AN ABSTRACT OF THE THESIS OF

Barry A. Long for the degree of Master of Science in
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Title: Recruitment and Abundance of Large Woody Debris in an
Oregon Coastal Stream System

Abstract approved: Henry A. Froehlich
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Research was conducted in the Oregon Coast Range to address the concern that conversion of large diameter old-growth forests to small diameter second-growth forests would lead to reduction of large woody debris in adjacent stream channels. The objective of the study was to quantify spatial trends in large woody debris recruitment and abundance in a stream system bordered by a second-growth forest. Big Creek in Lincoln County was selected for the study. The watershed was clearcut between 1922 and 1935, and subsequently burned by wildfire in 1936. A large woody debris inventory was conducted in first- through fourth-order stream channels. Comparisons were made between pre-disturbance (wood in place during logging and fire) and post-disturbance (contributions from new forest) woody debris types within each stream order.

Approximately 5200 pieces of large woody debris (greater than 0.1 m diameter and 1 m length) were measured in 11.5 kilometers of channel. Total volume per square meter and number of pieces varied considerably among stream orders. Second-order channels had the heaviest debris loading (0.0422 m^3/m^2), followed by first- (0.0308 m^3/m^2), third- (0.0242 m^3/m^2), and fourth-order (0.0201 m^3/m^2) channels. Piece numbers ranged from 54.8 to 35.6 per 100 meters of channel, with a basin average of 45.1 pieces per 100 meters. Pre-disturbance debris pieces constituted 63 to 70 percent of the total number of pieces and 86 to 89 percent of the total volume within all stream orders. Species composition within the post-disturbance group varied significantly among stream orders. Third- and fourth-order channels contained mostly hardwood post-disturbance debris, whereas first- and second-order channels contained a greater proportion of conifer post-disturbance debris. Riparian stand density and basal area per hectare were positively correlated with the recruitment of post-disturbance woody debris in some channel segments.

Flotation, windthrow, and logging were the most common delivery mechanisms for pre-disturbance debris. Fifty-two percent of pre-disturbance debris pieces were located in channels or on channel banks, and 17 percent influenced pool habitat formation. Bank cutting was the predominant delivery mechanism for post-disturbance debris. Thirty-two percent of post-disturbance pieces were in channels or on channel banks, and seven percent formed pools. Most post-disturbance pieces were suspended above channels or on side terraces. Fifty-two percent of the total debris pieces were found in debris accumulations. The largest debris accumulations commonly were located at tributary junctions.

RECRUITMENT AND ABUNDANCE OF LARGE WOODY DEBRIS IN AN OREGON COASTAL STREAM SYSTEM

by

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INTRODUCTION

Background and Problem Statement

Large woody debris can greatly influence the physical and biological character of stream ecosystems in the Pacific Northwest. Large wood pieces produce obstructions that dissipate flow energies, control routing of water-borne materials, and provide a diversity of habitat for stream organisms. Historical records depict natural stream systems as diverse, unchannelized waterways containing numerous accumulations of large wood. Wild fish stocks evolved in streams obstructed by fallen trees, beaver dams, and vegetation growing in and beside channel systems (Sedell and Luchessa 1981). Large wood pieces can persist in streams for more than 100 years (Swanson and Lienkaemper 1978), and provide a stabilizing effect to stream beds and banks. Reductions in the amount of woody debris in stream channels can decrease retention of organic matter, increase downcutting and channelization, and reduce stream habitat diversity (Swanson et al. 1976). The streamside forest is an important future source of large woody debris in stream channels.

The management emphasis regarding woody debris in stream channels has changed significantly in the last 25 years. From the late 1950's to late 1970's, some managers believed that streams in the Pacific Northwest contained too much woody debris and attempts were made to reduce debris loading, especially following logging. Eventually, many realized that natural stream systems contained large amounts of woody debris (Froehlich 1973), and that fish populations depended on the pools formed by debris. Concern now centers around whether enough woody debris is being contributed to stream channels by younger streamside stands. A number of management questions remain unanswered, including:

1. How does converting old-growth forests to second-growth forests affect debris loading in small streams?
2. Do young forests supply large woody debris at a rate that can maintain stream habitat diversity?
3. Can streamside forests be managed to increase amounts of large woody debris in stream channels?

Two recent studies have laid the groundwork for my research. Summers (1982) documented the regrowth of riparian vegetation that followed clearcutting in stands up to 29 years old at 35 sites within five vegetative zones in the Coast Range and Cascade Mountains. Five streams bordered by old-growth stands were measured for comparison. Total vegetative cover (ground, understory, overstory) and canopy density percentages were correlated with stand age. Vegetation values were low immediately following logging but after 22 years equaled or exceeded control conditions. Dense regrowth of <u>Alnus</u> <u>rubra</u> accounted for most overstory increases in the Coast Range. Standing crops of large woody debris were lower in managed forest streams, possibly due to debris cleanout activities. A total of 43.9 pieces (greater than

10 cm in diameter) per 100 meters of stream channel were counted in forested sites and 34.1 pieces per 100 meters in harvested sites. Heimann (in process) studied debris loading in 14 streams bordered by 21- to 135-year-old stands in the Coast Range. He found that large woody debris contributions to stream channels from the young stands increased from 0 to 0.02 m^3/m^2 during a 114 year time sequence of stand growth. Hardwood debris contributions from stands up to 65 years of age increased rapidly, then declined. Conifer debris contributions from stands up to 65 years of age were scarce, but then increased rapidly to become the largest new debris fraction after 90 years. Original woody debris from pre-harvest stands dominated total debris volumes in channels bordered by stands less than 100 years of age.

Study Objectives and Hypotheses

The broad objective of this study was to quantify spatial trends in large woody debris recruitment and abundance in a Coast Range stream system five decades after logging and wildfire. The specific study objectives were:

1. To determine the quantity and character of large woody debris present in a fourth-order stream system bordered by a second-growth forest.

   Hypotheses tested were:

   a. Total volumes of woody debris per unit area are greater in first- and second-order channels than in third- and fourth-order channels.

   b. Total volumes of woody debris in second-growth stream channels are dominated by resident, pre-disturbance coniferous debris.
   c. Post-disturbance additions of woody debris to channel systems from second-growth forests are dominated by deciduous species.
   d. Pre-disturbance debris pieces are larger than post-disturbance debris pieces.

2. To determine effects of riparian stand characteristics, channel morphology, hillslope morphology, and stream size on large woody debris in stream channels.
   Hypotheses tested were:
   a. Riparian stand species and density influence post-disturbance woody debris composition in the channels.
   b. Distribution of woody debris pieces is random in small channels and "clump-like" in large channels.
   c. Tributary junctions influence the formation of woody debris accumulations.

3. To determine effects of large woody debris contributions on stream habitat formation.
   The hypothesis tested was:
   a. Pre-disturbance woody debris has a greater influence on the formation of pools, gravel bars, fall drops, and stream cover than post-disturbance debris.

LITERATURE REVIEW

Riparian Zone Influences and Interactions

Riparian zones have been delineated by many different methods. Biologists defined riparian species and plant communities in streamside areas as life-forms which differed from those in surrounding upland communities. Hydrologists defined riparian areas as those with vegetation adjacent to perennial flows and ponded water that were influenced by the water table. Other approaches used soil moisture regime or topographical landform criteria. Recently, a broader perspective was developed to reduce complexity and overlap by scientists studying stream systems and their associated habitats. This approach considers riparian zones as areas where direct interaction occurs between terrestrial and aquatic environments (Swanson et al. 1982b). The types of interactions that take place are determined by the surrounding vegetation, hydrology, and topography. Furthermore, riparian zone boundaries are not constant in time and space (Meehan et al. 1977). Temporal variation occurs during vegetative succession following a disturbance (e.g. fire, flood, glacial retreat, timber harvesting, road building). Spatial variation occurs along gradients of increasing stream size and changing hillslope topography.

Riparian vegetation supplies large and fine plant detritus to stream systems, provides shade which controls water temperature and instream primary production, stabilizes stream banks with root systems, and retards movement of sediment, water, and debris during flood flows (Meehan et al. 1977). Zimmerman et al. (1967) studied the influence of streamside vegetation on channel form and found that channel dimensions, roughness, and shear strength of bed and bank sediment were determined by in place vegetation. Habitat factors that influence fish populations, such as: access for migration, stream temperatures, dissolved oxygen, cover for protection, food availability, and substrate composition, can be modified by the presence of riparian vegetation (Narver 1971, Reiser and Bjornn 1979).

Small headwater streams draining forested watersheds depend on terrestrial sources of wood and leaf litter to supply a significant proportion of fixed carbon and nutrients needed for biological processing (Triska et al. 1984). This allochthonous material constitutes the energy base of most Pacific Northwest first- and second-order streams and provides a food source for microbial colonization and invertebrate production (Cummins 1974; Sedell et al. 1974, 1982; Triska et al. 1982). Particulate organic matter enters streams by throughfall (fine material washed off leaves), litterfall (leaves, needles, and twigs that fall directly in or are blown in), and lateral movement (debris pieces moved by fluvial action and mass movements). While in streams, organic matter is broken down by stream organisms at rates influenced by piece size, species type, abundance, available nutrients, and the retention capacity of the channels (Meehan et al. 1977). Microbial colonization, invertebrate feeding, and mechanical abrasion are mechanisms which break down woody and leafy material into finer organic matter for use by other organisms in the food web. Processing time for large woody material may take from 25 to over 100 years (Cummins et al. 1983). Leaves and needles are processed much more rapidly (2-12 months) and are thus more readily available to consumer organisms (Anderson et al. 1978). Autochthonous primary producers such as mosses, algae, and vascular plants also contribute particulate organic matter to streams for processing by invertebrates. Fisher and Likens (1973) reported that at least one percent of the energy inputs in forested streams was derived from photosynthesis. Dissolved organic matter is the other major component of organic matter budgets. These micro- and macro-nutrients, which are leached from particulate organic matter, form building blocks for biological production and constitute the largest fraction (60-70 percent) of total organic matter cycled within stream systems (Triska et al. 1984).

First- and second-order streams commonly retain large amounts of organic matter. Anderson and Sedell (1979) reported that less than 50 percent of the organic matter delivered to headwater streams may be flushed downstream to larger order streams in a given year. As streams become larger, channel widths increase and the influence of terrestrial vegetation decreases. Transported organic matter breaks down into smaller size classes, biotic structure shifts gradually to an autotrophic regime in response to canopy opening, and channel storage becomes concentrated more on upper bank, point bar, and flood plain sites (Vannote et al. 1980).

Role of Large Woody Debris

Stream habitat structure and diversity is a major determinant of biotic conditions that support fish (Sedell et al. 1982). Large woody debris can be the principal factor determining the physical form and biological character of small and mid-sized streams (Swanson and Lienkaemper 1978, Keller and Swanson 1979, Bilby and Likens 1980). Large wood constitutes over 80 percent of the allochthonous biomass in most coniferous forest streams (Triska et al. 1982). Instream large wood pieces create roughness elements that dissipate stream energies (Heede 1972 Swanson et al. 1976, Swanson and Lienkaemper 1978, Keller and Swanson 1979, Marston 1982). Large stable pieces are important retention mechanisms that control routing of sediment and water through channel systems (Megahan and Nowlin 1976, Swanson et al. 1976, Meehan et al. 1977, Swanson and Lienkaemper 1978, Keller and Swanson 1979, Bilby and Likens 1980, Bilby 1981, Swanson et al. 1982a,b, Triska et al. 1982), provide cover, regulate pool and riffle formation (Hall and Baker 1975, Meehan et al. 1977, Swanson et al. 1982b, Sedell et al. 1982), and serve as food and substrate for biological activity (Sedell and Triska 1977, Meehan et al. 1977, Triska et al. 1982).

Possible deleterious effects of large woody debris on channel form include development of debris jams that cause flooding, flotation of pieces during high flows that cause potential downstream erosion, and deflection or concentration of flows that destabilize stream banks and increase sedimentation (Helmers 1966, Keller and

Swanson 1979). Also, debris jams may create blockages to fish migration and reduce fish spawning areas (Sheridan 1969, Hall and Baker 1975).

Standing crop and arrangement of woody debris in stream channels reflect a balance between input and output processes at one point in time (Keller and Swanson 1979, Swanson et al. 1982b). Live and dead vegetation from adjacent hillslopes and upstream channels provide the source of large woody debris to stream channels. Woody material enters stream channels by bank failure, windthrow, debris avalanche, and large litterfall that results from fire, disease, and decomposition (Keller and Swanson 1979, Swanston 1980, Swanson et al. 1982a). Standing crops of coarse debris may be either rapidly redistributed during debris torrent activity and peak streamflows, or exported slowly over time by physical breakdown, leaching, consumer processing, and decomposition (Swanson and Lienkaemper 1978, Keller and Swanson 1979, Swanson et al. 1982a,b). The ability of streams to mobilize and redistribute wood determines the arrangement of debris pieces. Small streams generally contain large concentrations of debris spaced randomly where fallen while larger streams have smaller loads spaced in "clump-like" accumulations (Keller and Swanson 1979, Swanson et al. 1982b).

Amounts of large wood (greater than 10 cm in diameter) in small and mid-sized Western Oregon streams bordered by old-growth stands may vary from 2.6 to 80.7 kg/m^2 dry weight (Froehlich et al. 1972; Froehlich 1973, 1975; Keller and Swanson 1979; Anderson and Sedell 1979). The relative habitat influence provided by large wood in two streams bordered by old-growth stands in the H. J. Andrews Experimental Forest was measured by Swanson and Lienkaemper (1978). They found that woody debris covered 11 percent of the active channel area in Mack Creek and 25 percent of the area in Devilsclub Creek. Wood-created habitat composed 16 and 21 percent of the area in Mack Creek and Devilsclub Creek, respectively.

