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Distribution of Biomass and Nutrients in Lodgepole Pine/Bitterbrush Ecosystems in Central Oregon

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Abstract

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We investigated the distribution of biomass and nutrients in lodgepole pine (*Pinus contorta* var. *murryana* Dougl.) ecosystems on pumice soils in south-central Oregon. Sixty-three trees were sampled to develop equations for estimating dry weights of tree crowns, boles, bark, and coarse roots from diameter at breast height and height. The concentrations of total carbon, nitrogen, phosphorus, and sulfur were determined for each of these components. Biomass, nutrient concentrations, and nutrient contents of the associated vegetation, forest floor, woody debris, fine roots, and soil horizons also were determined. An example stand illustrates the use of these data for determining the effects of bole versus whole-tree harvesting on nutrient capital in a lodgepole pine ecosystem.

Keywords: Nutrient concentrations, nutrient contents, biomass equations, lodgepole pine ecosystems, bole-only harvesting, whole-tree harvesting.

Summary

Biomass, nutrient concentrations, and nutrient contents were measured at several locations in the lodgepole pine/bitterbrush plant association in central Oregon. These estimates were used to construct an ecosystem nutrient budget and to compare the effects of bole-only and whole-tree harvesting on the nutrient budget. The biomass and nutrient concentrations of the forest floor, soil, residue, and shrubs were measured by area. Biomass equations for lodgepole pine trees were developed through destructive sampling.

The development of the local biomass equations indicated that more than 90 percent of the variation in bole, crown, root, and bark dry weight could be explained by height, diameter, or both. Biomass and nutrient concentrations were used to estimate nutrient content so that the effects of whole-tree and bole-only harvesting on ecosystem nutrient capital could be compared. The forest floor, the shrub component, and the crowns of trees had the highest nitrogen, phosphorus, and sulfur concentrations. The soil had the lowest nutrient concentrations but had high estimates of mass. Because of this high mass, total nutrient contents were greatest in the soil and comprised more than 90 percent of the carbon, nitrogen, phosphorus, and sulfur in the ecosystem.

The sampling method used did not examine whole stands but sampled representative individual trees and associated areas. Nutrient contents of whole stands were estimated by using stand table information from an inventory done in the area. The heights and diameters of the inventory stand were used to estimate biomass components for the trees from the locally developed biomass equations. Based on this specific stand, the whole tree component comprised 48.2 percent of the ecosystem's carbon, 4.6 percent of the nitrogen, 0.8 percent of the phosphorus, and 2.0 percent of the sulfur.

Based on these estimates, removal of whole trees resulted in about 10 percent more carbon loss from the site than that lost with bole-only harvesting. Because the aboveground portion of the trees contributed little to total ecosystem nitrogen, phosphorus, and sulfur (less than 5 percent for each), the whole-tree harvest removal of nitrogen differed from that of bole-only removal by 3 percent, and by less than 1 percent for phosphorus and sulfur. The differences between the two harvesting systems were determined by the fate of the crown material. The large apparent nutrient capital in the soil causes estimates of nutrients removed during harvest of the trees to appear rather small.

Contents

Introduction

Demand for wood products and energy continues to grow, but the land base to meet this demand may be declining (USDA 1990). Innovative ways of producing wood products include exploring underutilized species and alternative harvesting and processing technologies. Lodgepole pine (*Pinus contorta* var. *murryana* Dougl.), once considered to be of marginal economic value, is becoming recognized as a valuable resource by both the wood products and energy industries. In the United States, commercial forests of lodgepole pine occupy nearly 5.25 million hectares (Koch 1987). Although most stands are in Idaho and Montana, the species occupies large areas on the east side of the Cascade Range in Washington and Oregon (Bassett and Oswald 1983, Gedney and others 1989). In particular, extensive, nearly pure stands of lodgepole pine grow in the xeric environments of south-central Oregon.

Interest in the lodgepole pine resource comes as managers and landowners would like to convert large areas of declining or decadent stands to healthier ones. About 100 000 hectares of lodgepole pine in south-central Oregon have become decadent—pathologically old—with a consequent increased susceptibility to the mountain pine beetle (*Dendroctonus ponderosae*). This decline has created serious problems for land managers. Various markets for wood products from the declining stands must be explored so that their harvest can proceed ahead of the beetle epidemic. The National Forests have made some progress in selling dead lodgepole pine to fiber markets; however, they must look to new markets to harvest the susceptible timber and curtail the current beetle epidemic.

The potential loss of thousands of hectares of trees to beetles and the increase in the demand for wood make utilization of decadent stands both economically profitable and ecologically desirable. But intensive utilization may impair long-term site productivity because the pumice soils of south-central Oregon are relatively young and thought to be nutritionally impoverished. Examination of the pumice soils suggest that some nutrients are in short supply (Cochran 1975, 1979; Will and Youngberg 1978; Youngberg and Dyrness 1964, 1965). Research is needed to examine potential impacts of off-site export of nutrients that result from harvesting.

Choice of harvesting method and utilization will affect site resources and subsequent productivity through impacts on soil nutrient capital and soil physical properties. Numerous studies in a wide variety of forest types indicate that the nutrient capital of forest sites are directly influenced by the amount of tree biomass removed and the treatment of logging residue (Ballard 1976, 1978; Benson 1982; Boyle and Ek 1972; DeBayle 1980). Because of the propensity for foliage and branches of many conifers to contain a large store of nutrients (Auclair and Rencz 1982, Smith and others 1986, Webber 1976), several researchers suggest that harvesting all aboveground material, particularly in short rotations, may result in greater loss of nutrients than will occur with bole-only harvesting (Ballard 1976, Johnson 1983, Smith and others 1986, White 1974). Estimates from Kimmins and others (1985) also suggest whole-tree harvesting may result in twice the nutrient removal as bole-only harvesting. No information specific to our study area is documented in the literature.

The objective of this study was to provide estimates of biomass and nutrient distributions in south-central Oregon lodgepole pine ecosystems, so that the potential impacts of different harvesting strategies on the nutrient capital in these ecosystems could be evaluated. Data and examples presented in this paper are intended to provide estimates of nutrient loss from two harvest intensities in this forest type.

Materials and Methods

Site Description

We sampled from populations in the lodgepole pine/bitterbrush (*Pursia tridentata*) community of south-central Oregon. The sites are harsh and of poor quality (Carlson 1979). Elevation ranges from 1200 to 1500 meters above sea level (Carlson 1979). The climate is characterized by dry summers, with high temperatures during the day and nighttime temperatures near to below freezing, and cold winters when much of the 50 centimeters per year of precipitation falls as snow.

