the three largest.

The proportion of grouped CWD pieces ranged from 52 to 72% of the total. There was no trend with stream size (Table 3).

Coarse woody debris in the four smaller streams was of more recent origin than that in the Kadashan River (Table 3). The high percentage of decay classes I and II in the four smaller streams was probably the result of a major windstorm in the fall of 1984 (Roy Sidle, USDA Forest Service, Juneau, AK, pers. comm.), which illustrates the importance of infrequent CWD recruitment. The Kadashan River study reach was either less affected by the windstorm because of topography or less dependent on catastrophic blowdown for CWD recruitment.

The percentage of alder CWD (Table 3) was greatest in the Kadashan River, reflecting the proportion of alder in the riparian forest (Table 1). Field observations and aerial photos show that the greater stream discharge and more active meander bends of this river provide areas for alder to invade, grow, and be recruited during high flow. More alder, other hardwoods, and early successional species may be expected in streams like the Kadashan River because high flows cause local scour and deposition along streambanks and incremental lateral shifting of the channel across the floodplain, periodically resetting vegetation in the riparian area.

Orientation

In contrast to a theoretical frequency distribution of horizontal orientation of debris, which was based on the assumption that riparian trees fall in random direction (Fig. 7A), a high proportion of the actual distribution in relation to stream chan-

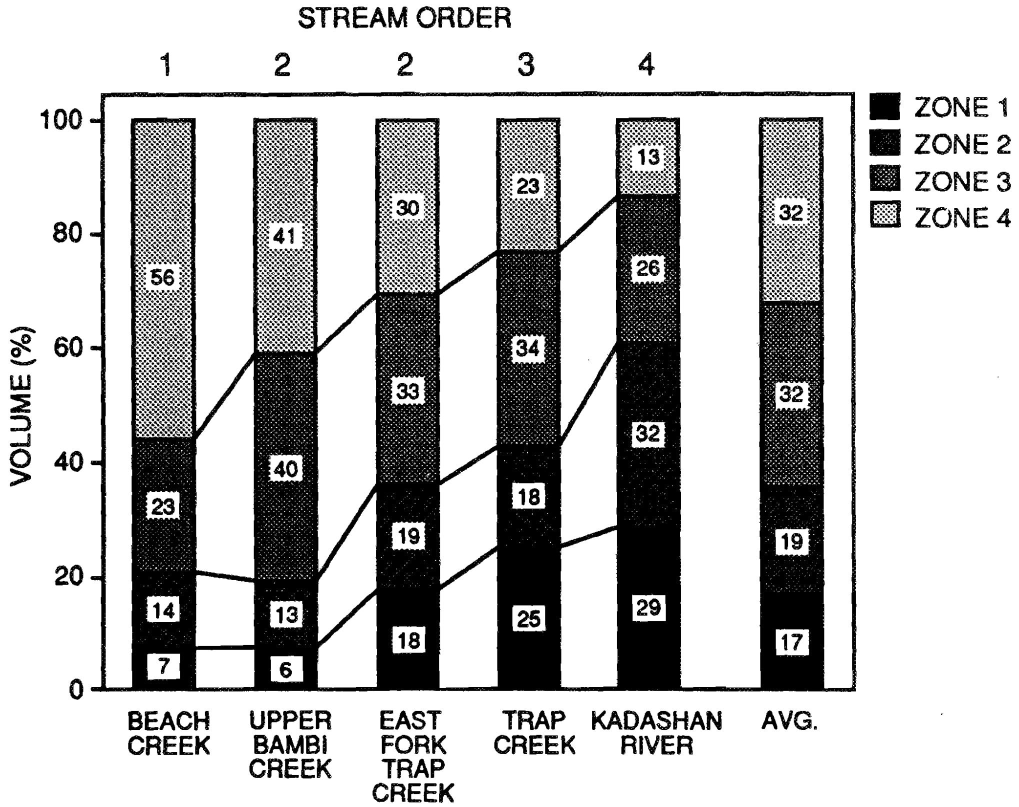

FIG. 5. Percentage of coarse woody debris volume within each of the four "influence zones."

