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From the Forest to the Sea: A Story of Fallen Trees

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Chapter 3. What We Know About Large Trees That Fall Into Streams and Rivers

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Summary

The most productive habitats for salmonid fish are small streams associated with mature and old-growth coniferous forests where large organic debris and fallen trees greatly influence the physical and biological characteristics of such streams.

Introduction

In western Oregon, most of the 17,000 miles of fish-bearing waterways are small streams averaging less than 10 feet wide; shown below is the mileage by ownership:

Owner	Miles	Source
Private	9,144	Oregon Department of Fish and Wildlife; Oregon Department of Forestry
Bureau of Land Management	2,025	U.S. Department of the Interior
USDA Forest Service	5,800	Everest and Summers (1982)
Total	16,969	

Dense vegetative canopies help keep waters cool, and falling tree litter delivers nutrients to the stream portion of the ecosystem. Large organic debris and fallen trees greatly influence the physical and biological characteristics of small streams that may contain as much as 200-700 tons/acre of such material (Anderson and others 1978, Bisson and others 1987, Franklin and others 1981, Harmon and others 1986, Keller and Swanson 1979, Swanson and Lienkaemper 1978).

History of Wood In Northwest Streams and Rivers

Most early descriptions of streams and rivers in the Northwest were recorded in British and United States army journals. Valleys were so wet that early travel was confined to edges of the hills (Dicken and Dicken 1979). Oregon's Tualatin Valley was "mostly water connected by swamps" (Ogden 1961, p. 122). Much of this flooding resulted from beaver dams, accumulated sediment, fallen trees, and living vegetation in the channels. The valley bottoms had long accumulated alluvial silt and organic material, so the land was drained for agriculture early in the time of settlement.

The condition of Willamette Valley streams in 1910 was described by Williams (1914, p. 13):

Many of the smaller streams...through these flat sections of the valley flow sluggishly and frequently overflow their banks during periods of heavy winter rainfall.... Most of these have sufficient grade to carry even more water than ordinarily comes to them; seldom less than 3, and usually more, feet of fall per mile. The annual overflow is caused from the obstructing of the channel by the growth of trees and the extension of their roots, the dams thrown across the channels by beavers and the consequent accumulation of sediment and other debris.... It is common condition, however, and usually all that is necessary is a clearing out and opening up of the clogged channel of the stream to afford entire relief...to the farmer....

Streams of the Puget Sound lowland in Washington State were also a network of sloughs, islands, beaver ponds, and driftwood dams with no main channel. The Skagit River lowlands encompass about 198 square miles, of which more than 50 square miles were once marsh, sloughs, and wet grass meadows. Maps of the lower Nooksack and Snohomish Rivers show large areas of sloughs, swamps, and grass marshes before 1900 (Reports of the Secretary of War 1875-1921).

The channels of both high- and low-gradient rivers contained large amounts of woody debris, regardless of the bed material. The lower Siuslaw River and North Fork Siuslaw River were so filled with fallen trees that trappers could not explore much of these systems in 1826 (Ogden 1961).

In 1870, the Willamette River flowed in five separate channels between Eugene and Corvallis. Reports of the Secretary of War (1875-1921) describe many obstacles to navigation of the Willamette River above Corvallis and say that the riverbanks were heavily timbered for half a mile on either side. More than 5,500 drifted, dead trees were pulled from a 50-mile stretch of river in a 10-year period. These trees ranged from 5 to 9 feet in diameter and from 90 to 120 feet in length. The river was also confined to one channel by engineering activities.

Many other rivers in Oregon and Washington were completely blocked by driftwood in the lower, main channels; the Skagit River had a driftwood jam three-fourths of a mile long and one-fourth of a mile wide. The Stillaguamish River was closed by six driftwood jams from the head of tidewater to river mile 17. Drifted, dead trees were so numerous, so large, and so deeply imbedded in the bottom that a steam "snag boat" operated for 6 months to open a channel only 100 feet wide.

Driftwood in high-gradient river systems often jams where the channel gradient is abruptly decreased. A section of the South Fork Nooksack River was described by Morse (1883, p. 9):

...we came to a place where the river, during freshets had ground sluiced all the earth away from the roots of the trees, and down some 6 feet to the gravel. This covered a region of country a mile in width by five in length. Overgrown yellow fir timber had once covered most of that section. If the river below there was only clear of jams that place would be paradise of hand loggers. On the gravel lay many million feet of sound fir timber, which only needed to be junked up during the summer and the winter freshets would float the logs down to the sea. Immediately below this place, the jams first extend clear across the river, and for the next 20 miles there is a jam across the river nearly every mile.

Large, woody debris was obviously an important part of early river systems of the Pacific Northwest; however, human objectives dictated that debris be cleared from river channels. Throughout North America, people have systematically cleaned downed trees and woody debris from streams for more than 150 years (Sedell and Luchessa 1982, Sedell and others 1982b). From the mid-1800's to about 1920, large and intermediate-size rivers in North America were cleaned so steamboats and rafts could navigate. From the 1880's to about 1915, small rivers and streams were cleaned so logs could be transported from the woods to the mills (fig. 3.1). Splash dams were built on many streams to temporarily augment the flow so logs could be floated (Sedell and Duval 1985, Sedell and Luchessa 1982) (fig. 3.2). Such channel clearance and splash damming removed large quantities of woody debris from medium to large streams, which significantly changed the physical and biological conditions of the streams (Harmon and others 1986).

During the 1950's and 1960's, west coast fishery managers feared that woody debris in streams restricted fish passage, supplied material for log jams, and caused channel scouring during floods (Hall and Baker 1982, Narver 1971). The great ecological value of organic debris was not yet known, and during times of extreme waterflow, all the managers' fears might be realized (Gharrett and Hodges 1950, McKernan and others 1950). The result of these fears was that fishery biologists were forced into the role of river engineers, a part for which they were not trained.

Debris is not now removed on the same scale as in the 1950's and 1960's, but removal is still a large part of salmon enhancement programs in several Western States and is mandated by virtually every State Forest Practices Act in the western United States and Canada. The combination of removal of debris in watershed headwaters so that fish could pass, splash damming, and removal of drifting wood and log jams from large rivers has left entire drainage systems almost devoid of large wood (Sedell and Swanson 1984).



Figure 3.1—Logs in a small stream awaiting enough water to be floated to the mill (photo from USDA Forest Service historical files).

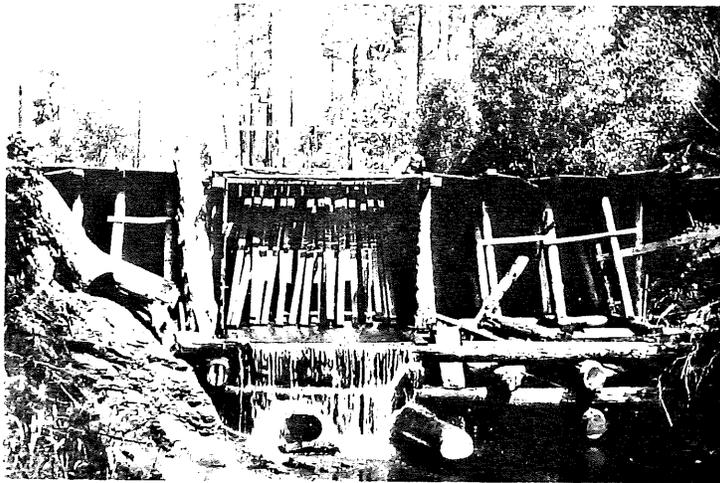


Figure 3.2—A splash dam at Austin Place, Hamilton Creek, Oregon, August 16, 1907. Such dams were used to regulate the flow of water to float logs down a stream to the mill (historical photo, courtesy of the Horner Museum, Oregon State University).

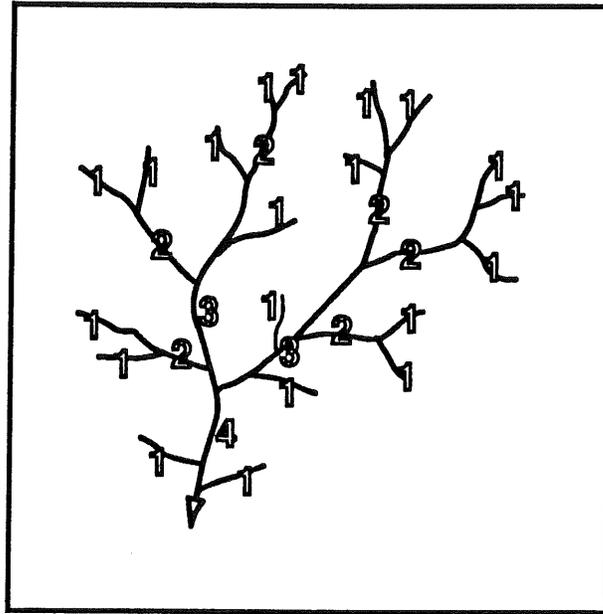


Figure 3.3—Stream order (after Strahler 1957) in a typical watershed. The majority of stream mileage is in first- and second-order tributaries in all watersheds of western Oregon and Washington.

Stream Categorization

Streams are characterized by their "order" (Strahler 1957) (fig. 3.3). Headwater stream channels are designated first-order; two first-order streams combine to form a second-order stream. Two second-order streams combine to form a third-order, and so forth.

In western Oregon, first- and second-order streams constitute 79 percent of the total stream mileage (Boehne and House 1983) (table 3.1). Such streams rise in very small watersheds with limited water storage capacity. These streams may have only scanty or intermittent flow during the dry season, but during high flows they may move large amounts of sediment and woody debris. Headwater streams mainly determine the type and quality of downstream fish habitat.

First- and second-order streams are influenced by the geomorphology, soils, and vegetation of their channels. Large woody debris is common, covering as much as 50 percent of the channel (Anderson and Sedell 1979, Swanson and Lienkaemper 1978, Triska and others 1982). The stream is continuously shaded by vegetation. Flow energy in the channel is continually dissipated by woody material and vegetation that slow erosion and foster deposition of organic and inorganic materials. The average gradient of these streams often exceeds 10 percent, but the channels usually have a stairstep configuration of flat reaches connected by riffles and low falls. Salmonid reproduction may be sufficient, even in some ephemeral streams, to furnish fry to larger waters downstream (Everest 1973, Everest and others 1985).

Table 3.1—Stream order analysis^a

Number of order	Total streams	Length	Average length	Average watershed area	Density
	<i>Number</i>	<i>-----Miles-----</i>		<i>Acres</i>	<i>Miles/acre</i>
Coastal watersheds:^b					
1	20	5.0	0.25	25	0.010
2	20	24.0	1.20	146	.008
3	20	94.9	4.70	410	.012
4	19	303.4	16.00	1,823	.010
5	9	393.3	43.70	4,635	.010
Cascade Range watersheds:^b					
1	20	5.0	.25	35	.007
2	20	27.9	1.40	222	.008
3	19	101.9	5.00	876	.008
4	20	407.9	20.40	2,761	.009
5	7	249.9	35.70	4,649	.008

^a Adapted from Boehne and House (1983).

^b Ordered on 1:12,000 scale.

Third- and fourth-order streams usually flow continuously. Average gradient is less than 5 percent, but there may be intermittent stretches of rapids or falls. Woody debris usually covers less than 25 percent of the channel. High flows may flush woody material from the system or deposit it in jams. The vegetative canopy over third- and fourth-order streams varies in density. These streams can transport large amounts of sediments, which are often deposited around channel obstructions, in narrow, winding areas, or in other areas of low velocity—accretion bars, estuaries, and the flood plain.

The direct influence of riparian areas is moderated in fifth-order and larger streams but remains important. Canopies of large, old-growth trees provide some shade, vegetated riparian zones keep the main channel confined, and the largest stems of down trees that remain in the stream provide important summer and winter salmonid habitat. Flood plains of the larger streams contain complex arrays of side channels, overflow channels, and isolated pools. Side channels are often created and maintained by large woody debris (Bisson and others 1987, Sedell and others 1984). The gradient in large streams is usually less than 1 percent, but rapids and falls may occur. Alluvial material and woody debris may be deposited in quiet areas, but accumulations are flushed and rearranged during high flows.

Table 3.2—Physical variables in relation to stream order in 2 Oregon watersheds^a

Watershed type and physical variable	Unit	Stream order			
		2	3	4	5
Coastal watersheds:					
Gradient	Percent	18	6	4	3
Width	Feet	2	5	10	11
Depth	Inches	8	16	16	33
Pool	Percent	22	27	31	37
Riffle	Percent	78	73	69	63
Spawning gravel	Square yards per mile	121	455	1,176	63
Bottom substrate—					
Bedrock	Percent	2	16	14	9
Boulder	Percent	11	15	15	14
Cobble	Percent	26	15	17	19
Rubble	Percent	9	10	15	11
Gravel	Percent	36	29	27	27
Fines	Percent	16	16	12	20
Cascade watersheds:					
Gradient	Percent	11	9	6	3
Width	Feet	4	7	9	24
Depth	Inches	2	4	8	12
Pool	Percent	55	56	58	49
Riffle	Percent	45	44	42	51
Spawning gravel	Square yards per mile	73	125	376	1,321
Bottom substrate—					
Bedrock	Percent	—	—	—	—
Boulder	Percent	—	—	—	—
Cobble	Percent	—	—	—	—
Rubble	Percent	—	—	—	—
Gravel	Percent	13	16	18	20
Fines	Percent	3	4	5	3

— = not available.

^a Adapted from Boehne and House (1983).

Most salmonids spawn in fourth-order coastal streams and fifth-order watersheds in the Cascade Range (table 3.2). Resident salmonids use some second-order coastal streams but are nearly always found in third-order or larger streams. Fourth- and fifth-order streams in western Oregon can support rearing of anadromous salmonids unless barriers or gradients of more than 12 percent stop upstream movement of adults.

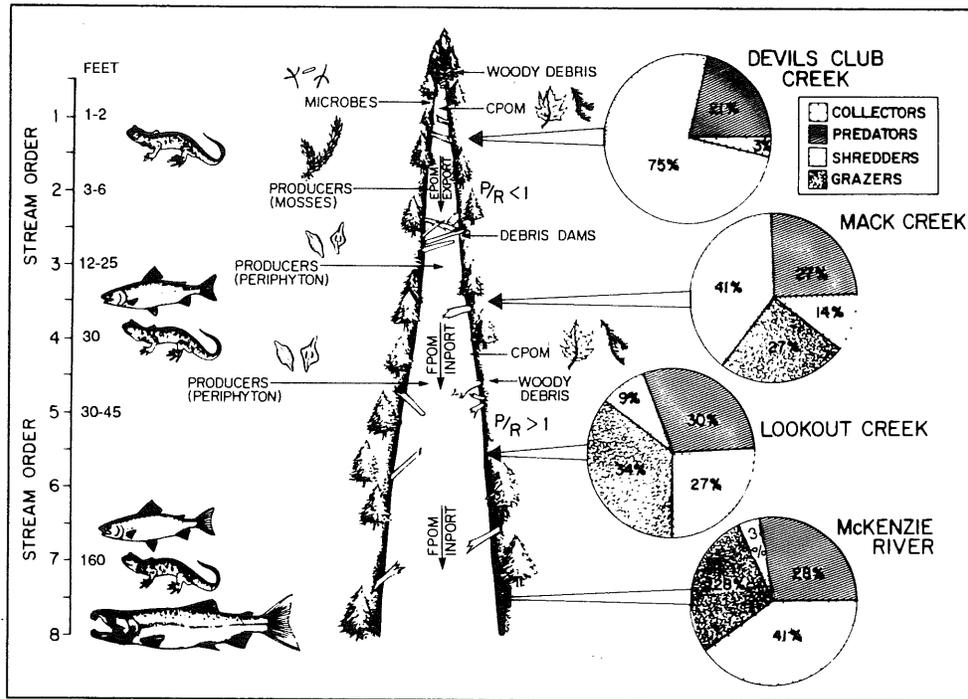


Figure 3.4—Diagram of first- to eighth-order streams showing width, dominant predators, producer groups, P:R (production:respiration) ratios, importance of wood, and proportion of invertebrate functional groups (adapted from Vannote and others 1980); CPOM = coarse particulate organic matter, FPOM = fine particulate organic matter.

Ecosystem Structure and Function in Unmanaged Streams

The stream network is a spectrum of physical environments and associated biotic communities (Vannote and others 1980). Streams form a longitudinally linked system in which downstream processes (cycling of organic matter and nutrients, ecosystem metabolism, new metabolism) are linked to upstream processes. The spectrum concept is a good framework for studying and managing streams as heterogeneous systems (O'Neil and Reichle 1980). Useful generalizations can be developed about magnitude and variation of organic matter through time and space, the structure of invertebrate and fish communities, and resource partitioning along the entire river.

First- and second-order streams feed third- and fourth-order streams with partially used food, the amount of which becomes progressively smaller as stream order increases. Small streams derive much food for invertebrates from wood or leaf litter under old-growth forests. The forest influence diminishes as streams become progressively larger and the stream energy base comes more from algae and less from forest litter (fig. 3.4). The forest influence is greatest in very small streams, but most diverse organic input mechanisms and habitats are in third- to fifth-order streams. Invertebrates reflect these downstream shifts with fewer shredders (leaf eaters) and more grazers (algal feeders) in small rivers (fig. 3.4). Dominant organisms change as the size of a forested stream changes, as does the role of each functional group of organisms in using organic materials (fig. 3.4).



Figure 3.5—Woody debris in a small pristine stream.

Consider a first-order woodland stream and a sixth-order stream (intermediate-size river) in the context of continuums of communities with associated abiotic factors (fig. 3.4). Both systems include the same organic processing components, but they vary in relative magnitude of the components, rates and amounts of organic transfer between components, and species engaged in the transfers. The two systems are essentially modifications of the same trophic scheme, so the entire stream-to-river complex can be considered a single system composed of a series of communities along a continuum.

The continuum example deals primarily with food resources for organisms ranging from invertebrates to fish. More important to resource management, however, is the ecological rationale for a protective vegetation zone along streams and rivers of all sizes. Streamside vegetation zones are justified on the grounds of stream temperature control, bank stabilization, and food resources. Streamside vegetation is also the primary supplier of large organic debris—snags or tree stems 8 inches in diameter with the rootwads attached, or tree branches more than 8 inches in diameter.

Forests adjacent to streams supply large debris (stems, rootwads, large limbs) (fig. 3.5). Erosion may contribute debris to streams and account for water transporting pieces of debris. Organic debris in streams increases aquatic habitat diversity by forming pools and protected backwater areas, provides nutrients and substrate for biological activity, dissipates energy of flowing water, and traps sediment.

Aquatic ecologists, hydrologists, and geomorphologists only recently have recognized that large organic debris has always been an important part of forested streams. For western streams, such recognition developed from the following viewpoints: manipulation by humans (Bisson and others 1987, Froehlich 1973, Heede 1972, Marzolf 1978), functions of the ecosystem (Bilby 1981, Bilby and Likens 1980, Harmon and others 1986, Meehan and others 1977, Sedell and Swanson 1984, Swanson and others 1976, Triska and others 1982), and the historical aspect (Sedell and Froggatt 1984, Sedell and Luchessa 1982, Sedell and others 1982a, Triska 1984).