Sites were provided by the Crescent District, Deschutes National Forest, and the Chemult and Chiloquin Districts, Winema National Forest. These sites were on pumice soils created by Mount Mazama. In some places, this mantle of Mazama pumice is overlain by subsequent pumice flows from South Sister, Devil's Hill, and Newberry Craters (Williams 1944) and is underlain at various depths by older soils. These pumice soils are relatively low in organic matter and often excessively well drained. The rooting zone of this community often is confined to the top 30-50 centimeters of soil because of the poor nutrient status, coarseness of pumice particles, and cementation of lower horizons. The water-holding capacity of the soil is high, but availability is low because of excessive drainage, thus reducing the ability of soil to store some essential nutrients. Temperature extremes also are common in these soils (Cochran and others 1967). Hence the climate, coupled with young, poorly developed soils, results in slow rates of decomposition of organic matter, nutrient turnover, and nutrient availability. Controlled experiments on seedlings and in fertilization trials suggest that pumice soils are deficient in nitrogen (N), sulfur (S), and phosphorous (P) (Cochran 1975, 1979; Will and Youngberg 1978; Youngberg and Dyrness 1964, 1965). Inputs from precipitation and N-fixation are low in this system.

Sample Design and Harvest Techniques

Our objective was to characterize biomass and nutrient concentrations for lodgepole pine/bitterbrush ecosystems likely to be entered for harvesting. We therefore restricted our sampling to stands older than 50 years and to living trees more than 2 meters tall. Sample trees were single stem (no forks or other physical injuries to the stem) and were not severely infected with mistletoe. These criteria best characterized the harvestable resource.

Our sampling design was based on the assumptions that (1) nutrient capital in the soil is relatively homogeneous over the lodgepole pine/bitterbrush type; (2) N, S, and P may be deficient in this ecosystem; (3) nutrient concentrations differ significantly among tree components for an individual tree; and (4) crown properties differ with tree size and competition factors. These assumptions were based on research conducted within the study area and in other lodgepole pine communities (Cochran 1975, 1979; Gary 1976; Singh 1982; Will and Youngberg 1978, 1979). Given these assumptions, we designed our sampling scheme to capture two principal sources of variation thought to influence total tree nutrient capital: tree size (as measured by diameter at breast height [d.b.h.]) and level of apparent competition affecting the individual tree (the number, size, and proximity of neighboring trees). We therefore stratified our sample of trees into 10 d.b.h. classes and 3 levels of competition based on subjective estimates of the degree of crown closure or overlap. Crown closure surrounding a sample tree of 0 to 30 percent was considered low competition, 31 to 70 percent was considered medium competition, and greater than 70 percent was considered high competition. This stratification was designed to encompass, but not necessarily explain, major sources of variation in tree biomass and nutrient concentration.

Trees were selected for sampling by using a random number generator and a mapping grid—equivalent to intersections of one-sixteenth of a township—laid across a map of the lodgepole pine/bitterbrush community on the two forests. Randomly selected points on the grid were located on the ground. A random azimuth and distance from the grid point were taken, and the tree nearest the end of this distance that met sampling requirements was selected for measurement. A second tree likewise was chosen after a new random azimuth and distance from the grid point were selected. Use of multiple locations defined by the grid ensured sampling some spatial variation in the lodgepole population. Sampling of two trees per location reduced field costs. The two trees selected at each grid point were at least 100 meters apart to avoid overlap in the fixed-area sampling (described below). If a location had no trees filling the sampling requirements, the next random point was visited. This procedure was repeated until all strata were filled (64 trees total). Data from 63 trees are reported here, as the first tree was sacrificed to perfect sampling procedures.

Each tree was felled, measured for volumetric calculations, and subsampled for moisture content and chemical concentrations (see below). Woody residue, shrubs, and large roots were sampled on fixed-area plots around each tree. Soil and fine roots were sampled from 0.25-square-meter columns at one randomly chosen location at each grid point. Methods are detailed below by component.

Figures 1 and 2 illustrate the measurement and sampling scheme used. The diameter of each tree was measured at 1.3 meters above the ground. The tree was felled and the total height and the length of the crown were measured to the nearest centimeter. We defined the base of the live crown as the position on the bole where two live branches in separate planes belonged to the same whorl (fig. 1). The live crown was divided into thirds by its length along the bole. Each third was removed, weighed, and divided into branch diameter size classes (0 to 1, 1 to 2, and > 2 centimeters). These branch diameter classes were then weighed and sampled for moisture and nutrient content. Open cones, closed cones, and dead branches above and below the base of the live crown were weighed and sampled separately. Branch material from each stratum was chipped in the field before sampling. A sample of about 500 grams was taken intact from each 0- to 1-centimeter branch strata for drying and separation into needles and twigs.