Effects of Forest Management on Large Woody Debris

Natural transfer processes such as debris avalanches and debris torrents are often accelerated by timber harvesting, road construction, and other management activities (Swanson and Dyrness 1976, Swanston and Swanson 1976, Swanson and Lienkaemper 1978). Wu et al. (1979) and Ziemer (1981) reported that reductions in soil rooting strength after logging influenced the frequency of slope failures on steep slopes. Large quantities of sediment and organic debris have been introduced into streams during road construction, tree felling and yarding operations, and after slope failures associated with logging (Rothacher 1959; Froehlich 1971, 1973, 1975; Lammel 1972; Brown 1974; Beschta 1978; Swanson and Lienkaemper 1978; Swanson et al. 1984). Excess logging slash in streams may influence stream channel stability by dislodging natural accumulations, which results in increased channel scour and sediment transport during flushouts (Rothacher 1959, Froehlich 1971, Brown 1974, Swanson and Lienkaemper 1978, Bryant 1980).

High levels of introduced woody debris may reduce habitat opportunities for fish by forming large debris jams which limit access for migration (Corthell 1962, Hall and Lantz 1969, Narver 1971, Brown 1974, Chamberlin 1982, Sedell et al. 1982). However, excessive stream cleaning can result in removal of stable pieces of woody debris that form pools (Froehlich 1973, Brown 1974, Swanson et al. 1976, Sedell and Triska 1977, Lestelle 1978, Swanson and Lienkaemper 1978, Beschta 1979, Bilby and Likens 1980, Bilby 1981).

Toews and Moore (1982) compared habitat impacts of different logging prescriptions in Carnation Creek, B. C. They found that the size and stability of woody debris in stream channels changed following clearcut logging adjacent to channels without stream protective measures. Debris pieces were smaller and less stable, and total reach volumes were lower. Debris levels measured in reaches with leave strips, or where directional felling was used next to channels, were not significantly different between pre- and post-logging periods.

Removal of riparian vegetation by clearcut harvesting and wildfire eliminates the source of new woody debris to stream channels until the riparian zone is restocked with suitably sized trees (Swanson et al. 1976, Meehan et al. 1977, Swanson and Lienkaemper 1978). Loss of streamside vegetation leads to reduction of protective cover afforded trout and young salmon. Fish utilize undercut banks stabilized by overhanging vegetation. Rootwads, undercut banks, logs, and debris accumulations are especially important cover sites for juvenile coho and steelhead during the winter (Bustard and Narver 1975, Tschaplinski and Hartman 1983, Grette 1985, Murphy et al. 1985).

Studies of timber harvesting on trout and salmon populations have yielded various results. Hall and Lantz (1969) and Moring and Lantz (1975) reported reductions in cutthroat trout populations in Needle Branch Creek following clearcut logging but increases in coho salmon populations. Narver (1972) found trout populations declined but fish biomass increased in logged sections of two streams on Vancouver Island. Aho (1976) reported that unshaded sections of Mack Creek in the H. J. Andrews Experimental Forest supported higher numbers of trout that had longer mean length, greater biomass, and greater annual production rates than fish observed in shaded sections of the same stream. Bisson and Sedell (1984) found that populations of cutthroat trout, juvenile steelhead trout, and juvenile coho salmon averaged one and a half times greater in logged versus unlogged reaches in several western Washington streams. Murphy and Hall (1981) and Murphy et al. (1981) reported higher primary production, microbial respiration, aquatic invertebrate biomass, and aquatic vertebrate biomass in clearcut (5-17 years after logging) versus old-growth sites in the Cascade Mountains of Oregon. However, they found that densely shaded second-growth (12-35 years after logging) sites had lower levels of productivity and aquatic biomass than either old-growth or clearcut sites. Also, pool areas were smaller in logged sections due to removal of woody debris from channels.

Grette (1985) reported little or no change in steelhead and cutthroat trout numbers among logged and unlogged reaches in 13 streams in the Olympic Peninsula. However, he found 35 percent more coho salmon fry in streams bordered by 23- to 37-year-old stands, and twice the number of coho in streams bordered by 40- to 62-year-old stands, than in streams in old-growth forests.

In summary, increases in fish productivity commonly occur at opened sites after logging, provided channels are not cleaned of debris or otherwise altered by harvest operations. Stream canopy removal permits increased light energy to reach streams which stimulates algal production, a food source for grazer invertebrates. Consequently, invertebrates grow larger and their populations increase, enabling fish populations to take advantage of abundant and visible new food sources. Long-term effects require further study.

AREA OF STUDY

Setting

Big Creek is a fifth-order stream originating in the Coast Range and flowing directly into the Pacific Ocean between Waldport and Yachats. It is located at 124^{o} $03^{'}$ west longitude and 44^{o} $21^{'}$ north latitude in Lincoln County, Oregon (Figure 1). Except for private holdings near the mouth of the stream, the entire Big Creek watershed is administered by the U. S. Forest Service, Siuslaw National Forest. Currently, water is diverted for domestic use from Big Creek and Dicks Fork by the Lincoln County Water and Sanitation District. Total basin relief from Yachats Mountain to mean sea level equals 518 meters (Figure 2). The length from drainage divide to stream mouth is 9250 meters.

Sampling for this study was conducted within the fourth-order sub-basin of Big Creek proper. The drainage area of the sub-basin was 16.2 square kilometers (2.5 square miles). During the summer of 1985, low-flow stream discharge leaving the sub-basin was approximately 0.212 cubic meters per second (7.5 cfs).

Geology

Big Creek drainage is located within the Coast Range physiographic province (Baldwin 1976). The lower portion of the basin is relatively flat and is composed of marine terrace deposits near the coast and Alsea Formation tuffaceous siltstone and sandstone further inland. An eight-meter bedrock falls separates

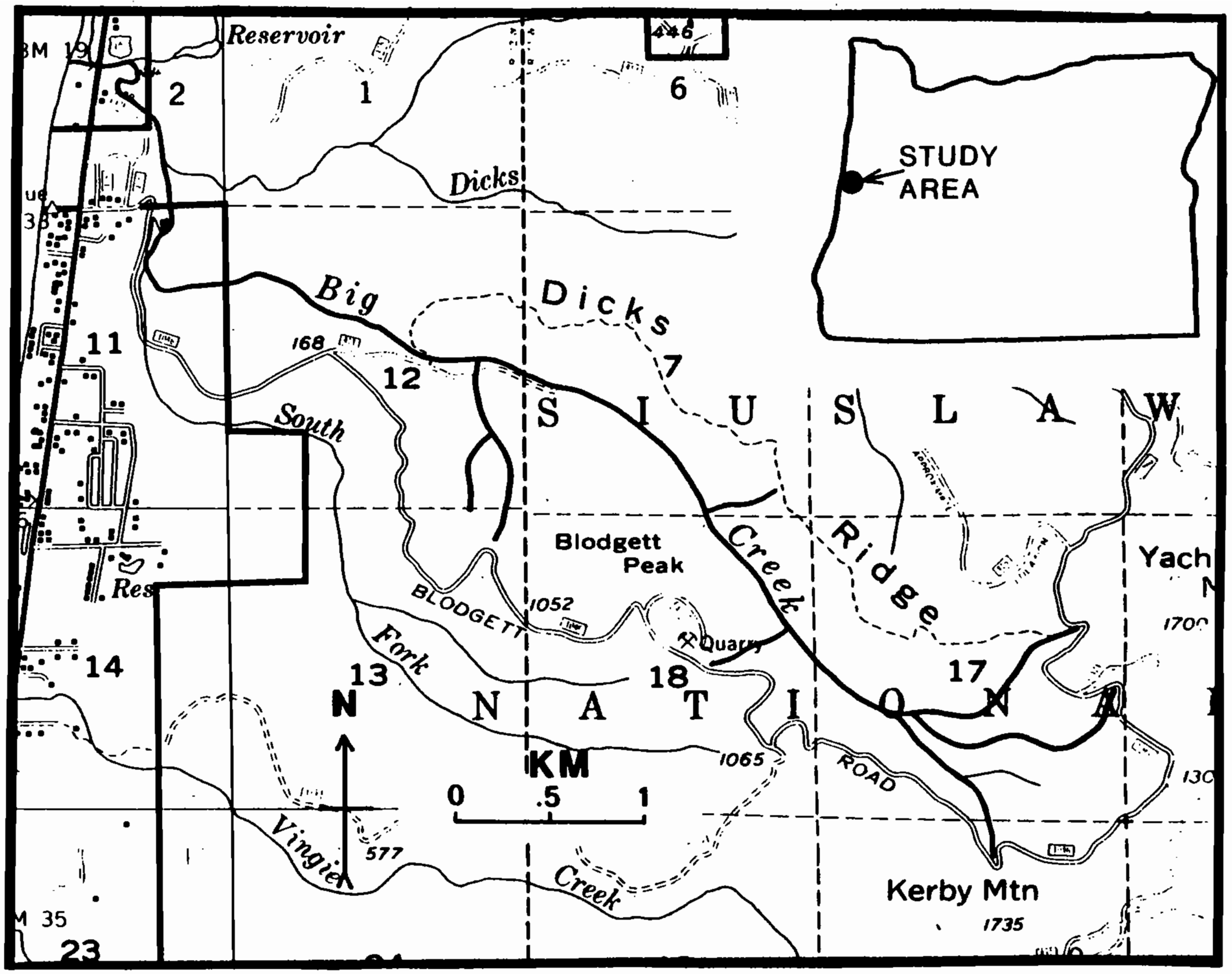

Figure 1. Location of Big Creek drainage in western Oregon.

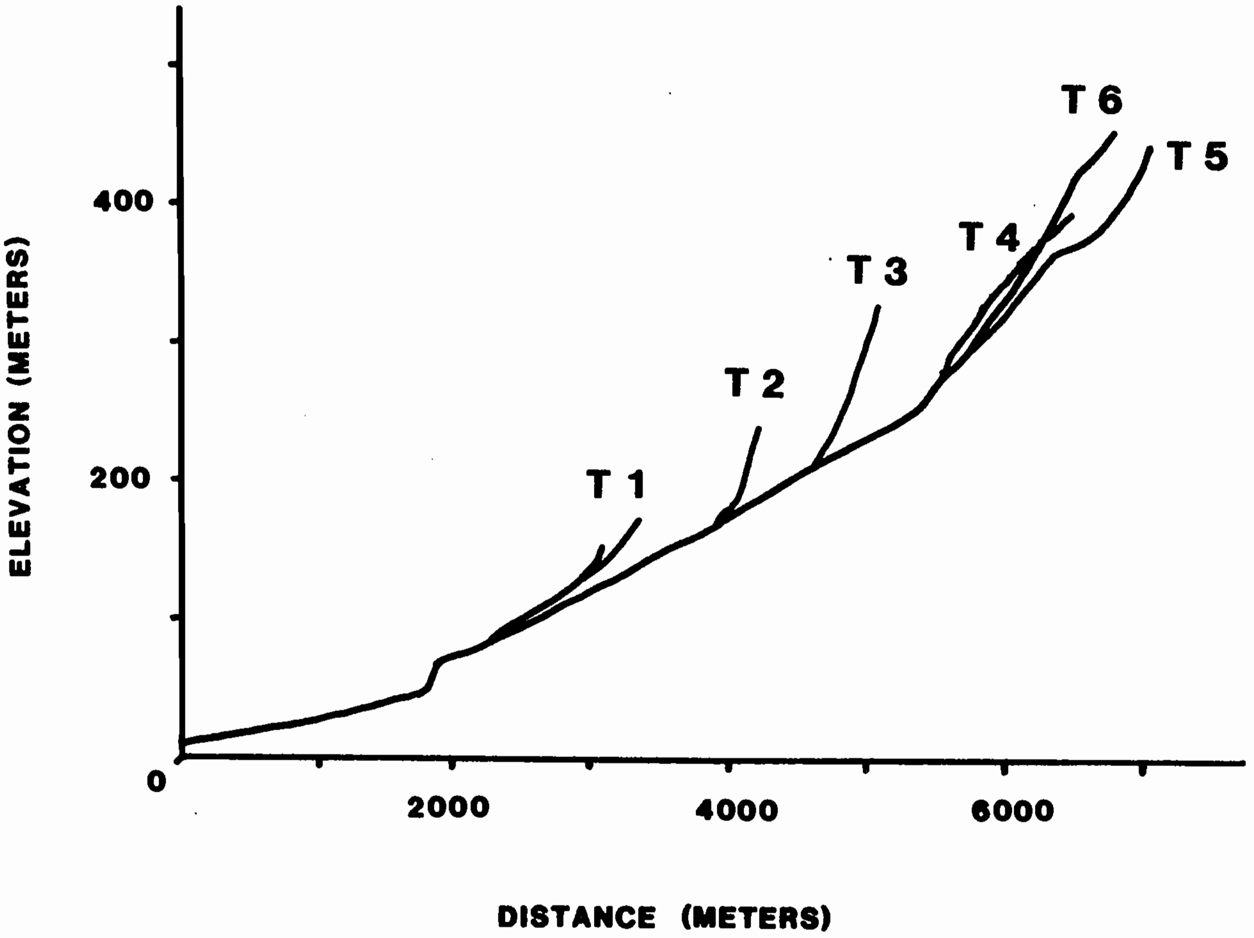

Figure 2. Channel profile of Big Creek.

the lower basin from the upper basin and is a barrier to salmon migration. Yachats Basalt, composed of volcaniclastic rocks and flows, is the principal geologic unit of the upper basin. Nepheline syenite outcrops are common in localized areas, such as on Blodgett Peak. The topography steepens significantly in those areas underlain by basalt in the upper basin.