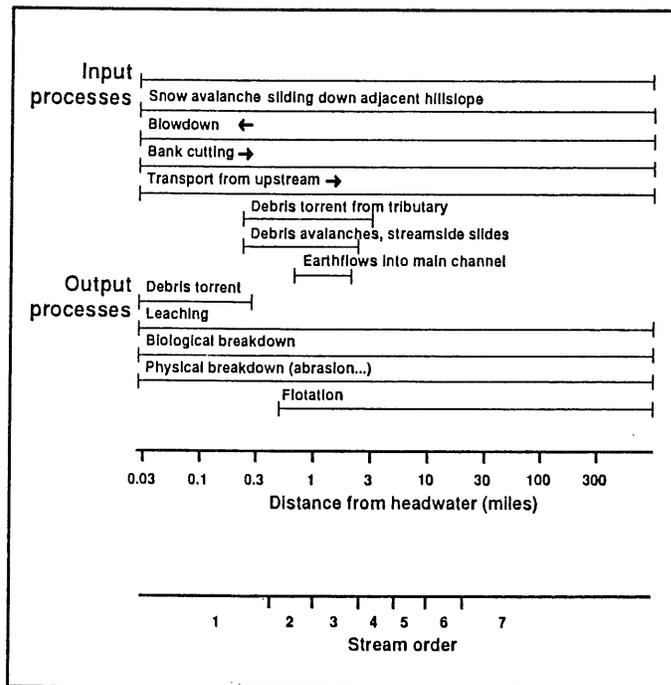


Figure 3.6—Debris input and transport processes by stream order in the McKenzie River system of western Oregon. Arrows indicate direction of increasing importance (adapted from Keller and Swanson 1979).

Several mechanisms transfer large woody debris to stream channels: bank undercutting and collapse, tree blowdown, tree collapse from snow or ice, snow avalanches, and mass soil movements (Keller and Swanson 1979). Each of these mechanisms contributes in some way to channel, slope, forest stand processes, watershed geology, and stream size.

The processes of transferring large pieces of wood from forests to stream channels are: chronic—frequent inputs irregular in time and space; and episodic—infrequently spaced, often very large inputs (fig. 3.6). Chronic input processes include tree mortality from disease and insects combined with windthrow or gradual stream undercutting of root systems. Episodic input processes include large-scale epidemics of insects or diseases, extensive blowdown (fig. 3.7), logging, debris avalanches, and massive erosion of banks during major floods.

Forest succession alters the composition of woody material entering streams through mortality and bank undercutting, causing trees to fall after logging. In young-growth plantations of the Pacific Northwest, low- to mid-elevation riparian zones are dominated by deciduous species, such as red alder, if no mature conifers remain along the stream after logging. Most trees that enter stream channels in young-growth sites are red alder (fig. 3.8, color), which has a shallow root system, and therefore, low resistance to undercutting. The rate of input of young-growth conifer debris is slow and does not increase until about 60 years after logging (Grette 1985) (fig. 3.9).



Figure 3.7—Blowdown is a major cause of large woody debris in streams.

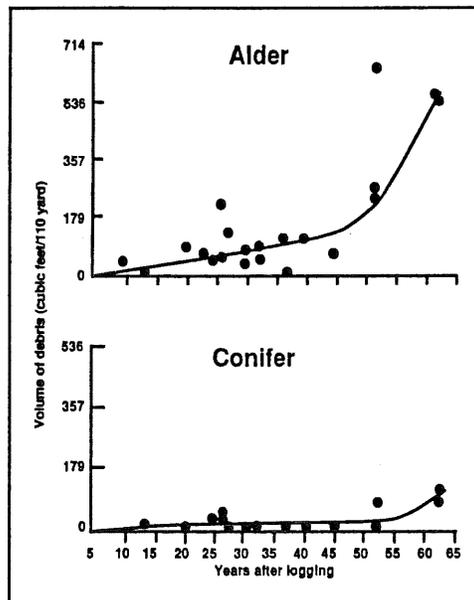


Figure 3.9—Red alder and conifer debris in small streams in second-growth forests in western Washington (adapted from Grette 1985).

Chronic inputs of woody debris larger than 20 inches in diameter are more common in mature and old-growth forests because of tree mortality than in young-growth stands where most or all of the trees are small. Inputs of smaller debris (less than 4-inch diameter) from young stands may, however, equal or exceed the rate of input of small debris from old-growth forests (Long 1987).

Distribution of Fallen Trees

The location, stability, and longevity of debris influence the quality of habitat in all fish-bearing streams, although the arrangement of woody debris varies according to stream size and valley morphology (Swanson and others 1976). Spacing of individual pieces of debris or clumps of pieces can be strongly influenced by input processes. If the dominant input is from bank undercutting of living trees or direct falling of dead trees, debris is spaced at random intervals along very small channels where discharge is insufficient to carry the debris pieces downstream. In most fish-bearing streams, however, there is some degree of debris clumping, the magnitude and spacing of which generally increases downstream. In streams wider than 5 to 7 feet (usually third- to fourth-order), woody debris enters the stream after bank undercutting. Trees that fall directly into the stream are moved during storms and deposited on channel obstructions and on the outsides of river bends near the high water line. Deposited debris may greatly increase width of the channel, produce midchannel bars, and facilitate the formation of meander cutoffs (Keller and Swanson 1979). Short, braided stream reaches and secondary channel systems formed in this manner are especially productive sites for rearing salmon and trout in Pacific Northwest rivers (Sedell and others 1984).

A major flood moves live trees to the stream, but downed trees and stumps can enter or leave streams annually with smaller floods. Large streams that flow through steep, narrow valley walls (for example, ravines) often cannot develop deposition zones, so they become dominated by boulders rather than by large woody debris.

Clumps caused by debris avalanches, extensive blowdown, or movement of large amounts of material from the flood plain in a major flood tend to be more widely spaced and of greater volume than those in streams where the foregoing input processes do not occur frequently.

Yet another input process is the debris torrent, a slurry of debris, soil, and water that can occur when a landslide enters a steep headwater channel (Swanson and Swanson 1976). Large logs jam at the terminus of a debris torrent, along with much sediment and debris, but the torrent itself scours the channel as it travels downstream. The result is a track that may be nearly devoid of debris and sediment—very poor fish habitat (Swanson and others 1976). A study of channels scoured by debris torrents in the Queen Charlotte Islands, British Columbia, revealed that debris remaining in torrent tracks usually lie parallel to the streamflow direction, in contrast to the more common diagonal orientation found in streams of unlogged areas or of channels with no torrents. This shift in orientation reduces channel width, depth variability, cut banks, pool areas, and channel stability, and thus reduces fish habitat diversity and quality. The debris dam formed by a torrent can be so extensive that it forms a major barrier to fish passage. Such dams are commonly found near tributary junctions where small first- and second-order channels that have suffered a debris torrent empty into larger, low-gradient streams.

Debris torrents usually travel short distances and may not affect large rivers unless a headwater channel discharges directly into a mainstream, as is the case in many glacial valleys. Large woody debris, however, can still be clumped along intermediate and large rivers as a result of infrequent events, such as major floods (Swanson and Lienkaemper 1978). Movement of floatable debris from headwaters or flood plains may form massive accumulations of driftwood wherever the channel narrows or low gradient depositional zones occur. Extensive driftwood dams, common in coastal streams before river clearance, are now rare (Sedell and Luchessa 1982). More common now are sporadic large accumulations of debris deposited on upper stream-banks and flood plain terraces inundated only during floods. Such debris is normally above the water line, so its use by fish is limited to high flows. The temporary refuge provided by inundated debris accumulations along the upper banks of streams with well-established flood plains, however, may be very important to survival of fish when main channel velocity is high (Tschaplinski and Hartman 1983).

Forest type and successional stage, disturbance history, and channel size all influence the amount of wood in streams. Woody biomass ranges widely—from 2 to 400 pounds per square yard (table 3.3)—as does woody volume, from 0.08 to 144 cubic feet per yard (Harmon and others 1986).

Stream biomass is also strongly influenced by geomorphic processes. Loss or deposition of sediment in channels may change the measurable biomass in streams (Harmon and others 1986).

Numbers of downed trees and large pieces of woody debris vary among streams in mature and old-growth forests, young-growth forests, and blowdown vegetation (table 3.4). Streams flowing through young-growth forests and recently harvested areas contain from one-fifth to one-twentieth the number of large woody pieces found in streams in mature forests.

Average length and frequency of large pieces of wood in pristine forested streams are greater than those of wood in manipulated streams or salvage-logged areas (fig. 3.10). Total pieces of wood and their average diameter and length were determined in two small Coast Range streams (fig. 3.11; Sedell, unpublished data). One stream drains a wilderness area; the other stream drained an area of which about 95 percent had been harvested over the past 30 years. The wilderness stream has more than one hundred times more pieces of wood and downed trees per unit length of channel. The average diameter class of wood for both streams was about 20 inches, but the average length of wood in the logged watershed was about 16 feet compared with 33 feet in the pristine stream. The role of wood in shaping and stabilizing habitats has been greatly diminished in the harvested watershed.

Table 3.3—Biomass of large woody debris in streams flowing through unmanaged old-growth forests along the Pacific Northwest coast

Location and dominant riparian tree species	Sample size ^a	Mean channel width	Large woody debris biomass	
			Mean	Range
	<i>Number</i>	<i>Feet</i>	<i>Pounds/square yard</i>	
Prince of Wales Island, Alaska:				
Sitka spruce and western hemlock	4	0.00 - 16.40	15.43	4.41 - 19.84
	1	32.81 - 49.21	26.46	—
Coastal British Columbia, Canada:				
Sitka spruce and western hemlock	1	32.81 - 49.21	39.68	—
	3	49.21 - 65.62	48.50	46.30 - 50.71
West slope Cascade Range, Oregon:				
Douglas-fir	19	0.00 - 16.40	55.12	4.41 - 121.25
	5	16.40 - 32.81	57.32	28.66 - 74.96
	1	32.81 - 49.21	50.71	—
	2	49.21 - 65.62	22.05	13.23 - 30.86
	2	>65.62	13.23	4.41 - 19.84
Northwest coast, California:				
Coast redwood	6	0.00 - 16.40	295.42	22.05 - 396.83
	4	16.40 - 32.81	141.09	39.68 - 242.51
	1	32.81 - 49.21	149.91	—
	1	49.21 - 65.62	35.27	—
Klamath Mountains, California:				
Douglas-fir	8	0.00 - 16.40	33.07	4.41 - 101.41
	2	16.40 - 32.81	55.12	2.20 - 110.23
	1	32.81 - 49.21	2.20	—

— = not available.

^a The number of stream reaches surveyed (from Harmon and others 1986).

Table 3.4—Number of large pieces of woody debris per 100 yards of stream length in streams with drainage areas less than 6 square miles, by forest condition^a

Forest condition	Stream location	Pieces of woody debris per 100 yards of stream reach
Old-growth or mature forest:		
Mack Creek	Oregon, Cascade Range	22 - 28
Lookout Creek	Oregon, Cascade Range	18 - 20
Lobster Creek	Oregon coast	18
Sheehan Creek	Southeast Alaska	33 - 45
Cummins Creek	Oregon coast	20 - 23
South Fork Hoh River tributaries	Washington, Olympic Peninsula	18 - 20
Young growth:		
Knowles Creek	Oregon coast	1 - 3
Lobster Creek	Oregon coast	1 - 2
Fish Creek (repeatedly salvaged)	Oregon, Cascade Range	4 - 5
Blowdown buffer strip:		
Sheehan Creek	Southeast Alaska	135

^a Adapted from Sedell and others (1984).



Figure 3.10—The average length of large pieces of downed wood in pristine forested streams, such as those shown, is greater than those in streams in managed forests.

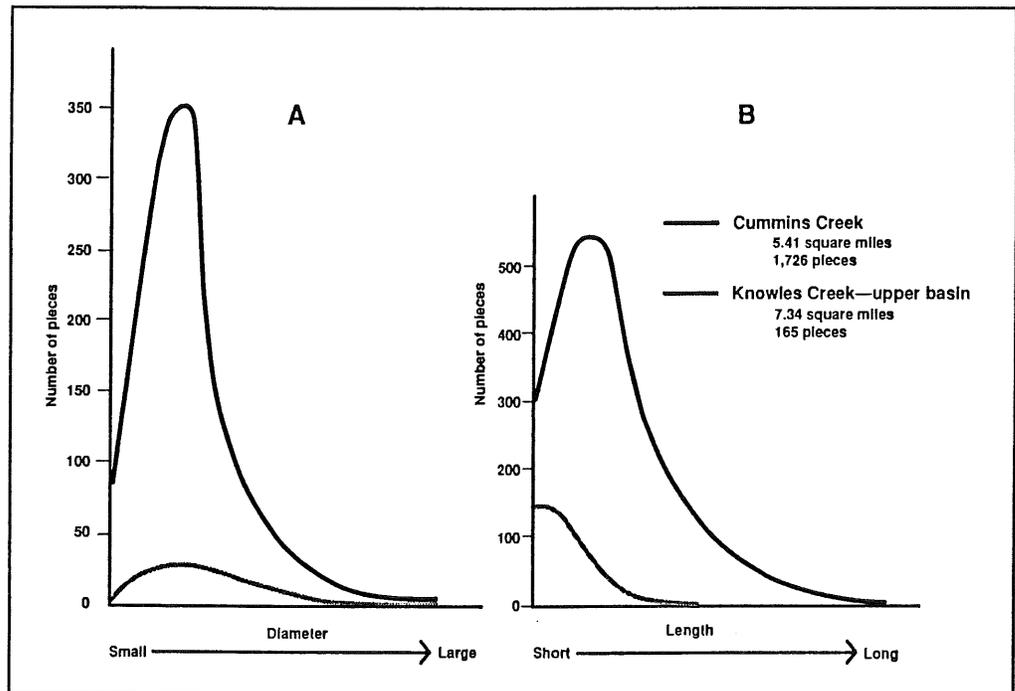


Figure 3.11—Instream frequency trends for an old-growth forested watershed (Cummins Creek) and a second-growth (less than 30 years) watershed (Knowles Creek) in the central Oregon Coast Range: A. Diameter of woody debris. B. Length of woody debris.

The North Fork Breitenbush, a high gradient, sixth-order stream in the central Cascades of Oregon, at bank-full stage is often wider than 98 feet, large enough to move even the largest and longest, downed trees. The river is divided by a wilderness boundary. Salvage logging had been carried out several times since 1965 on the lower 60 percent of the fish-bearing channels of the river. The average length of wood pieces in the managed stream was about 26 feet compared with 48 feet in the wilderness stream (fig. 3.12). Between 49 and 64 percent of the total large pieces of wood were less than 15 feet long in the managed stream compared with less than 18 percent in the wilderness stream. Pieces of wood longer than 50 feet accounted for more than 41 percent of the total wood in the wilderness stream compared with 8 to 17 percent in the managed stream (fig. 3.13). About 67 percent of the pieces of wood with a rootwad attached were longer than 49 feet in the wilderness stream compared with 14 to 23 percent in the logged stream. Stumps made up more than 60 percent of the wood in the managed stream compared with less than 6 percent in the wilderness stream. Total volume of wood had not changed for the wilderness or the managed streams, but the pieces were much less stable in the salvage-logged stream where the channel had widened by 40 percent. Clearly, the trend is toward smaller and fewer pieces of wood in stream channels of all sizes in the logged areas (fig. 3.14; compare with fig. 3.10). In addition, stream channels in the logged area are wider and less stable. The volume of wood may be the same in the managed and the unmanaged streams, but it is more clumped in the managed forest and volume per unit of stream area is less.

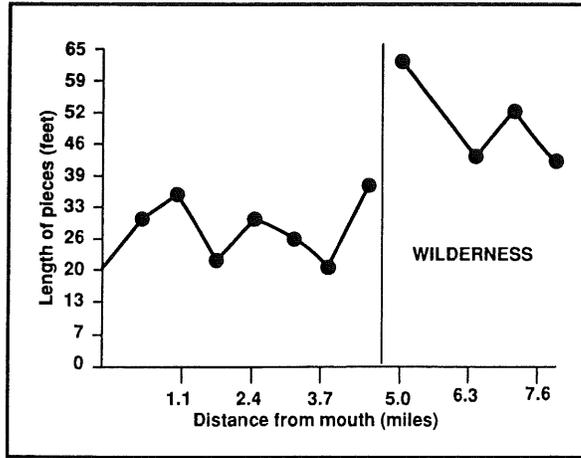


Figure 3.12—Length of pieces of wood in the North Fork Breitenbush River.

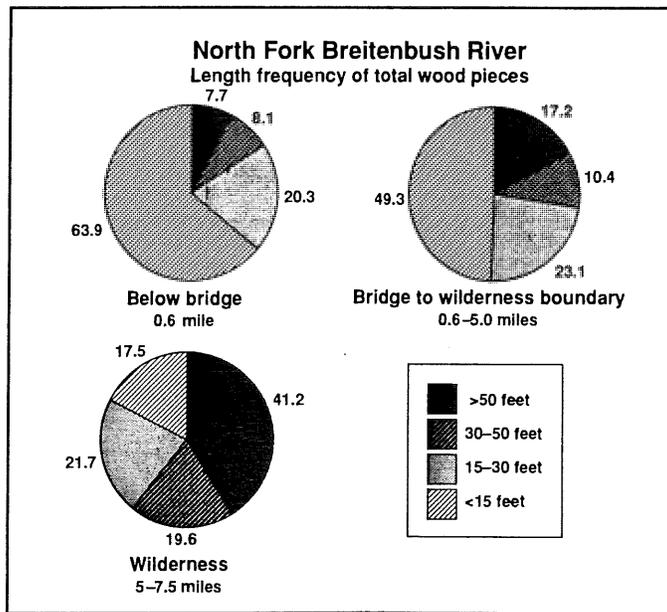


Figure 3.13—Frequency of wood pieces with rootwads, North Fork Breitenbush River.



Figure 3.14—The trend is toward smaller and fewer pieces of wood in channels of streams running through managed forests.

Residence Time and Stability of Fallen Trees

Longevity

The residence time of woody debris in stream channels is affected by transport processes, chemical constituents of the wood that affect decomposition rates, and resistance to breaking and abrasion. Dendrochronologic dating of instream debris in coniferous forests of the Pacific Northwest has identified pieces that have been in channels for 200 years or more (Keller and Tally 1979, Swanson and others 1976). Old-growth conifer debris is estimated to decay at a rate of 1 percent per year, although the rate may vary among tree species (Grette 1985). Western redcedar resists decomposition in streams better than does Douglas-fir or western hemlock, but all three conifer species far outlast red alder (Anderson and others 1978).

Logging alters the composition of riparian vegetation by reestablishing early successional stages. Debris from young-growth stands has a shorter residence time in stream channels than debris from preharvest forests. The frequency of red alder debris in young-growth forested streams is about twice that of alder in old-growth streams (Grette 1985). Red alder disappears from streams in young-growth forests more rapidly, however, than does conifer debris (primarily hemlock and spruce) because the alder debris is shorter, of smaller diameter, more easily broken, and less well anchored than conifer debris from the preharvest forest. The rate of input of alder debris from young-growth stands exceeds the input rate of conifer debris, but the reduced longevity of alder debris results in streams with less cover and fewer pools than streams in unlogged forests. Loss of cover in streams in young-growth forests has the most significant impact on salmonid populations in winter, when fish are strongly attracted to debris (Grette 1985) (fig. 3.15).