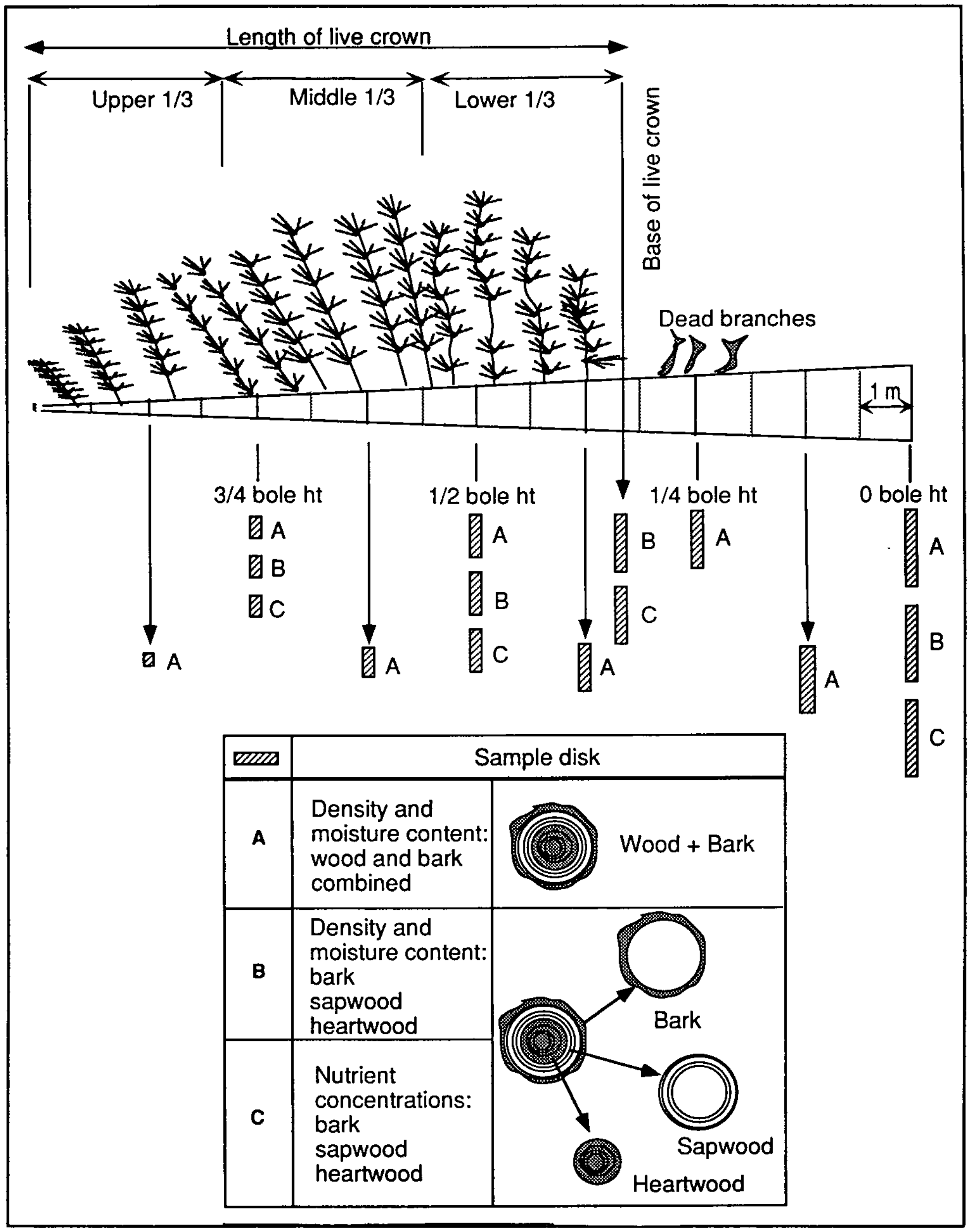

Figure 1—Sampling strategy for aboveground tree biomass and nutrient components.

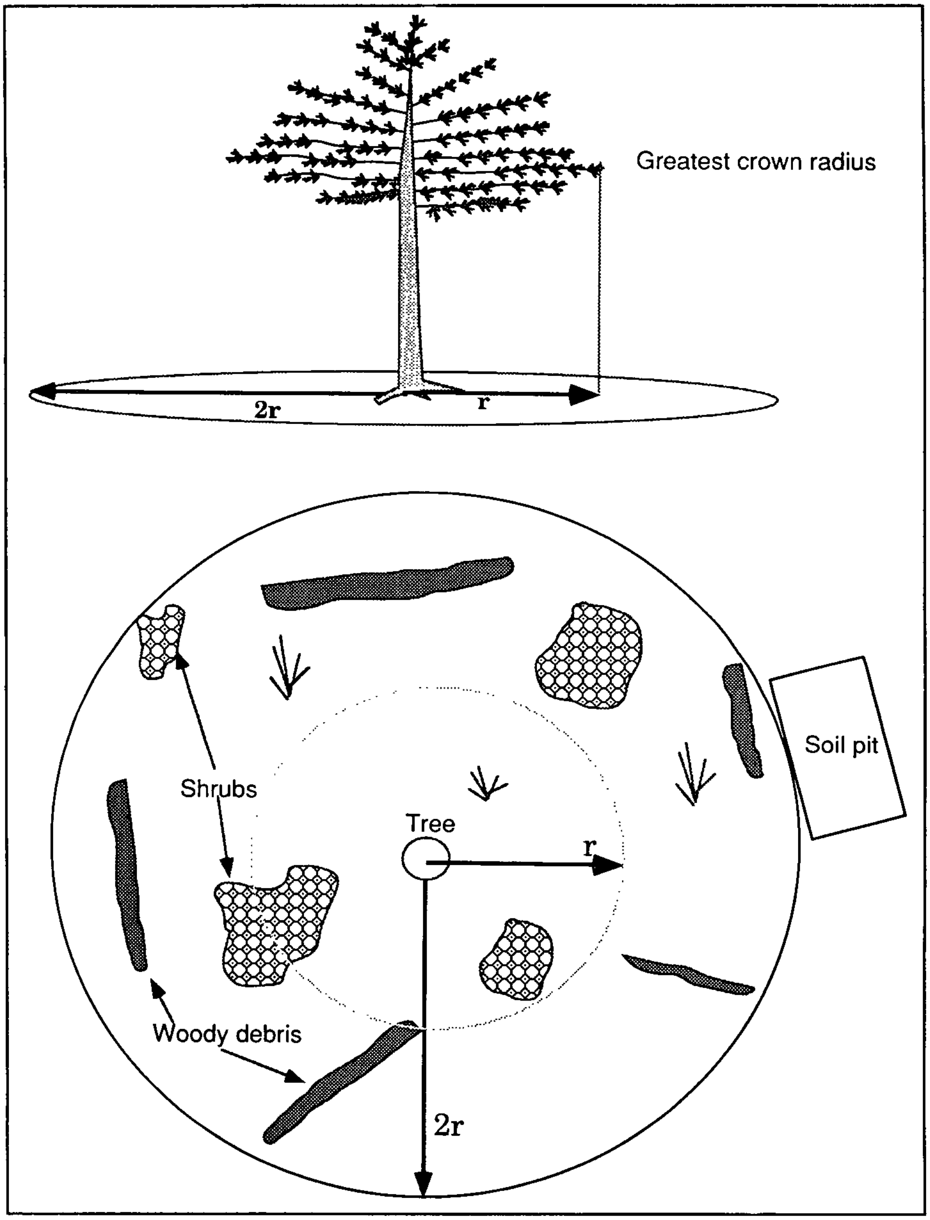

Figure 2—Sampling area for shrubs, herbs, and residue. Sampling was done in a circular area, with a radius of 2r, where r is the maximum live crown radius of the sample tree.

The bole of the tree was marked at 0.5-meter intervals beginning at the base. At every 0.5-meter location, diameter outside bark and bark thickness were measured to the nearest 0.5 centimeter. At every 2 meters, beginning at the base, a disk was cut for density and moisture analysis ("bole" disks) (fig. 1). Two additional disks ("component" disks) were taken at the 2-meter locations closest to one-fifth, two-fifths, three-fifths, and four-fifths of the bole length (fig. 1). Two disks at the base of the live crown were substituted for those that would have come from the closest one-fifth location to obtain information on bole attributes at the base of the live crown. One component disk of each pair was used to determine the density and moisture content of the heartwood, sapwood, and bark, and the other was for chemical analyses. All remaining bole segments were weighed in the field immediately after the disks were removed. The diameter of the bole disk and the radial width of components (sapwood, heartwood, and bark) were measured to the nearest 0.1 centimeter along two perpendicular axes for all disks. Bark, sapwood, and heartwood then were separated on the component disks. The bole disks and components were individually weighed (green weight) to the nearest gram on a single pan microbalance and then weighed while submerged in water to determine their volume (Heinrich and Lassen 1970).

Around each tree a circular area was established with a radius (2r) of twice the length of the longest live branch of the tree (fig. 2). All shrubs and herbaceous material aboveground within the sample area were removed, divided by species, weighed, chipped, and sampled for chemical and moisture analyses. Residue was defined as all woody material larger than 5 millimeters in diameter and sound enough to pick up without falling apart. Residue included dead branches and logs, standing or leaning dead trees, and dead shrubs but did not include cones, dead grass, dead animals, or synthetic material; the latter (except synthetics) were considered part of the forest floor. All residue within the sample area was collected and weighed in the field. A representative portion was chipped and sampled for moisture content and chemical analyses.