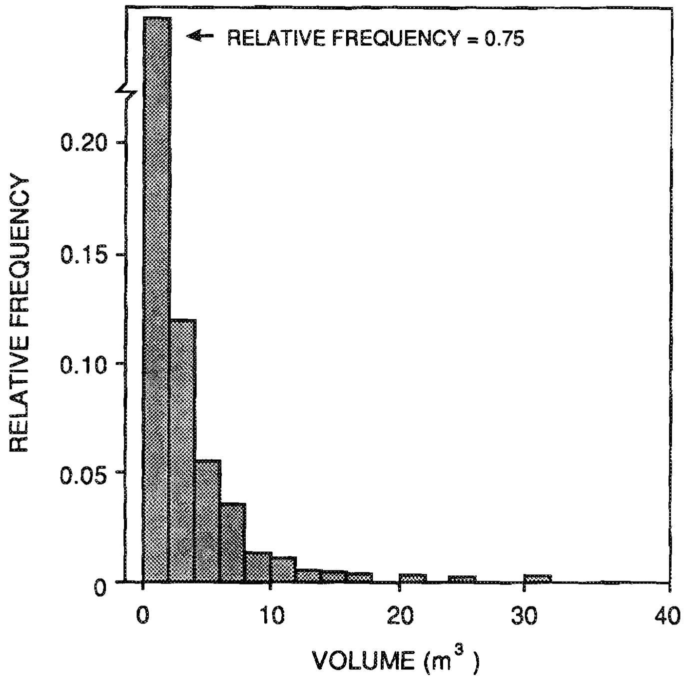

FIG. 6. Relative frequency of piece volumes of coarse woody debris for all study streams.

nels was between 80 and 100° (Fig. 7B, 7C). The peak around 90° may indicate that many trees enter a stream perpendicular to the channel. This orientation may be due to several factors. Streamside branches of riparian trees may receive more light and may have greater biomass than branches away from the stream, creating an unequal weight distribution that could increase the probability of a tree falling towards a stream. Streamside trees (especially alder) may exhibit "phototropism" and lean towards a stream in response to increased light, or bank erosion may cause trees to lean toward a stream. Further, with increasing distance from a channel, the range of horizontal angles at which a tree may fall and still provide large woody debris to a stream becomes more limited, ultimately approaching an angle perpendicular to the channel. The 90° orientation was prevalent regardless of volume, length, diameter, or grouping of CWD.

Hogan (1987) indicates that "stable" or "unmoved" CWD tends to be oriented perpendicular to or "slanted" to the stream channel, while unstable CWD tends to be parallel to the channel. In this study, the frequency of CWD that was relatively parallel to the channel (0°–40° and 140–180°) decreased and the perpendicular orientation (80–100°) increased with piece size (Fig. 7B, 7C), possibly indicating that greater length or volume decreased movement. Bilby (1985) suggests that longer CWD is more stable; it can span the stream width or have sufficient volume outside the active channel to be anchored during high flow. As stream size increased, more CWD was parallel to the channel, and the proportion of pieces with an orientation between 80 and 100° decreased from 34 to 28% (Fig. 7D, 7E, 7F). These shifts seemingly indicate greater potential for CWD transport in larger streams.

Spatial Distribution

The spatial distribution of CWD along the study streams was variable, reflecting the occurrence of episodic blowdown and other factors (Fig. 8). In Bambi Creek, the large peaks between 250 and 300 m along the channel represent local entry from blowdown during a windstorm in 1984. The woody debris at this spot created several side channels and a large sediment-deposition zone.

For medium-sized Trap Creek, CWD volumes indicate nearly continuous debris loading along the stream. However, several relatively large amounts of blowdown on Trap Creek had altered the channel. For example, at channel distance 220 m in Trap Creek (Fig. 8), debris accumulations in the channel caused an island to form.