Climate

The climate of Western Oregon is maritime, characterized by mild temperatures, wet winters, and cool, relatively dry summers. Mean annual precipitation in the Coast Range province ranges from 150 to 250 centimeters (180 cm in Big Creek), mostly in the form of rain. Approximately 80 percent of the annual precipitation occurs between October and March as a result of cyclonic, low-pressure systems that approach from the Pacific Ocean (Franklin and Dyrness 1973). Stormy or cloudy periods may occur for several days duration. Generally, rainfall intensity is moderate. Due to the influence of the Coast Range, precipitation typically is higher on west-facing slopes and at higher elevations. Temperature extremes in the Coast Range are minimal and diurnal fluctuations are narrow (6^{o} to 10^{o} C). The January mean minimum temperature in Big Creek drainage is 2^{o} C. The July mean maximum temperature is 22^{o} C.

Vegetation

Big Creek is located within the Picea sitchensis Zone, which is confined to a long, narrow strip along the Oregon coast (Franklin and Dyrness 1973). The zone is only a few kilometers wide, except where it extends up river valleys. In mountains adjacent to the ocean the zone may extend up to 600 meters in elevation.

Coniferous forest species are the dominant vegetative type in the watershed, although deciduous species dominate the riparian zones of third- and fourth-order channels. The forest composition consists of tree species Picea sitchensis, Tsuga heterophylla, Pseudotsuga menziesii and Thuja plicata. The first two are the most common. Deciduous tree and shrub species present in disturbed and moist sites are Alnus rubra, Sambucus racemosa var. aborescens, Acer circinatum, Rhamnus purshiana, Rubus spectabilis, Vaccinium parvifolium, and Oplopanax horridum. Vegetative succession following fire, logging, and slope failure trends toward development of dense shrub and alder. Often, conifer establishment is suppressed due to competition by alder and salmonberry.

Management History and Site Impacts

Much of the acreage in and around Big Creek drainage was granted to the state as school indemnity land by the federal government. Eventually, all of this property was sold and resold to private parties. By the early 1900's two influential land owners obtained control of over 20,000 acres in the Yachats country, Charles A. Smith and John W. Blodgett.

During World War I, forests in the Pacific Northwest were logged extensively to supply wood for aircraft construction. Sitka spruce had the toughness and lightness that the manufacturers wanted. As the demand for spruce increased, the U. S. Government purchased the Yachats acreage from Blodgett and Smith to "get the spruce out". The United States Spruce Production Corporation was formed and soldiers were brought in to build railroads and log timber. Also, construction was begun on a large sawmill in Toledo. At that time a government cruise showed that 786,102,000 board feet of timber was standing in the Blodgett Tract (Finucane 1980). At the end of World War I the government's logging operations ceased abruptly and the partially completed Alsea Southern railroad was abandoned. Since the Blodgett Tract had not been reached by railroad, no timber was cut.

In 1920, C. D. Johnson purchased the Blodgett Tract, Alsea Southern railroad and Toledo mill from the U. S. Army for two million dollars (Finucane 1980). He formed the Pacific Spruce Corporation and three subsidiary companies: C. D. Johnson Lumber Co., Manary Logging Co., and the Pacific Spruce Northern Railway Co. Logging operations began on the Blodgett Tract in 1922 and continued steadily until the Manarys left in 1928. Camp 1 was built a short distance south of Big Creek. Standard equipment consisted of steam powered "donkeys" mounted on sleds that were pulled into position by cables. A Willamette high-speed swing, a Willamette Humbolt yarder, and a 3-drum Willamette loader with a "double boom" rigged to a spar tree operated at each landing

(Finucane 1980). Logs were yarded downslope to the landings by cables. From the landings logs were transported to a log dump at South Beach with an 85-ton steam locomotive. From there the logs were towed by boat to the Toledo mill. C. D. Johnson Lumber Co. took over the Blodgett operation after Manary left, but logging activities were sporadic between 1928 and 1933. In 1933, rock from Blodgett Peak was selected for repair of the Newport jetty. A railroad spur was constructed to connect the main line with the rock quarry. Logging resumed in the Blodgett Tract in 1935 and continued until the timber stocks became depleted in the summer of 1936.

Most of the logged Blodgett Tract burned in a large fire in September and October of 1936. The fire burned long and hot due to dry conditions and abundant logging slash. A few uncut trees in the upper portion of the Big Creek watershed were all that remained standing. The post-harvesting fire was considered the major mechanism that established the time frame from which recovery and regrowth began. Scars from the rock quarry, railroad tracks, yarding corridors, and landings were observed from aerial photographs taken in July 1939 (Figure 3). In July 1941, the Blodgett Tract officially became part of the Siuslaw National Forest as a Weeks Law purchase. Brush control, road building, and tree planting projects were begun with help from the Civilian Conservation Corps. The herbicide 2-4D was sprayed in limited amounts on brush and alder by the U. S. Forest Service in 1948. A water diversion was installed in the Big Creek mainstem by the

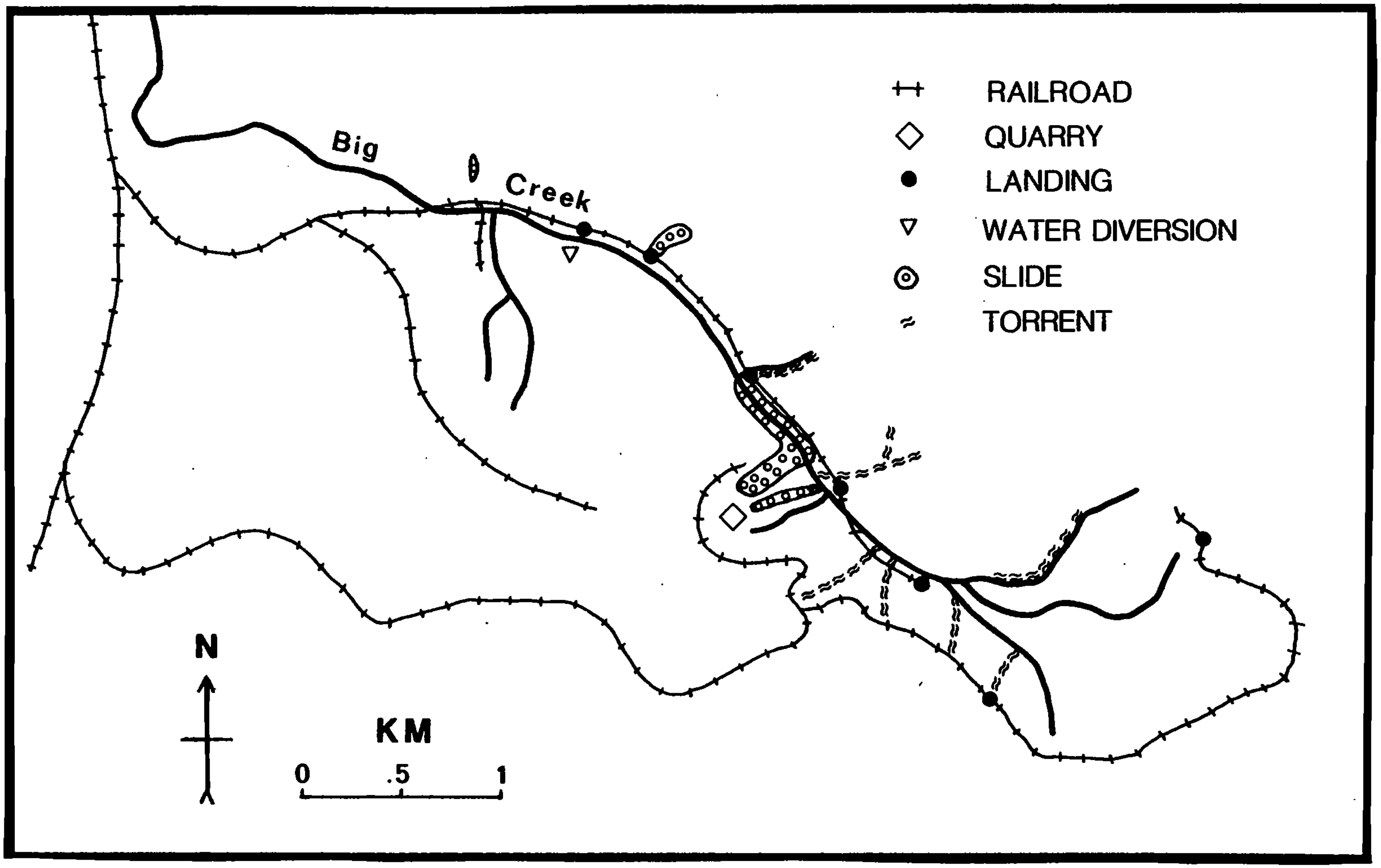

Figure 3. Site impacts in Big Creek.

Lincoln County Water and Sanitation District in 1952. Aerial photographs taken by the U. S. Forest Service in October 1952 showed a large slope failure below the quarry spoils pile and debris torrent activity in a major tributary channel (Figure 3). Photographs dated July 1958 showed that the large failure below the quarry had deposited rock and debris in the main channel for approximately 400 meters downstream. The deposit was partially vegetated and water was impounded behind it. Four other mass failures occurred between 1952 and 1958. One slide occurred above a landing in the main channel. Photographs taken in April 1964 showed new activity in the quarry, scouring on the large slide, three new torrent paths, and windthrow in the upper drainage. Photographs taken in July 1969 showed a new failure of the large slide with subsequent disturbance of the main channel for nearly 1000 meters downstream, and a new smaller slide adjacent to the larger one.

Recent timber management activities in Big Creek have included the harvest of four units adjacent to Forest Road 1046 in the last 20 years. One unit was logged a year after I completed my field measurements. No stream cleaning operations were reported or observed within the Big Creek watershed except for that around the water diversion.

RESEARCH PROCEDURES

Study Site Selection

The objectives of the study were met by an intensive field evaluation of one drainage impacted by management approximately 50 years after the disturbance. The drainage selection criteria included:

1. Presence of an anadromous salmonid population.
2. Location of the stream system within even-aged second-growth vegetation.
3. Stand age old enough to contribute significant volumes of post-disturbance woody debris to adjacent stream channels (>30 years).
4. Stream size large enough to rework large woody debris delivered to channels (fourth-order).
5. Absence of excessive stream cleaning operations.

Big Creek drainage was selected as the study site because it offered the possibility of studying contributions of woody debris from a reset system in the Coast Range. Aerial photographs (scale 1:12,000) were used to identify stand irregularities, large-scale channel adjustments, and slope failures within the Big Creek watershed. A pre-sampling cruise was conducted to view the channels on the ground and to determine the degree of variation of woody debris loading in the channels. Due to excessive channel disturbance and human development in the Reynolds Creek, Dicks Fork, and South Fork sub-drainages, only Big Creek proper was sampled.

Sampling Design

Two sampling designs for Big Creek proper were considered. In the first design, a network of stream segments would be intensively sampled within the watershed. Design of the segment sampling network would provide 10 to 20 percent coverage of the total stream length, which included tributaries. Tributaries within the watershed would be stratified by stream order and representative samples from each order would be selected. A systematic sampling scheme would be used to select stream segment lengths and spacings. Widths of sample segments would be fixed. Woody debris variables, channel characteristics, and riparian stand parameters would be measured within each segment.

In the second design, the entire mainstem channel and six representative tributaries would be sampled for large woody debris. Five to ten times the channel area would be sampled at a lower intensity, which could result in a more accurate measure of debris variation. Sampling would begin above the Alsea Veneer mill and work upstream. Width of the sample strip would be fixed at approximately 10 meters, five meters on either side of the mid-channel point. Tributaries contributing the largest flows to the mainstem would be sampled using the same techniques. Channel characteristics and riparian stand parameters would be measured at station intervals throughout the entire drainage. This second sampling design was chosen for the study (Figure 4).