Preliminary excavations revealed lateral root lengths in excess of 20 meters. To obtain some estimate of large root biomass associated with individual trees and stay within cost constraints, the roots of 20 sample trees were excavated within 1 meter of the stump. The stump also was removed for analysis. Roots were divided into four size classes: 0 to 1, 1 to 2, 2 to 5, and 5 centimeters and larger in diameter. Roots and stump were washed, air dried, weighed, chipped, and sampled for chemical and moisture analyses.

Soils and fine roots were sampled by horizon within a 0.25-square-meter frame. This frame was located at a random azimuth 1 meter outside the 2r radius of a randomly chosen sample tree at each location (fig. 2). Each horizon was sieved in the field to pass a 2-millimeter screen, rolled, and sampled for chemical analyses. We tested the adequacy of field sieving by drying and sieving all material 2 centimeters and larger on half of the soil pits, and found that additional soil obtained through this process was less than 3 percent of total soil by weight for all horizons sampled and less than 1 percent on all but three horizons—well within sampling error for the field-sieved weights. All roots were collected by horizon within the same sampling column, air dried, brushed clean, weighed, and sampled for moisture and chemical analyses. Bulk density was determined at midhorizon in adjacent soil by using a technique detailed in Flint and Childs (1984). About 500 grams of soil was removed for analysis. Soil volume was determined by measuring the volume of the hole remaining. This "irregular hole" technique was used because pumice does not core well.

Laboratory Techniques

All samples used for chemical analyses were air dried for 2 weeks and ground to pass a 20-mesh screen. Chemical analyses were conducted by the Oregon State University Department of Forest Science. Nitrogen and phosphorus samples were digested by the micro-Kjeldahl method (350 °C; K_2SO_4, $CuSO_4$, and Se as catalysts) and analyzed with a continuous flow analyzer (Scientific Instruments Model 200).[1] Soil S was analyzed by Perkin-Elmer 4000 Atomic Absorption Spectrophotometer. Plant S was analyzed by the turbidity method described by Tabatabai (1970). Carbon (C) was determined with a Leco induction furnace.

Weights presented are dry weights, unless otherwise specified, obtained through oven drying at 103 °C. Samples were dried until a consistent weight was obtained but not for less than 48 hours. Samples to be used for chemical analyses were air dried at room temperature for 2 weeks to prevent decomposition. Concentrations are presented by dry weight. Dry density of wood was calculated as dry weight per green volume.

Calculations

The volume of 1-meter bole-outside-bark segments was determined from Newton's formula:

$$V_m = 0.00007854(L)\ [(D_l^2 + 4D_m^2 + D_s^2)/6]\ ,$$

where

V_m = the cubic volume of the stem in cubic meters,

L = the length of the segment in meters,

D_l = the large-end diameter of the bole segment in centimeters,

D_m = the diameter at the middle of the bole segment in centimeters, and

D_s = the diameter at the small end of the bole segment in centimeters.

The volume inside bark was determined by using the same formula with inside-bark dimensions, and a similar procedure was used for the heartwood. Bark and sapwood volumes were calculated by subtraction. The volume of each 1-meter bole segment was multiplied by the dry density of the associated bole disk to obtain the dry weight of the whole segment. The dry density for each bole segment was determined from an average of the bole disks located on each end of the bole segment. The dry weight of each segment was computed by multiplying the segment volume by the segment density. The weights of segments were summed to a total for the entire bole. The same procedure was used to determine dry weights for the bark, sapwood, and heartwood from the five dissected disks.

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[1] The use of trade or firm names is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Chemical concentrations (C, N, P, and S) for bark, heartwood, and sapwood were computed by averaging the four bole disk samples. The contribution of each bole disk's value to the average was weighted by its diameter, the measurement found most valuable in describing the relation between concentration and vertical location within the bole. Data presented are for bolewood (heartwood + sapwood) and bark.

Chemical concentrations of samples within the crown and bole of individual trees differed by location within the tree ($p<0.05$ among all size classes and vertical positions). Because of the relation of concentration to vertical position in the crown, the estimates of nutrient concentration for crown components (needles and twigs) for each tree were computed based on proportion. For each component, the estimate of concentration was calculated as the sum of concentrations of the individual samples multipled by the proportion of total component weight represented by the vertical third of the crown from which the sample came.

Residue and shrubs were sampled around each tree in areas proportional to the crown width of the associated tree (fig. 1). Some locations had larger sample areas than others. Overall estimates of weight and chemical concentrations for residues and individual shrub species were calculated proportionally. Estimates of weight or chemical concentration were the sum of the weight or concentration of the sample multiplied by the ratio of that individual sample's area to the sum of all sampled areas.

Statistical Considerations

Each tree was regarded as an independent sample for the purpose of developing weight estimates and for investigating within-tree variation of nutrient concentrations. The assumption of independence was thought reasonable, because the distance between trees sampled at a location (>100 meters) was deemed sufficient that they did not influence each other. Standard deviations for these analyses therefore include between-tree variation at a given location and variation among locations.

All statistical analyses were performed by using SAS (SAS 1985). Biomass equations were developed through regression analysis. Dry weights of the total tree, bolewood, bark, crown, stump, and coarse roots were regressed against d.b.h., total tree height, and the height to the base of the live crown. Logarithmic transformations of both the dependent and independent variables were necessary to correct for the lack of homogeneity in variable variances. Although logarithmic tranformations commonly are used to develop biomass equations, such equations give biased estimates when retransformed.

The Student's *t*-statistic was used to determine the significance of differences in nutrient concentrations in different parts of the tree crown. Pearson correlations were used to examine interrelations between soil and tree variables. The tree closest to the soil pit was used in analyses of relations between soil and tree variables (sample size=32).

Results and Discussion

Table 1 summarizes the statistics for the trees sampled and gives the range, maximum, minimum, and standard deviation of measured parameters. The trees sampled ranged widely in size and in the number and basal area of trees surrounding them (expanded to a per-hectare basis for comparison to other stocking levels). Ranges of tree component weights also are provided in table 1.

Table 1—Average, standard deviation, and range of characteristics of sampled trees in lodgepole pine ecosystems in south-central Oregon on pumice soils

Component	Sample size	Mean	Standard deviation	Range	
				Minimum	Maximum
Tree density (trees/ha)[a]	61	1912	3722	99	22236
Basal area (m^2/ha)	61	215.8	2878	36	8402
D.b.h. (cm)	62	26.4	14.0	3.7	60.3
Height (m)	61	18.1	6.7	3.5	29.4
Weights (kg/tree):					
Crown	62	103.5	126.7	1.4	510.0
Bolewood (inside bark)	60	170.5	165.2	1.2	668.4
Bark	60	19.5	18.5	.2	72.1
Roots	23	53.7	46.0	.5	141.7
Stump	15	40.1	59.2	3.7	225.6

[a] Estimated from number and basal area of neighbors in an area = 2r.