The Kadashan River had several CWD accumulations (Fig. 8; channel distance 60 and 110 m), but these accumulations did not cause major sediment deposition as in smaller streams. The lack of debris-free stretches interspersed with large debris jams that are characteristic of fourth-order streams (Bisson et al. 1987) was surprising. Apparently, CWD along the Kadashan River is more stable than in streams of comparable size, perhaps because the river is relatively unconfined by hillslopes or high stream banks. At high flow, side channels carry excess water from the main channel so that less is available to transport CWD into jams.

Field observations also indicated little tendency for CWD to occur uniformly along channels. In the smaller streams, debris accumulations tended to be infrequent and largely controlled by the availability of trees susceptible to blowdown. In medium-sized streams, debris accumulations along the channel were more common because channel processes aided recruitment and transport of CWD of smaller size classes. In the largest stream, high-volume debris jams occurred locally, but without regular spatial distribution.

The two smallest streams had some portions with heavy accumulations, while others were almost wood free. Harmon et al. (1986) have suggested that because small streams cannot transport CWD, the entry mechanism dictates spatial distribution. Thus, CWD volumes at a given location are primarily dependent on whether the stream is flowing through an area of blowdown or not.

The occurrence of CWD along the larger second-order and smaller third-order stream in this study was relatively continuous, a finding similar to that of other studies (Bisson et al. 1987). The fourth-order stream also was typified by continuous debris along most of the channel, even though high flows were obviously instrumental in floating and rearranging debris into jams at various points.

In the Oregon Coast Range, Long (1987) found that debris jams or areas of high CWD accumulations occurred immediately downstream from junctions with tributaries of high gradient (>5%). These tributaries came from narrow valleys with steep side slopes, and CWD appeared to enter the main channel as debris torrents. The low-gradient streams evaluated in this study were in wide, alluvial valleys, and debris torrents were not a local source of CWD. There was no discernible relationship between CWD accumulations and tributary junctions.

Conclusions

Our study shows that the amount of CWD and the location with respect to the channel cross-section change with stream size. We therefore recommend that CWD locations be differentiated by stream influence zones in the inventories of forest streams.