Figure 3.15—Loss of cover in streams in young-growth forests has the most significant impact on salmonid populations in winter.

Stability of Fallen Trees

Stable debris accumulations are assumed to be important for maintaining good fish habitat. If debris does not move frequently, its functions of pool anchoring, cover, and substrate storage are increased over those of unstable accumulations (Bryant 1983). Size, including length and diameter (fig. 3.16), is a major factor contributing to debris stability (Bilby 1984, 1985; Bryant 1983; Grette 1985; Toews and Moore 1982). Other dimensions, such as the presence of a rootwad or branches, also influence when or where a piece of debris will move. Debris length appears to be most important to its stability where stream discharge is sufficient to float large diameter stems (Bilby 1985, Swanson and others 1984). Branches and rootwads add to the stability of debris pieces by increasing the mass and surface area available for snagging on instream obstructions; whole trees are thus potentially more stable than tree fragments. Tree fragments, about half the width of a bank-full channel, were floated downstream during winter storms, but large stems with intact rootwads remained in place for at least 70 years in small, low gradient streams in southeast Alaska (Bilby 1981, Swanson and others 1984). Relatively short pieces of debris can be stable in narrow channels, but longer pieces are necessary for stability in wider channels. Trees whose length exceeds that of a bank-full channel may have much of their weight supported by ground outside the channel where they lodge against standing trees during high streamflow (Swanson and others 1984).

Other aspects of debris that influence stability include orientation, degree of burial, and the proportion of the piece that lies in water. Whether a piece is buried depends in part on the rate of sediment input to the channel and the longevity of the piece. Pieces are stable if their angle of orientation relative to the axis of flow is less than 30 degrees; they are likely to move, however, if their angle of orientation is greater than 60 degrees (Bryant 1983). The degree of burial strongly influences debris movement; pieces with both ends anchored to the streambed or bank move less than pieces with only one or neither end buried. The degree of burial also influences potential movement (Bilby 1984). Partial burial is less effective than complete or nearly complete burial in preventing downstream transport during storms (Grette 1985, Toews and Moore 1982).

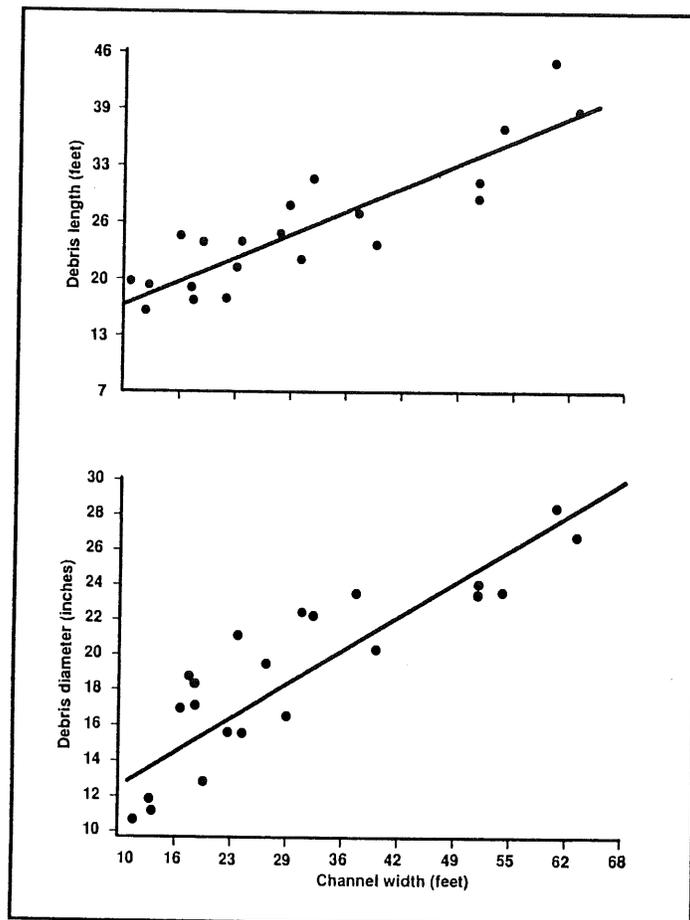


Figure 3.16—Relation between the length and diameter of stable debris and channel width. Each point represents the geometric mean length or diameter of logs not held in place by other debris at each of the western Washington study streams (adapted from Bilby (1985) and Bisson and others (1987)).

Even the largest fallen trees cannot span the bank-full channel width in large rivers. In such cases, the amount of wood and the number of fallen trees on exposed gravel bars provide constancy to wood in the river channel even though position of the material may change annually. The likelihood of fallen trees being transported back to the main channel is greatly reduced once they have formed jams at bends or outer margins of the flood plain, unless the river changes course.

Processes of Wood Removal

Much relatively small debris enters streams after logging and is therefore more apt to move than would naturally occurring debris (Bryant 1980, Grette 1985, Lammel 1972, Swanson and Lienkaemper 1978, Toews and Moore 1982). Removing all newly added debris after logging, a requirement of many forest practices regulations, may involve bucking large debris into smaller pieces that are removed to the high water line. Such mandatory debris cleaning, however, usually takes place during low flow periods, and some of the material deposited on the upper bank may subsequently re-enter the stream at high flows. This increases the amount of shorter, less stable pieces in the channel (Bisson and Sedell 1984, Hogan 1985, Lestelle 1978, Osborn 1981).

High quality fish habitat declines as debris is exported (Bryant 1985, Scrivener and Andersen 1984). Downstream transport of small, unstable debris can lead to accumulations in debris dams that may remain in place for only a few years before moving on. Although debris dams may temporarily block fish migration, a greater long-term consequence for fish populations is the lack of large structure in the channel after debris is removed. Debris loading increases immediately after logging, then declines as accumulations gradually wash away (Bryant 1982, 1985; Toews and Moore 1982).

Large floods move great quantities of wood onto the upper flood plain and downstream. Low frequency, high magnitude floods add much material to streams. The wood becomes more clumped through either flood or debris torrent forces. On small coastal streams, debris torrents may temporarily dam sections of streams draining basins larger than 6-9 square miles. When these dams fail, the resulting debris flood scours wood from the channel and deposits it high on banks or in estuaries.

Physical abrasion is the most powerful mechanism for removing stable pieces of wood from streams and rivers. Sand and gravel carried at flood velocities abrade large pieces of wood. Abrasion is greater in high gradient or sediment-rich streams than in gentle, spring-fed or low-gradient streams and rivers.

Biological decomposition is only a minor process in removing wood from streams. Water-logged wood decays slowly, but wood at the stream-terrestrial interface hosts very active microbial and invertebrate activity. Here, the biotic components respond to a gradient of temperature, moisture, and oxygen. Wetting and drying at the stream-terrestrial interface allows rapid biological decomposition of wood (Triska and Cromack 1980).

Forest management has greatly influenced the sequence of events in watersheds. The impact of natural processes that increase the rate at which woody debris disappears from stream systems is minimal compared with the impact of human activity on disappearance of wood over the last few decades.

Streams may be cleaned either immediately after logging to remove slash, or later to remove a specific blockage of fish passage (*fig. 3.17, color*). Postlogging stream cleaning is usually done by a professional crew with small equipment. Debris barriers to fish are usually removed under the supervision of a fishery biologist, who may need to use heavy equipment and explosives. Stream cleaning may damage fish habitat (Sedell and others 1985).

The State of Washington has required thorough removal of logging slash from streams for about the last 10 years. During this time, the effect of stream cleaning has been evaluated in several Pacific Northwest areas. In almost every such study, debris removal has resulted in loss of important habitat features and reduced fish populations (Bryant 1980, Dolloff 1983, Elliott and Hubartt 1978, House and Boehne 1985, Lestelle 1978, Lestelle and Cederholm 1984, Osborn 1981, Toews and Moore 1982).

Removing large, stable wood along with smaller material reduces channel stability and the quality of pools and cover. Small, easily floated wood has sometimes become temporarily abundant after stream cleaning (Meehan and others 1969, Toews and Moore 1982). Any such increases have come from new slash entering the water from debris stacked near the high water line during cleaning, or the breakup of wood in the stream before logging. In most cases, unstable debris is flushed from the cleaned reach within a few years, and channels are thus degraded.

The proportion of riffles increases and the number of pools decreases in cleaned stream channels (Bisson and Sedell 1984). The increased frequency of riffles increases the abundance of underyearling steelhead and cutthroat trout, which prefer riffle habitats; however, the abundance of coho salmon and older age classes of steelhead and cutthroat, which prefer pools, is correspondingly reduced.

State and Federal agencies annually spend more than \$6 million to remove debris jams, but the impact on habitat has had little study. In one study, fish populations in the vicinity of log jams were reduced immediately after complete removal of debris, but abundance did not decline significantly where part of the jam was allowed to remain (Baker 1979). Downstream spawning and rearing areas were damaged by large flows of sediment released when the log jams were removed. Partial removal appears to be biologically preferable to complete removal and is less expensive.

Most salvage logging in streams has been done since the great Pacific Northwest storm of 1964. Since then, Federal funds have been provided for cleaning and salvaging wood from streams after every major storm. Major timber sales on public land focus on streams of fifth-order or larger because access to established main roads is easy. A major reason for removing woody material from streams has been protection of downstream bridges and culverts to reduce property liability court cases. Even some sports clubs remove tree debris from rivers where such obstacles might impede travel (Oregonian 1986).

Use of wood-burning stoves has increased tremendously in the last 10 years (fig. 3.18). Most of the wood cut for fuel does not come from streams, but the demand for high quality wood that might otherwise reach a stream is great.

In the last 100 years, millions of trees have been cleared from rivers. County sheriffs, port commissions, and recreational boaters routinely clear fallen trees from rivers for safety and convenience. As a result, most Pacific Northwest rivers bear little resemblance to their pristine condition.

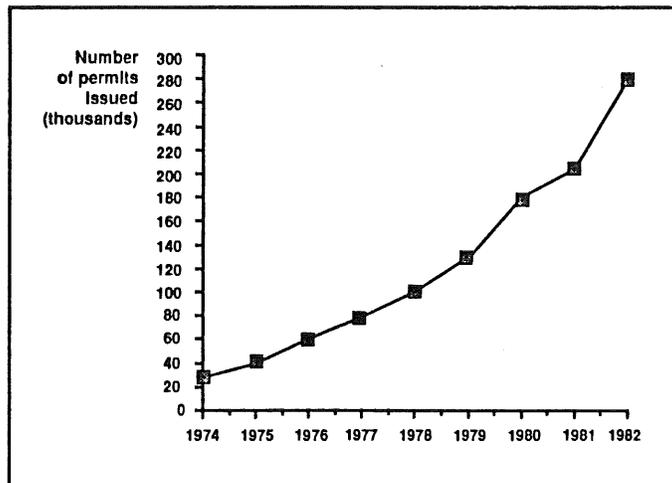


Figure 3.18—Forest Service, Pacific Northwest Region, free use wood permits.

Trends in Wood Inputs

Riparian zones in the past have supplied large trees to the stream, but most stream-banks now have smaller trees of fewer species. Most big cedars and Douglas-firs along streams in the Cascades and along most coastal streams greater than third-order have been removed or are about to be. On private land, 60-70 percent of conifer trees larger than 14 inches in d.b.h. have been harvested within 100 feet of a fish-bearing stream (table 3.5) in both the Oregon Coast Range and the Cascade Range. Fewer conifers than might be expected, larger than 12 inches in d.b.h., are growing along coastal streams (Sedell, unpublished data).

Table 3.5—Conifers larger than 14 inches in diameter harvested from 100-foot-wide leave strip

Location	Distance from stream (feet)		
	0-50	50-100	1-100
	<i>Percent</i>		
Coast Range:			
Drift Creek	0	0	0
Yaquina River	50	100	86
Siuslaw River at Pugh Creek—	44	74	65
Below North Creek	83	82	82
Above North Creek	0	13	9
Wolf Creek	53	90	68
Cascade Range:			
Santiam River	—	>57	57
Thomas Creek	57	92	76
Unnamed order 1 stream	100	100	100

— = not available.

Table 3.6—Stocking levels of large conifer trees (larger than 14 inches) in streamside areas after successive harvests

Streamside area	Pristine forest more than 70 years ago	Recently harvested stand	Leave strip stand
<i>Trees per acre</i>			
Cascade Range, both sides of unnamed order 1 stream, within 50 feet	43	24	0
Coast Range, 1 side of Yaquina River:			
Within 50 feet	16	6	3
Within 100 feet	36	22	3

The number of streamside conifers larger than 14 inches in d.b.h. has been drastically reduced from the number present 70 years ago at the first harvest (table 3.6). Conifers larger than 14 inches in d.b.h. ranged from only 0 to 19 percent of the pristine stocking level after recent logging.

Wood as Habitat in Freshwater Systems

Influences of Wood on Stream Characteristics

Woody debris influences stream channel flow and creates and maintains rearing habitat for salmonid fishes (Lisle 1982, Sullivan and others 1987). Free-swimming species, such as salmon and trout, require rearing sites where food is plentiful and little effort is needed to hold a feeding position against the current (Dill and others 1981, Fausch 1984). Such small, quiet areas are usually located behind boulders and are occupied by large, aggressive fish (Bachman 1984). Stream riffles have few such sites.

Some species, notably coho salmon, avoid riffle habitats almost entirely when competitors are present (Bisson and others 1982, Dolloff 1983, Hartman 1965); instead, they rely on pools with ample cover provided by large woody debris (Bisson and others 1985, Stein and others 1972).

Most stream fishes inhabit pools in which the current velocity is lower and the water usually deeper than in riffles. Deep pools offer fish a better chance of escaping from terrestrial predators, and also allow fish of different species or age classes to coexist in layers within the water column (Allee 1982, Fraser 1969).

Woody debris creates many of the pools in Pacific Northwest streams (Keller and Swanson 1979, Swanson and others 1976) (*fig. 3.19, color*). In small streams (up to about 3d order), single large pieces of debris or accumulations of smaller pieces anchored by a large piece often create a stepped longitudinal profile (*fig. 3.20; fig. 3.21, color*) that consists of an upstream sediment deposit, the debris structure,

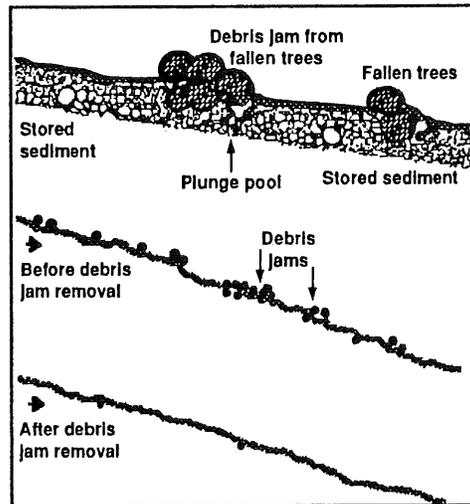


Figure 3.20—Role of woody debris in storing sediment and creating pools in streams: The "stepped profile" is characteristic of stored sediments and plunge pools created by woody debris. Removing a debris dam destroys and reduces these habitat features (adapted from Bisson and others 1987).

and a downstream plunge pool (Heede 1972, 1985). Numerous debris accumulations generally increase pool frequency (Lisle and Kelsey 1982). Numbers of pools are positively correlated with numbers of debris pieces in low-gradient streams (Grette 1985). Eighty percent of the pools in small streams of the panhandle of Idaho are caused by fallen trees larger than 10 inches in diameter (Rainville and others 1985). The frequency and volume of pools decrease in stream channels from which slash and naturally occurring debris were removed after logging (Bilby 1984, Bisson and Sedell 1984, Toews and Moore 1982).

The position of debris also influences the size and location of pools. The size of a single stem or the accumulation of stems spanning the channel affects the size of the associated pool. In an experimental flume, larger logs created longer and deeper pools, provided they were suspended above the streambed (Beschta 1983). In other studies, pool area was positively correlated with the volume of debris that anchored the pool, and the correlation improved as channel width increased in streams up to 7 feet wide (Bilby 1985, Bisson and others 1987) (fig. 3.22). Many pools, however, are created by eddies behind debris and other structures located at the channel margin rather than by the scouring action of channel flow. These backwater or eddy pools, common in all streams, are used by salmonids throughout the year for rearing (Bisson and others 1982; Bryant 1985; Bustard and Narver 1975a, 1975b; Dolloff 1983; Gibson 1981; Lister and Genoe 1979; Mundie 1969; Murphy and others 1984; Sedell and others 1982a, 1984; Stein and others 1972; Tschaplinski and Hartman 1983).

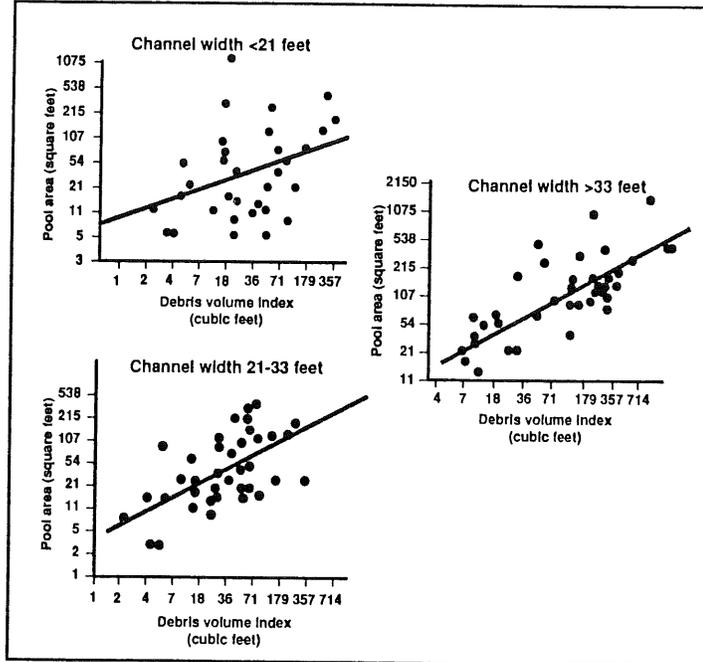


Figure 3.22—Relation between size of woody debris and pool area created for different-size streams in the Pacific Northwest. One 12-inch Douglas-fir tree contains about 72 cubic feet of wood; adapted from Bilby (1985).

Woody debris increases the complexity of stream habitats by physically obstructing waterflow. Trees extending partially across the channel deflect the current laterally, causing it to widen the streambed (Zimmerman and others 1967). Sediment stored by debris also adds to hydraulic complexity, especially in organically rich channels that are often wide and shallow and possess a high diversity of riffles and pools in low gradient streams of alluvial valley floors (Keller and Swanson 1979, Keller and Tally 1979). Even if the stream becomes so large that trees cannot span the main channel, debris accumulations along the banks cause meander cutoffs and create well-developed secondary channel systems (Keller and Swanson 1979, Swanson and Lienkaemper 1982). Debris also creates variation in channel depth by producing scour pools downstream from obstructions (Hogan 1985, Keller and Tally 1979). Wood therefore maintains a diverse physical habitat by (1) anchoring the position of pools along the direction of the stream, (2) creating backwaters along the stream margin, (3) causing lateral migration of the channel and forming secondary channel systems in alluvial valley floors, and (4) increasing depth variability.

