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Long-Term Experiments on Log Decomposition at the H.J. Andrews Experimental Forest

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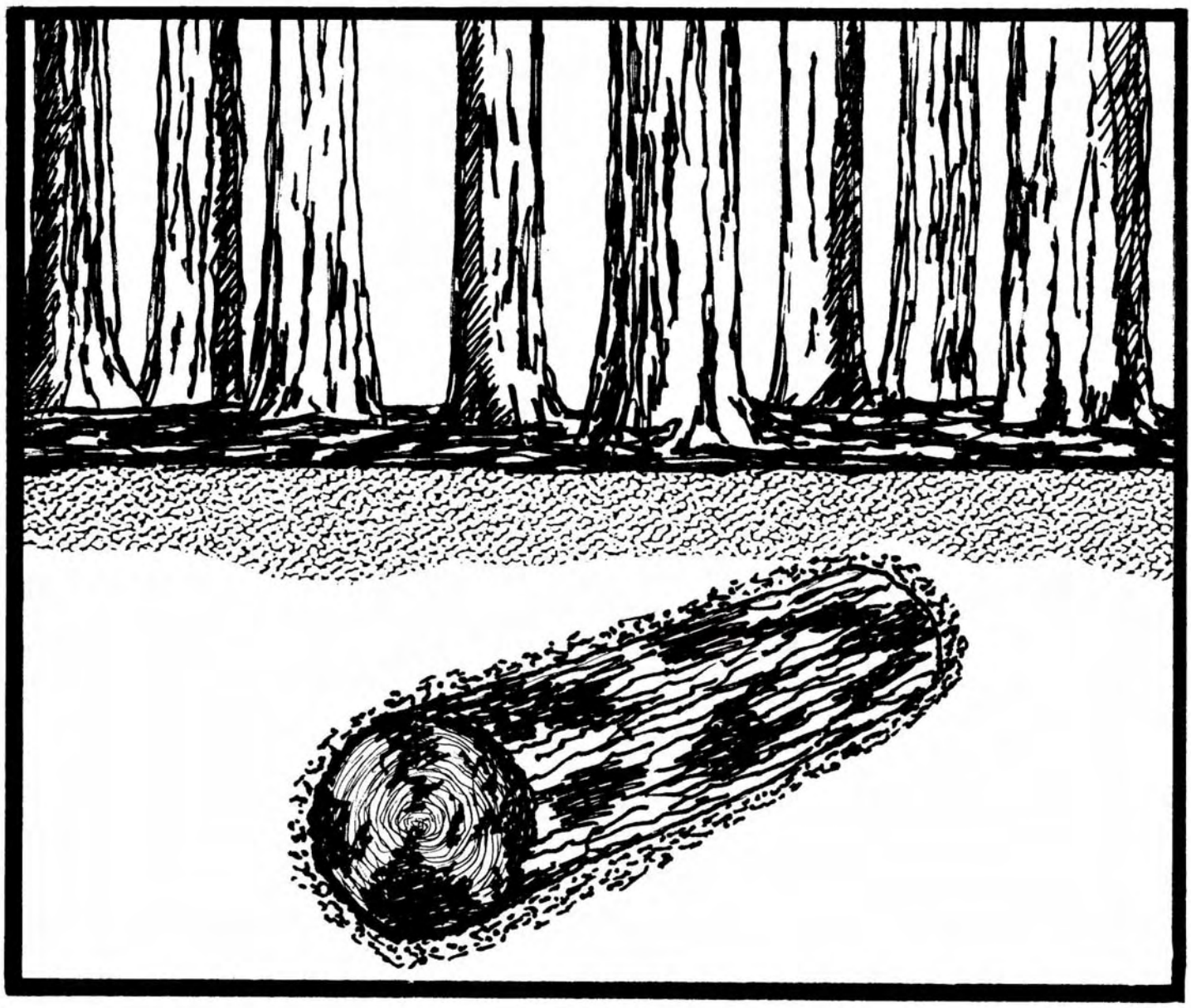

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Abstract

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A long-term decomposition experiment was established at the H.J. Andrews Experimental Forest, Oregon, during 1985 to test the importance of substrate heterogeneity, colonization patterns, and invertebrates on the decomposition of logs. The duration of the study is anticipated to be 200 years. A total of 530 logs (50 centimeters in diameter and 5.5 meters long) were placed at six old-growth forest sites. Characteristics measured for each log at the start of the experiment included diameter, length, volume, surface area, bark cover, and the total volume, density, and moisture content of outer bark, inner bark, sapwood, and heartwood. A subsample of logs was examined for lignin, cellulose, ash, calcium, copper, iron, nitrogen, potassium, magnesium, manganese, phosphorus, sulfur, and zinc content. Data on initial conditions and subsequent measurements are being stored at the Forest Science Data Bank, Oregon State University, Corvallis.

Keywords: Coarse woody debris, decay, decomposition, Douglas-fir, fallen trees, logs, Pacific silver fir, western hemlock, western redcedar.

Contents

Summary

The decomposition of coarse woody debris is an important but poorly understood aspect of nutrient cycling in forest ecosystems of the Pacific Northwest. This report describes the establishment and initial conditions of a long-term experiment to study this process at the H.J. Andrews Experimental Forest, Blue River, Oregon. Three hypotheses on the factors controlling decomposition and nutrient cycling are being tested: (1) processing rates decrease with the decay resistance of the heartwood, (2) processing rates increase with the rate the log is colonized by decomposers, and (3) insects are crucial in starting colonization.

Green, undecayed trees were felled, bucked into logs, and placed at six locations at the H.J. Andrews Experimental Forest in September 1985. The logs were 45 to 65 centimeters in diameter and 5.5 meters long. Four species—Douglas-fir, Pacific silver fir, western hemlock, and western redcedar—were used to include a wide range of decay resistance. Exclosures were built around a subset of Douglas-fir and western hemlock logs to test the effect of insects on colonization. A total of 530 logs were placed to allow for at least 18 sampling times.

The initial conditions of each log were sampled, including log diameter, length, volume, total surface area, bark cover, proportion of tissue types (for example, sapwood), density, and moisture content. A subsample of logs was used to characterize the initial acid detergent fiber, lignin, cellulose, nitrogen, phosphorus, potassium, and calcium content of the tissue types.

Introduction

Decaying wood is an important structural feature and functional component of forested ecosystems (Harmon and others 1986, Maser and Trappe 1984). A large proportion of the forest production is stored as wood, and in natural ecosystems, most of it eventually enters the detrital food chain. In addition to being a habitat for decomposer organisms (Frankland and others 1982), rotting wood forms a habitat for lichens, bryophytes, and vascular plants (Franklin and others 1981, Triska and Cromack 1980); and wildlife species often depend on logs and snags (Davis and others 1983). The interactions among wildlife, woody debris, and the forest can be quite complex. Fallen trees, for example, may influence the activities of small mammals which in turn introduce mycorrhizal fungi to the stand (Maser and others 1978). Because of its high mass and slow decay rate, woody debris often forms an important, long-term storage pool and may dampen effects of disturbances on forested ecosystems. On the other hand, woody debris adds to fuel and thus may increase the magnitude of the disturbance by fires. Woody debris, especially coarse material, can also significantly affect stream geomorphology (Swanson and Lienkaemper 1978), form important habitat for invertebrates (Anderson and others 1978) and vertebrates, and profoundly influence water quality (Bilby and Likens 1980). The role upturned tree roots play in soil formation and sediment movement in watersheds is generally appreciated (Lutz 1940); fallen trees also influence soil formation.

At the same time the importance of rotten wood in ecosystems is becoming better understood, management pressures are increasing to remove it from stands to reduce fire hazard, increase worker and visitor safety, remove potential blockages to fish passage, and fully use the fiber produced by forests. Knowledge on the rate at which coarse woody debris is added and removed from forests and the factors controlling these rates are generally lacking but are fundamental to informed management.

Determining rates of coarse woody debris input and loss is a long-term research problem. Data gathered from permanent plots provide information on tree mortality and coarse woody debris inputs (Sollins 1982). Long-term observations of woody debris are also important to understanding decomposition processes and testing the factors controlling them. Most studies have estimated decay rates using chronosequences, in which tree-fall scars, fire dates, insect attack records, living stumps, and tree seedlings are used to provide an estimate of log residence time on the forest floor (Harmon and others 1986). Wood pieces are often difficult to date accurately, however, and age estimates of logs can be up to a decade off. Initial conditions and environment may differ substantially among logs, but both factors increase variation and thus reduce the chance of detecting subtle controls of wood decay. Even the best chronosequence is still only a temporal hypothesis (McIntosh 1981); to test these hypotheses, logs should be observed over time. Long-term observations are especially appropriate if multiple pathways of log decay occur.

This report describes a set of long-term log-decomposition experiments established at the H.J. Andrews Experimental Forest in Blue River, Oregon, during 1985. These experiments were established as a cooperative effort between the USDA Forest Service and Oregon State University's Long-Term Ecological Research program. Many factors influence decay of logs, and no single study can adequately address all factors. The experiments described here examine three of the many basic questions about the decay of coarse woody debris. These experiments form a core, around which other experiments can be developed to add scope to our understanding of log

and snag decay. These experiments also represent a resource for scientists to test many hypotheses on the role of logs in ecosystems. This report provides a detailed explanation of the establishment of this study and describes the initial conditions of the experiment.