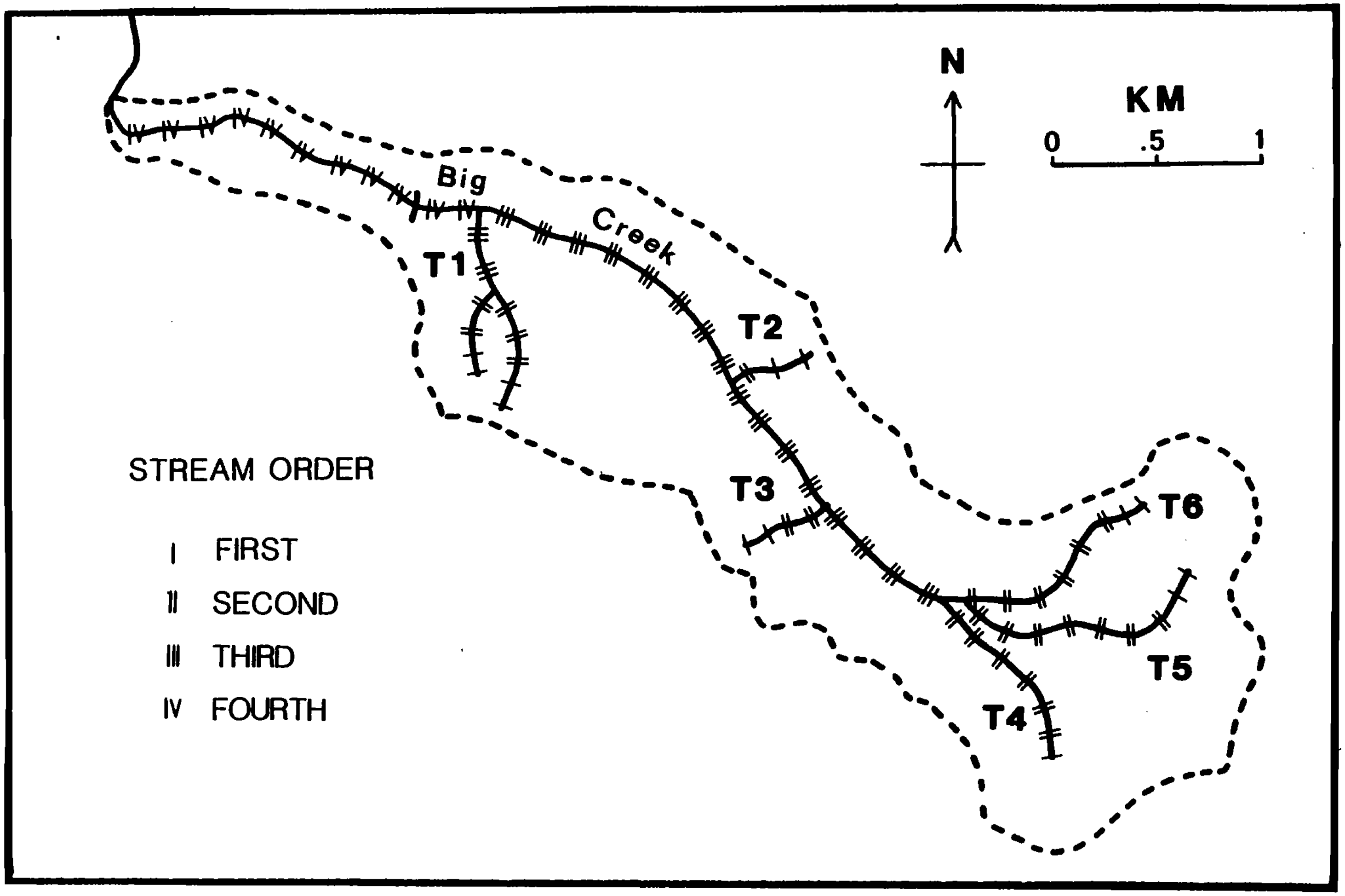

Figure 4. Sampling design in Big Creek.

Survey Methods

Sampling was begun in the Big Creek mainstem at station BC 0+00, located about 60 meters below the junction of Big Creek and South Fork. Stations were located at 50-meter intervals measured along the stream thalweg. Each station was marked with red ribbon above the channel. A metal tag with the station number was attached to the nearest tree. Six tributary channels were measured and marked in similar fashion. Photographs were taken at each station for documentation.

Channel characteristics were measured at each station. Measurements taken included: flow width, average flow depth, bankfull width, valley floor width, channel gradient, left and right sideslope, and substrate size. Width, depth, and bankfull width were measured with a meter stick. A clinometer was used to measure channel gradient and sideslope. Valley floor width and substrate size were estimated. Other slope and channel features, such as: tributary junctions, vertical banks, side terraces, multiple channels, flow constrictions, entrenched flow, bank cutting, debris avalanches, and debris torrents, were noted as either "present" or "not present".

Riparian stand parameters were measured at every other station (i.e. 100-meter intervals). Canopy densities were measured at mid-channel with a spherical densiometer mounted on an adjustable tripod. The method used was adopted from Strickler (1959). The method involved counting the number of covered points in a wedge-shaped area of the densiometer grid for each compass direction. Riparian stand densities were determined using the quarter method as described by Cottam and Curtis (1956). The authors reported that the quarter method produced the least variable distance results, provided more data on tree species per sampling point, and had the least subjective bias when compared to the nearest neighbor, random pairs, closest individual, and quadrat methods. By using the quarter method, each station was divided into four quarters with one dividing line down the thalweg and the other perpendicular to the channel. Distances were measured from the center point to the nearest conifer and hardwood trees in each quarter. The diameter at breast height (DBH), species, and distance of each tree were recorded.

A large woody debris inventory was conducted throughout all station segments. All visible pieces (greater than 10 cm diameter and 1 m length) within the 10 meter strip width were examined and measured. Data collected on debris included: piece length, mean diameter, type (pre- or post-disturbance), decay condition, delivery mechanism, clump index, species, degree of burial, location, horizontal and vertical position, and habitat influence (Table 1). Additional debris characteristics, such as: cut end, beaver, breakage, collects sticks, nurse tree sprouts, stump or rootwad, rootwad attached, spans channel, and snag, were noted as either "present" or "not present". Wood decay condition was used to index piece age and type. Wood delivery to the channels was evaluated to determine wood origin and transport dynamics. Debris accumulations were inventoried to determine factors that

Table 1. Descriptions of debris variable classes.

Variable	Class	Description
Debris Type	Pre-disturb.	Woody debris older than 49 years of age
	Post-disturb.	Woody debris younger than 49 years of age
Decay Condition	Live	Live tree with rootwad exposed, leaning
	Fresh	Bark intact, twigs and branches present
	No Twigs	Bark loose or intact, twigs absent, branches present
	No Branches	Bark loose or absent, branches absent
	Soft	Surface soft and rotted, center solid
	Rotten	Entire log rotted and falling apart
Delivery Mechanism	Windthrow	Action of the wind
	Bankcutting	Removal of root support by bank erosion
	Flotation	Piece flotation and transport by streamflow
	Logging	Slash from logging operations
	Slide	Slope failure ("Debris avalanche")
	Torrent	Channel sluice event ("Debris torrent")
Clump Index	Single	Single piece
	Loose Assoc.	Two to 3 touching pieces
	1-tier Jam	Single-layer jam with more than 3 pieces
	2-tier Jam	Multi-layer jam with more than 3 pieces
	Debris Dam	Jam that impounds or influences flow
Location	In	Present in the channels
	Bank,Bar	Present on channel banks and bars
	Above	Suspended above the channels
	Terrace	Present on side terraces
Habitat Influence	Pool	Forms a pool
	Gravel	Impounds gravels
	Cover	Provides stream cover
	Fall Drop	Creates a fall drop ("Log step")

influenced piece associations. Location and angular position were recorded to identify habitat potential provided by debris pieces. Woody debris influence on stream habitat was estimated by inventorying features created by debris in the channels.

Data Handling and Analysis

Data from field notebooks were entered into computer spreadsheet files. Personal computers were used to organize data files and summarize file variables. Software used for data analyses and text preparation included: SAS, SYSTAT, SYMPHONY, and WORDSTAR.

Three main data files were created; one for channel characteristics, another for riparian stand parameters, and the third for large woody debris. In the riparian stand file, mean distance and diameter values from each transect were entered into a series of equations to determine conifer stand density, hardwood stand density, total basal area, basal area per unit area, relative density, and relative dominance (Appendix A). In the woody debris file, piece volume, volume per unit area, and mass per unit area were calculated.

Data in all files were subdivided by the grouping variable, stream order. Woody debris values were further subdivided into two debris types, pre-disturbance and post-disturbance (Table 1). Summary statistics (minimum, maximum, mean, standard deviation, standard error) were generated for each variable within each subgroup. Tables were created to display variable averages.

Due to skewness of the woody debris populations, geometric means were used for piece size comparisons. The geometric mean is an often used measure of central tendency in a non-normal distribution with a positive skew. Single factor analyses of variance were performed to determine differences in volume per unit area and volume per piece between two debris types and among four stream orders. Student-Newman-Keuls (S-N-K) multiple range tests for unequal sample sizes were used for within group comparisons (Zar 1974). Log transformations of the data were used.

A fourth data file was created by combining selected variables from the other three files. Debris volumes were summed every 100 meters. Riparian stand values from each endpoint were averaged. Channel values from the middle and endpoints were averaged. Scatter plots and Pearson correlation matrices were constructed to compare variable association. Probability plots were produced to examine variable normality. Most variables were log transformed. Regression equations were generated by using SYSTAT's step-wise procedure (alpha to enter=0.05, alpha to remove=0.05) for the entire drainage and first- through fourth-order segments. The objective was to determine whether a linear relationship existed between woody debris volume in the channels and the neighboring stand and channel characteristics.

RESULTS

Channel Morphology

Channel characteristics in the mainstem and tributaries of Big Creek are presented in Table 2. Mean flow width, depth, bankfull width, and valley floor width were greatest in fourth-order channels and least in first-order channels. Mean width-depth ratio and channel gradient were greatest in first-order channels and least in fourth-order channels. Mean sideslope was greatest in second-order channels, followed by first-, third-, and fourth-order channels. Channel substrates in fourth-order channels were predominantly sand and gravels. Cobble and boulder substrates dominated first-, second-, and third-order channels. Fine-grained soil and organic matter were present between boulders in some headwater channels. Multiple channels were common in third- and fourth-order channels. Second- and third-order channels were highly dissected with many tributary junctions.

Riparian Stand

Riparian stand characteristics in the Big Creek drainage varied considerably among stream orders (Table 3, Figure 5). Mean canopy density, conifer stem density, and conifer basal area per hectare were greatest in first-order channels and least in fourth-order channels. Mean hardwood stem density and hardwood basal area per hectare were greater in third- and fourth-order channels than in first- and second-order channels. The mean stem

Table 2. Channel morphology of Big Creek.

Stream Order	1ST	2ND	3RD	4TH	Mean	Total
X-sections(n)	16	101	77	46		240
Width(m)	0.6(.1)[a]	1.1(.1)	2.4(.1)	3.2(.2)	1.9(.1)	
Depth(m)	.02(.00)	.04(.00)	.10(.01)	.18(.02)	.08(.01)	
W/D Ratio	45(9)	35(2)	34(2)	23(2)	33(2)	
Bankfull(m)	2.0(.2)	2.8(.1)	5.6(.2)	7.3(.2)	4.5(.2)	
Valley Floor(m)	5(1)	7(1)	23(1)	39(4)	18(1)	
Gradient(%)	22.6(2.3)	12.1(.5)	5.8(.2)	2.8(.4)	9.0(.4)	
L Sideslope(%)	74(3)	80(3)	68(3)	38(4)	67(2)	
R Sideslope(%)	70(4)	75(2)	72(3)	41(4)	67(2)	
Substrate	FCB[b]	SGCB	SCB	SG		
L Vertical Bank	1	14	33	30		78
R Vertical Bank	1	12	30	33		76
Trib. Junctions		36	44	9		89
Terrace		2	8	3		13
Constriction		1	3	1		5
Multiple Channels	2	5	8	8		23
Entrenched	1	3				4
Bank Cutting			5	1		6
Debris Avalanche	1	5	8			14
Debris Torrent	2	5	2			9

[a] Standard errors of the mean.

[b] Substrate symbols: F=fine
S=sand
G=gravel
C=cobble
B=boulder.

Table 3. Riparian stand characteristics in Big Creek.

Stream Order	1ST	2ND	3RD	4TH	Mean	Total
Transects(n)	8	45	38	24		115
Canopy Density(%)	79(2)[a]	76(1)	74(1)	69(2)	74(1)	
Conifer Species						
Density(#/ha)	188(82)	165(25)	78(13)	24(3)	108(13)	
DBH(m)	.43(.04)	.40(.02)	.45(.02)	.63(.03)	.47(.02)	
BasalA(m^2/ha)	33.4(15)	25.9(5)	14.7(3)	10.4(2)	19.5(3)	
Spec Dom(#)						
Spruce	13	44	85	69		211
Hemlock	13	112	56	21		202
D-fir	6	14	6	5		31
Cedar		10	5	1		16
Hardwood Species						
Density(#/ha)	59(26)	84(18)	189(24)	179(31)	137(13)	
DBH(m)	.39(.02)	.37(.01)	.35(.01)	.35(.02)	.36(.01)	
BasalA(m^2/ha)	7.7(3)	7.7(1)	17.9(2)	17.6(3)	13.1(1)	
Spec Dom(#)						
Alder	30	178	151	91		450
Elder	1		1	4		6
Buckthorn	1	1				2
Maple		1		1		2

[a] Standard errors of the mean.