Large, fallen trees affect live vegetation along watercourses. Trees carried by floodwaters can severely batter live plants on a flood plain, but normally only in a narrow belt along the immediate channel. Large, stabilized pieces of wood, on the other hand, protect riparian sites where alder and other species of plants can become established.

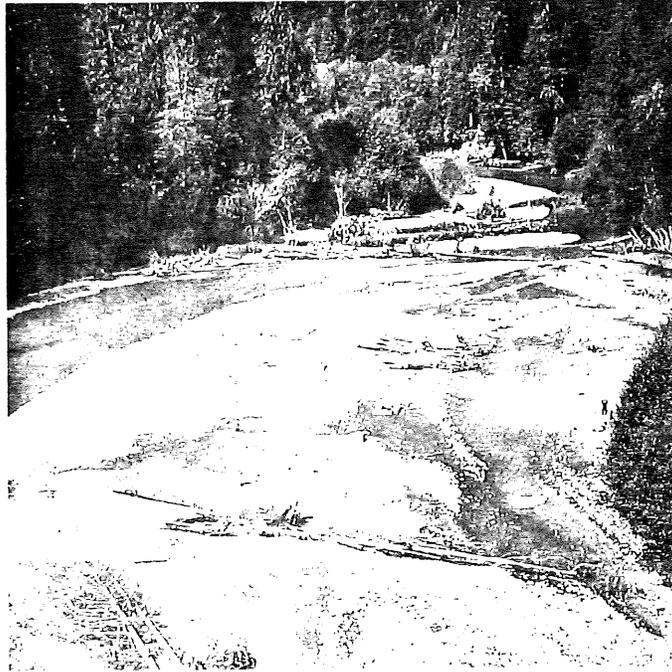


Figure 3.23—Note the large pieces of wood on the flood plain, especially in the lower right corner where stable wood has formed a protected site that has allowed the alder to grow.

Live vegetation eventually stabilizes a stream channel. Features, such as gravel bars, also become stabilized and enriched with fine sediments and organic materials as plant root systems develop and the stems resist the flow of water and reduce its velocity.

Fallen trees protect thickets of vegetation on exposed channel bars. Alders growing in channel bar areas not protected by down trees are repeatedly pruned heavily by floating woody debris and moving bedloads (Swanson and Lienkaemper 1982) (fig. 3.23). The down trees that protect the outer edge of a thicket and those in the thicket itself create local environments of quiet water where fine sediments and organic debris are deposited during high flows. This debris, coupled with leaf and woody litter from the stand, boosts soil development and vegetative growth. The large, fallen trees thus help a stand to reach a stage of structural development that allows it to better withstand floods. Fallen trees on gravel bars also provide sites where some stream-transported species of hardwoods and shrubs can reroot and grow.

Stream restabilization after major floods, debris torrents, or massive landslides is accelerated by large, woody debris along and within the channel. After wildfire, while the postfire forest is developing, an aquatic habitat may be maintained by large, woody debris supplied to the stream by the prefire forests (Swanson and Lienkaemper 1978). In many instances, however, streamside salvage logging destabilizes channel structure and, thereby, the quality of the habitat.

Sites of high biological activity and maximum habitat diversity are preferred spawning and rearing areas for salmonids. In the Pacific Northwest, many such zones of sediment and debris are located where a first-order channel debris torrent has entered a third- to fifth-order stream.

Wood as Habitat

Animal associations on woody debris in aquatic systems vary from those restricted to living on the wood to those using it only opportunistically. The sequence of colonists parallels the stage of wood decay. New wood entering a stream is used primarily as habitat, colonized by a community of algae and microbes that in turn provides food for a group of insects called grazers or collectors. This type of feeding does not significantly affect the structure of the wood, but colonization of the superficial layer by fungi softens wood enough that it may be abraded and ingested by invertebrates that scrape their food off surfaces. Most important, however, the wood becomes suitable for obligate wood grazers and the more generalized wood shredders, such as caddisflies and stoneflies, which eat fungal-infested wood. These activities result in a sculptured surface texture that provides habitat for many organisms. Decades of fungal colonization and growth soften the wood and allow oxygen to penetrate. Invertebrates that bore into the internal matrix of a fallen tree speed the decomposition process by consuming the wood and by transporting microbes into the tree. In the final phase of decay, detritivores, such as earthworms, penetrate the material; continued decomposition then resembles organic matter in soil and damp, terrestrial habitats (Anderson and others 1978, 1984; Dudley and Anderson 1982) (fig. 3.24).

Some wood that enters a small stream is already altered by fungi and other terrestrial organisms. Such preconditioning allows more rapid internal colonization by aquatic microbes and invertebrates and thereby shortens the aquatic decomposition process. Decomposition is also faster in large streams during periods of high water because physical abrasion removes softened tissue as the wood is transported or deposited in the stream. Rotting wood cannot retain enough structural integrity to provide a substrate for aquatic invertebrates during the final stages of decomposition except in small headwater streams or in backwaters of large streams.

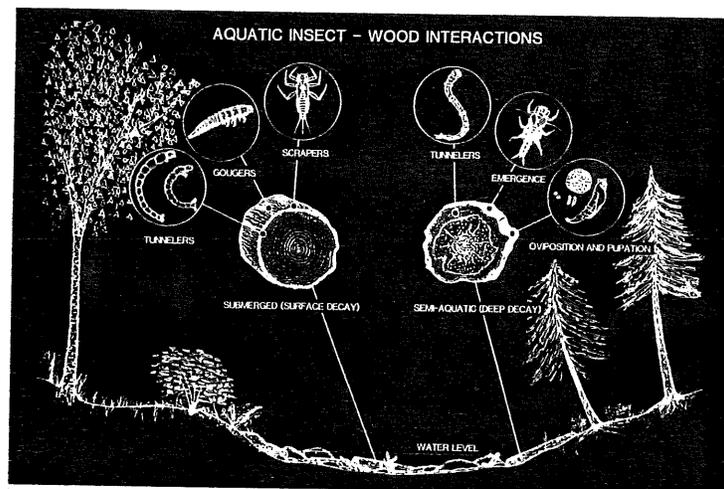


Figure 3.24—A model of wood-aquatic insect interactions in a small stream (redrawn from Anderson and others 1984, with permission).

Wood quality and texture help determine the kinds of organisms that will colonize a piece of wood. The species of wood, degree to which it is waterlogged, and decay class all affect the quality. The extent of colonization by terrestrial fungi and wood-boring insects also influences the attractiveness of the wood once it enters the water because such activity is closely associated with decay class.

The ecological role of wood-eating aquatic invertebrates is limited compared with that of terrestrial systems and marine environments. The three most important wood-processing invertebrates in Oregon streams consume about 2 percent of the available woody debris per year in small streams (Anderson and others 1978, Steedman and Anderson 1985). Wood processors are more abundant on hardwoods than on conifer wood. Microbial activity and nitrogen content are greater in decaying alder than in decaying conifer wood, a nutritional difference that helps explain the higher abundance of processors in hardwoods.

Summer populations of salmonids in western Washington streams flowing through old-growth forests have been compared with those in recently clearcut areas (Bisson and Sedell 1984). Total salmonid biomass increased after logging, but species richness declined to a population of only steelhead trout, most less than 1 year old. Coho salmon and cutthroat trout, between 1 and 3 years old, were proportionately less abundant in logged areas (Bisson and Sedell 1984). The shifts in species composition and age groups are related to habitat changes after logging of old growth and removal of large, stable, woody debris from the stream channel. Stable debris declined and unstable debris increased in the years after the 1976 Washington Forest Practices Act that mandated immediate removal of debris after logging (fig. 3.25). Pool size decreased and riffle size increased after old growth was clearcut and the stream channel cleared. Numbers of pools and riffles per unit of stream length declined after logging, which suggests that normal stairstep stream profiles had been reduced to a more even gradient (fig. 3.26).

Coho biomass in coastal Oregon streams is directly related to pool volume. Large, stable, woody debris is preferred as protective cover by young coho salmon, yearling steelhead, and older cutthroat trout, particularly in high-gradient river systems (Bisson and others 1987; Bustard and Narver 1975a, 1975b; Everest and Meehan 1981; Lister and Genoe 1979; Nickelson and others 1979; Osborn 1981; Sedell and others 1982a, 1982b, 1985).

Most salmonid species use different habitat in winter than in summer. Large, stable, woody debris is important winter habitat for coho salmon, steelhead trout, and cutthroat trout because it enhances the use of other habitats within pools. All species prefer pools during base streamflows in winter, but the level of preference is determined by pool quality and abundance of woody debris; the more woody debris, the more fish use the pool. Large, stable debris also attracts fish to pools along the stream edge rather than to those in midchannel.

During winter floods, the pool-riffle sequence or stairstep stream profile becomes a continuous, high-velocity torrent, in which there is little protection for salmonids from moving bedload sediment or swift, turbulent waters. During these brief flood periods, slack water refuges are associated almost exclusively with debris as fallen trees and standing vegetation in riparian flood plains. All three species of salmonids enter these

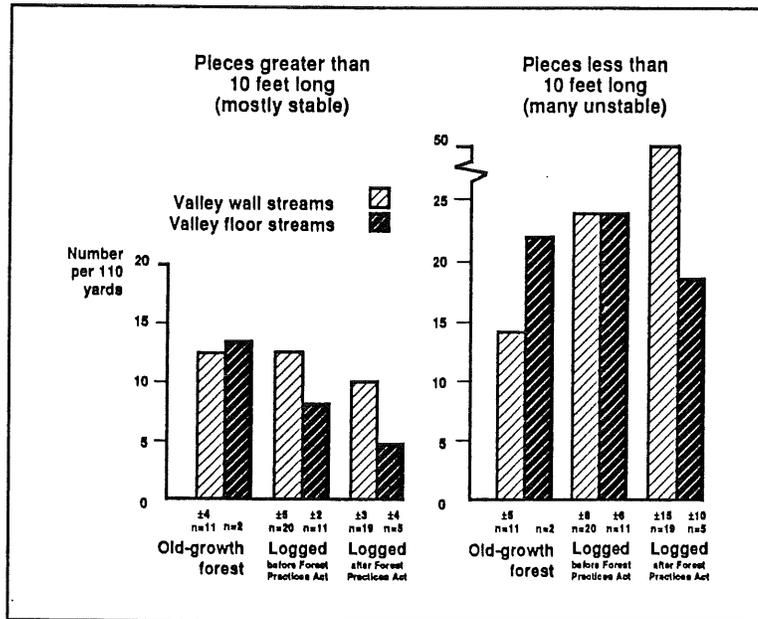


Figure 3.25—Effects of stream cleaning on the relative abundance of stable and unstable debris in steep valley wall streams and low-gradient valley floor streams in southwestern Washington; after implementation of the Washington Forest Practices Act; adapted from Bisson and Sedell (1984). Number of sample sizes is indicated on each bar.

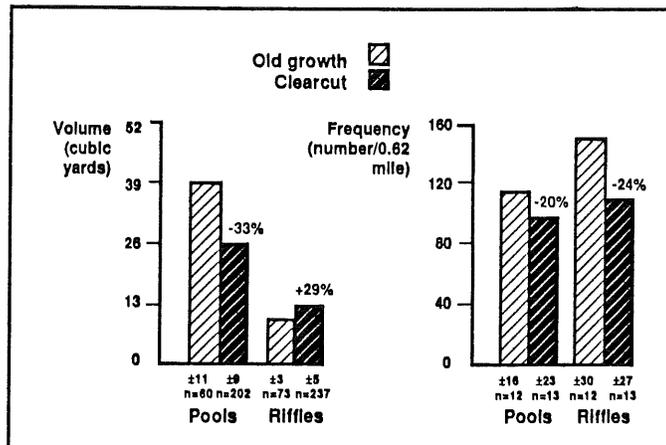


Figure 3.26—Comparison of volumes and frequencies of pools and riffles in streams in old-growth forests with streams in recently clearcut areas; 95-percent confidence limits and sample sizes are indicated on each bar.

debris-enhanced refuges until streamflows subside. Large, woody debris may also expand the feeding space by creating or enhancing areas of slow-moving or standing water in organic-rich flood plains, even along the smallest streams (Bustard and Narver 1975a, 1975b; Koski and others 1985; Murphy and others 1984).

Table 3.7—Juvenile chinook and coho salmon densities from different woody habitat types in the main channels of the Chickamin River, southeast Alaska, March-April 1984

Woody habitat type	Number of sample sites	Average number of salmon	
		Chinook	Coho
No woody habitat, slack water along edges	3	5	8
Rootwads without boles, stumps	12	56	50
Single downed trees, rootwad and stem	14	87	90
Log jam, several downed trees	7	292	195

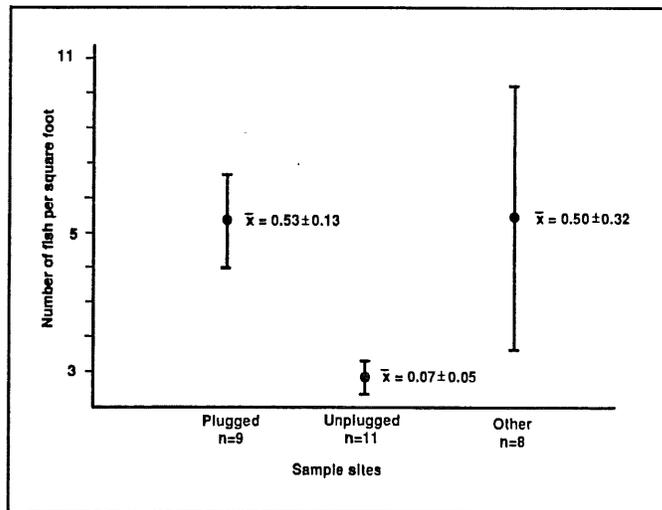


Figure 3.27—Densities of coho salmon in Upper Queets River side-channels, which are capped or plugged at the head by cobble and organic debris. Plugged side-channel areas represent 58 percent of total side-channel habitat; unplugged side-channels, 31 percent; and intermediate side-channels, 11 percent. Bars represent 95-percent confidence intervals.

Almost all juvenile anadromous fish in large rivers are reared on stream edges in a wood-rich environment (table 3.7 and fig. 3.27). Whole fallen trees or debris jams offer more productive, more diverse habitat than that around rootwad or stump habitats (Canadian Fisheries and Marine Service and The International Pacific Salmon Fisheries Commission 1979; Cornelius and Siedelman 1984; Sedell and others

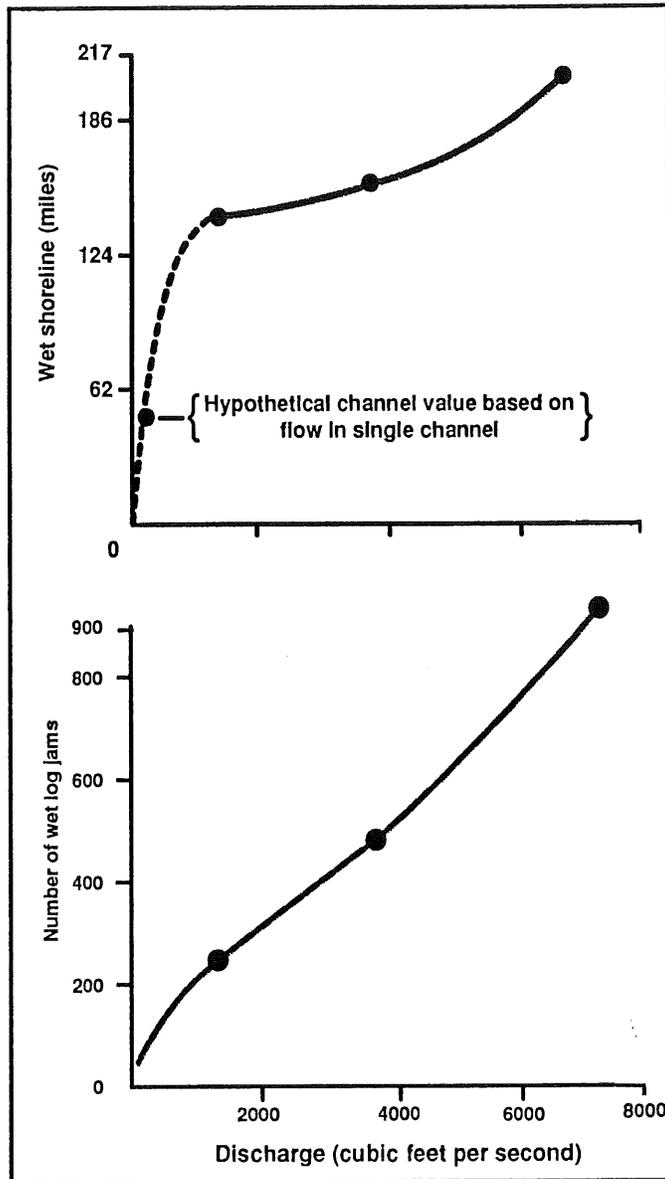


Figure 3.28—Relation between discharge and selected rearing indices in the Morice River.

1982a, 1984). Essentially, the hydraulic forces around any rough element such as fallen trees or stumps mainly determine the quality of fish habitat. Relations between discharge and wet debris jams can be quickly constructed to determine changes in fish habitat quality caused by salvage operations or water diversions (fig. 3.28).

Decomposition and Nutrient Cycling

Trees falling in streams decompose at different rates and in different patterns than those that fall to the ground. Wood decomposes more slowly in water than on land; waterlogging prevents deep penetration of oxygen into the wood. The fungi and invertebrates that cause the most rapid decomposition of fallen trees on land are also strongly aerobic (Triska and Cromack 1980). Waterlogged parts of fallen trees decompose in thin (0.25 inch) surface layers. As the decomposed surface is grazed or abraded, oxygen penetrates farther into the wood, and that area becomes food for the decomposers. If only part of a fallen tree is constantly in contact with water, that part decomposes slowly, but the exposed part may decompose rapidly because neither low oxygen nor extremes of moisture limit decomposer activity. Trees that fall in very small streams may contact water only during the rainy season when streamflow is highest. Low stream level and air drying the rest of the year may speed wood decomposition.

The concentration of essential nutrient elements increases as large pieces of wood decompose. Nitrogen increases primarily through biotic use of the carbon and through nitrogen-fixing micro-organisms. Nitrogen fixation on fallen trees in streams accounts for 5 to 10 percent of the annual nitrogen supply to the stream (Triska and others 1982). Although bark decays more slowly than wood, the tannins in Douglas-fir bark do not affect nitrogen fixation (Baker and others 1983).

Although rates of biotic wood processing differ in stream systems from headwaters to mouth (terrestrial to marine) (table 3.8), the slow decomposition of wood in freshwater streams maximizes the influence of wood on stream stability and as habitat. As we understand better the critical function of large organic material in streams and rivers, we realize that productivity of aquatic habitats depends on the biological diversity provided by a continuous supply of coarse woody debris.