Objectives and Hypotheses

The general objective of establishing the long-term log-decomposition experiment is to create a resource to answer basic questions on the processes affecting coarse woody debris decomposition. At the outset of the experiment, there were three specific objectives:

1. Test the effect the structural components (that is, outer bark, inner bark, sapwood, and heartwood) have on the decomposition of Pacific silver fir, Douglas-fir, western redcedar, and western hemlock logs, and test if species differences are primarily caused by differences in heartwood resistance to decay (hypothesis 1).

Differences in log-decay rates among species in the terrestrial environment correspond to the decay resistance of the heartwood. Those species with a high proportion of bole volume as decay-resistant heartwood will decay slowest, whereas species with less resistant heartwood will decay fastest. Many laboratory studies have shown that the resistance of heartwood to decay differs markedly among tree species (Scheffer and Cowling 1966). These differences are caused by phenolic extractives in heartwood (Hillis 1977, Scheffer and Cowling 1966). In contrast, the inner bark and sapwood of trees do not resist decay, and differences among species are probably minor. Heartwood is a major portion of large logs; therefore, variations in heartwood decay-resistance will strongly influence the decay of logs.

2. Examine the influence that decomposer colonization patterns have on log decomposition of Pacific silver fir, Douglas-fir, western redcedar and western hemlock logs, and test if a lag occurs before the maximum rate of decay (hypothesis 2).

Colonization patterns of decomposers cause a lag in log decay. Although decay starts immediately after death, maximum rates of decay do not occur until the substrate is fully colonized. Currently, log-decay is simulated with a single exponential model. This model is based on the assumption that the greatest loss (in absolute terms) occurs in the earliest phases of decay. Although this model is appropriate for fine-litter decay, where colonization of decomposers is rapid and leaching losses are high, these simple exponential models do not reflect decay processes in logs. Timber salvage studies have demonstrated that large logs often are not colonized fully by decomposers for decades (Buchanan and Englerth 1940, Kimmey and Furniss 1943). The influence of colonization patterns on log decomposition has generally not been appreciated by ecologists.

3. Test if invertebrate boring and feeding during the first two decades speeds the decomposition of logs by increasing rates of microbial colonization (hypothesis 3).

Attack by invertebrates increases the colonization rate of fallen trees by microbes and therefore increases the decay rate. The amount of material directly removed by invertebrates is minor compared to losses caused by the microbes introduced by invertebrates. Previous studies have shown that invertebrate activities allow microbes

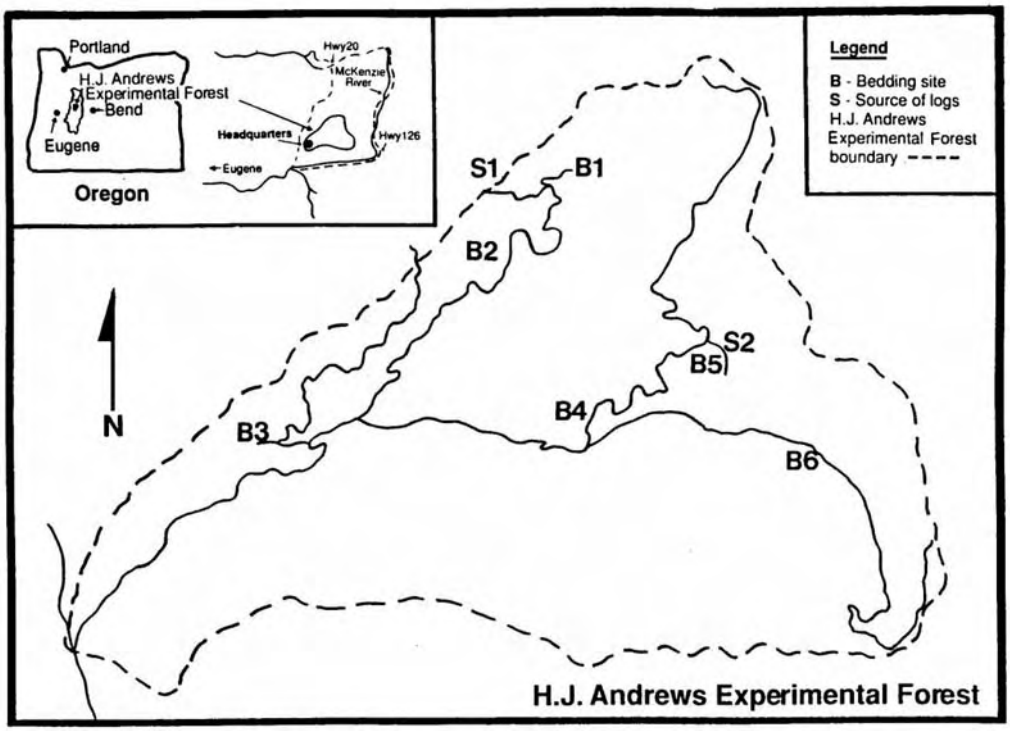

Figure 1–Vicinity map of the log-decomposition experiment at the H J. Andrews Experimental Forest, Oregon.

to colonize logs rapidly (Leach and others 1934, 1937); however, none of these studies seems to have examined how this influences the decay rate. Comparing screened with unscreened logs will show the influence of invertebrate activity on decomposer colonization patterns as well as weight loss. I anticipate that the lack of invertebrates will increase the lag in decay but will not influence the decay rate once the log is fully colonized.

Study Area

The H.J. Andrews Experimental Forest is 80 kilometers east of Eugene, Oregon, on the west slope of the Cascade Range (fig. 1). The Andrews Forest was established in 1948 by the USDA Forest Service and has been the site of extensive research on timber and watershed management in the commercially important Douglas-fir forests of the Pacific Northwest. The site is administered jointly by the Pacific Northwest Research Station, the Willamette National Forest, and Oregon State University.

The climate is maritime with wet, relatively mild winters and dry, cool summers. Mean annual temperature is 8.5 ^{o} C , and mean annual precipitation is 2300 millimeters, with more than 75 percent falling between October and March. Annual actual evapotranspiration is 530 millimeters. Soils are deep, well-drained typic dystrochrepts; slope gradients range from 20 to 60 percent. The forests are classified into two major zones, the western hemlock zone (300-1050 meters elevation) and the Pacific silver fir zone (1050-1550 meters elevation). Douglas-fir and western redcedar are major components of both zones (Dyrness and others 1976).

Table 1--Partitioning of degrees of freedom for the upland time-series experiment

Source of variation	Degrees of freedom	Levels
Sites (R)	5	Six sites
Species (A)	3	Pacific silver fir, Douglas-fir, western redcedar, western hemlock
$Error_a$	15	
$Total_a$	23	
Substrates (B)	3	Outer bark, inner bark, sapwood, heartwood
A X B	9	
Error B	60	
$Total_b$	72	
Time (C)	15	1, 2, 3, 4, 5, 6, 8, 16, 24, 32, 60, 90, 120, 150, 180, 210 years
A X C	45	
B X C	45	
A X B X C	135	
$Error_c$	1200	
$Total_c$	1440	
Total	1535	

Experimental Design

Hypotheses 1 and 2

The experiments are being conducted at six sites located within intact old-growth Douglas-fir/western hemlock forests. The experimental design is a split-split plot in time (table 1). Each site represents a block, and log species is the the main plot effect. Substrate layer (that is, inner bark, outer bark, sapwood, and heartwood) is the subplot effect.

Hypothesis 3

To test the effect invertebrates have on the colonization and decay process, an invertebrate exclusion study was used at four of the sites. The experimental design of the exclusion study is a split-split-split plot in time (table 2). Each site represents a block; log species is the main plot effect, with invertebrate exclusion and substrates as subplot effects.

Methods

Site Descriptions

Moisture, temperature, and soil conditions are moderate at all six sites, although elevations range from 533 to 1133 meters (table 3). The topographic position of the sites ranged from valley bottom to side slopes, but the slopes of all sites were gentle and less than 20 percent. The habitat type for sites 1 and 6 are *Tsuga/Abies/Rhododendron/Berberis;* for sites 2, 3, and 4 it is *Tsuga/Rhododendron/Berberis* and for site 5, it is Tsuga/Abies/Linnaea. Although timber salvage operations had been conducted at two sites, all the stands are fairly intact. Mean annual temperature during 1986-88 ranged from 8.0 to 9.9 °C (fig. 2). Mean annual precipitation from the nearest precipitation-gauging stations ranged from 207 to 232 centimeters during 1979-86. Climatic conditions include only a subset of those occurring at the H.J. Andrews Experimental Forest.

Table 2--Partitioning of the degrees of freedom for the invertebrate-exclusion experiment

Source of variation	Degrees of freedom	Levels
Sites (R)	3	Four sites
Species (A)	1	Douglas-fir, western hemlock
$Error_a$	3	
$Total_a$	7	
Exclusion (B)	2	Insects, no insects, increased insects
A X B	2	
$Error_b$	12	
$Total_b$	16	
Substrates (C)	3	Outer bark, inner bark, sapwood, heartwood
A X C	3	
B X C	6	
A X B X C	6	
$Error_c$	54	
$Total_c$	72	
Time (D)	3	1, 5, 10, 16 years
A X D	3	
B X D	6	
C X D	6	
A X B X D	6	
B X C X D	18	
A X C X D	9	
A X B X C X D	18	
$Error_d$	219	
$Total_d$	288	
Total	384	

Source Areas

Logs of the four species used in the experiments were removed from four locations during September 1985 (fig. 1). A stand along the 1506-630 road at 1500 meters elevation was the source of Pacific silver fir logs. Trees were removed 30 meters above and below the road. The source area for Douglas-fir was a 2-hectare clearcut along the 1506-320 road at 1000 meters elevation. Logs of western hemlock were removed primarily from a 6-hectare clearcut along the north side of the 1506-354 road. Fewer western hemlock logs were removed from along the 1506-350 road. Most of the redcedar was removed from along the 1506-350 road, although a few were removed from the 3-hectare clearcut adjacent to the 1506-354 road.