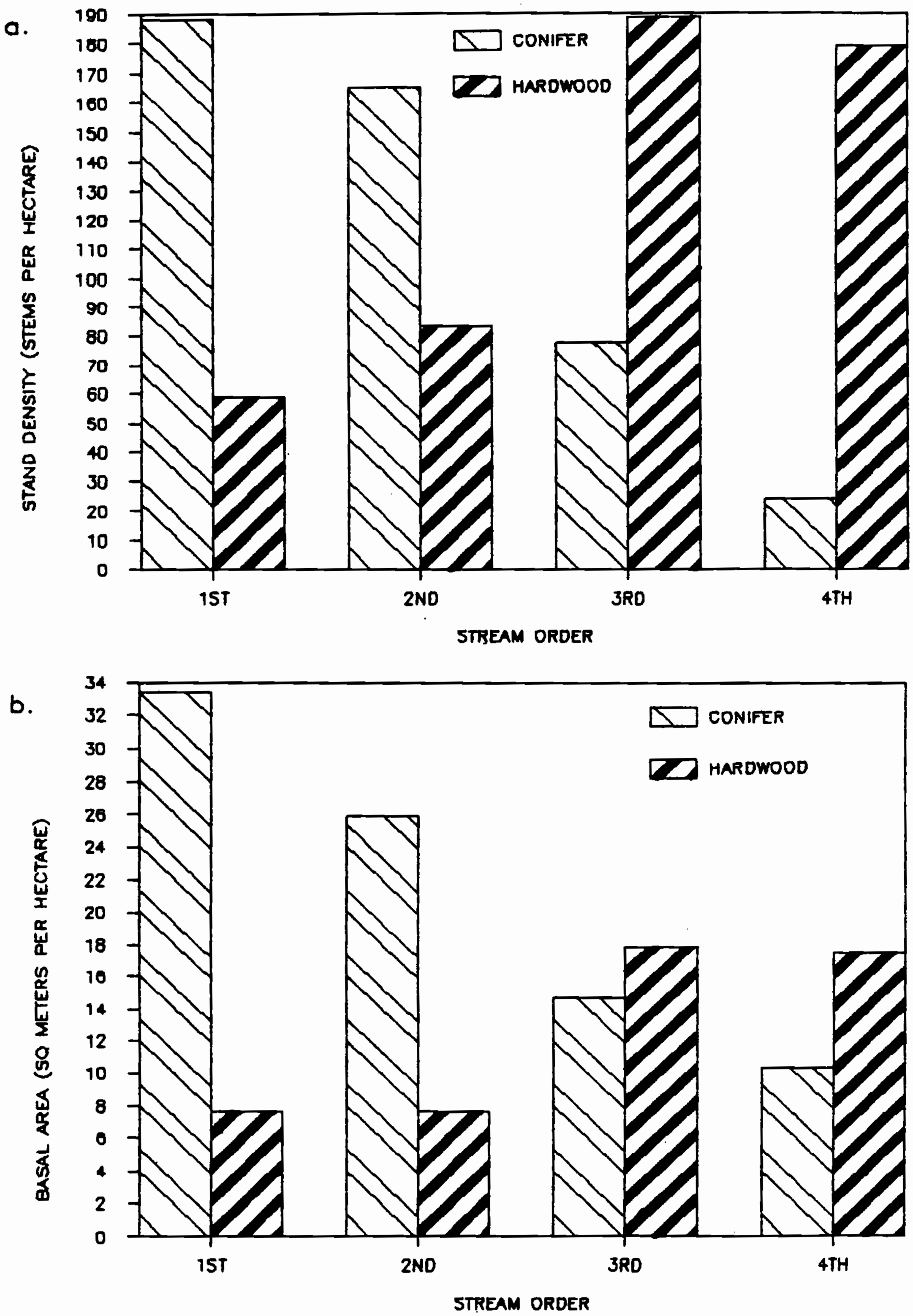

Figure 5. Riparian stand density and basal area by stand species and stream order.

diameter (DBH) of conifers was 0.47 meters and hardwoods 0.36 meters. Relative densities of conifer species were 46 percent for *Picea sitchensis*, 44 percent for *Tsuga heterophylla*, seven percent for *Pseudotsuga menziesii*, and three percent for *Thuja plicata*. The relative density of *Picea sitchensis* was twice that of *Tsuga heterophylla* in third- and fourth-order channels, and the reverse was observed in first- and second-order channels. Relative densities of hardwood species were 98 percent for *Alnus rubra*, one percent for *Sambucus racemosa* var. *aborescens*, 0.5 percent for *Acer circinatum*, and 0.5 percent for *Rhamnus purshiana*. Relative dominance values paralleled that for relative density.

Large Woody Debris

Quantities. Approximately 5200 pieces of large woody debris were measured in 11.5 kilometers of channel in the Big Creek drainage. Total number of pieces per 100 meters and total volumes per square meter varied considerably among stream orders (Table 4, Figure 6a and b). Second-order channels had the heaviest debris loading (0.0422 m^3/m^2), followed by first- (0.0308 m^3/m^2), third- (0.0242 m^3/m^2), and fourth-order (0.0201 m^3/m^2) channels. Piece numbers ranged from 54.8 to 35.6 per 100 meters of channel, with a basin average of 45.1 pieces per 100 meters. Pre-disturbance debris pieces constituted 63 to 70 percent of the total number of pieces and 86 to 89 percent of the total volume within all stream orders. Debris volumes per stream reach differed significantly between debris types and among stream orders (Table 5a and b).

Table 4. Large woody debris volumes in Big Creek.

Stream Order	1ST	2ND	3RD	4TH	Mean	Total
Segment Length(m)	780	4725	3685	2280		11470
Number of Pieces						
Pre-conifer	200	1622	941	541		3304
Post-conifer	48	475	83	7		613
Post-hardwood	38	491	468	264		1261
Total	286	2588	1492	812		5178
Pieces(#)/100 m						
Pre-conifer	25.6	34.3	25.5	23.7	28.8	
Post-conifer	6.2	10.0	2.3	0.3	5.3	
Post-hardwood	4.9	10.4	12.7	11.6	11.0	
Total	36.7	54.8	40.5	35.6	45.1	
Volume(m^3)						
Pre-conifer	213.2	1704.8	767.2	398.1		3083.2
Post-conifer	19.6	181.4	34.1	3.0		238.1
Post-hardwood	7.6	106.0	89.9	56.4		260.0
Total	240.4	1992.2	891.2	457.4		3581.3
Volume/Area(m^3/m^2)						
Pre-conifer	0.0273	0.0361	0.0208	0.0175	0.0269	
Post-conifer	0.0025	0.0038	0.0009	0.0001	0.0020	
Post-hardwood	0.0010	0.0022	0.0024	0.0025	0.0022	
Total	0.0308	0.0422	0.0242	0.0201	0.0312	
Mass/Area(kg/m^2)[a]						
Pre-conifer	15.8	20.9	12.1	10.2	15.6	
Post-conifer	1.4	2.2	0.5	0.1	1.2	
Post-hardwood	0.6	1.3	1.4	1.4	1.3	
Total	17.9	24.5	14.0	11.7	18.1	

[a] Specific weight=0.58 g/cm3.

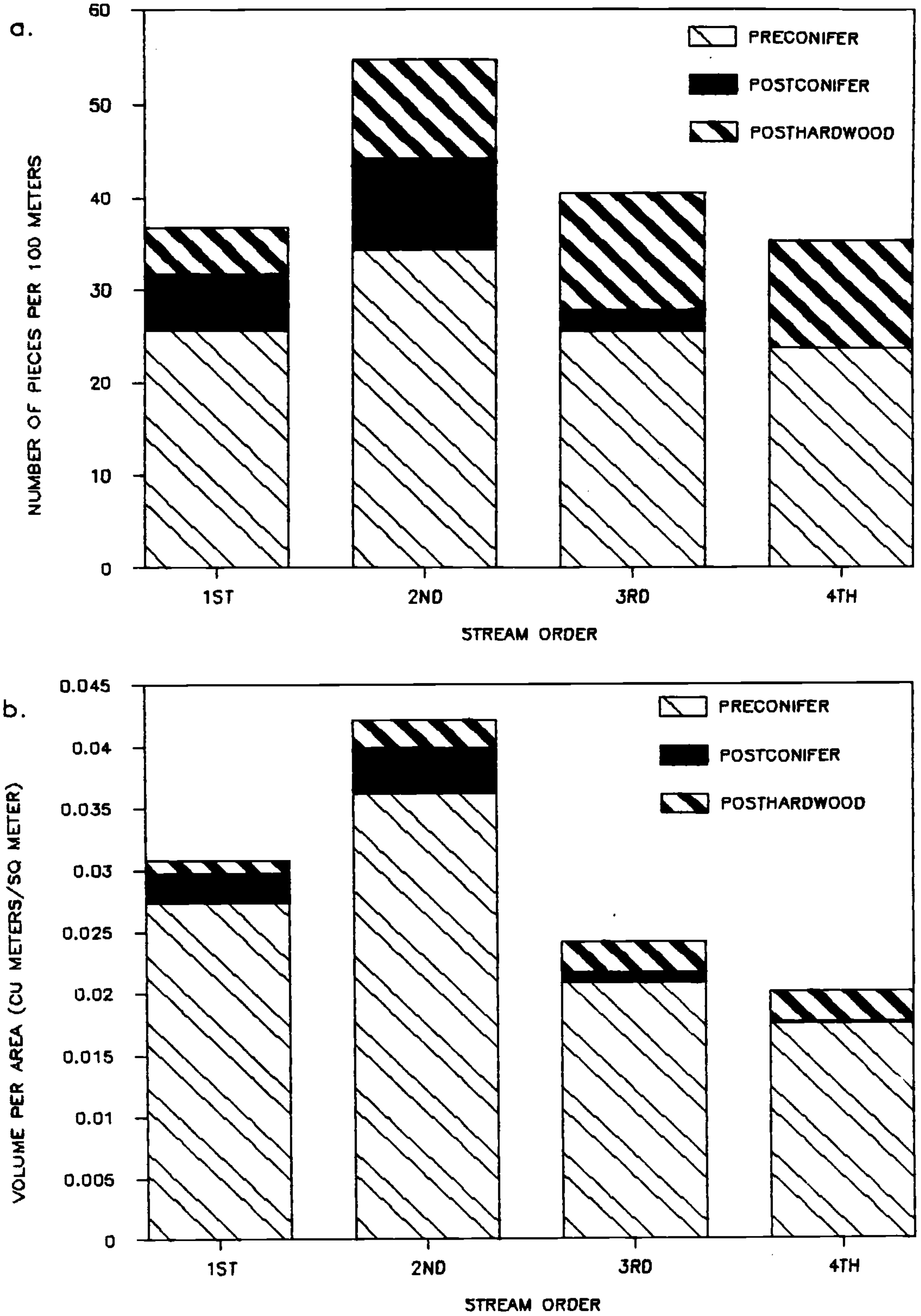

Figure 6. Woody debris piece number and volume per unit area by debris type and stream order.

Table 5. Analysis of variance for volume per 500 m^2 by debris type and stream order.

a. Summary of significant differences between debris types within stream orders using two-sample F tests ($p<0.05$).

Debris Type	Pre	Post	Postcon	Posthard
1st Order	a[1]	b	c	c
2nd Order	a	b	c	d
3rd Order	a	b	c	d
4th Order	a	b	c	d

b. Summary of significant differences between stream orders within debris types using S-N-K multiple range tests ($p<0.05$).

Stream Order	1st	2nd	3rd	4th
Pre-disturbance	ab	a	bc	c
Post-disturbance	ab	a	b	b
Post conifer	a	a	b	c
Post hardwood	a	a	a	a

[1] Categories with same letter across are not significantly different.

Also, species composition within the post-disturbance debris type varied significantly among stream orders. Third- and fourth-order channels contained predominantly hardwood post-disturbance debris, whereas first- and second-order channels contained more conifer post-disturbance debris.

Sizes. Debris piece size varied by debris type and among stream orders (Table 6). The geometric mean length of post-disturbance pieces was 50 percent greater than pre-disturbance pieces. Post-disturbance debris had a wider range of piece lengths than pre-disturbance debris (Figure 7a). In contrast, the geometric mean diameter of pre-disturbance pieces was two times greater than post-disturbance pieces. Post-disturbance debris had a very narrow range of piece diameters compared to that measured for pre-disturbance debris (Figure 7b). Pre-disturbance geometric mean piece lengths and diameters, and post-disturbance piece lengths, were greater in first- and second-order channels than in third- and fourth-order channels. Post-disturbance geometric mean diameters did not vary among stream orders.

Differences in piece volumes between debris types and among stream orders paralleled that for piece diameters (Figure 8a and b). The geometric mean volume of pre-disturbance debris was significantly greater than post-disturbance debris (Table 7a). Pre- and post-disturbance geometric mean piece volumes were significantly greater in first- and second-order channels than in third- and fourth-order channels (Table 7b).

Table 6. Large woody debris piece sizes in Big Creek.

Stream Order	1ST	2ND	3RD	4TH	Mean
		(Arithmetic Means)			
Piece Length(m)					
Pre	4.2(.2)[a]	4.2(.1)	3.3(.1)	3.4(.1)	3.8(.0)
Post	6.3(.4)	6.3(.1)	4.9(.1)	4.5(.2)	5.7(.1)
Piece Diameter(m)					
Pre	.48(.02)	.46(.01)	.46(.01)	.40(.01)	.45(.00)
Post	.21(.01)	.20(.00)	.21(.00)	.21(.01)	.21(.00)
Piece Volume(m^3)					
Pre	1.07(.11)	1.05(.05)	.82(.04)	.74(.05)	.93(.03)
Post	.32(.05)	.30(.01)	.23(.01)	.22(.02)	.27(.01)
		(Geometric Means)			
Piece Length(m)					
Pre	3.6	3.5	2.8	2.8	3.2
Post	5.1	5.3	4.1	3.8	4.7
Piece Diameter(m)					
Pre	0.43	0.42	0.40	0.34	0.40
Post	0.20	0.19	0.19	0.19	0.19
Piece Volume(m^3)					
Pre	0.53	0.47	0.36	0.26	0.41
Post	0.16	0.15	0.12	0.10	0.13

[a] Standard errors of the mean.