Table 3.8—Processing rate of large woody debris in the forest floor, in streams, and in estuarine habitats^{a b}

Organism	Forest floor (fast)	Stream (slow)	Estuary (fast)
Microbes	Rot fungi diverse and abundant	Aquatic hyphomycetes (rot fungi, virtually absent)	Fungi minor or absent
Invertebrates: Insects	Diverse and abundant, including gallery-forming social insects	Few species (for example, <i>Lara</i> , <i>Brilla</i> (Tipulidae), no social insects)	Absent
Others	Oligochaeta important in later forms	Absent	Annelida, Mollusca, and Crustacea diverse (some boring forms with cellulase)
Vertebrates	Gallery or destroy wood in search of invertebrate food	Absent	Absent
Environmental controls	Temperature, moisture, and oxygen ^c	Temperature and oxygen ^c	Temperature and oxygen ^c

^a Adapted from Cummins and others (1984).

^b Hardwoods decompose faster than conifers.

^c Lignin little decomposed anaerobically.



Figure 3.8—Most trees that enter stream channels in young-growth sites are red alder, which has a shallow root system and low resistance to undercutting.



Figure 3.17—A terminus of a debris torrent that would have been a candidate for stream cleanup in the 1960's and 1970's because of the slash.

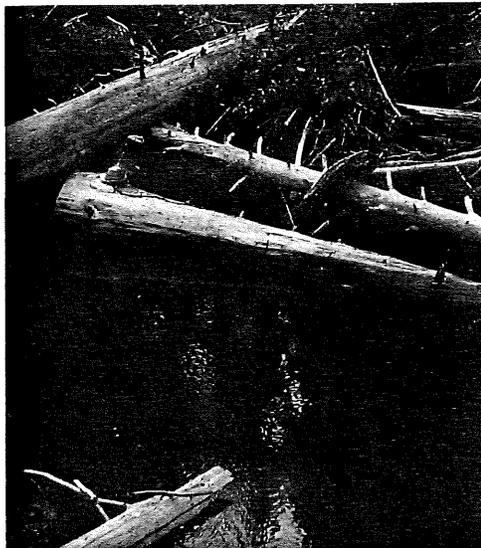


Figure 3.19—Woody debris creates many of the pools in Pacific Northwest streams.



Figure 3.21—Accumulations of small debris behind one large piece of debris often create a longitudinal, stepped profile.

References

- Aho, P.E. 1966.** Defect estimation for grand fir, Engelmann spruce, Douglas-fir and western larch in the Blue Mountains of Oregon and Washington. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 26 p.
- Aho, P.E. 1982.** Indicators of cull in western Oregon. Gen. Tech. Rep. PNW-144. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 17 p.
- Alban, D.H. 1967.** The influence of western hemlock and western redcedar on soil properties. Pullman, WA: Washington State University. 167 p. Ph.D. dissertation.
- Allee, B.A. 1982.** The role of interspecific competition in the distribution of salmonids in streams. In: Brannon, E.L.; Salo, E.O., eds. Proceedings of the salmon and trout migratory behavior symposium. Seattle: University of Washington: 111-122.
- Allison, F.E. 1973.** Soil organic matter and its role in crop production. London: Elsevier Scientific Publishing Co. 637 p.
- Anderson, N.H.; Sedell, J.R. 1979.** Detritus processing by macroinvertebrates in stream ecosystems. Annual Reviews of Entomology. 24: 351-377.
- Anderson, N.H.; Sedell, J.R.; Roberts, L.M.; Triska, F.J. 1978.** The role of aquatic invertebrates in processing wood debris from coniferous forest streams. American Midland Naturalist. 100: 64-82.
- Anderson, N.H.; Steedman, R.J.; Dudley, T. 1984.** Patterns of exploitation by stream invertebrates of wood debris (xylophagy). Verhandlungen-Internationale Vereinigung fuer Theoretische und Angewandte Limnologie (International Association of Theoretical and Applied Limnology). 22: 1847-1852.
- Bachman, R.A. 1984.** Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Transactions of the American Fisheries Society. 113: 1-32.
- Badura, G.J.; Legard, H.A.; Meyer, L.C. 1974.** Siuslaw National Forest, soil resource inventory. Corvallis, OR: U.S. Department of Agriculture, Forest Service, Siuslaw National Forest. 189 p.
- Baker, C.O. 1979.** The impacts of logjam removal on fish populations and stream habitat in western Oregon. Corvallis, OR: Oregon State University. 86 p. Ph.D. dissertation.
- Baker, J.H.; Morita, R.Y.; Anderson, N.H. 1983.** Bacterial activity of woody substrates in a stream sediment. Applied Environmental Microbiology. 45: 516-521.
- Balgooyen, T.G. 1976.** Behavior and ecology of the American kestrel (*Falco sparverius*) in the Sierra Nevada of California. Publ. Zool. 103. Berkeley, CA: University of California Press. 83 p.

- Barnes, C.A.; Duxbury, A.C.; Morse, B.A. 1971.** Circulation and selected properties of the Columbia River effluent at sea. In: Pruter, A.T.; Alverson, D.L., eds. The Columbia River estuary and adjacent waters bioenvironmental studies. Seattle: University of Washington Press: 41-80.
- Bartels, R.; Bell, J.D.; Knight, R.L. [and others]. 1985.** Dead and down woody material. In: Brown, E.R., tech. ed. Management of wildlife and fish habitats in forests of western Oregon and Washington. Part 1—Chapter narratives. R6-F & WL-192-1985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region: 171-186.
- Bayer, R.D. 1978.** Aspects of Oregon estuarine great blue heron population. In: Sprunt, A., IV; Ogdan, J.C.; Winckler, S., eds. Wading birds. Res. Rep. 7. New York, NY: National Audubon Society: 213-217.
- Bayer, R.D. 1980.** Birds feeding on herring eggs at the Yaquina estuary, Oregon. *Condor*. 82: 193-198.
- Bayer, R.D. 1981.** California sea lions in the Yaquina River estuary, Oregon. *Murrelet*. 62: 56-59.
- Bayer, R.D. 1983.** Nesting success of western gulls at Yaquina Head and on man-made structures in Yaquina estuary, Oregon. *Murrelet*. 64: 87-91.
- Bayer, R.D. 1985.** Six years of harbor seal censusing at Yaquina estuary, Oregon. *Murrelet*. 66: 44-49.
- Beasley, R.S. 1976.** Contribution of subsurface flow from the upper slopes of a forested watershed to channel flow. *Soil Science Society of America Journal*. 40: 955-957.
- Beatty, S.W. 1984.** Influence of microtopography and canopy species on spatial patterns of forest understory plants. *Ecology*. 66: 1406-1419.
- Beatty, S.W.; Stone, E.L. 1985.** The variety of soil microsites created by tree falls. *Canadian Journal of Forest Research*. 16: 539-548.
- Beebe, S.B. 1974.** Relationships between insectivorous hole-nesting birds and forest management. New Haven, CT: Yale University, School of Forestry and Environmental Studies. 49 p. Multilithed.
- Benner, P.A.; Sedell, J.R. [In press].** Chronic reduction of large woody debris on beaches at Oregon river mouths. Proceedings, 8th annual meeting of the Society of Wetland Scientists; 1987 May 24-27; Seattle, WA. Wilmington, NC: Society of Wetland Scientists.
- Bent, A.C. 1964.** Life histories of North American woodpeckers. New York: Dover Publishers. 334 p. Reprint of 1939 ed.
- Berg, B. 1986.** Nutrient release from litter and humus in coniferous forest soils - a mini review. *Scandinavian Journal of Forest Research*. 1: 359-369.

- Berg, B.; McClaugherty, C. [In press].** Nitrogen release from litter in relation to lignin disappearance. *Biogeochemistry*.
- Beschta, R.L. 1983.** The effects of large organic debris upon channel morphology: a flume study. In: Li, R.; Lagasse, P.F., eds. *Proceedings, D.B. Simons symposium on erosion and sedimentation*. Fort Collins, CO: Simons, Li, and Associates: 8.63-8.78.
- Bilby, R.E. 1981.** Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. *Ecology*. 62: 1234-1243.
- Bilby, R.E. 1984.** Post-logging removal of woody debris affects stream channel stability. *Journal of Forestry*. 82: 609-613.
- Bilby, R.E. 1985.** Influence of stream size on the function and characteristics of large organic debris. In: *Proceedings, west coast meeting of National Council on Air and Stream Improvement; 1985 May 7-8; Portland, OR*. New York, NY: National Council of the Paper Industry for Air and Stream Improvement: 1-14.
- Bilby, R.E.; Likens, G.E. 1980.** Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology*. 61: 1107-1113.
- Binkley, D.; Lousier, J.D.; Cromack, K., Jr. 1984.** Ecosystem effects of Sitka alder in a Douglas-fir plantation. *Forest Science*. 30: 26-35.
- Bisson, P.A.; Bilby, R.E.; Bryant, M.D. [and others]. 1987.** Large woody debris in forested streams in the Pacific Northwest: past, present, and future. In: Cundy, T.; Salo, E., eds. *Proceedings of a symposium; streamside management - forestry and fisheries interactions: 1986 February 12-14*. Seattle: University of Washington: 143-190.
- Bisson, P.A.; Nielson, J.L.; Palmason, R.A.; Grove, L.E. 1982.** A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. In: Armantrout, N.B., ed. *Acquisition and utilization of aquatic habitat inventory information*. Portland, OR: Western Division, American Fisheries Society: 62-73.
- Bisson, P.A.; Nielson, J.L.; Ward, J.W. 1985.** Experimental release of coho salmon (*Oncorhynchus kisutch*) into a stream impacted by Mount Saint Helens volcano. *Proceedings of the Western Association of Fish and Wildlife Agencies*. 1984: 422-435.
- Bisson, P.A.; Sedell, J.R. 1984.** Salmonid populations in streams in clearcut vs. old-growth forests of western Washington. In: Meehan, W.R.; Merrell, T.R., Jr.; Hanley, T.A., eds. *Fish and wildlife relationships in old-growth forests*. Juneau, AK: American Institute of Fisheries Research Biologists: 121-129.
- Blaschke, H.; Bäumler, W. 1986.** Über die Rolle der Biogeozönose in Wurzelbereich von Waldbäumen. *Forstwissenschaftliches Centralblatt*. 105: 122-130.

- Boehne, P.L.; House, R.A. 1983.** Stream ordering: a tool for land managers to classify western Oregon streams. Portland, OR: U.S. Department of the Interior, Bureau of Land Management. 6 p.
- Boone, R.D. 1983.** Patterns of soil organic matter and microclimate accompanying the death and regeneration of a Mt. hemlock (*Tsuga mertensiana*) forest. Corvallis, OR: Oregon State University. 36 p. M.S. thesis.
- Borror, D.J.; DeLong, D.M. 1964.** [Revised ed.] An introduction to the study of insects. New York: Holt, Rinehart and Winston, Inc. 819 p.
- Bosatta, E.; Staff, H. 1982.** The control of nitrogen turn-over in forest litter. *Oikos*. 39: 143-151.
- Bourke, R.H.; Glenne, B.; Adams, B.W. 1971.** Environment of the Pacific Northwest coast. Reference 71-45. Corvallis, OR: Oregon State University, Department of Oceanography. 127 p.
- Bratton, S.P. 1976.** Resource division in an understory herb community: responses to temporal and microtopographic gradients. *American Naturalist*. 110: 679-693.
- Breznak, J.A. 1975.** Symbiotic relationships between termites and their intestinal microbiota. In: Jennings, D.H.; Lee, D.L., eds. Proceedings, symbiosis symposium, Society of Forest Experimental Biology. Ser. 29. Cambridge, MA: Cambridge University: 559-580.
- Brill, R.W.; Holland, K.N.; Ferguson, J.S. 1984.** Use of ultrasonic telemetry to determine the short-term movements and residence times of tunas around fish aggregating devices. In: Proceedings of the Pacific Congress on Maritime Technology PACON; 1984 April 24-27. Honolulu, HI: Marine Resources Management: 1: 1-7.
- Broadbent, F.E. 1970.** Variables affecting A values as a measure of soil nitrogen availability. *Soil Science*. 141: 208-213.
- Brock, R.E. 1985.** Fish aggregation devices: how they work and their place in fisheries enhancement. In: Strond, R.H., ed. Proceedings of the 1st world angling conference; 1984 September 12-18; Cap d'Agde, France. Fort Lauderdale, FL: International Game Fish Association: 193-202.
- Brown, E.R., tech. ed. 1985.** Management of wildlife and fish habitats in forests of western Oregon and Washington. Part 2—Appendices. Publ. R6-F & WL-192-1985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 302 p.
- Bruck, R.I.; Roberge, W.P. 1984.** Observations of boreal montane forest decline in the southern Appalachian Mountains: soil and vegetation studies. In: Aquatic effects task group (E) and terrestrial effects task group (F) research summaries. Raleigh, NC: North Carolina State Acid Deposition Program: 425.

- Bruun, A.F. 1957.** Deep sea and abyssal depths. In: Hedgpeth, J.W., ed. Treatise on marine ecology and paleoecology. Memoir 67. New York: Geological Society of America: 641-672. Vol. 1, Ecology.
- Bruun, A.F. 1959.** General introduction to the reports and list of deep sea stations. In: Bruun, A.F.; Greve, Sv.; Sparck, R., eds. Galathea report. Copenhagen: Danish Science Press Ltd.: 7-48. Vol. 1.
- Bryant, M.D. 1980.** Evolution of large, organic debris after timber harvest: Maybeso Creek, 1949 to 1978. Gen. Tech. Rep. PNW-101. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 30 p.
- Bryant, M.D. 1982.** Organic debris in salmonid habitat in southeast Alaska: measurement and effects. In: Armantrout, N.B., ed. Acquisition and utilization of aquatic habitat inventory information. Portland, OR: Western Division, American Fisheries Society: 259-265.
- Bryant, M.D. 1983.** The role and management of woody debris in west coast salmonid nursery streams. North American Journal of Fisheries Management. 3: 322-330.
- Bryant, M.D. 1985.** Changes 30 years after logging in large woody debris and its use by salmonids. In: Johnson, R.R.; Ziebel, C.D.; Patton, B.R.; Ffolliott, P.F.; Hamre, R.H., eds. Riparian ecosystems and their management: reconciling conflicting uses: In: Proceedings of the 1st North American riparian conference; 1985 April 16-18; Tucson, AZ. Gen. Tech. Rep. RM-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 329-334.
- Bull, E.L. 1975.** Habitat utilization of the pileated woodpecker, Blue Mountains, Oregon. Corvallis, OR: Oregon State University. 58 p. M.S. thesis.
- Bull, E.L. 1978.** Specialized habitat requirement of birds: snag management, old growth, and riparian habitat. In: DeGraaf, R.M., ed. Proceedings of the workshop on nongame bird habitat management in the coniferous forests of the Western United States; 1977 February 7-9; Portland, OR. Gen. Tech. Rep. PNW-64. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 74-82.
- Bull, E.L.; Twombly, A.D.; Quigley, T.M. 1980.** Perpetuating snags in managed mixed conifer forests of the Blue Mountains, Oregon. In: Management of western forests and grasslands for nongame birds. Gen. Tech. Rep. INT-86. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 325-336.
- Burroughs, E.R., Jr.; Thomas, B.R. 1977.** Declining root strength in Douglas-fir after felling as a factor in slope stability. Res. Pap. INT-190. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 27 p.

- Bustard, D.R.; Narver, D.W. 1975a.** Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada. 32: 667-680.
- Bustard, D.R.; Narver, D.W. 1975b.** Preferences of juvenile coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*Salmo clarki*) relative to simulated alteration of winter habitat. Journal of the Fisheries Research Board of Canada. 32: 681-687.
- Calambokidis, J.; Bowman, K.; Carter, S. [and others]. 1979.** Chlorinated hydrocarbon concentrations and the ecology and behavior of harbor seals in Washington State waters. Olympia, WA: Evergreen State College; student-originated-study. 120 p.
- Canadian Fisheries and Marine Service and The International Pacific Salmon Fisheries Commission. 1979.** Vol. I. Summary of salmon studies conducted on Nechako, Murice, and Nanika River systems relative to the proposed Kemano II power development, Vancouver, B.C. 117 p.
- Carroll, G.C. 1980.** Forest canopies: complex and independent subsystems. In: Waring, R.H., ed. Forests: fresh perspectives from ecosystem analysis: Proceedings of the 40th annual biology colloquium; 1979 April 27-28; Corvallis, OR. Corvallis, OR: Oregon State University Press: 87-107.
- Chamberlin, T.W. 1972.** Interflow in the mountainous forest soils of coastal British Columbia. In: Mountain geomorphology: geomorphological processes in the Canadian cordillera, B.C. Vancouver, BC: Geographical Society Tantalus Research, Ltd.: 121-127. Vol. 14.
- Childs, T.W.; Clark, J.W. 1953.** Decay of windthrown timber in western Washington and northwestern Oregon. Spec. Release 40. Beltsville, MD: U.S. Department of Agriculture, Agricultural Research Administration, Bureau of Plant Industry, Soils, and Agricultural Engineering, Division of Forest Pathology. 20 p.
- Christner, J.; Harr, R.D. 1982.** Peak streamflows from the transient snowzone, western Cascades, Oregon. In: Proceedings, 50th western snow conference; 1982 April 19-23; Reno, NV. Fort Collins, CO: Colorado State University Press: 27-38.
- Christy, E.J.; Sollins, P.; Trappe, J.M. 1982.** First-year survival of *Tsuga heterophylla* without mycorrhizae and subsequent ectomycorrhizal development on decaying logs and mineral soil. Canadian Journal of Botany. 60: 1601-1605.
- Cline, S.P.; Berg, A.B.; Wight, H.M. 1980.** Snag characteristics and dynamics in Douglas-fir forests, western Oregon. Journal of Wildlife Management. 44: 773-786.
- Conner, R.N. 1979.** Seasonal changes in woodpecker foraging methods: strategies for winter survival. In: Dickson, J.G.; Conner, R.N.; Fleet, R.R. [and others], eds. The role of insectivorous birds in forest ecosystems: Proceedings of a symposium; 1978 July 13-14; Nacogdoches, TX. New York: Academic Press, Inc.: 95-105.
- Cornaby, B.W.; Waide, J.B. 1973.** Nitrogen fixation in decaying chestnut logs. Plant and Soil. 39: 445-448.