Table 3-Description of log-decomposition experimental sites at H.J. Andrews Experimental Forest

Site number	Salvaged	Elevation	Temperature[a]	Precipitation[b]	Habitat type[c]	Hypotheses addressed
		Meters	*°C*	*Centimeters*		
1	No	1065	8.9	229	TSHE/ABAM/RHMA/BENE	1,2,3
2	No	935	9.6	207	TSHE/RHMA/BENE	1,2
3	Yes	535	9.4	209	TSHE/RHMA/BENE	1,2,3
4	No	865	9.9	219	TSHE/RHMA/BENE	1,2,3
5	No	1135	9.0	232	TSHE/ABAM/LIBO	1,2,3
6	Yes	935	8.0	222	TSHE/ABAM/RHMA/BENE	1,2

[a] Based on 1986-88 period.

[b] Based on 1979-86 period.

[c] Based on map of habitat types of the H.J. Andrews Experimental Forest: TSHE/RHMA/BENE = *Tsuga heterophylla/Rhododenron macrophyllum/Berberis nervosa* habitat type. TSHE/ABAM/RHMA/BENE = *Tsuga heterophylla/Abies amabalis/Rhododenron macrophyllum/Berberis nervosa* habitat type. TSHE/ABAM/LIBO = *Tsuga heterophylla/Abies amabalis/Linnaea borealis* habitat type.

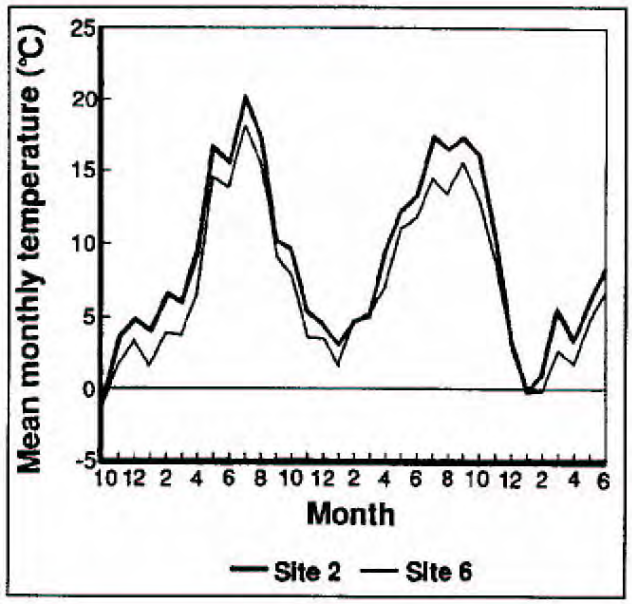

Figure 2—Mean weekly air temperature for the coolest and warmest sites of the log-decomposition experiment at the H.J. Andrews Experimental Forest, Oregon.

Transportation and Placement

Low-standard access roads were constructed at each site during July and August 1985 to place the logs, and then the roads were closed. Logs were placed on either side of the access roads after the 50-meter point to reduce the microclimatic effects of stand edge on the experiment. To reduce the effects of road work on the stand, trees were not felled unless necessary. Saving old-growth trees and large snags was given priority over saving small trees. Wherever possible, preexisting skidding roads were used. Logs lying across the road were removed to minimize damage to the logs and soil. The preferred method was to remove only the log section that lay across the road.

The logs used in the experiment met specifications for diameter, length, amount of bark cover, and degree of decay. Technicians present during tree felling, bucking, and yarding chose suitable logs. Logs ranging in diameter between 45 and 60 centimeters over their length were deemed suitable. The final log length at the experimental sites was 5.5 meters. Because the ends were trimmed after placement, the logs were bucked to 6 meters long after felling. Damage to the bark during yarding, transport, and placement was minimized; however, logs with more than 10 percent of their bark missing were considered unsuitable. These experiments were designed to use undecayed logs to limit the range of initial conditions; therefore, logs with large decay columns, conks, or both were rejected. No western redcedar without a small amount of heartrot could be found, however.

The use of undecayed, green logs warrants some explanation because this condition might be considered unnatural. Although many trees die standing, about one-half of trees in the Cascade Range fall to the forest floor in a green condition as a result of wind-related damage (Franklin and others 1987). In the coastal environment, over 70 percent fall to the forest floor in a green condition. Decomposers and heart-rotting species have undoubtably colonized some of this fallen wood, but most is colonized the following spring when insects begin their attacks. Therefore, the logs used in the experiments mimic a large (but not all-inclusive) subset of initial conditions for decomposition of coarse woody debris.

Logs were transported to the experimental sites on short-bed logging trucks and placed along the access road by mobile loader (fig. 3). Before placement, the approximate location of logs was marked with color-coded flags, and each "bed" was cleared of logs. For insect exclosures, polyester netting was placed on the ground before logs were placed. All branches that might tear the netting were removed from the exclosure beds.

Enough logs of each species were placed so that destructive samples could be made at least 18 times after placement—a total of 432 logs that could be used to test hypotheses 1 and 2. To test hypothesis 3, an additional 20 logs were moved to four of the sites.

A map indicating the position of logs at each site was prepared to aid relocation (fig. 4).[1] Each log was marked with an aluminum numbered tag nailed at the top of each end. The position of fiberglass T-posts along each access road was surveyed by using a jacobs staff, compass, fiberglass tape, and clinometer. Backsight measurements were made at each position. The distance, compass bearing, and slope of each log was surveyed from the nearest fiberglass T-post.

Exclosure Construction

Invertebrates were excluded by placing logs onto polyester mesh and then building an A-frame over the log. The frame was covered with 0.8-millimeter polyester mesh (fig. 5). One-half of the exclosure length was also covered with a 0.1-millimeter mesh to exclude small insects, such as ambrosia beetles.

[1] Maps on file with: Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 S.W. Jefferson Way, Cowallis, Oregon 97331.

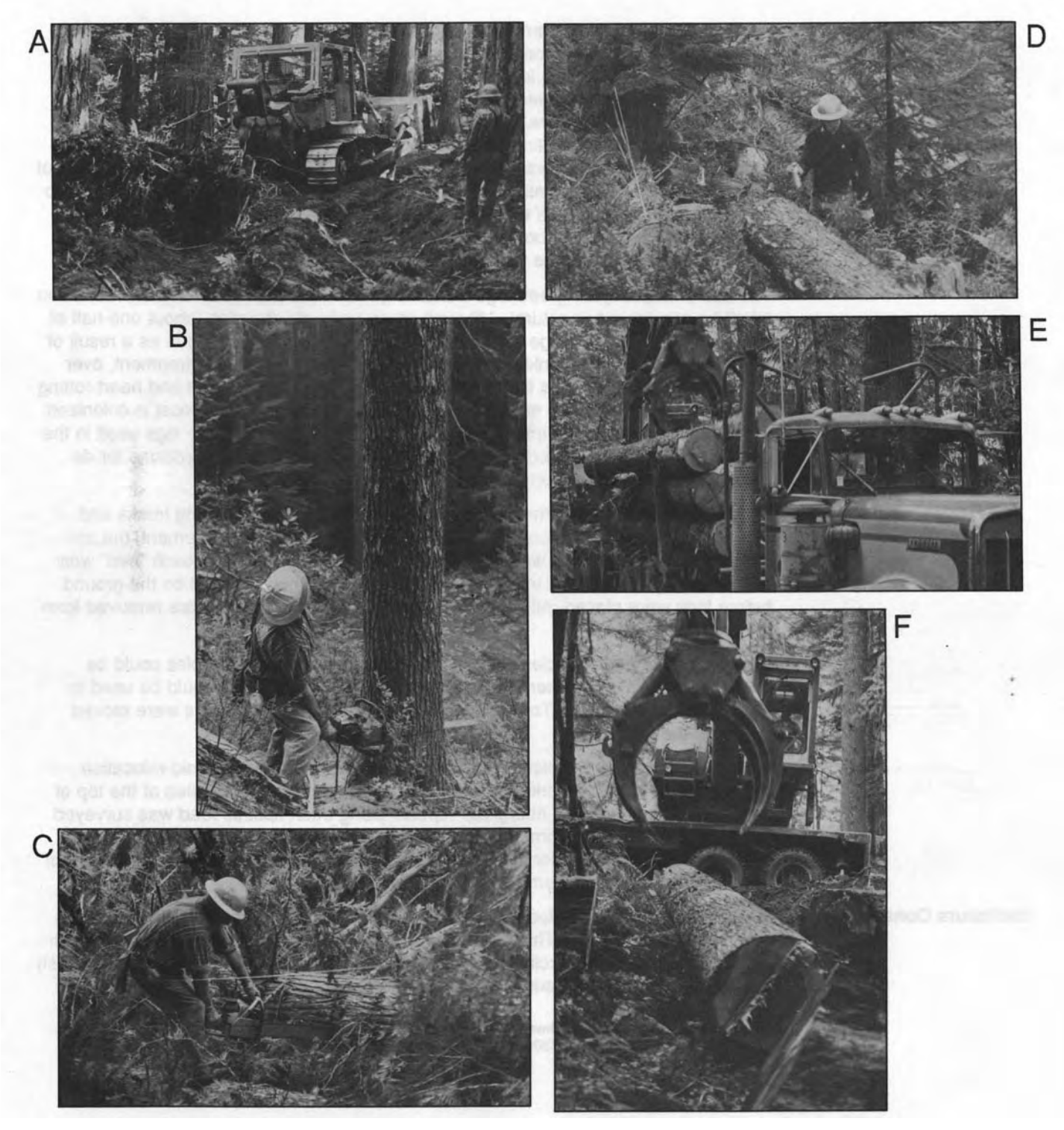

Figure 3--Establishment of log-decomposition experiment during September 1985 at the H.J. Andrews Experimental Forest, Oregon. (A) Construction of access road. (B) Felling trees used for experiment. (C) Bucking trees into logs. (D) Inspection and marking of suitable logs. (E) Placing logs at site using shortbed truck and mobile loader. (F) Placing log at bedding site.