Allometric equations for predicting tree component weights from d.b.h. and height are presented in table 2. Diameter at breast height was always a significant variable (at the 95-percent confidence level) predicting crown, bolewood, bark, root, and stump biomass (table 2). Total tree height was a significant variable only in the equations predicting bolewood and bark weight (table 2). Ninety percent or more of the variation in tree biomass components was attributable to d.b.h. or height, or both, in logarithmically derived relations, thereby indicating an adequacy for prediction of dry weights for lodgepole pine trees and their components in this region.

Estimates of Ecosystem Biomass

Mean values for biomass estimates of other ecosystem components are provided in table 3. *Purshia* sp. was the most abundant shrub in terms of biomass. Average biomass for area roots, forest floor, and residue were on the order of 10.3, 20.0, and 23.7 metric ton per hectare, respectively. Soil components comprised the greatest mass in the ecosystem, ranging from 1141 to 3096 metric ton per hectare. Variation in these estimates of biomass per hectare from sample to sample was high (table 3).

Nutrient Concentrations

A summary of nutrient concentrations, expressed as the percentage of total dry weight of the component, is provided in table 4, with details for tree components displayed in table 7 in the appendix. Carbon concentration within all plant components ranged from 49 to 51 percent and differed little among species or tree components (table 4). Concentrations of C in the soil were considerably less, ranging from 0.02 to 3.3 percent.

Table 2—Equations for predicting biomass components of lodgepole pine from diameter by height (d.b.h.) and total height (ht)[a]

Biomass component	Equation	Coefficient of determination used for the regressions	Sample size
Crown DWT[b]	$\exp\{-3.60224246 + 2.35937645[\ln(d.b.h.)]\}$	0.93	62
Bole DWT[b]	$\exp\{-3.69827199 + 1.82510722[\ln(d.b.h.)] + 1.02277263[\ln(ht)]\}$	.94	62
Bark DWT[b]	$\exp\{-4.72344497 + 1.80138021[\ln(d.b.h.)] + .51273919[\ln(ht)]\}$	.92	62
Root DWT[b]	$\exp\{-3.35510955 + 2.14759125[\ln(d.b.h.)]\}$	.71	23
Stump DWT[b]	$\exp\{-5.43383555 + 2.40323151[\ln(d.b.h.)]\}$	.24	23

[a] All parameter estimates are significantly different from 0 at the 95 percent level of confidence.
[b] DWT = dry weight/tree in south-central Oregon on pumice soils.

Table 3—Average, standard deviation, and range of measured biomass components in lodgepole pine ecosystems in south-central Oregon on pumice soils

Component	Sample size	Mean	Standard deviation	Range	
				Minimum	Maximum
Purshia spp. (kg/ha)	62	945.0	739.0	0	2529.0
Ribes spp. (kg/ha)	62	15.0	96.0	0	624.0
Advanced regeneration (kg/ha)	62	214.0	580.0	0	2610.0
Area roots (t/ha)	32	10.3	7.8	1.7	44.4
Forest floor (t/ha)	34	20.0	19.5	0	70.9
Residue (t/ha)	62	23.7	35.9	0	179.1
Soil profile (t/ha):					
Horizon 1	34	1690.5	1726.5	76.0	8410.5
Horizon 2	34	2981.3	2209.7	216.0	10440.0
Horizon 3	34	3096.2	2819.4	129.0	11421.0
Horizon 4	32	1295.2	1593.7	0	5548.0
Horizon 5	31	1141.1	3592.2	0	19437.6

The shrubs had the highest concentrations of N, P, and S of all ecosystem components sampled (table 4). The composite sample of plant parts for the shrubs had twice the N-concentration and nearly twice the concentration of P as the crowns of the trees. Of all sampled tree components, the greatest concentrations of N, P, and S resided in the crown (table 4), with average concentrations of 0.42 percent N, 0.06 percent P, and 0.01 percent S. Within the crown, the highest concentrations of N, P, and S were in the youngest, most metabolically active, least lignified components, such as the needles (table 7). The stump had the lowest concentrations of all sampled nutrients. The nutrient concentrations in the soil were the lowest of all ecosystem components and, in general, declined with depth of horizon (table 4).

Table 4—Average nutrient concentrations of lodgepole pine tree components and other ecosystems in south-central Oregon, expressed as the percentage of component weight (kg of nutrient/kg dry weight of component × 100)[a]

Ecosystem component	Nutrients			
	Carbon	Nitrogen	Phosphorus	Sulfur
	Percent of component weight			
Tree components:				
Crown	51.3 (1)	0.42 (0.12)	0.064 (0.020)	0.016 (0.004)
Bolewood	49.3 (.6)	.06 (.01)	.008 (.003)	.003 (.002)
Bark	50.1 (1.5)	.25 (.06)	.050 (.010)	.012 (.010)
Roots	50.0 (1.9)	.07 (.02)	.018 (.009)	.007 (.004)
Stump	50.8 (.8)	.05 (.01)	.006 (.003)	.002 (.002)
Shrubs:				
Purshia spp.	50.0 (7.0)	1.33 (.33)	.102 (.046)	.022 (.007)
Ribes spp.	49.8 (1.2)	1.05 (.43)	.141 (.107)	.032 (.019)
Other:				
Area roots	49.1 (2.2)	.36 (.14)	.080 (.025)	.022 (.007)
Forest floor	40.2 (10.8)	.80 (.27)	.095 (.020)	.026 (.010)
Residue	48.9 (9.1)	.14 (.13)	.010 (.007)	.006 (.003)
Soil horizons:				
1	3.34 (2.54)	.12 (.12)	.056 (.028)	.0084 (.005)
2	.59 (.59)	.05 (.05)	.035 (.017)	.0054 (.003)
3	.12 (.22)	.04 (.03)	.031 (.018)	.0041 (.003)
4	.02 (.01)	.04 (.03)	.032 (.020)	.0040 (.004)
5	.02 (.02)	.03 (.02)	.035 (.020)	.0028 (.003)

[a] Standard deviations are given in parentheses.

Our values for individual component concentrations of nitrogen and phosphorus are within the range of those previously reported for needles, branchwood, and boles (Comeau 1986, Fahey 1983, Pearson and others 1984). Our needle concentrations were comparible to Comeau's mesic-poor site and slightly higher than Pearson's site (although values are within one standard deviation as calculated from our data). Based on a rating system published in Weetman and Fournier (1982), our sites would be considered "very severely deficient" in N and "slight to moderately deficient" in P.