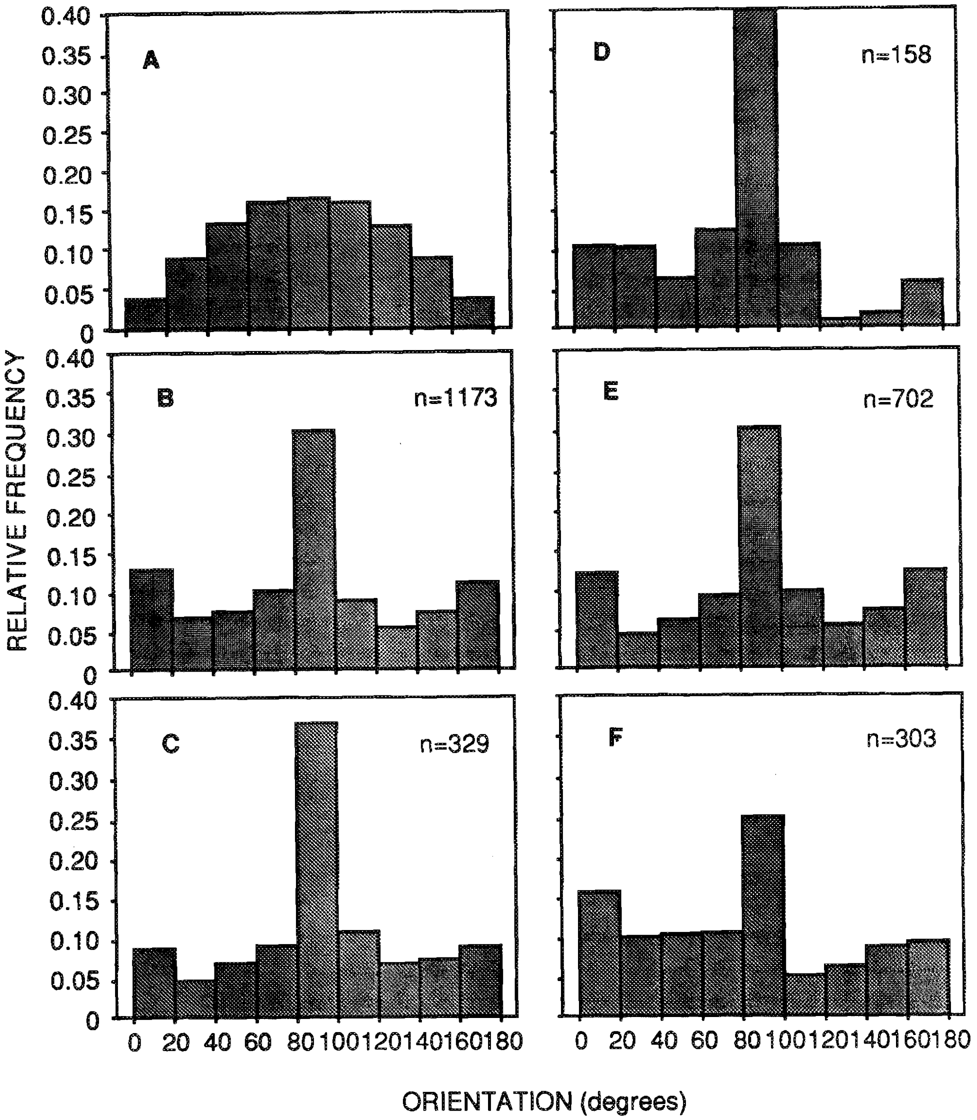

FIG. 7. Relative frequency of horizontal orientations of coarse woody debris (CWD): (A) a theoretical distribution, (B) all CWD in all study streams, (C) pieces >1.8 m^3 in volume in all study streams, (D) Bambi Creek, (E) Trap Creek, and (F) Kadashan River.

The simple computation of average CWD volume per unit of stream length or surface area may not adequately index spatial irregularities in debris accumulations. For instance, one stream may have large CWD jams interspaced with areas of almost no CWD, and another may have evenly spaced CWD. Athough the gross volumes of CWD may be similar, the habitat formed in the two systems may be very different. Large jams can form pools, trap organic matter (Harmon et al. 1986) and cause deposition of sediment immediately upstream, but if such jams are located at only a few places, the overall effect on the stream is localized and limited. Ungrouped CWD does not form pools or store sediments and organic matter as well as jams (Harmon et al. 1986), but because resistance to flow is spread over an entire stream system, it may have a greater overall effect on channel morphology.

The dimensional characteristics of CWD pieces in this study changed with stream size; the average piece volume of CWD was 55% greater on the Kadashan River than in the four smaller streams. The capacity of a large stream to transport woody debris at high flows indicates that larger debris may be needed to provide stability for larger streams. From a forest management perspective, longer rotations would be needed to provide sources of larger CWD.

The perpendicular orientation of much CWD in this study probably indicates that it is stable (Hogan 1987). R. E. Bilby and J. W. Ward (Weyerhaeuser Co., Western Forestry Research Center, Centralia, WA, 98531, USA unpubl. data) found that such CWD tends to span the channel and provide "plunge" rather than backwater pools. It appears that orientation has important effects on the types of pools formed, and thus on fisheries habitat.

We found no systematic spacing of CWD along these undisturbed streams in southeast Alaska. The irregular spacing of individual debris pieces and accumulations may provide maximum variability of debris-influenced habitat.