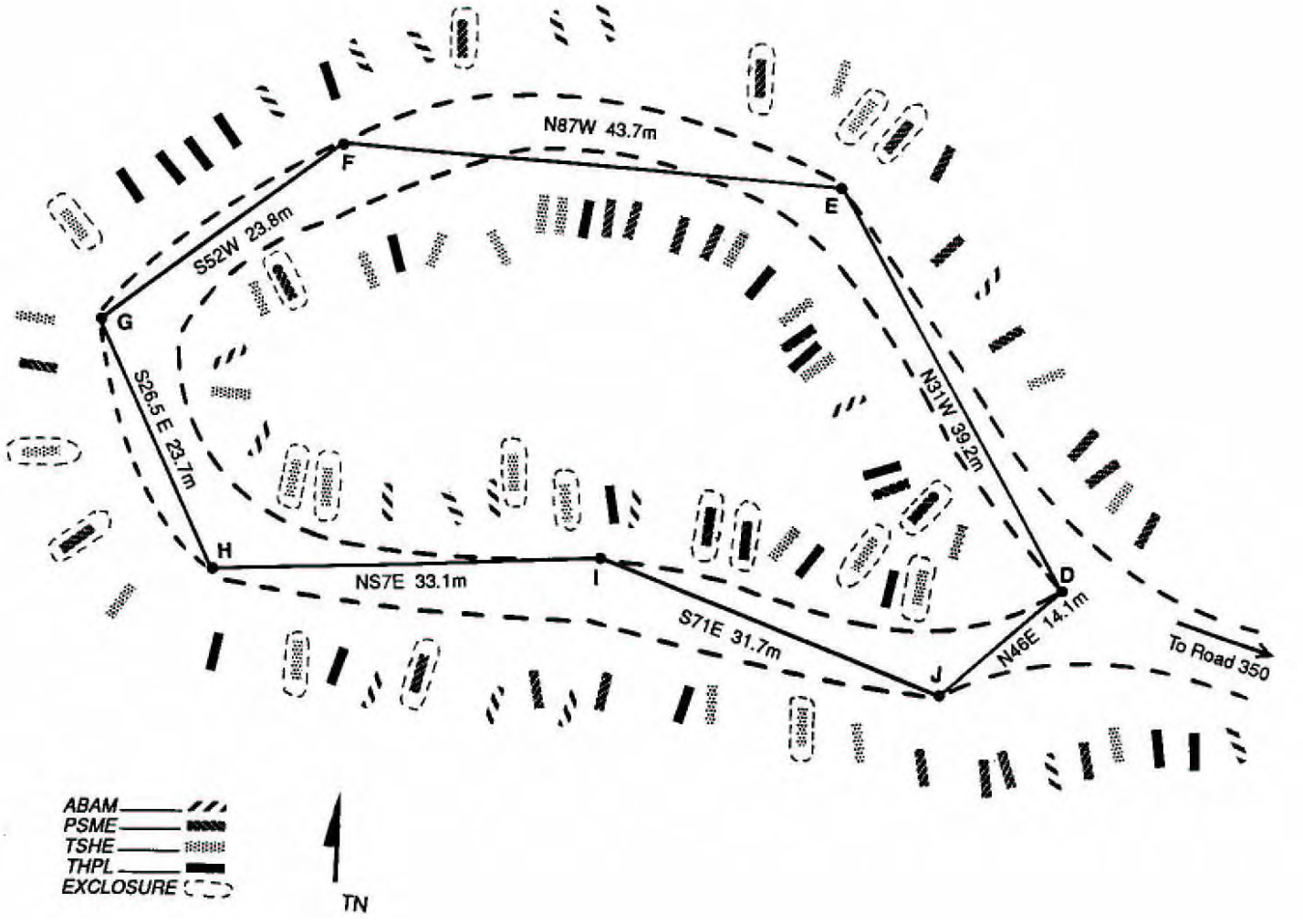

Figure 4-Placement of logs at site 4 of the log-decomposition experiment at the H.J. Andrews Experimental Forest, Oregon. ABAM-*Abies amabilis*, PSME--*Pseudorsuga* menziesii, THPL–*Thuja plicata*, TSHE–*Tsuga heterophylla*.

Exclosures were constructed during October 1985, with the intent of avoiding the flight periods of bark and ambrosia beetles. A few ambrosia beetles bored into the logs, however. To prevent further beetle attack, the exclosure logs were covered with plastic sheeting and fumigated for 24 hours with methyl bromide. Some beetles were still actively boring galleries in logs after fumigation. Active galleries (that is, those with wood dust) were injected with formalin to kill the beetles. These treatments were only partially successful; in summer 1986, many ambrosia beetles attacked logs in exclosures after the normal spring flight period. These attacks were probably by beetles that emerged from the logs and were trapped in the exclosures. Presently, it seems that about 20 percent of the logs in exclosures have low numbers of beetle galleries.

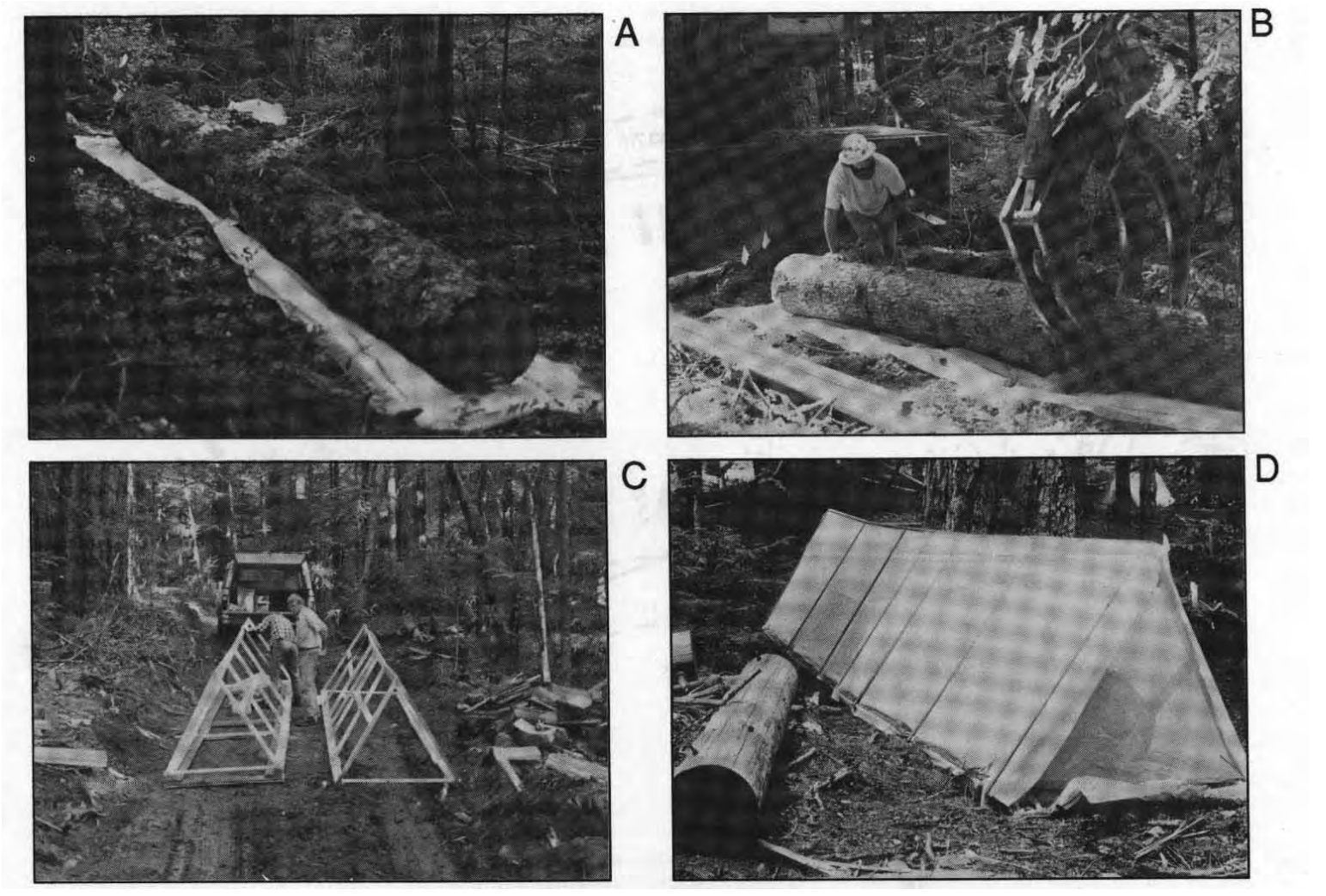

Figure 5—Construction of insect exclosures used in log-decomposition experiment at the H.J. Andrews Experimental Forest, Oregon. (A) Screen placed on cleared bed. (B) Log being guided onto screen. (C) Construction of exclosure frames. (D) Completed exclosure with log inside.