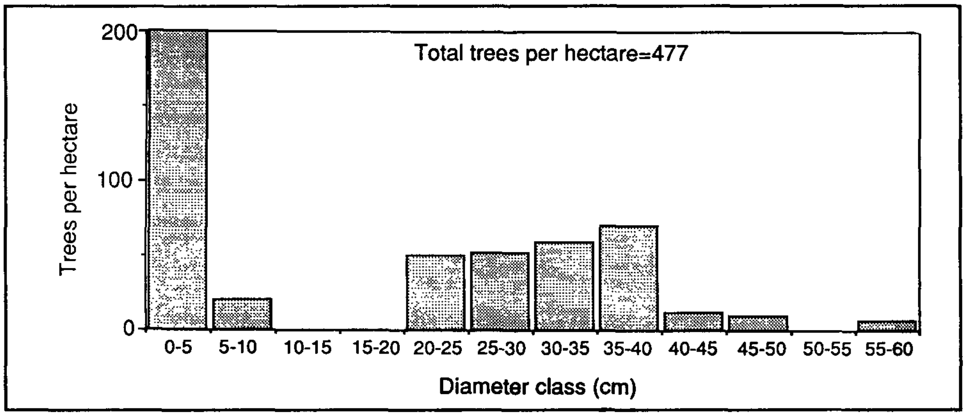

Figure 3—Diameter distribution for the example stand.

Research on lodgepole pine in Canada indicates that nutrient concentrations of tree components differ with site and stand factors (Beaton and others 1965). Research on lodgepole pine in central Oregon indicates that nutrient concentrations within individual components of a tree do not vary with site factors (Will and Youngberg 1979). Our data support this and indicate that variation in tree nutrient concentration cannot be associated with any site factor or consistently correlated with any soil variables. Sampling more trees per site on sites specifically chosen for particular soil or stand attributes might provide for a more powerful test of among-site variation. The only detectable pattern in nutrient concentrations was that some of them changed with tree size. Crown N, P, and S were all negatively correlated with d.b.h. and height ($p<0.0001$), as were bark N and P ($p<0.0001$) and bolewood P ($p<0.001$).

Samples used for nutrient concentration determinations were removed from the field over an entire summer and thus represent a seasonal average. Seasonal changes in foliar nutrient content have been observed by various researchers in other locations. Gower and others (1989) showed that for lodgepole pine in the northern Cascades, N and P contents in needles are fairly constant across the season for older foliage. New foliage peaked in concentrations of both N and P in July, declined through August, and stablized into November. Specific impacts of harvesting on nutrient removal may be more refined if nutrient concentrations for a target harvest period are determined. Whether temporal fluctuations in nutrients are insignificant when considering the degree of accuracy in other values such as biomass estimates, sampling, and other errors is unknown.

Example Application

Example Stand Characteristics

Because we did not sample a whole stand, estimates of potential harvest impacts were developed for an example stand drawn from forest inventory plots established and measured by the USDA Forest Service within the study area. The stand chosen was, of those available, the least affected by previous mortality of harvesting. A distribution of diameters was generated from the inventory of live trees on variable radius plots and is illustrated in figure 3. Individual tree biomass components were predicted from the biomass equations (table 2) to convert d.b.h. and height to crown, Step 1. Calculate kilograms/tree biomass for each component by using the biomass equations (table 2) to convert diameter and height data to biomass estimates for each tree component.

For each d.b.h. class:
Crown weight = exp{-3.60 + 2.36(Ln[DBH])} -->kg crown/tree
Bole weight= exp{-3.70 + 1.82(Ln[DBH] + 1.02(Ln[HT])} -->kg bole /tree
Bark weight= exp{-4.72 + 1.80 (Ln[DBH] + 0.51(Ln[HT])} -->kg bark/tree

Step 2. Calculate nutrient content by multiplying tree biomass components by their respective nutrient concentrations (table 4).

For each d.b.h. class:
Crown N= (kg crown/tree from step 1) x (0.42) -->kg crown N/tree
Crown P= (kg crown/tree from step 1) x (0.064) -->kg crown P/tree
Bole N= (kg bole/tree from step 1) x (0.06) -->kg bole N/tree
Bole P= (kg bole/tree from step 1) x (0.008) -->kg bole P/tree
Similarly for nutrient contents in bark.

Step 3. Calculate nutrients per hectare by multiplying kilograms/tree estimates obtained in step 2 by tree density (stocking) if a clearcut method is used, or by the number of trees to removed, if selective cutting is used.

For each d.b.h. class:
kg crown N/tree x trees/ha -->kg crown N/ha
kg crown P/tree x trees/ha -->kg crown P/ha
kg bole N/tree x trees/ha -->kg bole N/ha
kg bole P/tree x trees/ha -->kg bole P/ha
kg bark N/tree x trees/ha -->kg bark N/ha
kg bark P/tree x trees/ha -->kg bark P/ha

Step 4. Calculate total nutrient removal based on type of harvest (bole vs whole tree; high or low thinning) by selecting the biomass components the dbh classes to be removed.

For whole-tree clearcutting, the removal of N will be:
a. Sum of crown N/ha (from step 3) over all dbh classes -->kg/ha
b. Sum of bole N/ha (from step 3) over all dbh classes- -->kg/ha
c. Sum of bark N/ha (from step 3) over all dbh classes -->kg/ha

Sum of crown, bole, and bark N/ha -->kg/ha

For bole-only clearcutting, the removal of N will be:
a. Sum of bole N/ha (from step 3) over all d.b.h. classes -->kg/ha
b. Sum of bark N/ha (from step 3) over all d.b.h. classes -->kg/ha

Sum of bole and bark N/ha -->kg/ha

Figure 4—Step-by-step process for using the data provided in this report to estimate nutrient removal. Examples are for N and P, but the process can be used for any chemical for which concentrations are known.

bolewood, bark, root, and stump weights in kilograms per tree. Estimates of each biomass component were then summed across all trees to provide estimates of tree components per hectare. Nutrient contents were calculated as the product of weight and concentrations for each component from table 4. Figure 4 provides the step-by-step procedure for use in the field for any data set and illustrates how standard information from routine stand exams can be used.