- Cornellus, D.; Sledelman, D.L. 1984.** Log salvage: Chickamin and Unuk Rivers. Alaska Department of Fish and Game. 16 p. Intern. Rep., on file at: Director, Habitat Division, Department of Fish and Game, Juneau, Alaska.
- Cowling, E.B.; Merrill, W. 1966.** Nitrogen in wood and its role in wood deterioration. Canadian Journal of Botany. 44: 1539-1554.
- Cramer, H.H. 1984.** On the predisposition to disorders of middle European forests. Pflanzenschutz-Nachrichten. 37: 98-207.
- Cromack, K., Jr.; Monk, C.D. 1975.** Litter production, decomposition, and nutrient cycling in a mixed hardwood watershed and a white pine watershed. In: Howell, F.G.; Gentry, J.B.; Smith, M.H., eds. Mineral cycling in southeastern ecosystems. Springfield, VA: U.S. Energy Research and Development Administration: 609-624.
- Crouch, G.L. 1969.** Animal damage to conifers on National Forests in the Pacific Northwest Region. Resour. Bull. PNW-28. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.
- Cummins, K.W.; Minshall, J.W.; Sedell, J.R. [and others]. 1984.** Stream ecosystem theory. Verhandlungen Internationale Vereinigung Limnologie. 22: 1818-1827.
- Curtis, R.O.; Clendenen, G.W.; Reukema, D.L.; Demars, D.J. 1982.** Yield tables for managed stands of coast Douglas-fir. Gen. Tech. Rep. PNW-135. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 182 p.
- Damant, G.C.C. 1921.** Illumination of plankton. Nature. London; 108: 42-43.
- Dayton, P.K. 1971.** Competition, disturbance, and community organization: the provision and subsequent utilization of space in a rocky intertidal community. Ecological Monographs. 41(4): 351-389.
- de Hann, S. 1977.** Humus, its formation, its relation with the mineral part of the soil and its significance for soil productivity. In: Organic matter studies. Vienna: International Atomic Energy Agency: 21-30. Vol. 1.
- de Vries, J.; Chow, T.L. 1978.** Hydrolic behavior of a forested mountain soil in coastal British Columbia. Water Resources Research. 14: 935-942.
- Dicken, S.N.; Dicken, E.F. 1979.** The making of Oregon: a study in historical geography. Portland, OR: Oregon Historical Society. 207 p. Vol. 1.
- Dill, L.M.; Ydenberg, R.C.; Fraser, H.G. 1981.** Food abundance and territory size in juvenile coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Zoology. 59: 1801-1809.
- Dodge, O. 1898.** Pioneer history of Coos and Curry Counties. Bandon, OR: Coos-Curry Pioneer and Historical Association. 468 p. Reprinted in 1969.

- Dolloff, C.A. 1983.** The relationships of wood debris to juvenile salmonid production and microhabitat selection in small southeast Alaska streams. Bozeman, MT: Montana State University. 100 p. Ph.D. thesis.
- Dudley, T.; Anderson, N.H. 1982.** A survey of invertebrates associated with wood debris in aquatic habitats. *Melandria*. 39: 1-21.
- Durall, D.E.; Todd, A.; Trappe, J.M. 1987.** Unpublished data. On file at: Oregon State University, School of Forestry, Department of Forest Science, Corvallis, OR.
- Durrieu, G.; Genard, M.; Lescouret, F. 1984.** Les micromammifères et la symbiose mycorhizienne dans une forêt de montagne. *Bulletin of Ecology*. 15: 253-263.
- Edmonds, R.L. 1980.** Litter decomposition and nutrient release in Douglas-fir, red alder, western hemlock, and Pacific silver fir ecosystems in western Washington. *Canadian Journal of Forest Research*. 10: 327-337.
- Eilers, H.P. 1975.** Plants, plant communities, net production and tide levels: the ecological biogeography of the Nehalem Salt Marshes, Tillamook County, Oregon. Corvallis, OR: Oregon State University. 368 p. Ph.D. thesis.
- Elliott, S.; Hubartt, D. 1978.** Study of land use activities and their relationship to sport fish resources in Alaska: sport fish in Alaska. Annual performance report, 1 July 1977 - 30 June 1978; Federal Aid in Fish Restoration. Juneau, AK: Alaska Department of Fish and Game. 52 p. Vol. 19.
- Elton, C.S. 1966.** Dying and dead wood. In: *The pattern of animal communities*. New York: John Wiley & Sons, Inc.: 279-305.
- Etheridge, D.E. 1973.** Wound parasites causing tree decay in British Columbia. *For. Pest Leaflet*. 62. Vancouver, BC: Pacific Forest Research Centre. 15 p.
- Evans, K.E.; Conner, R.N. 1979.** Snag management. In: DeGraaf, R.M.; Evans, K.E., eds. *Proceedings of the workshop on management of north central and northeastern forests for nongame birds; 1978 January 23-25*. Gen. Tech. Rep. NC-51. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 211-225.
- Everest, F.H. 1973.** Ecology and management of summer steelhead in the Rogue River. *Fish. Res. Rep.* 7. Corvallis, OR: Oregon State Game Commission. 48 p.
- Everest, F.H.; Armantrout, N.B.; Keller, S.M. [and others]. 1985.** Salmonids. In: Brown, R.E., tech. ed. *Management of wildlife and fish habitats in forests of western Oregon and Washington. Part I—Chapter narratives*. R6-F-WL-192. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region: 200-230.
- Everest, F.H.; Meehan, W.R. 1981.** Forest management and anadromous fish habitat productivity. *Transactions of the North American Wildlife Natural Resources Conference*. 46: 521-530.

- Everest, F.H.; Summers, P.B. 1982.** The sport fishing resource of the National Forests: its extent, recreational use, and value. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 50 p.
- Fausch, K.D. 1984.** Profitable stream positions for salmonids: relating specific growth rate to net energy gain. *Canadian Journal of Zoology*. 62: 441-451.
- Fogel, R.; Cromack, K., Jr. 1977.** Effect of habitat and substrate quality on Douglas-fir litter decomposition in western Oregon. *Canadian Journal of Botany*. 55: 1632-1640.
- Fogel, R.; Ogawa, M.; Trappe, J.M. 1973.** Terrestrial decomposition: a synopsis. Intern. Rep. 135. Seattle, WA: U.S.-International Biological Program, Coniferous Forest Biome, University of Washington. 12 p.
- Foster, J.R.; Lang, G.E. 1982.** Decomposition of red spruce and balsam fir boles in the White Mountains of New Hampshire. *Canadian Journal of Forest Research*. 12: 617-626.
- Franklin, J.F. 1988.** Structural and functional diversity in temperate forests. In: Wilson, E.C., ed. *Biodiversity*. Washington, DC: National Academy Press: 166-175.
- Franklin, J.F.; Cromack, K., Jr.; Denison, W. [and others]. 1981.** Ecological characteristics of old-growth Douglas-fir forests. Gen. Tech. Rep. PNW-118. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 48 p.
- Franklin, J.F.; Dyrness, C.T. 1973.** Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 417 p.
- Franklin, J.F.; Forman, R.T.T. 1987.** Creating landscape patterns by forest cutting: ecological consequences and principles. *Journal of Landscape Ecology*. 1: 5-18.
- Franklin, J.F.; Hemstrom, M.A. 1981.** Aspects of succession in the coniferous forests of the Pacific Northwest. In: West, D.C.; Shugart, H.H.; Botkin, D.B., eds. *Forest succession: concepts and application*. New York: Springer-Verlag: 212-229.
- Franklin, J.F.; Klopsch, F.M.; Luchessa, K.J.; Harmon, M.E. 1986.** Tree mortality in some mature and old-growth forests in the Cascade Range of Oregon and Washington. Manuscript in preparation. On file at: U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, Corvallis, OR.
- Franklin, J.F.; Waring, R.H. 1980.** Distinctive features of the northwestern coniferous forest: development, structure, and function. In: Waring, R.H., ed. *Forests: fresh perspectives from ecosystem analysis: Proceedings of the 40th annual biology colloquium; 1979 April 27-28; Corvallis, OR*. Corvallis, OR: Oregon State University Press: 59-86.

- Fraser, F.J. 1969.** Population density effects on survival and growth of juvenile coho salmon and steelhead trout in experimental stream channels. In: Northcote, T.G., ed. Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries. Vancouver, BC: Institute of Fisheries, University of British Columbia: 253-266.
- Froehlich, H.A. 1973.** Natural and man-caused slash in headwater streams. *Loggers Handbook*, Vol. 33. Portland, OR: Pacific Logging Congress. 8 p.
- Froidevaux, L. 1981.** Les ectomycorrhizes micro-usines productrices de bois et de champignons comestibles. *Pêcheur Romand*. 38: 18-20.
- Fujimori, T. 1971.** Primary productivity of a young *Tsuga heterophylla* stand and some speculations about biomass of forest communities on the Oregon coast. Res. Pap. PNW-123. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 11 p.
- Furniss, R.L.; Carolin, V.M. 1977.** Western forest insects. Misc. Publ. 1339. Washington, DC: U.S. Department of Agriculture. 654 p.
- Gaiser, R.N. 1952.** Root channels and roots in forest soils. *Soil Science Society of America Proceedings*. 16: 62-65.
- Gale, R.M. 1973.** Snags, chainsaws and wildlife: one aspect of habitat management. Presentation to the 4th annual joint conference of the American Fisheries Society and Wildlife Society. In: Yoakum, J., ed. Cal-Neva wildlife transactions. North Lake Tahoe, NV: [Publisher unknown]: 97-112.
- Gedney, D.R. 1981.** The occurrence of laminated root rot on non-Federal timberland in northwestern Oregon, 1976. Res. Note. PNW-381. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 7 p.
- Geppert, R.R.; Lorenz, C.W.; Larson, A.G., eds. 1984.** Cumulative effects of forest practices on the environment, a state of the knowledge. Olympia, WA: Ecosystems, Inc. 208 p.
- Gharrett, J.T.; Hodges, J.I. 1950.** Salmon fisheries of the coastal rivers of Oregon south of the Columbia. *Contrib.* 13. Portland, OR: Oregon Fish Commission. 31 p.
- Gibson, R.J. 1981.** Behavioural interactions between coho salmon (*Oncorhynchus kisutch*), Atlantic salmon (*Salmo salar*), brook trout (*Salvelinus fontinalis*), and steelhead trout (*Salmo gairdneri*) at the juvenile fluvial stages. *Can. Tech. Rep. Fish. Aquat. Sci.* St. John's, Newfoundland: Research & Resource Services: 1029.
- Gooding, R.M.; Magnuson, J.J. 1967.** Ecological significance of a drifting object to pelagic fishes. *Pacific Science*. 21: 486-497.
- Graham, R.L. 1982.** Biomass dynamics of dead Douglas-fir and western hemlock boles in mid-elevation forests of the Cascade Range. Corvallis, OR: Oregon State University. 152 p. Ph.D. dissertation.

- Graham, R.L.; Cromack, K., Jr. 1982.** Mass, nutrient content, and decay rate of dead boles in rain forests of Olympic National Park. *Canadian Journal of Forest Research*. 12: 511-521.
- Gratkowski, H.J. 1956.** Windthrow around staggered-settings in old-growth Douglas-fir. *Forest Science*. 2(1): 60-74.
- Grette, G.B. 1985.** The abundance and role of large organic debris in juvenile salmonid habitat in streams in second growth and unlogged forests. Seattle: University of Washington. 105 p. M.S. thesis.
- Grier, C.C. 1978.** A *Tsuga heterophylla*-*Picea sitchensis* ecosystem of coastal Oregon: decomposition and nutrient balances of fallen logs. *Canadian Journal of Forest Research*. 8: 198-206.
- Grier, C.C.; Logan, R.S. 1977.** Old-growth *Pseudotsuga menziesii* communities of a western Oregon watershed: biomass distribution and production budgets. *Ecological Monographs*. 47: 373-400.
- Gutiérrez, R.J.; Carey, A.B., eds. 1985.** Ecology and management of the spotted owl in the Pacific Northwest. Gen. Tech. Rep. PNW-185. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 119 p.
- Hadfield, J.S. 1985.** Laminated root rot: a guide for reducing and preventing losses in Oregon and Washington forests. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Forest Pest Management. 13 p.
- Hall, E.R. 1981.** The mammals of North America. New York: John Wiley & Sons: 601-1177. Vol. 2.
- Hall, J.D.; Baker, C.O. 1982.** Rehabilitating and enhancing stream habitat: I. Review and evaluation. In: Meehan, W.R., ed. Influence of forest and rangeland management on anadromous fish habitat in western North America. Gen. Tech. Rep. PNW-138. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 1-29.
- Harmon, M.E.; Cromack, K., Jr.; Smith, B.G. [In press].** Coarse woody debris in mixed-conifer forests, Sequoia National Park, California. *Canadian Journal of Forest Research*.
- Harmon, M.E.; Franklin, J.F.; Swanson, F.J. [and others]. 1986.** Ecology of coarse woody debris in temperate ecosystems. In: Macfadyen, A.; Ford, E.D., eds. *Advances in ecological research*. London; New York: Academic Press: 133-302. Vol. 15.
- Harr, R.D. 1982.** Fog drip in the Bull Run municipal watershed, Oregon. *Water Resources Bulletin*. 18(5): 785-789.
- Harris, L.D. 1984.** The fragmented forest. Chicago: University of Chicago Press. 211 p.

- Harris, L.D.; Maser, C. 1984.** Animal community characteristics. In: Harris, L.D. The fragmented forest. Chicago: University of Chicago Press: 44-68.
- Harrison, C. 1978.** A field guide to the nests, eggs and nestlings of North American birds. New York: Collins. 416 p.
- Hartman, G.F. 1965.** The role of behavior in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada. 22: 1035-1081.
- Hawksworth, F.G.; Wiens, D. 1972.** Biology and classification of dwarf mistletoes (*Arceuthobium*). Agric. Handb. 401. Washington, DC: U.S. Department of Agriculture. 234 p.
- Hedges, J.I.; Ertel, J.R.; Leopold, E.B. 1982.** Lignin geochemistry of a late quaternary sediment core from Lake Washington. Geochimica et Cosmochimica Acta. 46: 1869-1877.
- Hedges, J.I.; Mann, D.C. 1979.** The lignin geochemistry of marine sediments from the southern Washington coast. Geochimica et Cosmochimica Acta. 43: 1809-1818.
- Heede, B.H. 1972.** Influences of a forest on the hydraulic geometry of two mountain streams. Water Resources Bulletin. 8: 523-530.
- Heede, B.H. 1985.** The evolution of salmonid streams. In: Richardson, F.; Hamre, R.H., tech. ed. Proceedings of the symposium Wild Trout III; 1984 September 24-25; Yellowstone National Park. Vienna, VA: Trout Unlimited: 33-37.
- Henry, J.D.; Swan, J.M.A. 1974.** Reconstructing forest history from live and dead plant material—an approach to the study of forest succession in southwest New Hampshire. Ecology. 55: 772-783.
- Heyerdahl, T. 1952.** American Indians in the Pacific. London: Allen and Unwin. 415 p.
- Hogan, D. 1985.** The influence of large organic debris on channel morphology in Queen Charlotte Island streams. Proceedings of the Western Association of Fish and Wildlife Agencies. 1984: 263-273.
- House, R.A.; Boehne, P.L. 1985.** Evaluation of instream enhancement structures for salmonid spawning and rearing in a coastal Oregon stream. North American Journal of Fisheries Management. 5: 283-295.
- Houston, D.R. 1981.** Stress triggered tree diseases, the diebacks and declines. Rep. NE-INF-41-81. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 36 p.
- Howard, J.O. 1978.** A technique for predicting logging residue volume in the Douglas-fir region. Res. Pap. PNW-235. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.

- Howard, J.O. 1981.** Ratios for estimating logging residue in the Pacific Northwest. Res. Pap. PNW-288. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 26 p.
- Hunter, J.R.; Mitchell, C.T. 1968.** Field experiments on the attraction of pelagic fish to floating objects. *Journal du Conseil, Conseil International pour l'Exploration de Mer.* 31: 427-434.
- Inone, M.; Amano, R.; Iwasaki, Y. 1963.** Studies on environments alluring skipjack and other tunas. 1: On the oceanographical condition of Japan adjacent waters and the drifting substances accompanied by skipjack and other tunas. Tokyo, Japan: Fisheries Research Laboratory, Tokai University; report; 1(1): 12-23. [In Japanese, English summary].
- Inone, M.; Amano, R.; Iwasaki, Y.; Yamanti, M. 1968.** Studies on environments alluring skipjack and other tunas. 2: On the driftwoods accompanied by skipjack and tunas. *Bulletin of the Japanese Society of Scientific Fisheries.* 34: 283-287.
- Jackman, S.M. 1974a.** Some characteristics of cavity nesters: can we ever leave enough snags? Paper presented at the Oregon chapter, The Wildlife Society; 1974 January; Corvallis, OR. Corvallis, OR: Oregon State University, Oregon Cooperative Wildlife Research Unit. 10 p.
- Jackman, S.M. 1974b.** Woodpeckers of the Pacific Northwest: their characteristics and their role in the forest. Corvallis, OR: Oregon State University. 147 p. M.S. thesis.
- Jackson, J.A. 1976.** How to determine the status of a woodpecker nest. *Living-Bird.* 15: 205-219.
- Johannessen, C.L. 1964.** Marshes prograding in Oregon: aerial photographs. *Science.* 146: 1575-1578.
- Johnson, G.E.; Gonor, J.J. 1982.** The tidal exchange of *Callinassa californiensis* larvae between the ocean and the Salmon River estuary. *Estuarine Coastal and Shelf Science.* 14: 511-516.
- Johnson, N.E.; Shea, K.R.; Johnsey, R.L. 1964.** Mortality and deterioration of looper-killed hemlock in western Washington. *Journal of Forestry.* 62: 162-163.
- Jones, E.B.G.; Turner, R.; Furtado, S.E.; Kuhne, H. 1976.** Marine biodeteriogenic organisms. I: Lignicolous fungi and bacteria and wood boring mollusca and crustacea. *International Biodeterioration Bulletin.* 12(4): 120-134.
- Keller, E.A.; Swanson, F.J. 1979.** Effects of large organic material on channel form and fluvial processes. *Earth Surface Processes.* 4: 361-380.
- Keller, E.A.; Tally, T. 1979.** Effects of large organic debris on channel form and fluvial processes in the coastal redwood environment. In: Rhodes, D.D.; Williams, G.P., eds. *Adjustments on the fluvial system: Proceedings of the 10th annual geomorphology symposium.* Binghamton: State University of New York: 169-197.