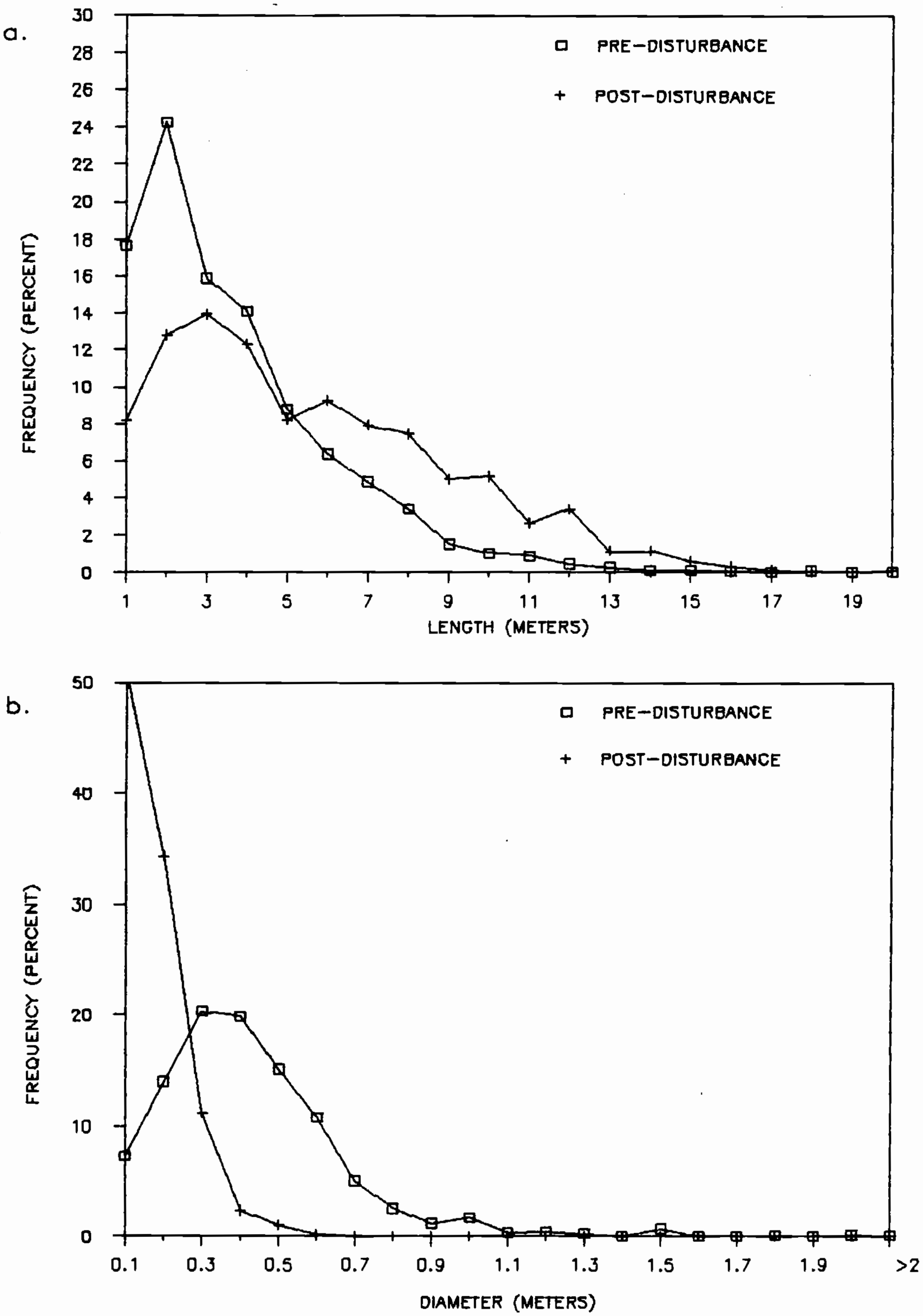

Figure 7. Woody debris piece length and diameter frequency by debris type.

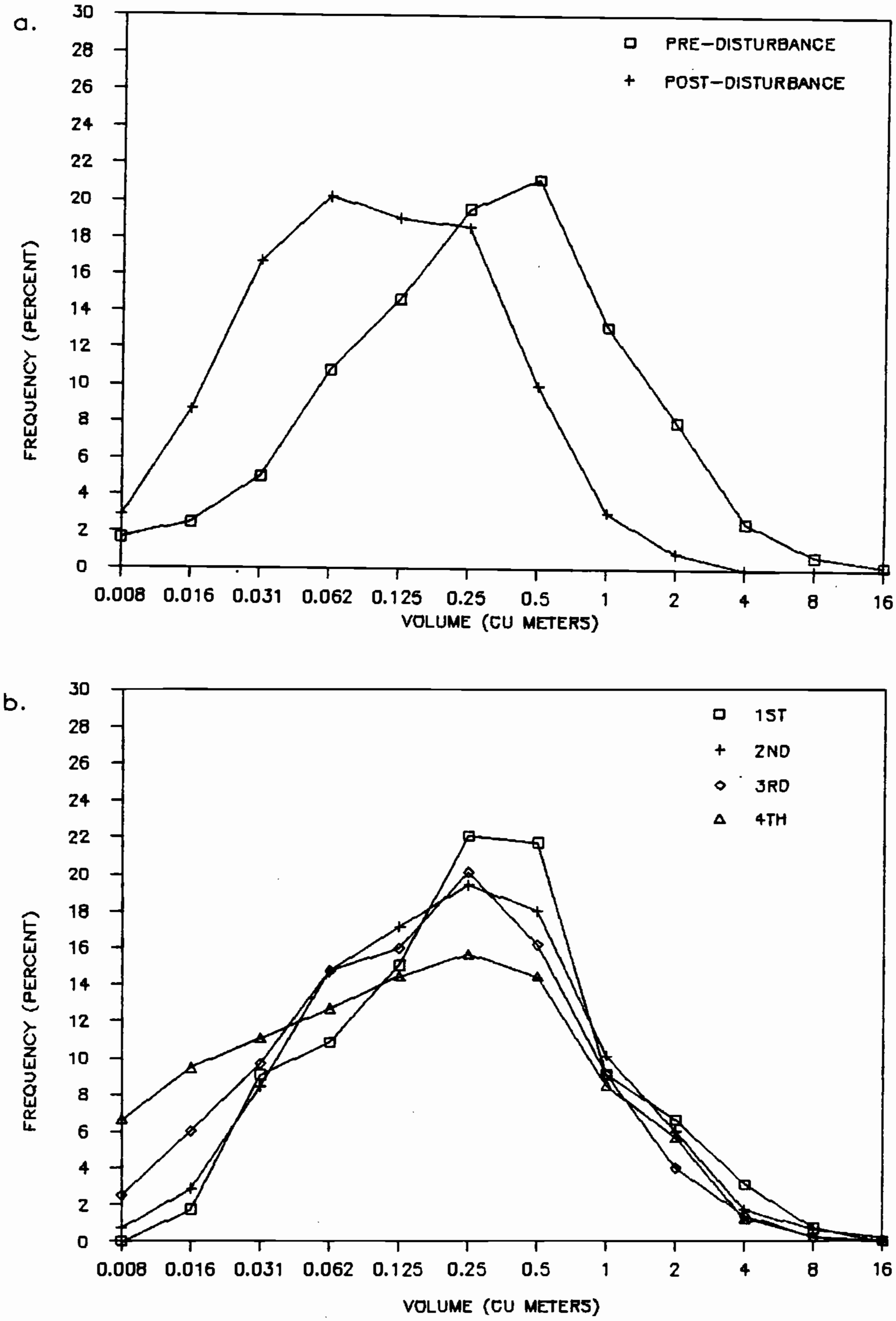

Figure 8. Woody debris piece volume frequency by debris type and stream order.

Table 7. Analysis of variance for volume per piece by debris type and stream order.

a. Summary of significant differences between debris types within stream orders using two-sample F tests ($p<0.05$).

Debris Type	Pre-disturbance	Post-disturbance
1st Order	a[1]	b
2nd Order	a	b
3rd Order	a	b
4th Order	a	b

b. Summary of significant differences between stream orders within debris types using S-N-K multiple range tests ($p<0.05$).

Stream Order	1st	2nd	3rd	4th
Pre-disturbance	a	a	b	c
Post-disturbance	ab	a	bc	c

[1] Categories with same letter across are not significantly different.

Delivery. Flotation, windthrow, and logging were the most common delivery mechanisms for pre-disturbance woody debris (Table 8). Bank cutting was the most common delivery mechanism for post-disturbance woody debris. Flotation was most common in third- and fourth-order channels, and windthrow was most common in first- and second-order channels. Logging and mass movements were important delivery mechanisms in first- through third-order channels, especially below the rock quarry in the main channel, adjacent to landings, and in channels that were impacted by debris torrents.

Arrangement. Fifty-two percent of the pre-disturbance debris pieces and 60 percent of all pieces in third- and fourth-order channels were located in the channels or on channel banks (Table 8, Figure 9a). Sixty-eight percent of the post-disturbance debris pieces and 67 percent of all pieces in first- and second-order channels were located suspended above the channels or on side terraces. The mean horizontal position of both pre- and post-disturbance pieces was 119^{o} with the small end downstream (Figure 9b). The mean vertical position of pre-disturbance pieces was 98^{o} with the small end toward the channel. The mean vertical position of post-disturbance pieces was 83^{o} with the small end away from the channel.

Fifty-two percent of the total debris pieces were found in debris accumulations of more than three pieces (Table 8). The number of debris accumulations per 100 meters of channel distance did not vary significantly among stream orders, although the

Table 8. Large woody debris characteristics in Big Creek.

Stream Order	1ST		2ND		3RD		4TH		Total	
Debris Type	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Species (#)										
Conifer	200	48	1622	475	941	83	541	7	3304	613
Hardwood		38		491		468		264		1261
Decay Class (#)										
Live		14		66		69		32		181
Fresh		19		352		186		81		638
No Twigs		36		335		183		79		633
No Branches	36	15	512	203	389	110	222	70	1159	398
Soft	128	2	926	10	512	3	285	9	1851	24
Rotten	36		184		40		34		294	
Delivery Mechanism (#)										
Windthrow	92	35	918	443	301	122	171	62	1482	662
Bank Cutting	7	42	93	401	40	274	19	108	159	825
Flotation	20	1	342	83	433	150	336	101	1131	335
Logging	19	1	191	26	82	1	15		307	28
Slide	15	7	22	13	60	4			97	24
Torrent	47		56		25				128	
Clump Index (#)										
Single	59	21	395	185	245	159	157	77	856	442
Loose Association	72	36	365	225	196	122	113	41	746	424
Single-tier Jam	47	11	204	155	78	43	66	25	395	234
Multi-tier Jam	7	16	224	251	50	52	37	21	318	340
Debris Dam	15	2	434	150	372	175	168	107	989	434
Location (#)										
In	34	9	273	46	310	80	264	78	881	213
Bank and Bar	44	20	352	169	257	131	194	74	847	394
Above	65	36	616	417	208	207	48	90	937	750
Terrace	57	21	381	334	166	133	35	29	639	517
Horizontal Position (%)	130(5)[a]	127(9)	124(1)	123(2)	122(2)	125(3)	94(2)	94(3)	119(1)	119(2)
Vertical Position (%)	101(1)	73(4)	101(0)	86(1)	95(1)	80(1)	95(1)	84(2)	98(0)	83(1)
Habitat Influence (#)										
Pool	4		196	30	169	39	183	66	552	135
Gravel	17	2	282	61	273	61	246	61	818	185
Cover	1		38	11	69	32	65	36	173	79
Fall Drop			24	1	28	8	12	3	64	12
Other Characteristics (#)										
Beaver					6	5	1	16	7	21
Breakage	35	14	355	176	204	110	85	20	679	320
Buried										
Full Length Not Exposed	23	1	153	19	156	11	105	8	437	39
Full Length Exposed	93	39	717	372	413	195	151	40	1374	646
Collects Sticks			21	10	84	42	16	14	121	66
Cut End	17	1	143	23	48	2	7	2	215	28
Nurse Tree Sprouts	6		51	1	34	1	16		107	2
Rootwad Attached	8	38	80	486	28	224	10	44	126	792
Snag		5	2	13		8		11	2	37
Spans Channel	36	40	266	393	95	135	76	50	473	618
Stump/Rootwad	6	2	31	4	24	4	12		73	10

[a] Standard errors of the mean.