Table 5—Nutrient content of tree and other ecosystem components estimated for a sample lodgepole pine ecosystem in south-central Oregon on pumice soils[a]

Ecosystem component	Total weight of component	Nutrients: Carbon	Nitrogen	Phosphorus	Sulfur
	Ton/hectare	*Million grams/hectare*	*Kilograms/hectare*		
Trees:					
Crown	28.0 (18.5)	14.4 (18.6)	118.8 (57.1)	17.8 (55.3)	4.3 (45.7)
Bolewood	94.6 (62.6)	46.7 (62.0)	59.6 (28.6)	7.9 (24.5)	3.0 (31.9)
Bark	6.3 (4.2)	3.1 (4.1)	15.6 (7.5)	3.1 (9.6)	0.8 (8.5)
Roots	16.9 (11.1)	8.4 (11.1)	11.3 (5.4)	3.1 (9.6)	1.2 (12.8)
Stump	5.2 (3.4)	2.7 (3.6)	2.8 (1.3)	.3 (.9)	.1 (1.0)
Total	151.0	75.3	208.1	32.2	9.4
Soil profile:					
Horizon 1	1690.0	40543.6	1342.2	816.5	102.5
Horizon 2	2981.3	12380.7	1434.5	1078.2	143.0
Horizon 3	3096.2	2643.4	844.8	1182.6	131.9
Horizon 4	1295.2	252.9	331.4	541.3	52.6
Horizon 5	1141.1	133.0	142.8	436.8	19.5
Horizons 1+2	4671.3	52924.3	2776.7	1894.7	245.5
Total	10203.8	55953.6	4095.8	4055.5	450.1
	Kilograms per hectare				
Other components:					
Residue	123723	11856.1	23.1	2.0	1.0
Forest floor	20085.0	7577.9	161.1	19.4	5.5
Fine roots	10346.0	5056.0	33.2	7.7	2.2
Shrubs	1174.0	588.9	12.9	1.3	.2

[a] Percentage of total tree nutrients found in each tree component indicated in parentheses. For soil and other components, percentage of ecosystem totals found in each ecosystem component are provided in parentheses.

Weights and Contents

The tree component contained the most carbon of all ecosystem components, with an estimated total of 75.3 megagrams per hectare (table 5). The tree C-component comprised 48.2 percent of the total ecosystem C (table 6). The soil profile had the next highest amount of C, with 55.9 megagrams per hectare, which comprised 35.8 percent of the ecosystem's C. The rest of the ecosystem components contributed less than 10 percent each to the total ecosystem C.

Table 6—Percentage of total nutrient capital represented by each ecosystem component

Ecosystem component	Nutrient			
	Carbon	Nitrogen	Phosphorus	Sulfur
	Percent			
Trees (total)	48.2	4.6	0.8	2.0
Soil profile	35.8	90.3	98.5	96.1
Residue	7.6	.5	>.1	.2
Forest floor	4.8	3.6	.5	1.1
Fine roots	3.2	.7	.2	.5
Shrubs	.4	.3	>.1	>.1

Despite its low nutrient concentrations, the soil had the greatest N, P, and S contents because of its large mass. More than 4000 kilograms per hectare of N and P were contained in soil (table 5), which represented more than 90 percent (table 6) of the ecosystem totals for those key nutrients. Ninety-six percent of the ecosystem's S was contained in the 450 kilograms per hectare estimated for the soil component (tables 5 and 6). The tree component represented the next largest store of ecosystem nutrients, with 4.6, 0.8, and 2.0 percent of the ecosystem's N, P, and S, respectively, at estimated contents of 208.1, 32.2, and 9.4 kilograms per hectare. Other components had little of the total nutrients in the ecosystem (tables 5 and 6).

Focus on the tree component of the ecosystem indicated that the bulk of the C, N, P, and S in this example stand resided in the aboveground parts (fig. 5). As expected, most of the C was in the bole, whereas the crowns contained a high proportion of tree N, P, and S.

This example is within the range of nutrient capital estimates for lodgepole pine sites in British Columbia. Comeau and Kimmins (1986) found bole and crown weights to be 68.1-156.3 and 5-25 tons per hectare, respectively, in lodgepole pine stands ranging in ages from 53 to 121 years and densities of 356 to 6,352 trees per hectare in xeric and mesic sites in British Columbia. They estimated foliar nitrogen at 41.4-111.5 kilograms per hectare. In our example, total crown N, including branches, was 118.8 kilograms per hectare. The example presented here had a stocking level of 477 trees per hectare and may not be fully stocked. In a more fully stocked stand, the proportion of C, N, P, and S in the aboveground portions of trees likely will be higher.

Removal of whole trees resulted in about 10 percent more loss of C from the site, according to the estimates displayed in figure 6. Because aboveground portions of trees contributed little to the overall site N, P, and S capital (less than 5 percent for each in the example stand), the difference in harvest strategy in N removal was about 3 percent, and less than 1 percent for P and S (fig. 6).

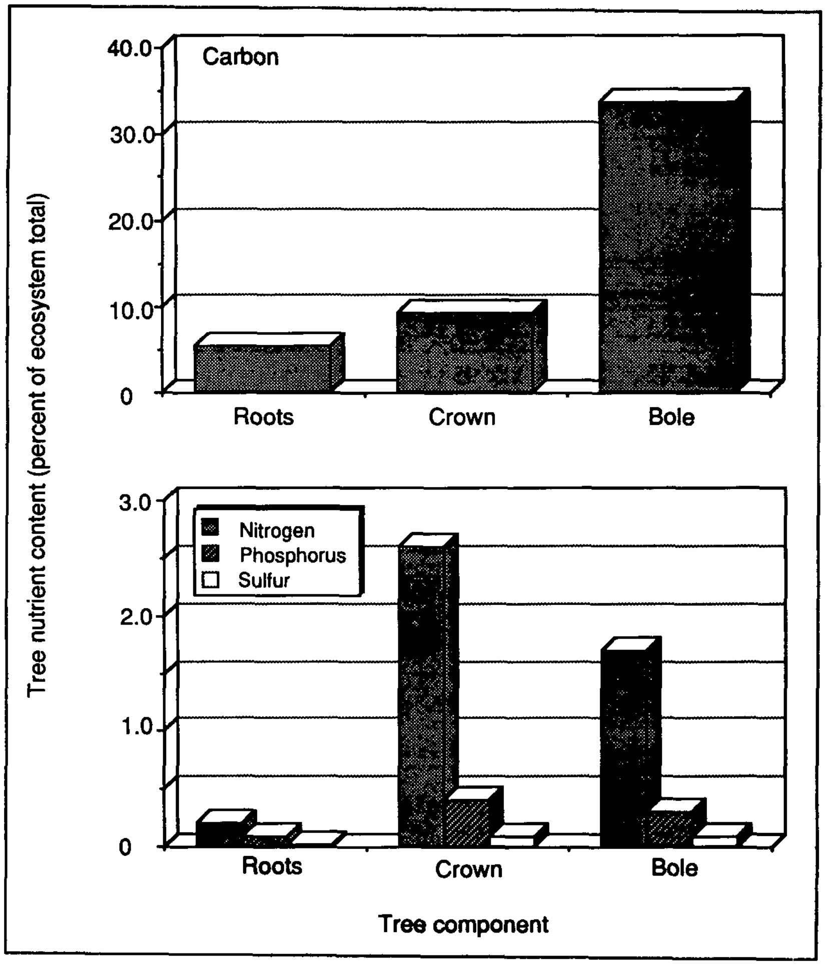

Figure 5—Percentage of total ecosystem nutrient content contained in trees.