- Kiilsgaard, C.W.; Greene, S.E.; Stafford, S.G. [In press].** Nutrient concentrations in litterfall from some western conifers with special reference to calcium. *Plant and Soil*.
- Kilham, L. 1979.** Courtship and the pair-bond of pileated woodpeckers. *Auk*. 96: 587-594.
- Kimmins, J.; Scoullar, K. 1979.** FORCYTE: a computer simulation approach to evaluating the effect of whole-tree harvesting on the nutrient budget in Northwest forests. In: Gessel, S.P.; Kenady, R.M.; Atkinson, W.A., eds. Forest fertilization conference. Contrib. 40. Seattle: Institute of Forest Resources, University of Washington: 266-273.
- Kimura, K. 1954.** Analysis of skipjack (*Katsuwonus pelamis*) shoals in the water of "Tohoku Kaiku" by its association with other animals and objects based on the records by fishing boats. Bull. 3. Senolai, Japan: Tohoku Region, Fisheries Research Laboratory. 87 p. [In Japanese, English synopsis].
- Knight, H.A. 1987.** The pine decline. *Journal of Forestry*. 85: 25-28.
- Knudsen, J. 1961.** The bathyal and abyssal *Xylophaga* (Pholadidae, Bivalvia). In: Wolff, T., ed. Galathea report. Copenhagen: Danish Science Press Ltd.: 163-209. Vol. 5.
- Knudsen, J. 1970.** The systematics and biology of abyssal and hadal Bivalvia. In: Wolff, T., ed. Galathea report. Copenhagen: Danish Science Press Ltd.: 7-236. Vol. 2.
- Kodata, H. 1958.** Cellulose-decomposing bacteria in the sea. In: Ray, D.L., ed. Marine wood boring and fouling organisms. Seattle: University of Washington Press: 332-341.
- Komar, P.D. 1983.** The erosion of Siletz Spit, Oregon. In: Komar, P.D., ed. Handbook of coastal processes and erosion. Boca Raton, FL: CRC Press: 65-77.
- Komar, P.D.; Rea, C.C. 1976.** Erosion of Siletz Spit, Oregon. *Shore and Beach*. 44(1): 9-15.
- Koonce, A.L.; Roth, L.F. 1980.** The effects of prescribed burning on dwarf mistletoe in ponderosa pine. In: Proceedings of the conference on fire and meteorology. Seattle, WA: Society of American Foresters; 197-203. Vol. 6.
- Koski, K.V.; Heifetz, J.; Johnson, S.; Murphy, M.; Thedinga, J. 1985.** Evaluation of buffer strips for protection of salmonid rearing habitat and implications for enhancement. In: Hassler, T.J., ed. Pacific Northwest stream habitat management workshop. Arcata, CA: Western Division of American Fisheries Society and Cooperative Fisheries Unit, Humboldt State University: 138-155.
- Krebill, R.G. 1968.** Histology of canker rusts in pines. *Phytopathology*. 58: 155-164.
- Lambert, R.L.; Lang, G.E.; Reiners, W.A. 1980.** Loss of mass and chemical change in decaying boles of a subalpine fir forest. *Ecology*. 61: 1460-1473.

- Lammel, R.F. 1972.** Natural debris and logging residue within the stream environment. Corvallis, OR: Oregon State University. 78 p. M.S. thesis.
- Leaphart, C.D. 1959.** Drought damage to western white pine and associated tree species. *Plant Disease Reporter*. 43: 809-813.
- Lestelle, L.C. 1978.** The effects of forest debris removal on a population of resident cutthroat trout in a small headwater stream. Seattle: University of Washington. 133 p. M.S. thesis.
- Lestelle, L.C.; Cederholm, C.J. 1984.** Short-term effects of organic debris removal on resident cutthroat trout. In: Meehan, W.R.; Merrell, T.R., Jr.; Hanley, T.A., eds. *Fish and wildlife relationships in old-growth forests*. Juneau, AK: American Institute of Fisheries Research Biologists: 131-140.
- Li, C.Y.; Castellano, M.A. 1987.** *Azospirillum* isolated from within sporocarps of the mycorrhizal fungi *Hebeloma crustuliniforme*, *Laccaria laccata*, and *Rhizopogon vinicolor*. *Transactions British Mycological Society*. 88: 563-565.
- Li, C.Y.; Maser, C.; Maser, Z.; Caldwell, B.A. 1986.** Role of three rodents in forest nitrogen fixation in western Oregon: another aspect of mammal-mycorrhizal fungus-tree mutualism. *Great Basin Naturalist*. 46: 411-414.
- Lisle, T.E. 1982.** Roughness elements: a key resource to improve anadromous fish habitat. In: *Proceedings, propagation, enhancement, and rehabilitation of anadromous salmonid populations and habitat in the Pacific Northwest symposium; 1981 October 15-17*. Arcata, CA: California Cooperative Fisheries Research Unit, Humboldt State University: 93-98.
- Lisle, T.E.; Kelsey, H.M. 1982.** Effects of large roughness elements on the thalweg course and pool spacing. In: Leopold, L.B., ed. *American geomorphological field group field trip guidebook, 1982 conference, Pinedale, WY*. Berkeley, CA: American Geophysical Union: 134-135.
- Lister, D.B.; Genoe, H.S. 1979.** Stream habitat utilization by cohabiting underyearlings of chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) in the Big Qualicum River, British Columbia. *Journal of the Fisheries Research Board of Canada*. 27: 1215-1224.
- Long, B.A. 1987.** Recruitment and abundance of large woody debris in an Oregon coastal stream system. Corvallis, OR: Oregon State University. 68 p. M.S. thesis.
- Lucla, E. 1983.** Tillamook Burn country, a pictorial history. Caldwell, ID: Caxton Printers, Ltd. 305 p.
- Lyford, W.H.; MacLean, D.W. 1966.** Mound and pit microrelief in relation to soil disturbance and tree distribution in New Brunswick, Canada. *Harvard For. Pap.* 15. Cambridge, MA: Harvard University. 18 p.
- Lynott, R.E.; Cramer, O.P. 1966.** Detailed analysis of the 1962 Columbus Day windstorm in Oregon and Washington. *Monthly Weather Review*. 94: 105-117.

- MacMillan, P.C.; Means, J.; Hawk, G.M. [and others]. 1977.** Log decomposition in an old-growth Douglas-fir forest. In: Northwest Scientific Association abstract of papers presented at the 50th annual meeting. Pullman, WA: Washington State University Press. 13 p.
- Mahendrappa, M.K.; Foster, N.W.; Weetman, G.F.; Krause, H.H. 1986.** Nutrient cycling and availability in forest soils. *Canadian Journal of Soil Science*. 66: 547-571.
- Mannan, R.W.; Meslow, E.C.; Wight, H.M. 1980.** Use of snags by birds in Douglas-fir forests, western Oregon. *Journal of Wildlife Management*. 44: 787-797.
- Martin, R.E.; Robinson, D.D.; Schaeffer, W.H. 1976.** Fire in the Pacific Northwest—perspectives and problems. In: Proceedings of the 15th annual tall timbers fire ecology conference. 1974 October 15-16; Portland, OR. Tallahassee, FL: Tall Timbers Research Station: 1-23.
- Marzolf, G.R. 1978.** The potential effects of clearing and snagging on stream ecosystems. Rep. FWS/OBS-78/14. Washington, DC: Office of Biological Service, Fish and Wildlife Service, U.S. Department of the Interior. 31 p.
- Maser, C. 1967.** Black bear damage to Douglas-fir in Oregon. *Murrelet*. 48: 34-38.
- Maser, C.; Anderson, R.; Bull, E.L. 1981.** Aggregation and sex segregation in northern flying squirrels in northeastern Oregon, an observation. *Murrelet*. 62: 54-55.
- Maser, C.; Anderson, R.G.; Cromack, K., Jr. [and others]. 1979.** Dead and down woody material. In: Thomas, J.W., tech. ed. *Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington*. Agric. Handb. 553. Washington, DC: U.S. Department of Agriculture: 78-95. In cooperation with: Wildlife Management Institute and the U.S. Department of the Interior, Bureau of Land Management.
- Maser, C.; Trappe, J.M. 1984a.** The fallen tree—a source of diversity. In: *New forests for a changing world: Proceedings, Society of American Foresters national convention; 1983 October 16-20; Portland, OR*. Bethesda, MD: Society of American Foresters: 335-339.
- Maser, C.; Trappe, J.M., tech. eds. 1984b.** The seen and unseen world of the fallen tree. Gen. Tech. Rep. PNW-164. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 56 p. In cooperation with: U.S. Department of the Interior, Bureau of Land Management.
- McClougherty, C.; Berg, B. [In press].** Cellulose, lignin and nitrogen levels as rate regulating factors in forest litter decomposition. *Pedobiologia*.
- McClelland, B.R. 1979.** The pileated woodpecker in forests of the northern Rocky Mountains. In: Dickson, J.G.; Conner, R.N.; Fleet, R.R. [and others], eds. *The role of insectivorous birds in forest ecosystems: Proceedings of a symposium; 1978 July 13-14; Nacogdoches, TX*. New York: Academic Press Inc.: 283-299.

- McComb, W.C.; Noble, R.E. 1981.** Microclimates of nest boxes and natural cavities in bottomland hardwoods. *Journal of Wildlife Management*. 45: 284-289.
- McKernan, D.L.; Johnson, D.R.; Hodges, J.I. 1950.** Some factors influencing the trends of salmon populations in Oregon. *Transactions of the 15th North American Wildlife Conference*. 1950: 427-449.
- McNabb, D.H.; Cromack, K., Jr. 1983.** Dinitrogen fixation by a mature *Ceanothus velutinus* (Dougl.) stand in the western Oregon Cascades. *Canadian Journal of Microbiology*. 29: 1014-1021.
- McNeely, R.L. 1961.** Purse seine revolution in tuna fishing. *Pacific Fisherman*. 59(7): 27-58.
- Means, J.; Cromack, K., Jr.; MacMillan, P.C. 1985.** Comparison of decomposition model, using wood density of Douglas-fir logs. *Canadian Journal of Forest Research*. 15: 1092-1098.
- Meehan, W.R.; Farr, W.A.; Bishop, D.M.; Patric, J.H. 1969.** Some effects of clearcutting on salmon habitat in two southeastern Alaska streams. Res. Pap. PNW-82. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 45 p.
- Meehan, W.R.; Swanson, F.J.; Sedell, J.R. 1977.** Influences of riparian vegetation on aquatic ecosystems with particular references to salmonid fishes and their food supply. In: Importance, preservation and management of riparian habitat, a symposium. Gen. Tech. Rep. RM-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 217 p.
- Melillo, J.M.; Aber, J.D.; Muratore, J.F. 1982.** Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology*. 63: 621-626.
- Miller, E.; Miller, D.R. 1980.** Snag use by birds. In: DeGraaf, R.M., tech. coord. Proceedings of the workshop on management of western forests and grasslands for nongame birds; 1980 February 11-14; Salt Lake City, UT. Gen. Tech. Rep. INT-86. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 337-356.
- Morris, W.G. 1936.** Forest fires in Oregon and Washington. *Oregon Historical Quarterly*. 34(4): 313-339.
- Morrison, P.H. 1984.** The history and role of fire in forest ecosystems of the central western Cascades of Oregon determined by forest stand analysis. Seattle, WA: University of Washington. 183 p. M.S. thesis.
- Morse, E. 1883.** Morse's monthly: a Puget Sound magazine for the people of the Northwest. Snohomish City, Washington Territory. 1(1): 1-14. Available from: Washington State Archives, Olympia, WA.

- Mundie, J.H. 1969.** Ecological implications of the diet of juvenile coho in streams. In: Northcote, T.G., ed. Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries. Vancouver, BC: Institute of Fisheries, University of British Columbia: 135-152.
- Murphy, M.L.; Thedinga, J.F.; Koski, K.V.; Grette, G.B. 1984.** A stream ecosystem in an old-growth forest in southeast Alaska. Part 5: Seasonal changes in habitat utilization by juvenile salmonids. In: Meehan, W.R.; Merrell, T.R., Jr.; Hanley, T.A., eds. Fish and wildlife relationships in old-growth forests. Juneau, AK: American Institute of Fisheries Research Biologists: 89-98.
- Narver, D.W. 1971.** Effects of logging debris on fish production. In: Krygier, J.T.; Hall, J.D., eds. Proceedings of the symposium on forest land uses and stream environments; 1970 October 19-20; Oregon State University, Corvallis, OR. Corvallis, OR: Continuing Ed. Publications, Oregon State University Department of Printing: 100-111.
- Neff, J.A. 1928.** A study of the economic status of the common woodpeckers in relation to Oregon horticulture. Marionville, MO: Free Press Print. 68 p.
- Neitro, W.A.; Binkley, V.W.; Cline, S.P. [and others]. 1985.** Snags (wildlife trees). In: Brown, E.R., tech. ed. Management of wildlife and fish habitats in forests of western Oregon and Washington. Part 1—chapter narratives. R6-F & WL-192-1985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region: 129-169.
- Nelson, E.E.; Martin, N.E.; Williams, R.E. 1981.** Laminated root rot of western conifers. For. Insect and Dis. Leaf. 159. Washington, DC: U.S. Department of Agriculture, Forest Service. 6 p.
- Nickelson, T.E.; Beidler, W.M.; Willis, M.J. 1979.** Streamflow requirements of salmonids. Portland, OR: Oregon Department of Fish and Wildlife, Research and Development Section; Federal Aid Progress Rep. AFS-62. 30 p.
- Ogden, P.S. 1961.** Peter Skene Ogden's snake country journal 1826-27. In: Davies, K.G., ed. Peter Skene Ogden's snake country journal 1826-27. London: Hudson's Bay Record Society: lvii-lxi, 122. Vol. 23.
- Old-Growth Definition Task Group. 1986.** Interim definitions for old-growth Douglas-fir and mixed-conifer forests in the Pacific Northwest and California. Res. Note PNW-447. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 7 p.
- Oliver, C.D. 1981.** Forest development in North America following major disturbances. Forest Ecology and Management. 3: 153-168.
- Oliver, C.D. 1986.** Silviculture: the next thirty years, the past thirty years. Part I: Overview. Journal of Forestry. 84(4): 32-42.
- O'Loughlin, C.L. 1974.** The effect of timber removal on the stability of forest soils. Journal of Hydrology. New Zealand; 13: 121-134.

- Olson, J.S. 1963.** Energy storage and the balance of producers and decomposers in ecological systems. *Ecology*. 44: 322-331.
- O'Neil, R.V.; Reichle, D.E. 1980.** Dimensions of ecosystem theory. In: Waring, R.H., ed. *Forests: fresh perspectives from ecosystem analysis: Proceedings of the 40th annual biology colloquium; 1979 April 27-28; Oregon State University, Corvallis, OR. Corvallis, OR: Oregon State University Press: 11-26.*
- Oregonian, The.** Logging river banks for firewood after high water idles anglers' sport. 1986. March 13: 34 (col. 1-3, sect. E, p. 7).
- Orr, P.W. 1963.** Windthrown timber survey in the Pacific Northwest, 1962. Portland, OR: Insect and Disease Control Branch, Division of Timber Management, Pacific Northwest Region. 22 p.
- Osborn, J.G. 1981.** The effects of logging on cutthroat trout (*Salmo clarki*) in small headwater streams. FRI-UW-8113. Seattle: Fisheries Research Institute, University of Washington. 89 p.
- Pacific Tuna Development Foundation. 1979.** 1978 annual report. Honolulu, HI: Pacific Tuna Development Foundation. 22 p.
- Parmenter, T.; Bailey, R. 1985.** Oregon ocean book. Corvallis, OR: Oregon Department of Conservation and Development and Sea Grant, Oregon State University. 85 p.
- Peattie, D.C. 1953.** A natural history of western trees. Boston: Houghton Mifflin Co. 751 p.
- Percy, K.L.; Sutterland, C.; Bella, D.A.; Klingemen, P.C. 1974.** Descriptions and information sources for Oregon estuaries. Corvallis, OR: Sea Grant College Program, Oregon State University. 294 p.
- Petersen, R.C. 1984.** The chemical composition of wood. In: Rowell, R., ed. *The solid chemistry of wood.* Washington, DC: American Chemical Society: 57-126.
- Plochmann, R. 1968.** Forestry in the Federal Republic of Germany. Hill Family Foundation Series. Corvallis, OR: School of Forestry, Oregon State University. 52 p.
- Poelker, R.J.; Hartwell, H.D. 1973.** Black bear of Washington. *Biol. Bull.* 14. Olympia, WA: Washington State Game Department. 180 p.
- Pong, W.Y.; Henley, J.W. 1978.** Characteristics of residues in a helicopter logged area of old-growth Douglas-fir. Res. Note PNW-320. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 33 p.
- Rainville, R.P.; Rainville, S.C.; Lider, E.L. 1985.** Riparian silvicultural strategies for fish habitat emphasis. In: *Silviculture for wildlife and fish: a time for leadership: Proceedings of the 1985 technical session of the Wildlife and Fish Ecology Working Group.* Bethesda, MD: Society of American Foresters: 186-196.

- Raphael, M.G.; White, M. 1976.** Avian utilization of snags in a northern California coniferous forest (phases 1 and 11). Berkeley, CA: University of California, Department of Forestry and Conservation; presented to the U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, San Francisco, CA. 28 p.
- Raphael, M.G.; White, M. 1984.** Use of snags by cavity-nesting birds in the Sierra Nevada. *Wildlife Monographs*. 86: 1-66.
- Ray, D.L. 1959a.** Nutritional physiology of *Limnoria*. In: Ray, D.L., ed. Marine boring and fouling organisms. Seattle: University of Washington Press: 46-61.
- Ray, D.L. 1959b.** Some properties of cellulas from *Limnoria*. In: Ray, D.L., ed. Marine boring and fouling organisms. Seattle: University of Washington Press: 372-396.
- Report of the Secretary of War. 1883-84.** Report of the Chief of Engineers. Vol. 2, Pt. 1. In: House executive documents, Vol. 5. 2d session, 48th Congress. Washington, DC: U.S. Government Printing Office.
- Report of the Secretary of War. 1894-95.** Report of the Chief of Engineers. Vol. 2, Pt. 1. In: House executive documents, Vol. 8. 1st session, 54th Congress. Washington, DC: U.S. Government Printing Office.
- Report of the Secretary of War. 1904-5.** Report of the Chief of Engineers. Vol. 7, Pt. 3. In: House executive documents, Vol. 8. 1st session, 59th Congress. Washington, DC: U.S. Government Printing Office.
- Reports of the Secretary of War. 1875-1921.** Reports of the Chief of Engineers. In: House executive documents, sessions of Congress. Washington, DC: U.S. Government Printing Office; annual reports.
- Reukema, D.L. 1970.** Forty-year development of Douglas-fir stands planted at various spacings. Res. Pap. PNW-100. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 21 p.
- Robbins, C.S.; Bruun, B.; Zim, H.S. 1983.** Birds of North America. Racine, WI: Western Publishing Co., Inc. 360 p.
- Roth, L.F. 1970.** Disease in young-growth stands of Douglas-fir and western hemlock. In: Berg, A.B., ed. Management of young-growth Douglas-fir and western hemlock. Pap. 666. Corvallis, OR: Oregon State University, School of Forestry: 38-43.
- Ruediger, W.C. 1985.** Implementing a spotted owl management plan: the Gifford Pinchot National Forest experience. In: Gutiérrez, R.J.; Carey, A.B., eds. Ecology and management of the spotted owl in the Pacific Northwest. Gen. Tech. Rep. PNW-185. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 10-13.