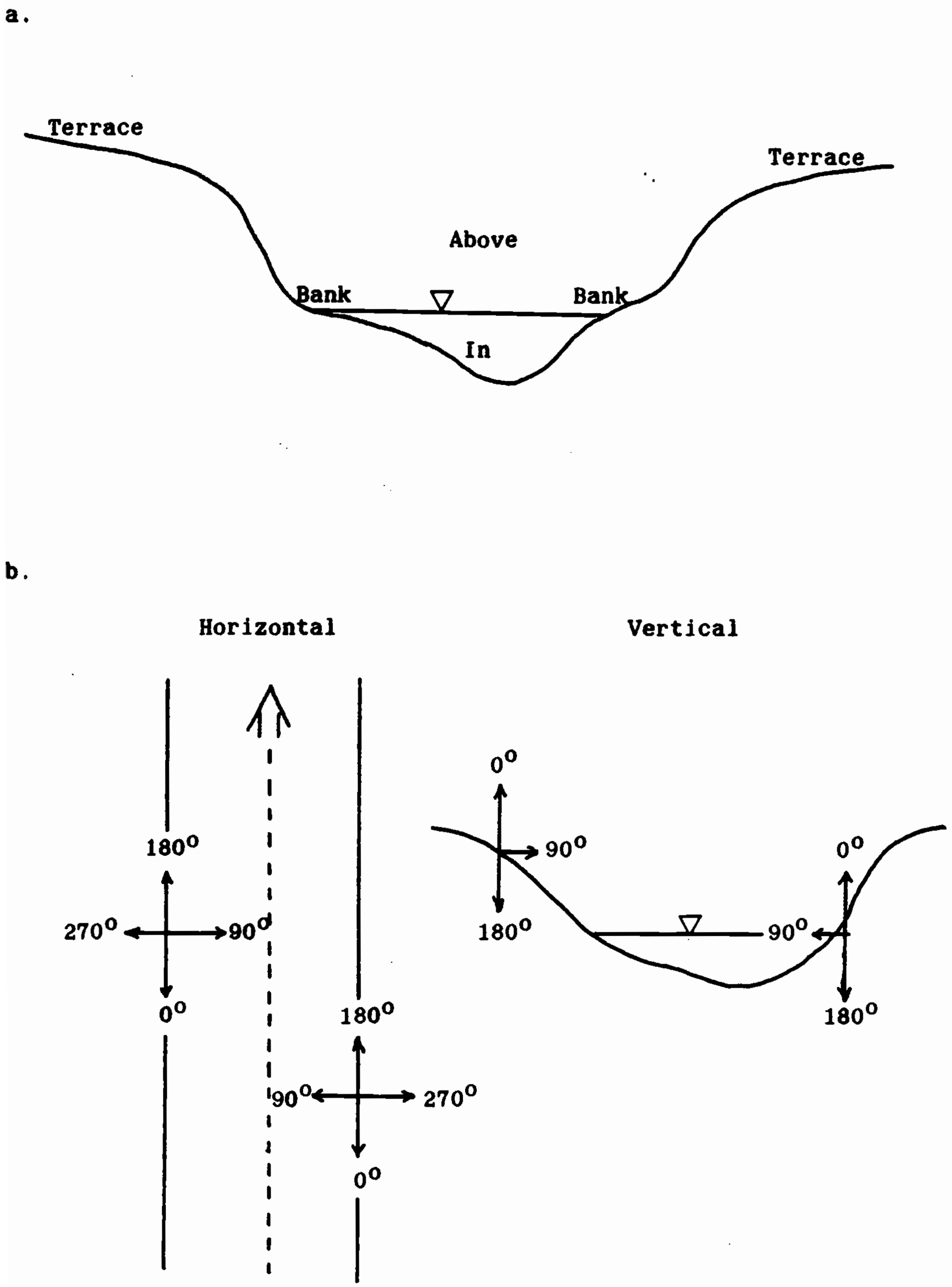

Figure 9. Woody debris geomorphic location and angular position.

type of accumulation did vary (Table 9). First- and second-order channels contained more single- and multi-tier jams, whereas third- and fourth-order channels contained more debris dams. The largest debris accumulations were present at or directly downstream from tributary junctions (Figure 10).

Habitat Influence. Seventeen percent of the pre-disturbance debris pieces formed pools (Table 8). Seven percent of the post-disturbance debris pieces formed pools. Fourth-order channels had the largest percentage of pieces that formed pools within both debris types, followed by third-, second-, and first-order channels (Figure 11). As a result, more debris-formed pools were present in the higher order channels (Table 9). Also, a larger percentage of pre-disturbance pieces impounded gravels, provided stream cover, and formed fall drops than post-disturbance pieces.

Relationships Among Variables

Total woody debris volumes per stream reach (100 m long and 10 m wide) varied from 1.9 to 105.4 cubic meters. Regression equations were developed to account for variations in debris volumes within stream orders (Appendix B). Total debris volumes per reach were significantly associated with channel depth and sideslope. Pre-disturbance debris volumes per reach were significantly associated with valley floor width and sideslope. Post-disturbance debris volumes per reach were significantly associated with channel depth, gradient, and sideslope. Also, stand density and basal area per hectare appeared to influence the volumes and

Table 9. Debris accumulations and debris-formed pools in Big Creek.

Stream Order	1ST	2ND	3RD	4TH	Mean	
Debris accum(#/100 m)						
1-tier Jams	1.3	1.0	0.6	0.8	0.9	(6.2)[a]
2-tier Jams	0.5	1.0	0.4	0.4	0.6	(9.4)
Debris Dams	0.5	1.6	2.0	2.1	1.7	(7.1)
Total	2.3	3.6	3.0	3.3	3.2	
Pools(#/100 m)	0.5	2.8	3.4	5.0	3.2	

[a] Mean number of pieces per accumulation.

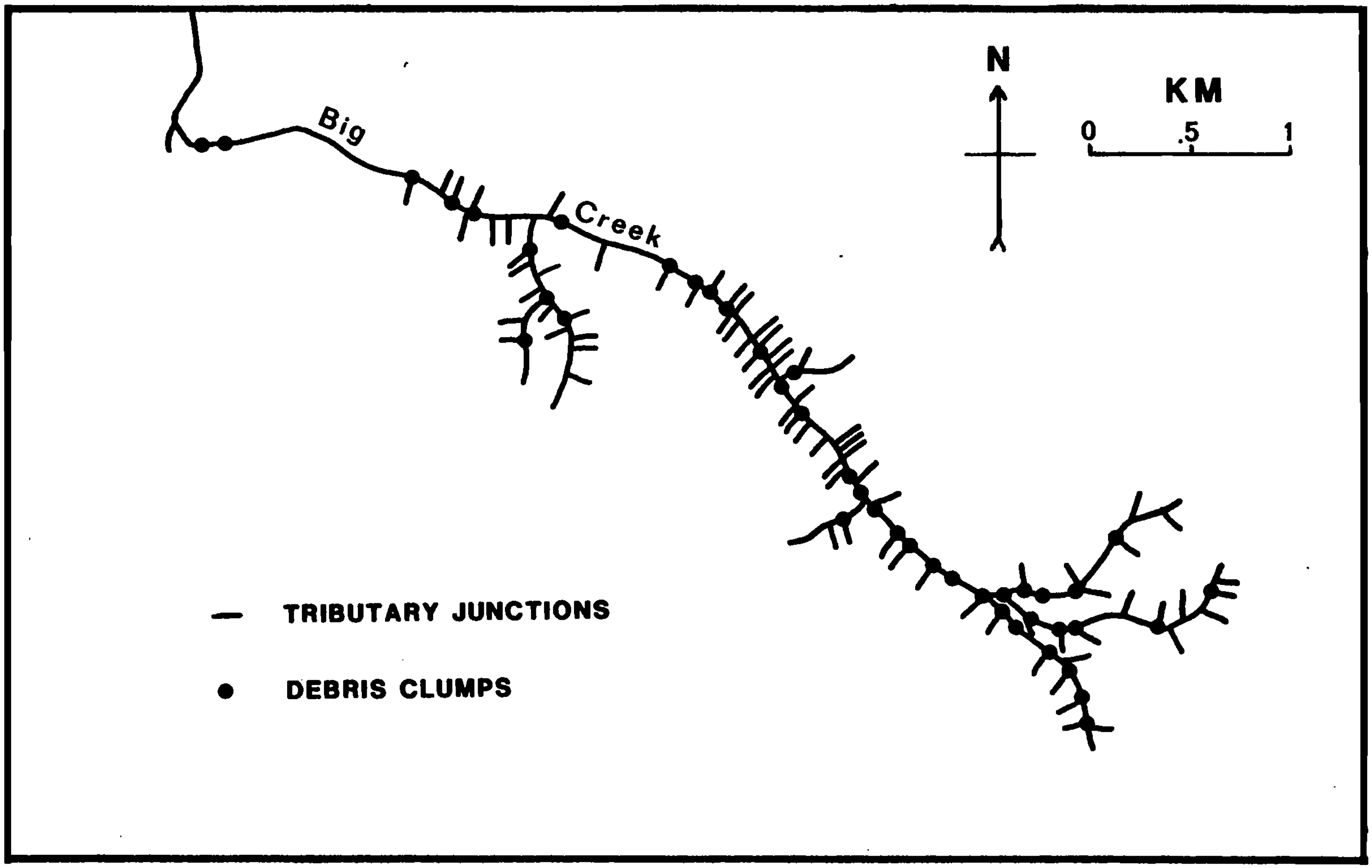

Figure 10. Debris accumulations and tributary junctions in Big Creek.

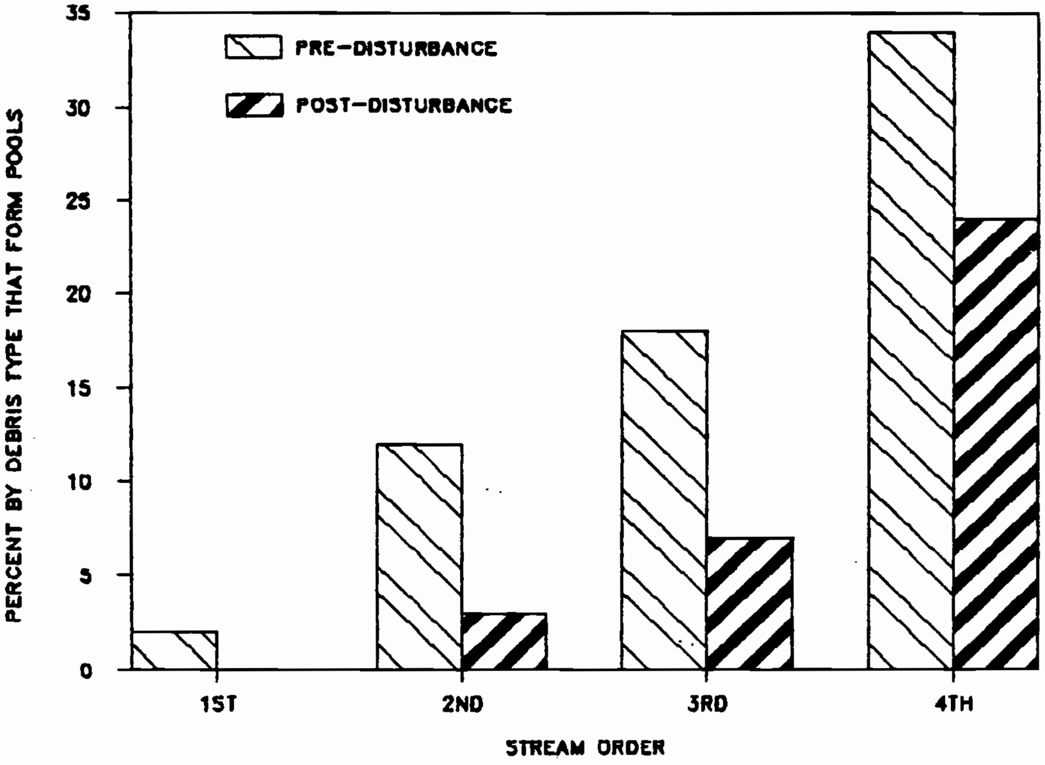

Figure 11. Woody debris influence on pool formation by debris type and stream order.

species composition of post-disturbance large woody debris in the channels (Appendix C). Post-conifer debris volumes were positively correlated with conifer stand values at a five percent level of significance on a stream order and 100-meter reach basis. However, conifer stand and debris associations were not significant within stream order groups. Post-hardwood debris volumes were positively correlated with hardwood stand values at a five percent level of significance on a 100-meter stream reach basis but not on a stream order basis.

DISCUSSION

Factors That Influenced Woody Debris Recruitment and Abundance

The degree of channel disturbance, past and present riparian stand composition, and geometry of the channels were dominant factors that influenced the amount and variability of large woody debris in Big Creek. Total volumes, piece sizes, and species of large woody debris in the channels were extremely variable among 50-meter stream reaches. Woody debris volumes in Big Creek were most variable in reaches disturbed by log yarding operations, debris avalanches, and debris torrents. In third-order channels, pre-disturbance debris volumes were greater in reaches impacted by landings, railroad stream crossings, and mass movement deposits. In fourth-order channels, pre-disturbance debris volumes were lower in reaches impacted by roads, the veneer mill, and the water diversion. Less post-disturbance volume was present in recently perturbed reaches of both stream orders, possibly due to the time required for regrowth of suitably sized trees. Indicators of riparian zone disturbance included: channel widenings, gradient changes, multiple channels, sediment and debris deposits, young alder stands, buried debris in channel banks, and slope failure scars.

Recruitment of post-disturbance woody debris was generally greater in reaches bordered by higher stand densities and basal areas per hectare, however, significant relationships were not observed in several cases. Although the watershed was clearcut and subsequently burned, riparian stand variability was high among stream reaches. Older-aged conifers remained in areas that were protected from the fire. Multi-aged deciduous stands grew on slope failure deposits, along streambanks, and on wide valley floors in the mainstem. Conifer dominated overstories grew on narrow valley floors and steep sideslopes in headwater channels. Some stream reaches supported brush understories that suppressed stand establishment and growth.

Stream size, channel gradient, and channel bed form also were factors that influenced the amount of large woody debris in the channels. Large woody debris volumes per unit area generally decreased as the stream size increased. Debris torrents in steep tributaries transported large volumes of woody debris to larger downstream channels. High flows in the main channel floated and rearranged some debris pieces during large winter storms. Large debris accumulations were formed at tributary junctions, channel bends, and gradient breaks. The roughness of the stream bed in the main channel appeared to affect the retention of debris pieces. The heaviest debris loading occurred in the upper portion which had a cobble and boulder substrate. The lower mainstem with a sand and gravel substrate had a smaller level of debris loading. The smooth bedrock reach above the basalt geologic break had the least debris loading. A large debris jam was formed below the falls downstream from the bedrock reach.