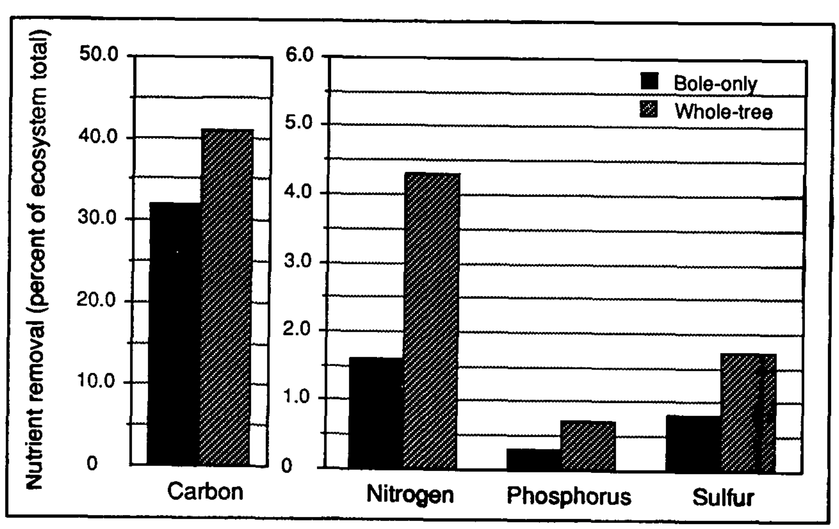

Figure 6—Percentage of total ecosystem nutrients removed by using bole-only and whole-tree harvesting in an example lodgepole pine stand.

Implications for Harvest Strategy

Substantial C is removed from the site under both harvesting methods. Although site productivity often is associated with the status of nutrients such as N and P, removing C from the site could be of equal or more concern in these forest types. In the lodgepole pine/bitterbrush ecosystems, soil C can be important in developing soil structure and in buffering against extremes in soil moisture and temperatures, particularly on these glasslike pumice soils.

Estimates of the impact of tree harvest on site capital can be influenced by the degree to which various depths or horizons of the soil are included (Kimmins 1977). In general, only those soil compartments representing potentially usable nutrient reservoirs should be considered. Our data indicated that 86 percent of the roots sampled, by area, were in the top two horizons of the soil, while 9, 1.9, and 0.4 percent were observed in the third, fourth, and fifth horizons, respectively. We calculated, however, the percentage of nutrients removed based on a sum of all soil horizons. Past simulations indicated that inclusion of all horizons gave similar results to calculations using only the first two horizons, mostly because of the immense differences between nutrient contents of the trees and of the soil.

Although the amount of nutrients removed from a site can be quantified from estimates of weight and nutrient concentrations of tree components, the impact of such removals on the ability of a site to support tree growth is more difficult to determine. The impacts of differential nutrient removals must be addressed given the total nutrient status of the soils and ecosystem and the potential for replenishment from sources such as atmospheric inputs and weathering. In addition, nutritional requirements of tree species are needed, yet often are undocumented.

A site budget for total nutrient capital derived in a static fashion, as presented here, does not address the temporal changes in these nutrient capitals or in the demand for them. More importantly, the availability of nutrients for uptake is difficult to evaluate. The nutrient contents in the soil, forest floor, and residue represent the future legacy for productivity. These pools are dynamic, though, and portions of the soil and residue resource may never be available for the production of fiber. Indeed, the soil nutrient content values are high because the weights of the soil horizons are on the order of thousands of metric tons per hectare, and not because nutrient concentrations are high. In fact, the soil had the lowest average nutrient concentrations of all ecosystem components. Our estimates of soil nutrient contents represent total nutrients, and do not necessarily represent those immediately available to the trees. Moore (1980) and Van Cleve and others (1981) showed that available N and P can be as little as one-one hundredth of the measured total N and P. In addition, little is known about the nutrient requirements of lodgepole pine. Processes by which removals are compensated by weathering, atmospheric input, or organic matter breakdown through microbial activity are relatively unquantified.

Nutrient capital budgets can be used to consider the potential direct loss of site nutrients through removal of tree biomass, but other losses may be important to the effects of logging on soil nutrient capital. Runoff and leaching also may respond differentially to whole-tree vs bole-only harvesting; for example, removal of whole trees will result in reduced residue under bole-only harvesting where crown materials are left. Reduced residues may result in elevated soil temperatures and ultimately affect mineralization and decomposition. Differential effects of use and residue manipulation on the reinvasion of vegetation also may indirectly influence nutrient balance through changes in nutrient capture, organic matter input, and cycling.

Although the example presented here is useful for illustration, we recommend that alternative harvest strategies be evaluated with site-specific information from the stand in question. This study provides estimates of nutrient concentrations and average nutrient contents for ecosystem components. Estimates of nutrient capital for specific stands can be obtained by applying these concentrations to estimates of biomass made from applying the biomass equations to stand inventory data. Average nutrient contents for soil, shrub, and residues can be adjusted by comparing the site in question to our average conditions. Residue loadings range widely, respond to different managment practices, and should be adjusted to local conditions.

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Appendix

Table 7—Average nutrient concentrations of lodgepole pine crown components: weighted average of all vertical positions[a]

Tree component	Nutrient concentration			
	Carbon	Nitrogen	Phosphorus	Sulfur
	Percent			
Needles	51.8 (0.6)	1.01 (0.26)	0.12 (0.03)	0.028 (0.06)
Twigs 0-1 cm	51.7 (.9)	.43 (.07)	.08 (.02)	.018 (.005)
Branches 1-2 cm	5.7 (1.4)	.22 (.06)	.04 (.01)	.010 (.002)
Branches >2 cm	5.3 (1.4)	.15 (.06)	.02 (.02)	.008 (.002)
Open cones	5.2 (1.0)	.23 (.09)	.02 (.01)	.007 (.003)
Closed cones	51.1 (1.8)	.61 (.30)	.13 (.11)	.018 (.011)

[a] Standard deviations are given in parentheses.

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Little, Susan N.; Shainsky, Lauri J. 1992. Distribution of biomass and nutrients in lodgepole pine/bitterbrush ecosystems in central Oregon. Res. Pap. PNW-RP-454. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p.

We investigated the distribution of biomass and nutrients in lodgepole pine (*Pinus contorta* var. *murryana* Dougl.) ecosystems on pumice soils in south-central Oregon. Sixty-three trees were sampled to develop equations for estimating dry weights of tree crowns, boles, bark, and coarse roots from diameter at breast height and height. The concentrations of total carbon, nitrogen, phosphorus, and sulfur were determined for each of these components. Biomass, nutrient concentrations, and nutrient contents of the associated vegetation, forest floor, woody debris, fine roots, and soil horizons also were determined. An example stand illustrates the use of these data for determining the effects of bole versus whole-tree harvesting on nutrient capital in a lodgepole pine ecosystem.

Keywords: Nutrient concentrations, nutrient contents, biomass equations, lodgepole pine ecosystems, bole-only harvesting, whole-tree harvesting.

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