- Rushmore, F.M. 1973.** Techniques for calling sapsuckers and finding their nesting territories. Res. Pap. NE-281. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.
- Russell, E.W. 1973.** Soil conditions and plant growth. 10th ed. London: Longman Publishers. 849 p.
- Ruth, R.H.; Yoder, R.A. 1953.** Reducing wind damage in the forests of the Oregon Coast Range. Res. Pap. 7. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 30 p.
- Sanders, C.J. 1964.** The biology of carpenter ants in New Brunswick. Canadian Entomologist. 96: 894-909.
- Schowalter, T.D. 1985.** Adaptations of insects to disturbance. In: The ecology of natural disturbance and patch dynamics. New York: Academic Press: 235-455.
- Schütt, P.; Cowling, E.B. 1985.** Waldsterben, a general decline of forests in central Europe: symptoms, development and possible causes. Plant Disease. 69: 548-558.
- Scott, V.E.; Whelan, J.A.; Svoboda, P.L. 1980.** Cavity-nesting birds and forest management. In: DeGraaf, R.M., tech. coord. Proceedings of the workshop on management of western forests and grasslands for nongame birds; 1980 February 11-14; Salt Lake City, UT. Gen. Tech. Rep. INT-86. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 311-324.
- Scrivener, J.C.; Andersen, B.C. 1984.** Logging impacts and some mechanisms that determine the size of spring and summer populations of coho salmon fry (*Oncorhynchus kisutch*) in Carnation Creek, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences. 41: 1097-1105.
- Secretary of the Treasury. 1859.** The report of the superintendent of the coast survey showing the progress of the survey in 1858. In: House executive documents, No. 33: 2d session, 35th Congress. Washington, DC: U.S. Government Printing Office.
- Sedell, J.R.; Bisson, P.A.; June, J.A.; Speaker, R.W. 1982a.** Ecology and habitat requirements of fish populations in South Fork Hoh River, Olympic National Park. In: Starkey, E.E.; Franklin, J.F.; Matthews, J.W., eds. Ecological research in national parks of the Pacific Northwest. Corvallis, OR: Oregon State University, Forest Research Laboratory: 47-63.
- Sedell, J.R.; Duval, W.S. 1985.** Water transportation and storage of logs. In: Meehan, W.R., ed. Influence of forest and rangeland management on anadromous fish habitat in western North America. Gen. Tech. Rep. PNW-186. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 1-68.

- Sedell, J.R.; Everest, F.H.; Swanson, F.J. 1982b.** Fish habitat and streamside management: past and present. In: Proceedings of the Society of American Foresters, annual meeting; 1981 September; Bethesda, MD. Bethesda, MD: Society of American Foresters: 244-255.
- Sedell, J.R.; Froggatt, J.L. 1984.** Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, U.S.A., from its floodplain by snagging and streamside forest removal. *Verhandlungen-Internationale Vereinigung fuer Theoretische und Angewandte Limnologie (International Association of Theoretical and Applied Limnology)*. 22: 1828-1834.
- Sedell, J.R.; Luchessa, K.J. 1982.** Using the historical record as an aid to salmonid habitat enhancement. In: Armantrout, N.B., ed. Acquisition and utilization of aquatic habitat inventory information. Portland, OR: Western Division, American Fisheries Society: 210-223.
- Sedell, J.R.; Swanson, F.J. 1984.** Ecological characteristics of streams in old-growth forests of the Pacific Northwest. In: Meehan, W.R.; Merrell, T.R., Jr.; Hanley, T.A., eds. Fish and wildlife relationships in old-growth forests. Juneau, AK: American Institute of Fisheries Research Biologists: 9-16.
- Sedell, J.R.; Swanson, F.J.; Gregory, S.V. 1985.** Evaluating fish response to woody debris. In: Hassler, T.J., ed. Proceedings of the Pacific Northwest stream habitat management workshop; 1984 October 10-12. Arcata, CA: Western Division of the American Fisheries Society and Cooperative Fisheries Unit, Humboldt State University: 222-245.
- Sedell, J.R.; Yuska, J.E.; Speaker, R.W. 1984.** Habitats and salmonid distribution in pristine, sediment-rich river valley systems: S. Fork Hoh and Queets River, Olympic National Park. In: Meehan, W.R.; Merrell, T.R., Jr.; Hanley, T.A., eds. Fish and wildlife relationships in old-growth forests. Juneau, AK: American Institute of Fisheries Research Biologists: 33-46.
- Sheffield, R.M.; Cost, N.D.; Bechtold, W.A.; McClure, J.P. 1985.** Pine growth reductions in the Southeast. *Resour. Bull. SE-83*. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 112 p.
- Shigo, A.L. 1973.** A tree hurts, too. *Inf. Bull. NE-INF-16-73*. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 28 p.
- Shigo, A.L. 1979.** Tree decay, an expanded concept. *Agric. Inf. Bull.* 419. Washington, DC: U.S. Department of Agriculture, Forest Service. 72 p.
- Shigo, A.L.; Marx, H.G. 1977.** Compartmentalization of decay in trees. *Agric. Inf. Bull.* 405. Washington, DC: U.S. Department of Agriculture, Forest Service. 73 p.
- Shortle, W.C. 1979.** Mechanisms of compartmentalization of decay in living trees. *Phytopathology*. 69: 1147-1151.
- Shugart, H.H. 1984.** A theory of forest dynamics: the ecological implications of forest succession models. New York: Springer-Verlag. 278 p.

- Siccama, T.G.; Bliss, M.; Vogelmann, H.W. 1982.** Decline of red spruce in the Green Mountains of Vermont. *Bulletin of the Torrey Botanical Club*. 109: 163.
- Silvester, W.B.; Sollins, P.; Verhoeven, T.; Cline, S.P. 1982.** Nitrogen fixation and acetylene reduction in decaying conifer boles: effects of incubation time, aeration, and moisture content. *Canadian Journal of Forest Research*. 12: 646-652.
- Simon and Schuster. 1978.** Simon and Schuster's guide to trees. Fireside Book Publication by Simon and Schuster. New York: Fireside Book Publication. 55 p., 300 plates.
- Society of American Foresters. 1984a.** Acidic deposition and forest. SAF Resource Policy Series. Bethesda, MD: Society of American Foresters. 48 p.
- Society of American Foresters. 1984b.** Scheduling the harvest of old-growth. Washington, DC: Society of American Foresters. 44 p.
- Sollins, P. 1982.** Input and decay of coarse woody debris in coniferous stands in western Oregon and Washington. *Canadian Journal of Forest Research*. 12: 18-28.
- Sollins, P.; Cline, S.P.; Verhoeven, T. 1986.** Chemical, physical, and microbiological properties of decaying wood in the Pacific Northwest. On file at: U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, Corvallis, OR. 39 p.
- Sollins, P.; Grier, C.C.; McCorison, F.M. [and others]. 1980.** The internal element cycles of an old-growth Douglas-fir ecosystem in western Oregon. *Ecological Monographs*. 50: 261-285.
- Spies, T.A.; Franklin, J.F.; Thomas, T.B. [In press].** Coarse woody debris in Douglas-fir forests of western Oregon and Washington. *Ecology*.
- Stalmaster, M.V.; Knight, R.L.; Holder, B.L.; Anderson, R.J. 1985.** Bald eagles. In: Management of wildlife and fish habitats in forests of western Oregon and Washington. R6-F&WL-192-1985. Portland, OR: U.S. Department of Agriculture, Forest Service: 269-291.
- Steedman, R.J.; Anderson, N.H. 1985.** Life history and ecological role of the xylophagous aquatic beetle, *Lara avara* LeConte (Dryopoidea: Elmidae). *Freshwater Biology*. 15: 535-546.
- Stein, R.A.; Reimers, P.E.; Hall, J.D. 1972.** Social interaction between juvenile coho (*Oncorhynchus kisutch*) and fall chinook salmon (*O. tshawytscha*) in Sixes River, Oregon. *Journal of the Fisheries Research Board of Canada*. 29: 1737-1748.
- Stembridge, J.E. 1975.** Recent shoreline changes of the Alsea sandspit, Lincoln County, Oregon. Paper presented at the Corvallis meeting of the Association of Pacific Coast Geographers. *The Ore Bin*. 37(5): 77-82.
- Stembridge, J.E. 1976.** Recent changes of the Oregon coast U.S.A. 55 p. Available from: National Technical Information Services, Springfield, VA; AD A048436.

- Stembridge, J.E., Jr. 1979.** Beach protection properties of accumulated driftwood. In: Proceedings of the specialty conference on coastal structures 79. ASCE/Alexandria, Virginia. 1979 March 14-16: 1052-1068. Reprints available from: Coast Environmental Resources Institute, 1695 Winter Street S.E., Salem, OR 97302.
- Stephens, E.P. 1956.** The uprooting of trees: a forest process. Soil Science Society Proceedings. 113-116.
- Stewart, G.H. 1984.** Forest structure and regeneration in the *Tsuga heterophylla*-*Abies amabilis* transition zone, central western Cascades, Oregon. Corvallis, OR: Oregon State University. 148 p. Ph.D. dissertation.
- Strahler, A.N. 1957.** Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union. 38: 913-920.
- Strong, C.C.; Skolmen, R.G. 1963.** Origin of drift logs on the beaches of Hawaii. Nature. 197: 890.
- Sudworth, G.B. 1967.** Forest trees of the Pacific slope. New York: Dover Publishers, Inc. 455 p.
- Sullivan, K.; Lisle, T.E.; Dolloff, C.A. [and others]. 1987.** Stream channels: the link between forests and fishes. In: Cundy, T.; Salo, E.O., ed. Proceedings of a symposium streamside management-forestry fisheries interactions; 1986 February 12-14; University of Washington, Seattle, WA. Seattle, WA: Institute of Forest Resources, University of Washington: 39-97.
- Suyehiro, Y. 1952.** Textbook of ichthyology. [In Japanese]. Tokyo: Iwanami. Shoten. 332 p.
- Swan, J.G. 1857.** The Northwest coast. Seattle, WA: University of Washington Press. 435 p. Reprinted in 1982.
- Swan, J.G. 1971.** Almost out of this world. Scenes from Washington Territory. Tacoma, WA: Washington State Historical Society. 126 p.
- Swanson, F.J.; Bryant, M.D.; Lienkaemper, G.W.; Sedell, J.R. 1984.** Organic debris in small streams, Prince of Wales Island, southeast Alaska. Gen. Tech. Rep. PNW-166. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.
- Swanson, F.J.; Fredriksen, R.L.; McCorison, F.M. 1982.** Material transfer in a western Oregon forested watershed. In: Edmonds, R.L., ed. Analysis of coniferous forest ecosystems in the Western United States. US/IBP Synth. Ser. 14. Stroudsburg, PA: Hutchinson Ross: 233-266.
- Swanson, F.J.; Lienkaemper, G.W. 1978.** Physical consequences of large organic debris in Pacific Northwest streams. Gen. Tech. Rep. PNW-69. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.

- Swanson, F.J.; Lienkaemper, G.W. 1982.** Interactions among fluvial processes, forest vegetation, and aquatic ecosystems, South Fork Hoh River, Olympic National Park. In: Starkey, E.E.; Franklin, J.F.; Matthews, J.W., eds. Ecological research in national parks of the Pacific Northwest. Corvallis, OR: Oregon State University, Forest Research Laboratory: 30-34.
- Swanson, F.J.; Lienkaemper, G.W. 1985.** Geologic zoning of slope movements in western Oregon, U.S.A. In: Proceedings, 4th international conference and field workshop on landslides, 1985. Tokyo: The Japan Landslide Society: 41-45.
- Swanson, F.J.; Lienkaemper, G.W.; Sedell, J.R. 1976.** History, physical effects, and management implications of large organic debris in western Oregon streams. Gen. Tech. Rep. PNW-56. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 15 p.
- Swanston, D.N.; Swanson, F.J. 1976.** Timber harvesting, mass erosion, and steep-land forest geomorphology in the Pacific Northwest. In: Coates, D.R., ed. Geomorphology and engineering. Stroudsburg, PA: Dowden, Hutchinson, and Ross: 199-221.
- Swearingen, E.M. 1977.** Group size, sex ratio, reproductive success and territory size in acorn woodpeckers. *Western Birds*. 8: 21-24.
- Tabata, S. 1975.** The general circulation of the Pacific Ocean and a brief account of the oceanographic structure of the north Pacific Ocean. *Atmosphere*. 13(4): 134-167.
- Tarrant, R.F.; Miller, R.E. 1963.** Accumulation of organic matter and soil nitrogen beneath a plantation of red alder and Douglas-fir. *Soil Science Society of America Proceedings*. 27: 231-234.
- Terich, T.A.; Milne, S. 1977.** The effects of wood debris and drift logs on estuarine beaches of northern Puget Sound. Bellingham, WA: Department of Geography and Regional Planning, Western Washington University. 74 p.
- Thomas, J.W.; Anderson, R.G.; Maser, C.; Bull, E.L. 1979.** Snags. In: Thomas, J.W., tech. ed. Wildlife habitats in managed forests—the Blue Mountains of Oregon and Washington. Agric. Handb. 553. Washington, DC: U.S. Department of Agriculture: 60-77.
- Thompson, J.N. 1980.** Treefalls and colonization patterns of temperate forest herbs. *American Midland Naturalist*. 104: 176-184.
- Thornburgh, D.A. 1967.** Dynamics of the true fir-hemlock forests of western Washington. Seattle: University of Washington. 210 p. Ph.D. dissertation.
- Toews, D.A.A.; Moore, M.K. 1982.** The effects of streamside logging on large organic debris in Carnation Creek. Land Manage. Rep. 11. Vancouver, BC: Ministry of Forests. 29 p.

- Triska, F.J. 1984.** Role of wood debris in modifying channel geomorphology and riparian areas of a large lowland river under pristine conditions: a historical case study. *Verhandlungen-Internationale Vereinigung fuer Theoretische und Angewandte Limnologie (International Association of Theoretical and Applied Limnology)*. 22: 1876-1892.
- Triska, F.J.; Cromack, K., Jr. 1980.** The role of wood debris in forests and streams. In: Waring, R.H., ed. *Forests: fresh perspectives from ecosystem analysis: Proceedings of the 40th annual biology colloquium*. Corvallis, OR: Oregon State University Press: 171-190.
- Triska, F.J.; Sedell, J.R.; Gregory, S.V. 1982.** Coniferous forest streams. In: Edmonds, R.L., ed. *Analysis of coniferous forest ecosystems in the Western United States*. US/IBP Synth. Ser. 14. Stroudsburg, PA: Hutchinson Ross Publishing Company: 292-332.
- Tschaplinski, P.J.; Hartman, G.F. 1983.** Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. *Canadian Journal of Fisheries and Aquatic Sciences*. 40: 452-461.
- Turner, D.P.; Franz, E.H. 1985.** The influence of western hemlock and western redcedar on microbial numbers, nitrogen mineralization, and nitrification. *Plant and Soil*. 88: 259-267.
- Turner, R.D. 1977.** Wood, mollusks, and deep-sea food chains. *Bulletin of the American Malacological Union for 1976*: 13-19.
- Turner, R.D. 1981.** "Wood islands" and "thermal vents" as centers for diverse communities in the deep sea. *Soviet Journal of Marine Biology*. 7(1): 3-4. Translation of *Biologiya Morya* 7(1): 3-10; 1987.
- U.S. Laws, Statutes, etc.; Public Law 94-588. [S.3091], Oct. 22, 1976.** National Forest Management Act of 1976. In: *United States code congressional and administrative news*. 94th Congr. 2d Sess., 1976. 16 U.S.C. sec. 1600 (1976). St. Paul, MN: West Publishing Co.; 2949-2963. Vol. 2.
- Uda, M. 1952.** Types of skipjack schools and their fishing qualities. [In Japanese]. *Bulletin of the Japanese Society of Scientific Fisheries*. 2: 107-111. (English translation. In: Van Campen, W.G. *Five Japanese papers on skipjack*. U.S. Fish and Wildlife Service, Spec. Sci. Rep. Fish. 83: 68-73).
- Vannote, R.L.; Minshall, G.W.; Cummins, K.W. [and others]. 1980.** The river continuum concept. *Canadian Journal of Fisheries and Aquatic Science*. 37: 130-137.
- Wargo, P.M. 1984.** How stress predisposes trees to attack by *Armillaria mellea*—a hypothesis. In: Kile, G.A., ed. *Proceedings of the 6th IUFRO conference on root butt rots*. Melbourne, Australia: CSIRO: 115-122.
- Waring, R.H.; Franklin, J.F. 1979.** Evergreen coniferous forests of the Pacific Northwest. *Science*. 204: 1380-1386.

- Waring, R.H.; Schlesinger, W.H. 1985.** Forest ecosystems: concepts and management. Orlando, FL: Academic Press, Inc. 340 p.
- White, M.; Raphael, M. 1975.** Importance of wildlife to forest ecosystems. In: Report for California State Board of Forestry; prepared by study committee on snags. Berkeley, CA: University of California, Department of Forestry and Conservation: Appendix B-5.
- Williams, I.A. 1914.** Drainage of farm lands in the Willamette and tributary valleys of Oregon. The Mineral Resources of Oregon. Salem, OR: Oregon Bureau of Mines and Geology; 1(4): 13.
- Wright, K.H.; Harvey, G.M. 1967.** The deterioration of beetle-killed Douglas-fir in western Oregon and Washington. Res. Pap, PNW-50. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 22 p.
- Wright, K.H.; Lauterbach, P.G. 1958.** A 10-year study of mortality in a Douglas-fir sawtimber stand in Coos and Douglas Counties, Oregon. Res. Pap. 27. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 29 p.
- Yabe, H.; Mori, T. 1950.** An observation on a school of skipjack and Kimeji accompanying a drift log: [In Japanese with English summary]. Journal of the Japanese Society of Scientific Fisheries. 16: 35-39. (Translation available from: National Marine Fisheries Service, Honolulu Laboratory, Honolulu, HI).
- Yavitt, J.B.; Fahey, T.J. 1982.** Loss of mass and nutrient changes of decaying woody roots in lodgepole pine forests, southeastern Wyoming. Canadian Journal of Forest Research. 12: 745-752.
- Yavitt, J.B.; Fahey, T.J. 1985.** Chemical composition of interstitial water in decaying lodgepole pine bole wood. Canadian Journal of Forest Research. 15: 1149-1153.
- Youngberg, C.T.; Wollum, A.G., II. 1976.** Nitrogen accretion in developing *Ceanothus velutinus* stands. Soil Science Society of America Journal. 40: 109-112.
- Zarn, M. 1974.** Habitat management series for unique or endangered species— osprey *Pandion haliaetus carolinensis*. Tech. Note 254, Rep. 12. Denver, CO: U.S. Department of the Interior, Bureau of Land Management. 41 p.
- Zedaker, S.M.; Hyink, D.M.; Smlth, D.W. 1987.** Growth declines in red spruce. Journal of Forestry. 85: 34-36.
- Zhang, X.W.; Guang, H.; Zhen, H.Y. [and others]. 1980.** Repeated plantation of *Cunninghamia lanceolata* and toxicis of soil. In: Ecological studies on the artificial *Cunninghamia lanceolata* forests. [City unknown], People's Republic of China: Institute of Forestry and Soil Science, Academia Sinica: 148-151.
- Ziemer, R.R. 1981.** Roots and the stability of forested slopes. In: Davis, T.R.H.; Pearce, A.J., eds. Erosion and sediment transport in Pacific Rim steeplands symposium. Publ. 132. Christchurch, New Zealand: IAHS-AISH: 343-361.

Zimmerman, R.C.; Goodlet, J.C.; Comer, G.H. 1967. The influence of vegetation on channel form of small streams. In: Symposium on river morphology. Publ. 75. Gentbrugge, Belgium: International Association of Science Hydrologists: 255-275.

Zinke, P.J.; Crocker, R.L. 1962. The influence of giant sequoia on soil properties. Forest Science. 8(1): 2-11.