Acknowledgements

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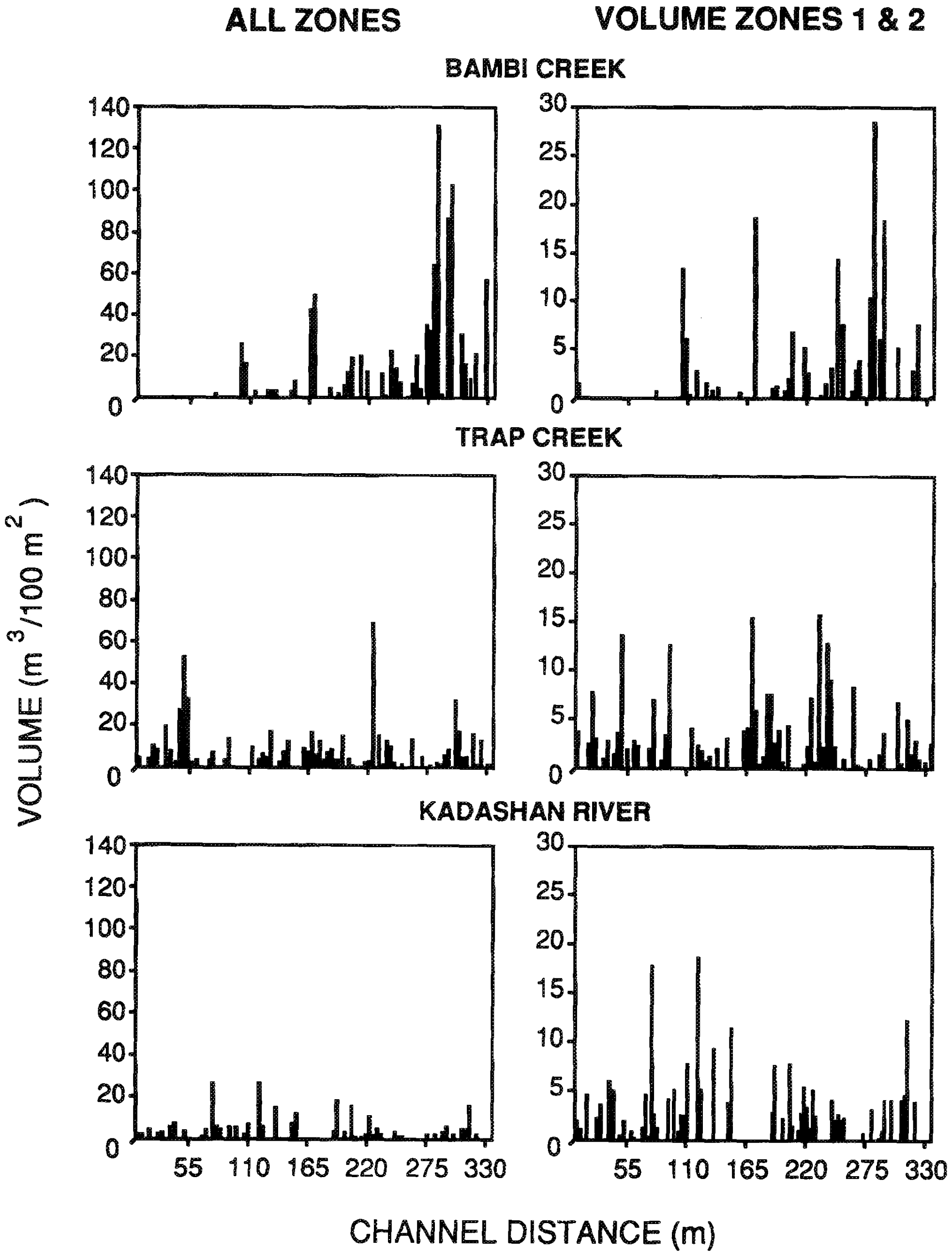

FIG. 8. Spatial distribution of the volume per bankfull surface area for selected 330-m reaches of three study streams (the width of each bar represents 3 m of stream length).

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