Another factor that may have influenced woody debris variability was the stability of the debris pieces themselves. Large, anchored debris pieces evidently have withstood several high flow events. Woody debris characteristics that appeared to affect piece stability included: piece length relative to bankfull channel width, piece diameter, decay condition, position relative to flow direction, and degree of anchoring. Long pieces of wood often hang up on stream banks when rotated perpendicular to streamflow. Large diameter pieces usually are more difficult to float. Fresh pieces are more resistant to breakage than decayed pieces. Lastly, debris pieces that are imbedded in stream banks and beds, or those with large attached root masses, are more difficult to mobilize.

Comparison of Results With Other Studies

Two recent studies have documented large woody debris abundance in streams flowing through various aged forests in the Coast Range. Grette (1985) measured woody debris characteristics, stream habitat features, and fish populations in 28 western Washington streams. Sites were sampled in old-growth, young second-growth (10-26 years old), middle-aged second-growth (27-37 years old), and old second-growth (40-62 years old) stands. He found that large woody debris volumes were more abundant in streams in old-growth forests than in streams in second-growth forests (Table 10). Grette also found that the average size of woody debris pieces was larger in streams in old-growth forests. The total number of pieces per 100 meters, total volume per square meter, post-disturbance volume per square meter, and mean

Table 10. Large woody debris in streams bordered by old-growth and second-growth stands in the Coast Range.

Debris Studies		pieces (#/100m)	total vol (m^3/m^2)	post vol (m^3/m^2)	mean piece vol (m^3)
Old-growth					
Cummins Cr.		37.7	0.0726	n/a	2.6
Wash.		48.8	0.0689	n/a	1.6
Second-growth					
Wash.	young	48.1	0.0389	0.0024	0.9
	middle	35.9	0.0344	0.0021	1.0
	old	47.3	0.0444	0.0084	1.2
Big Cr.		45.1	0.0312	0.0042	0.7

piece size of large woody debris in Big Creek compared favorably to that measured by Grette in streams in second-growth forests.

Data collected by Sedell (unpublished) from Cummins Creek in western Oregon represented debris loading in an old-growth forested stream. The mean piece size of large woody debris was considerably larger in Cummins Creek than in Big Creek, or in any of the streams that Grette sampled, due to the presence of many large Sitka spruce in the drainage bottom. Also, large accumulations of woody debris from debris torrents were present in middle sections of Cummins Creek.

Implications For Management of Riparian Zones

Comparisons of long-term trends in the abundance of woody debris in channels following wildfire and clearcut harvesting may not accurately reflect current management impacts. Many stream channels have been drastically disturbed by past logging practices. Reductions of large woody debris in stream channels during logging adjacent to streams have been reported and documented (Lammel 1972, Froehlich et al. 1972, Swanson et al. 1976, Toews and Moore 1982). Subsequent displacement of whole pieces and decayed woody material during high streamflows, and excessive removal of woody debris from stream channels during stream cleanout, are factors that have contributed to debris reductions. Protection of instream large woody debris during yarding and the establishment of uncut buffer strips around streams have moderated debris losses and are designed to provide new recruitment sources. Also, studies have shown that significant volumes of large woody debris have been contributed to channels from young forests (Grette 1985, Heimann in process). However, second-growth debris additions only partially offset natural losses to stream systems and might not be adequate to provide desired habitats for fish (Grette 1985). Questions that still need to be answered concerning the quantity and quality of wood habitat in streams surrounded by second-growth forests are:

1. How much volume of large woody debris should there be in stream channels to provide sufficient habitat for fish?
2. What is the effectiveness of buffer strips in providing long-term, continuous sources of wood to channels?
3. What is the influence of shortened rotation ages on recruitment of large woody debris in channels from second-growth forests with buffer strips?
4. What is the effectiveness of smaller-diameter debris pieces in providing year-round habitat opportunities for aquatic organisms?

SUMMARY AND CONCLUSIONS

This study focused on the effects of forest management on large woody debris in a fourth-order stream system in the Oregon Coast Range. Big Creek drainage was selected for the study because of its location and management history. The area was extensively logged between 1922 and 1935, and denuded by wildfire in 1936. Objectives of the study were to determine the amount and character of large woody debris in the stream system, and to identify factors that influenced woody debris quantities, piece sizes, delivery, arrangement, and stream habitat function. Study conclusions were as follows:

1. Total unit volume of woody debris (m^3/m^2) in first- and second-order channels was nearly twice that found in third- and fourth-order channels.
2. Pre-disturbance woody debris constituted 64 percent of the total number of pieces and 86 percent of the total volume in the channels in all stream orders.
3. Average piece volume of pre-disturbance woody debris was about three times greater than for post-disturbance woody debris.
4. Post-disturbance volumes of woody debris were dominated by coniferous species in first- and second-order channels and by deciduous species in third- and fourth-order channels, as was the species composition of the riparian stands adjacent to the channels.

5. Post-conifer volumes of woody debris were positively correlated with conifer stand density (r = 0.99) and basal area per hectare (r = 0.91) among stream orders.
6. Post-hardwood volumes of woody debris were positively correlated with hardwood stand density (r = 0.40) and basal area per hectare (r = 0.47) among 100-meter stream reaches.
7. Distribution of woody debris pieces was "clump-like" in both small and large channels, however, first- and second-order contained more single- and multi-tier jams, whereas third- and fourth-order channels contained more debris dams.
8. Tributary junctions appeared to influence the locations of major debris accumulations, especially those formed by debris torrents.
9. Pre-disturbance woody debris pieces formed over twice as many pools, gravel bars, fall drops, and stream cover features as post-disturbance woody debris (standardized by percent within debris type).
10. Total unit volume of large woody debris (m^3/m^2) in Big Creek was about 44 percent of that measured by Grette and Sedell in streams flowing through old-growth forests in the Coast Range.

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APPENDICES

Appendix A. Riparian stand formulas.

Average canopy density (Cd) = (N+S+E+W)(1.5) -1 if <=66% or
-2 if >66%

Mean distance from stream midpoint (d) = Lup+Ldown+Rup+Rdown/4

Area occupied by individual (A) = (mean distance)^2 = (d)^2

Stem density (D) = unit area/area occupied by individual = 1 ha/A

Mean stem diameter (DBH) = Σ(circum./π)/n = Σ(DBH)/n

Mean basal area (bA) = $\Sigma\ \pi$(circum./2π)^2/n = $\Sigma\ \pi$(DBH/2)^2/n

Basal area per hectare (BA) = (bA)(D)

Relative density (r) = (number of individuals of species/number of individuals of all species)(100)

Relative dominance (R) = (basal area of species/basal area of all species)(100)

Appendix B. Regression equation summaries.

Segment	n	Equation ($p<0.05$)	Adjusted r^2
Basin	119	logvol = 3.112 - 3.861 logdep + 0.000087 sidesqr	0.37
1st	9	logvol = 2.664 - 0.728 logwid + 61.592 logdep	0.92
2nd	49	logvol = 2.537 + 1.120 logwid + 0.000046 sidesqr	0.36
3rd	38	logvol = 4.738 - 1.378 logwid - 5.206 logdep + 0.000084 sidesqr	0.41
4th	23	logvol = 1.463 + 0.579 logcbah	0.24
Basin	119	logpre = 3.356 - 0.284 logval + 0.000091 sidesqr	0.34
1st	9	logpre = 2.207 + 60.313 logdep	0.71
2nd	49	logpre = 2.275 + 1.091 logwid + 0.000061 sidesqr	0.33
3rd	38	logpre = 6.433 - 1.471 logbank - 8.860 logdep	0.28
4th	23	logpre = 2.159 + 0.000205 sidesqr	0.21
Basin	119	logpost = 2.392 - 0.357 loggrad - 6.042 logdep + 0.000059 sidesqr	0.22
1st	9	logpost = -0.550 + 124.226 logdep	0.68
2nd	49	logpost = 0.942 + 1.171 logwid	0.15
3rd	38	logpost = 0.842 + 0.000084 sidesqr	0.15
4th	23	logpost = 0.019 + 0.552 loghbah +0.344 logcbah - 0.948 loggrad	0.70
Basin	119	logcon = 2.773 - 0.202 loghden - 0.489 logbank - 3.181 logdep	0.40
1st	9	logcon = 3.804 - 0.725 logratio	0.34
2nd	49	logcon = 3.064 - 0.189 loghden - 0.665 loggrad + 1.001 logwid	0.21
3rd	38	logcon = -0.029 + 0.212 logcbah	0.06
4th	23	logcon = -2.129 + 4.649 logdep + 0.482 logratio	0.34
Basin	119	loghard = 1.207 + 0.322 loghbah - 0.261 logcden - 2.461logdep + 0.000054 sidesqr	0.32
1st	9	loghard = -10.856 + 0.367 loghden + 2.699 logval + 5.337 logwid + 98.362 logdep + 0.000191 sidesqr	0.98
2nd	49	loghard = -0.632 + 0.355 loghbah + 22.522 logdep	0.41
3rd	38	loghard = 2.305 - 0.279 logcden - 5.776 logdep + 0.000075 sidesqr	0.37
4th	23	loghard = 2.067 + 0.643 loghbah - 1.057 loggrad - 0.406 logval	0.66

logvol = natural log of total volume (m^3/1000 m^2).
logpre = natural log of pre-disturbance volume (m^3/1000 m^2).
logpost = natural log of post-disturbance volume (m^3/1000 m^2).
logcon = natural log of conifer post-disturbance volume (m^3/1000 m^2).
loghard = natural log of hardwood post-disturbance volume (m^3/1000 m^2).
logwid = natural log of wetted stream width (m).
logdep = natural log of average wetted stream depth (m).
logratio = natural log of width/depth ratio.
logbank = natural log of bankfull channel width (m).
logval = natural log of valley floor width (m).
loggrad = natural log of channel gradient (%).
sidesqr = sideslope squared (%)^2.
logcden = natural log of conifer stem density (#/ha).
loghden = natural log of hardwood stem density (#/ha).
logcbah = natural log of conifer basal area (m^2/ha).
loghbah = natural log of hardwood basal area (m^2/ha).

Appendix C. Pearson correlation matrices.

Segment	n		Correlation Coefficients (r)						
			logpost	logcon	loghard	logcden	logcbah	loghden	loghbah
Basin	4 stream orders	logpost	1.00						
		logcon	0.82	1.00					
		loghard	-0.04	-0.50	1.00				
		logcden	0.73	0.99	-0.64	1.00			
		logcbah	0.64	0.91	-0.79	0.96	1.00		
		loghden	-0.54	-0.75	0.83	-0.82	-0.95	1.00	
		loghbah	-0.73	-0.82	0.67	-0.85	-0.94	0.97	1.00
Basin	119 stream reaches	logpost	1.00						
		logcon	0.66	1.00					
		loghard	0.56	-0.17	1.00				
		logcden	0.19	0.48	-0.28	1.00			
		logcbah	0.07	0.37	-0.35	0.77	1.00		
		loghden	-0.17	-0.50	0.40	-0.42	-0.43	1.00	
		loghbah	-0.07	-0.47	0.47	-0.37	-0.44	0.92	1.00
1st Order	9 stream reaches	logpost	1.00						
		logcon	0.80	1.00					
		loghard	0.47	-0.12	1.00				
		logcden	-0.03	-0.00	-0.17	1.00			
		logcbah	0.32	0.31	-0.06	0.90	1.00		
		loghden	-0.51	-0.56	-0.01	-0.52	-0.72	1.00	
		loghbah	-0.49	-0.52	-0.00	-0.50	-0.69	0.99	1.00
2nd Order	49 stream reaches	logpost	1.00						
		logcon	0.71	1.00					
		loghard	0.49	-0.20	1.00				
		logcden	-0.33	-0.09	-0.42	1.00			
		logcbah	-0.30	-0.03	-0.45	0.82	1.00		
		loghden	0.05	-0.28	0.50	-0.27	-0.26	1.00	
		loghbah	0.10	-0.23	0.51	-0.25	-0.29	0.97	1.00
3rd Order	38 stream reaches	logpost	1.00						
		logcon	0.50	1.00					
		loghard	0.88	0.07	1.00				
		logcden	-0.02	0.26	-0.23	1.00			
		logcbah	-0.19	0.29	-0.43	0.67	1.00		
		loghden	0.25	-0.14	0.38	0.29	-0.21	1.00	
		loghbah	0.28	-0.14	0.38	0.26	-0.31	0.73	1.00
4th Order	23 stream reaches	logpost	1.00						
		logcon	0.09	1.00					
		loghard	0.98	-0.08	1.00				
		logcden	0.07	-0.03	0.08	1.00			
		logcbah	0.21	0.24	0.16	0.72	1.00		
		loghden	0.16	0.00	0.15	-0.48	-0.22	1.00	
		loghbah	0.70	-0.14	0.73	-0.09	-0.03	0.55	1.00

logpost = natural log of post-disturbance volume (m^3/1000 m^2).
logcon = natural log of conifer post-disturbance volume (m^3/1000 m^2).
loghard = natural log of hardwood post-disturbance volume (m^3/1000 m^2).
logcden = natural log of conifer stem density (#/ha).
logcbah = natural log of conifer basal area (m^2/ha).
loghden = natural log of conifer stem density (#/ha).
loghbah = natural log og hardwood basal area (m^2).