Initial Conditions

Log descriptions—Bark coverage, length, and diameters were measured to characterize the initial condition of each log. The total area of bark missing was measured to the nearest 0.01 square meter by using a 20- by 50-centimeter metal-framed grid. Diameter was measured at both ends and the middle of the log by using calipers. The maximum and minimum diameters were measured at each point to calculate the mean diameter. Log length was measured to the nearest 1 centimeter and represented a mean length when the ends were not cut parallel. The total length of the log suspended off the ground was measured to the nearest 0.1 meter. The number of freshly cut branches was counted on each log to indicate if the log was from the bole or the crown of a tree. Log volume was calculated by using Newton's formula,

$$V = L\,(A_b + 4A_m + A_t) / 6\ ,$$

where V is the volume; L is the length; and A_b, A_m, and A_t are the area of the base, midpoint, and top of the log. Surface area was calculated as if the logs were frustums of cones.

A total of 66 logs were remeasured by a second crew to test the precision of the length, diameter, and bark-cover measurements. Remeasured length averaged 0.19 percent lower than the initial measurement (sd = 0.48 percent). Diameter measurements were less precise; remeasurements averaged 1.2 percent higher than the original measurements (sd = 1.9 percent). The area of bark missing had the lowest precision of the three variables; however, when expressed as a percentage of the log covered in bark, the remeasurement was 0.63 percent higher than the original values (sd = 1.51 percent). To increase the precision of future measurements, the original values should be checked against the remeasurement values.

Log density and moisture content--To characterize initial density, moisture content, and volume of tissue in each log, a cross section 8- to 10-centimeters thick was removed from each end. All cross sections were wrapped in black plastic bags and stored at 2 °C until they were processed. The cross sections were photographed and digitized to estimate the volume of outer bark, inner bark, sapwood, and heartwood (fig. 6).

To assess the influence of colonization patterns on log decomposition, wood density was sampled radially. A rectangular block of wood was roughcut through the center of each cross section by chainsaw. In symmetrical cross sections (that is, pith in the center), a single block was removed. In asymmetrical cross sections, the first block was removed along the long axis, and a second block was removed perpendicular to the long axis of the cross section. For both types of cross sections, portions of the cross section with large knots were avoided when possible. A table saw was used to trim the blocks to precise cross-sectional area (75 by 50 millimeters), and then smaller blocks were cut-either 25 millimeters or 38 millimeters wide in the radial dimension (fig. 7). Each block was assigned a number according to the order it was removed from the larger blocks. The prepared blocks were sorted into sapwood, mixed, or heartwood categories. Samples were identified as to type, log number, end, and piece by bar-code labels. All subsequent measurements (weight and dimensions) were referenced to these labels by microcomputer and a bar-code reader. The volume of knots within each block was visually estimated by checking against prepared standards.

The radial, longitudinal, and tangential dimensions were measured with calipers to the nearest 0.1 millimeter on each cross-section cut. Sampling a subset of trimmed large blocks indicated that the cross-sectional area was smaller in the center than at the ends (fig. 8). A polynomial relation was found that could be used to estimate the cross-sectional area at any point to within 1.8 percent of the actual value by using the cross-sectional area at both ends and the middle. The tangential and longitudinal dimensions at both ends and the middle were used to parameterize this relation for each cross section. The weight of each block before and after ovendrying was determined to the nearest 0.01 gram by using an electronic digital balance linked to a microcomputer. Ovendrying was at 55 °C for 7 days.

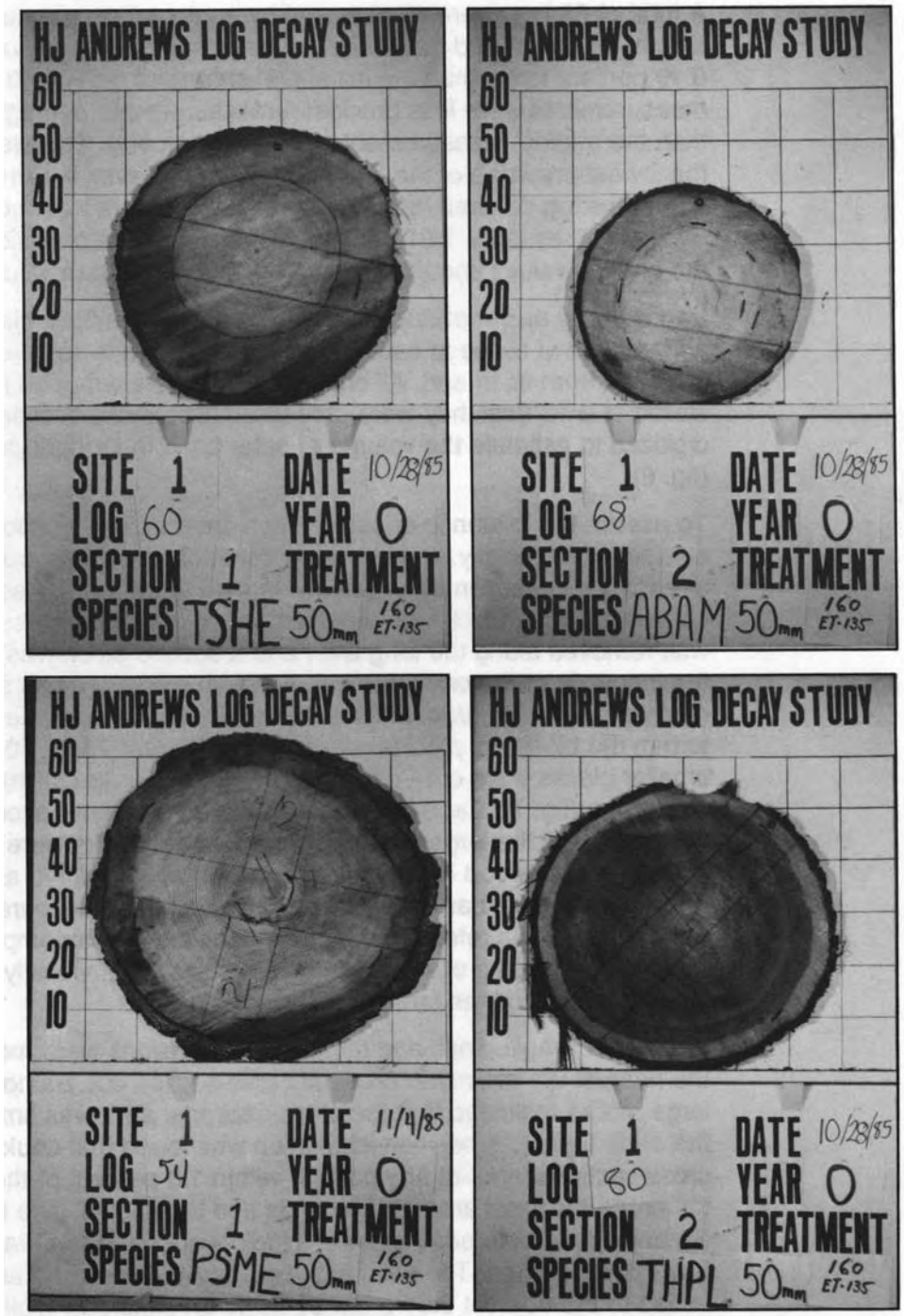

Figure 6-Example of photographs taken to document the initial conditions of log.

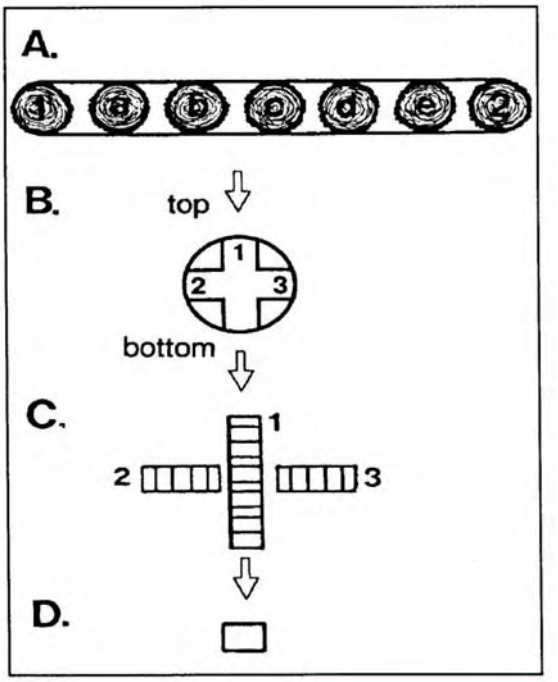

Figure 7—Cutting of samples for density profiles in log-composition experiment (A) Cross sections 1 and 2 were removed initially from logs, whereas cross sections a to e were removed during subsequent sampling (B) Each cross section is divided into one or three blocks for density Sampling. (C) Each block is subdivided into smaller blocks. (D) Smaller blocks are used for density determination.

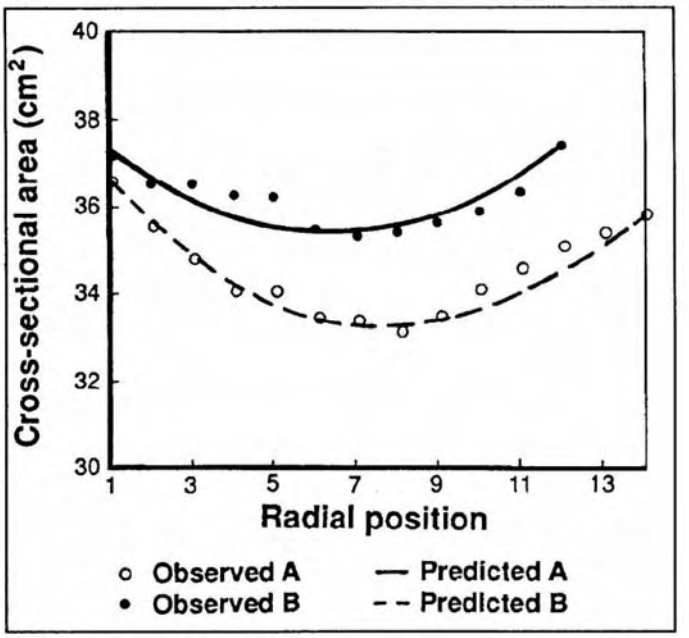

Figure 8 --Cross-sectional area of blocks cut on tablesaw as a function of radial position. The lines were predicted by assuming cross-sectional area was a polynomial function of the distance from the center.

Outer and inner bark were also sampled for density and moisture content for each cross section. After recording the thickness at four points of each cross section, a subsample of bark was removed along a 20- to 30-centimeter length of the circumference. The radial, longitudinal, and tangential dimensions of these pieces were recorded. For radial dimensions, at least six measurements were made to give a reasonable average. The area in voids in the outer bark was also estimated to the nearest 10 square millimeters by using a grid. Outer and inner bark were separated by chisel for all species, except Pacific silver fir. The weight of each bark sample before and after ovendrying was determined to the nearest 0.01 gram by using an electronic digital balance linked to microcomputer. Ovendrying was at 55 ^{o}C for 7 days.

Even when the area in outer bark voids was accounted for, a comparison to water displacement indicated significant problems with accuracy. The previously ovendried outer bark samples were therefore soaked in water 48 hours, and then volume was measured to the nearest 1 cubic centimeter by water displacement.

Moisture content, calculated from the weight before and after ovendrying, was expressed as a percentage of ovendry weight. Density was calculated as ovendry weight over green volume. For outer bark samples, volume was based on water displacement; for other tissues it was based on dimensional analysis. A subsampling of wood blocks at 5-percent moisture content indicated a mean shrinkage of 7.8 percent (se = 0.3, N = 70). Assuming a linear relation between shrinkage and moisture content below 25 percent, ovendry volume would be 9.7 percent smaller than green volume. This shrinkage relation is slightly less than those previously reported (12.4-13.0 percent) (USDA 1972).

Nutrient content and carbon chemistry--Each tissue type was sampled from a subset of 10 logs of each species for nutrient content and cell wall carbon chemistry (that is, lignin, cellulose, acid detergent fiber). For bark, a separate set of subsamples was removed and stored frozen until processing. Sapwood and heartwood samples were removed from the ovendried pieces. All tissues were first coarse ground and then fine ground with a Wiley mill to pass a 40-mesh screen. Nitrogen content was measured by using microKjeldahl digestion. Concentration of assorted elements—including calcium, copper, iron, potassium, magnesium, manganese, phosphorus, sulfur, and zinc--were measured by inductively coupled argon spectroscopy. Acid detergent fiber, permanganate lignin, and cellulose were measured by using the procedures of Goering and Van Soest (1970). Unextracted material was used for these analyses.

Long-Term Data Storage

The data collected on initial conditions and from subsequent samples have been stored on magnetic disk in the Department of Forest Science Data Bank, Oregon State University, Cowallis. Copies of the original data forms are also stored in Cowallis with the project principal investigator. In addition to the data itself, the experimental design, sampling frequency, type and format of the data, and programs used to process the data are stored in the data bank (table 14). Those interested in the data should contact the project principal investigator or the data bank manager.

Table 4-Characteristics of logs used in the decomposltion experiments at H.J. Andrews Experimental Forest

Parameter	Species			
	Douglas-fir	Pacific silver fir	Western hemlock	Western redcedar
Diameter (centimeters)	51.8	51.7	51.4	53.1
Standard error	.4	.6	.4	.5
Length (meters)	5.51	5.52	5.52	5.52
Standard error	.01	.01	.01	.01
Volume (cubic meters)	1.178	1.164	1.170	1.246
Standard error	.019	.025	.019	.026
Surface area (meters^2)	8.963	8.904	8.924	9.207
Standard error	.069	.099	.074	.095
Bark cover (percent)	98.4	99.0	97.5	99.3
Standard error	.1	.2	.2	.1
Sample size	120	108	120	108

Initial Conditions of Experiment

Log Characteristics

The initial exterior characteristics of the species used in this experiment were quite similar. Logs of all four species were similar in final length, but differed in diameter, volume, surface area, and bark cover (table 4). The mean diameter of western redcedar was 53.1 centimeters, in contrast to 51.4 to 51.7 centimeters for the other three species. These differences in diameter caused western redcedar to have a slightly higher volume and surface area than the other three species, which were quite similar to each other. Mean log volume ranged from 1.164 to 1.246 cubic meters, and mean surface area ranged from 8.904 to 9.207 square meters. Mean bark cover of all the species was high, ranging from 97.5 to 99.3 percent, thereby indicating logs were yarded, transported, and placed without major bark loss. The lowest bark cover occurred for western hemlock, which has the thinnest bark.

Tissue Volume

In all species, except western hemlock, heartwood comprised the greatest proportion of log tissues, and inner bark comprised the least (table 5). Wood comprised most log tissues in all four species, with Douglas-fir having the least (87.2 percent) and Pacific silver fir having the largest (91.3 percent) fraction of logs in wood. For all species, except western hemlock, heartwood volume was larger than sapwood volume. The amount of heartwood was smallest in western hemlock (41.3 percent of log) and largest in western redcedar (74.1 percent of log). The proportion of sapwood versus heartwood in the experimental logs was similar to previously reported values (Lassen and Okkonen 1969). Although sapwood thickness was most variable in Pacific silver fir and western hemlock, variations in these two species are less likely to affect the decomposition rate than they are for Douglas-fir or western redcedar. Bark comprised a smaller proportion of the logs than wood, but still made up 8.7 to 12.8 percent of the logs. The values for all species except Douglas-fir are comparable with the values reported by Wilson and others (1987).

Table 5--Proportion of logs in 4 tissue types

Species of log parameter	Proportion of log volume			
	Outer bark	Inner bark	Sapwood	Heartwood
	Percent			
Douglas-fir:				
Mean	8.9	4.0	28.5	58.7
Standard error	.6	.3	1.0	1.0
Sample size	24	24	24	24
Pacific silver fir:				
Mean	8.7	na	39.5	51.8
Standard error	.27	na	1.8	1.8
Sample size	24	24	24	24
Western hemlock:				
Mean	6.2	3.2	49.4	41.3
Standard error	.3	.1	1.9	1.9
Sample size	24	24	24	24
Western redcedar:				
Mean	6.5	3.4	16.0	74.1
Standard error	.3	.2	1.3	1.4
Sample size	24	24	24	24

Density and Moisture Content

The initial moisture content differed both among species of log and type of tissue (tables 6-9). The differences in moisture content reflected the physiological activity of the tissues, with sapwood and inner bark having higher moisture content than heartwood and outer bark. The highest moisture content was in western redcedar sapwood (220.5 percent), whereas the lowest was in Douglas-fir outer bark (30.4 percent). Heartwood of Pacific silver fir and western hemlock had higher moisture content than that of Douglas-fir and western redcedar because some logs contained wetwood. Pacific silver fir outer bark was intermediate between the outer and inner bark of the other three species. The relative values of the tissues reported here are similar to those reported by Peck (1953) and Wilson and others (1987), although the absolute values sometimes differed substantially.

The initial density of tissues also differed among species and matched previously reported values closely (Maeglin and Wahlgren 1972, Wilson and others 1987). Inner bark had the lowest density, ranging from 0.352 to 0.417 gram per cubic centimeter (tables 6-9). The highest density was for Pacific silver fir outer bark (0.571 gram per cubic centimeter), which was very hard and stiff. The wood of Pacific silver fir and western redcedar (0.318-0.350 gram per cubic centimeter) was considerably less dense than that of Douglas-fir and western hemlock (0.403-0.473 gram per cubic centimeter). With the exception of western redcedar, sapwood for all species was denser than heartwood. Density tended to increase with radial distance from the pith (fig. 9). The lower density of western redcedar sapwood may be a reflection of the high extractive content of the heartwood of this species.

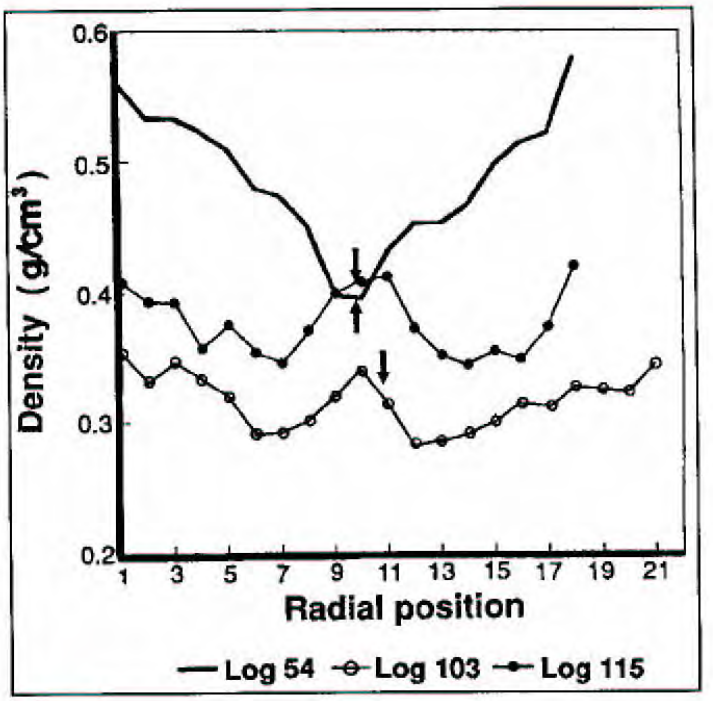

Figure 9--Radial-density profiles of selected log cross sections. Log 54 is typical of anincrease from the center. Logs 103 and 115 illustrate a high density in the center and the outer portions of the cross section. Arrows indicate the center of each cross section.

Density profiles were variable enough that a simple, accurate relation between density and distance from the center could not be developed to predict initial density. Understanding the initial wood-density profile will be essential to test the effects of colonization patterns on log decomposition. The density of wood was a function of the distance from the center, differing as much as 30 percent within a cross section (fig. 9). In many cross sections, wood density increased with distance from the pith, as described by Spurr and Hsiung (1954). Density in some logs, however, was high both in the center and in the outer parts of the stem. This pattern reflected an early period of suppression followed by rapid growth.

Nutrient Content

The inner bark of all species was highest in nitrogen, phosphorus, potassium, and calcium content (figs. 10-13). Sapwood and heartwood of all four species were similar in initial concentrations of these elements, although the heartwoods of Pacific silver fir, Douglas-fir, and western redcedar were extremely low in phosphorus (less than 27 parts per million). Outer bark element concentrations were similar to wood for phosphorus and potassium, but for nitrogen and calcium were intermediate between wood and inner bark. The initial concentration of these four elements was similar to those reported by Harmon and others (1986) for bark and wood of conifers.

The initial carbon/nitrogen (C/N) ratio of all the tissues was very high compared to leaf litter of the Pacific Northwest region (leaves have a range of 23-166; Harmon and others 1990). Inner bark, which had the highest nitrogen content, had a C/N ratio that ranged between 178 and 250. The C/N ratio of woods of all the species was similar and ranged between 454 and 714.

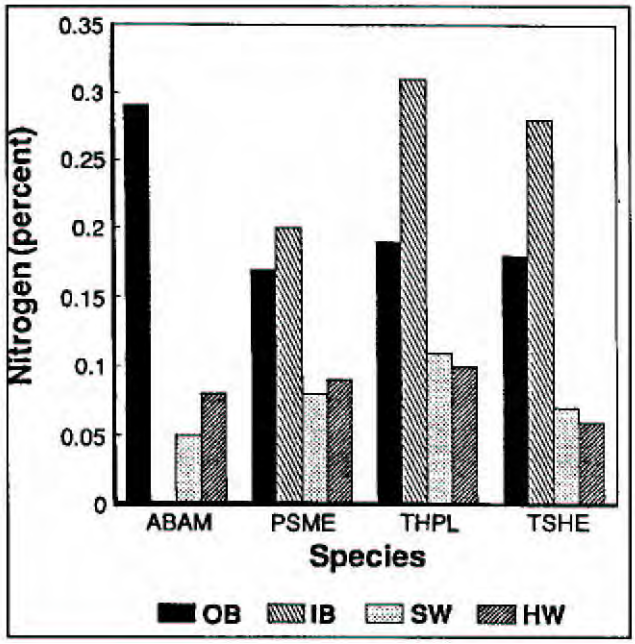

Figure 10–Initial nitrogen content of log tissues used in log-decomposition experiments at the H.J. Andrews Experimental Forest, Oregon.

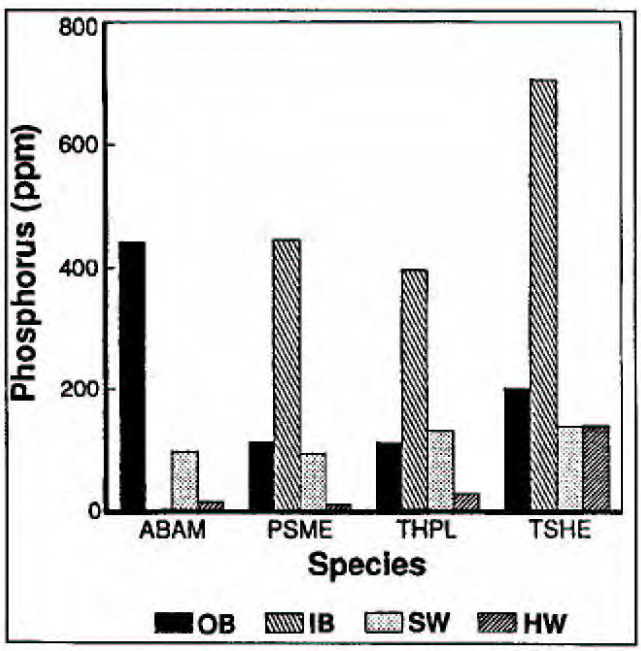

Figure 11-Initial phosphorus content log tissues used in log-decomposition experiments at the H.J. Andrews Experimental Forest, Oregon.

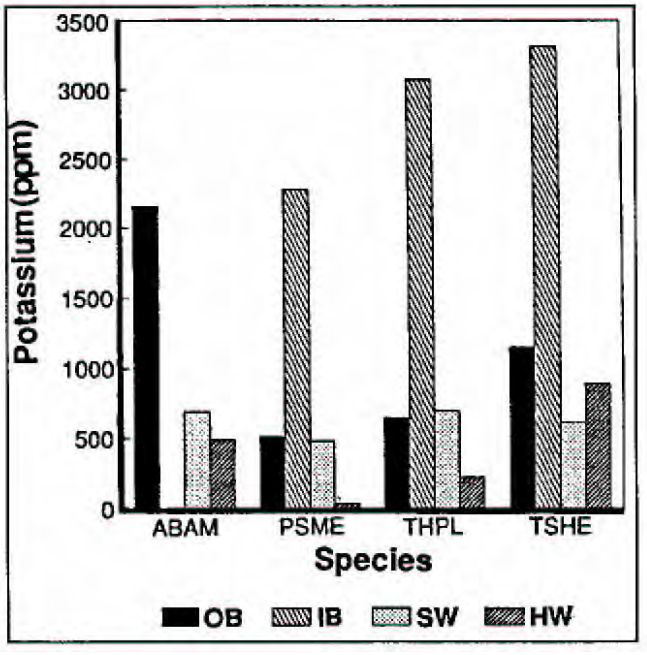

Figure 12–Initial potassium content log tissues used in log-decomposition experiments at the H.J. Andrews Experimental Forest, Oregon.

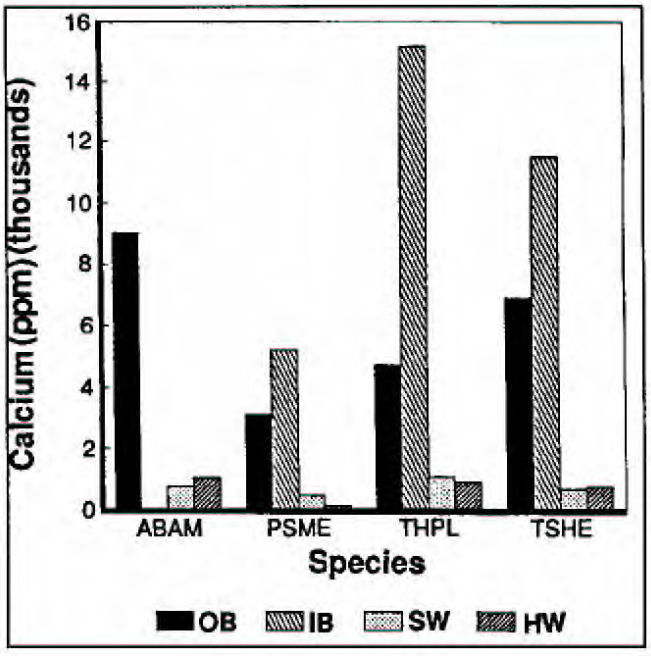

Figure 13-Initial calcium content log tissues used in log-decomposition experiments at the H.J. Andrews Experimental Forest, Oregon.

Lignin/nitrogen ratio, another index of decomposability, was also very high for the tissues from the experimental logs when contrasted to leaf litter (leaves have a range of 5-80, Harmon and others 1990). Inner bark had the lowest lignin/nitrogen ratio ranging from 93 to 132. The lignin/nitrogen ratio for wood was very similar and ranged from 318 to 399. Based on the lignin/nitrogen ratio, the decomposition rate of all the tissues would be expected to be similar because at ratios exceeding 50 the relation is asymptotic.

Cell Wall Carbon Chemistry

Of all the tissues, outer bark was the highest in lignin (36 to 41 percent) and the lowest in cellulose (20 to 32 percent) (tables 10-13). The bark lignin is unlikely to be chemically equivalent to wood lignin, however, and may actually be composed of several compounds (Chang and Mitchell 1955). The sapwood and heartwood in each species was generally similar in composition. Hemicellulose, cellulose, and lignin in wood ranged from 22 to 28 percent, 38 to 43 percent, and 29 to 35 percent, respectively. The values of wood lignin were generally 2 to 3 percent higher than those reported for extractive free wood, but the ordering of species was similar (Harmon and others 1986). Conversely, cellulose was 4 to 7 percent lower than that reported for extractive free wood.

Conclusions

This report described the establishment of a long-term experiment on three factors that control the decomposition and nutrient cycling in coarse woody debris. It is tempting to conclude that the results from a long-term study will not be realized until the distant future. This downplays the role long-term studies have in providing continuity for generations of scientists. Each generation will discover new aspects of the log-decomposition process as new stages are entered. Thus it is more useful to consider this a series of short-term studies linked by a common set of sites and experimental material.

It is also tempting to suggest that a long-term study will become inactive between the establishment and concluding stages. This is a misleading application of the long-term study concept. The log-decomposition experiment is currently very active, and density and nutrient samples have been taken from the logs for 4 years. Even at this early stage, the dual effects of substrate heterogeneity and colonization have been expressed, and the relative ranking of decay rates for species has changed over the course of the experiment. For example, western hemlock decomposed slower than Douglas-fir for the first 3 years, but in the long term the opposite should occur. The speed of decomposition for some species (Pacific silver fir) are more rapid than expected with 9 percent of the mass being lost between the third and fourth years. Other species (western hemlock) are decomposing slower than expected, and some (Douglas-fir and western redcedar) are decomposing at rates close to those observed in chronosequences. Studies of insect attacks (Zhong and Schowalter 1989) and colonization of the decomposer food web (Carpenter and others 1988) have revealed the variety of species and individuals causing the start of the decay process. New discoveries are being made that were not anticipated at the outset of this study. The role excess moisture plays in limiting respiration of decomposers has also been revealed by seasonally examining decomposition (Carpenter and others 1988). Repeated measurements of nitrogen fixation, denitrification, leaching, fragmentation, and fungal phenology from the log experiment indicated that fungal fruiting bodies are the major pathway through which nitrogen is exported from logs during early decomposition. This is contrary to results from fine litter studies, in which fungi initially immobilize nitrogen. What other surprises lay ahead?

Common and Scientific Names

Plants:

Douglas-fir	Pseudotsuga menziesii (Mirb.) Franco
Oregon grape	Berberis nervosa Pursh
Pacific silver fir	Abies amabilis Dougl. ex Forbes
Western rhododendron	Rhododendron macrophyllum G. Don
Western hemlock	Tsuga hetemphylla (Raf.) Sarg.
Western redcedar	Thuja plicata Donn ex D. Don
Western twinflower	Linnaea borealis L.

Invertebrates:

Ambrosia beetles	Gnathotrichus sulcatus (LeConte)
	Trypodendron lineatum (Oliver)

Acknowledgments

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Appendix

Table 6—Initial density and moisture content of Douglas-fir log-tissue types

Parameter	Outer bark	Inner bark	Sapwood	Heartwood
		Grams/cubic centimeters		
Density:				
Mean	0.443	0.417	0.473	0.445
Standard error	.003	.006	.004	.002
Sample size	302	307	316	316
		Percent of dry weight		
Moisture content:				
Mean	30.4	112.9	122.0	31.4
Standard error	.5	1.2	1.3	.3
Sample size	305	306	316	316

Table 7—Initial density and moisture content of Pacific silver fir log-tlssue types

Parameter	Outer bark	Inner bark	Sapwood	Heartwood
		Grams/cubic centimeters		
Density:				
Mean	0.571	na	0.377	0.354
Standard error	.022	na	.003	.003
Sample size	211	na	215	216
		Percent of dry weight		
Moisture content:				
Mean	74.4	na	147.1	65.2
Standard error	1.0	na	1.9	2.3
Sample size	213	na	215	216

na = not applicable.

Table 8—Initial density and moisture content of western hemlock log-tissue types

Parameter	Outer bark	Inner bark	Sapwood	Heartwood
		Grams/cubic centimeters		
Density:				
Mean	0.442	0.261	0.417	0.403
Standard error	.004	.006	.002	.002
Sample size	303	312	314	314
		Percent of dry weight		
Moisture content:				
Mean	33.4	119.7	138.5	53.2
Standard error	-6	1.4	1.4	1.6
Sample size	315	309	314	314

Table 9—Initial density and moisture content of western redcedar log-tissue types

Parameter	Outer bark	Inner bark	Sapwood	Heartwood
		Grams/cublc centimeters		
Density:				
Mean	0.322	0.352	0.318	0.347
Standard error	.004	.005	.007	.003
Sample size	213	215	215	215
		Percent of dry weight		
Moisture content:				
Mean	36.2	129.5	220.5	38.4
Standard error	.7	1.2	218	1.1
Sample size	213	215	215	215

Table 10-Initial acid detergent, lignin, and cellulose content of Douglas-fir log-tissue types

Parameter	Outer bark	Inner bark	Sapwood	Heartwood
		Percent		
Acid detergent fiber:				
Mean	31.58	34.44	24.61	27.01
Standard error	.99	1.08	.47	.87
Sample size	11	12	11	11
Lignin:				
Mean	47.23	34.07	28.78	29.80
Standard error	.81	.54	1.19	.32
Sample size	11	12	11	11
Cellulose:				
Mean	20.78	31.13	46.18	42.74
Standard error	1.01	.67	1.07	.88
Sample size	11	12	11	11

Table 11 —Initial acid detergent, lignin, and cellulose content of Pacific silver fir log-tissue types

Parameter	Outer bark	Inner bark	Sapwood	Heartwood
		Percent		
Acid detergent fiber:				
Mean	33.76	na	26.49	26.86
Standard error	1.09	na	.48	.69
Sample size	11	na	11	11
Lignin:				
Mean	39.04	na	31.92	31.66
Standard error	.53	na	1.75	.69
Sample size	11	na	11	11
Cellulose:				
Mean	26.32	na	40.94	40.72
Standard error	1.16	na	1.78	.81
Sample size	11	na	11	11

na = not applicable.

Table 12—Initial acid detergent, lignIn, and cellulose content of western hemlock log-tIssue types

Parameter	Outer bark	Inner bark	Sapwood	Heartwood
		Percent		
Acid detergent fiber:				
Mean	38.39	33.63	26.59	28.54
Standard error	.66	.75	.61	.44
Sample size	9	11	9	9
Lignin:				
Mean	40.64	37.16	31.71	32.93
Standard error	5 4	.84	.40	1.33
Sample size	9	11	9	9
Cellulose:				
Mean	20.36	28.88	41.19	38.13
Standard error	.66	1.13	.79	1.23
Sample size	9	11	9	9

Table 13—Inltial acid detergent, lignin, and cellulose content of western redcedar log-tissue types

Parameter	Outer bark	Inner bark	Sapwood	Heartwood
		Percent		
Acid detergent fiber:				
Mean	29.42	37.81	22.38	26.76
Standard error	1.39	2.01	1.05	.80
Sample size	10	12	9	9
Lignin:				
Mean	36.55	29.16	34.97	34.03
Standard error	.75	1.14	.86	1.51
Sample size	10	12	9	9
Cellulose:				
Mean	32.59	32.74	42.21	37.62
Standard error	1.07	1.25	.77	1.85
Sample size	10	12	9	9

Table 14--Definition of format types within the Forest Science Data Bank that store data from the log-decomposition experiment[a]

Format number	Definition
1	External characteristics of logs including diameter, length, bark cover, volume, and surface area
2	Area of outer bark, inner bark, sapwood, heartwood, stain, and rot in log cross sections
3	Volume, external dimensions, density, and moisture content of for each sample
4	Wet and dry weight of each sample used in density and moisture content calculations
5	External dimensions of regular-shaped wooden samples
6	Arrangement of samples within a cross section
7	Volume of knot tissue within wood samples
8	Weight and moisture content of twig and branchwood samples used in the size experiment being run in conjunction with the log experiment
9	Radial thickness of outer and inner bark from cross sections
10	Number of insect galleries for logs sampled subsequent to establishment
11	Lignin, cellulose, acid detergent fiber, and ash content of tissue samples from logs
12	Nutrient content of tissue samples from logs including nitrogen, phosphorus, potassium, calcium, magnesium, manganese, zinc, and sulfur
13	Survey notes on the distance, bearing, and slope between logs and posts
14	Counts of fungal fruiting bodies for selected logs after establishment

[a] Located at Oregon State University, Corvallis; all files are stored under the datacode TD14.

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Harmon, Mark E. 1992. Long-term experiments on log decomposition at the H.J. Andrews Experimental Forest. Gen. Tech. Rep. PNW-GTR-280. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 28 p.

A long-term decomposition experiment was established at the H.J. Andrews Experimental Forest, Oregon, during 1985, to test the importance of substrate heterogeneity, colonization patterns, and invertebrates on the decomposition of logs. The duration of the study is anticipated to be 200 years. A total of 530 logs (50 centimeters in diameter and 5.5 meters long) were placed at six old-growth forest sites. Characteristics measured for each log at the start of the experiment included diameter, length, volume, surface area, bark cover, and the total volume, density, and moisture content of outer bark, inner bark, sapwood, and heartwood. A subsample of logs was examined for lignin, cellulose, ash, calcium, copper, iron, nitrogen, potassium, magnesium, manganese, phosphorus, sulfur, and zinc content. Data on initial conditions and subsequent measurements are being stored at the Forest Science Data Bank, Oregon State University, Cowallis.

Keywords: Coarse woody debris, decay, decomposition, Douglas-fir, fallen trees, logs, Pacific silver fir, western hemlock, western redcedar.

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