AN ABSTRACT OF THE THESIS OF

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in Forest Soils presented on January 16, 1973.

Title: Plant Biomass and Nutrient Distribution in
a Young Pseudotsuga menziesii (Mirb.) Franco
Forest Ecosystem

Redacted for Privacy

Abstract approved:

Biomass and nutrient distribution in a forest ecosystem can be validly discussed, qualitatively or quantitatively, on either a component or a total basis. In the spring of 1968, a study was initiated to determine the biomass and nutrient distribution patterns in a young Pseudotsuga menziesii (Mirb.) Franco forest ecosystem on the Greater Victoria Watershed, Vancouver Island. Such information is basic to a more complete understanding of the effects of management practices upon ecosystems and such processes as nutrient cycling.

The ecosystem was fractionated into three main components - soil, understory vegetation and standing trees. Soil nutrient estimates were made on a volume/area basis for each horizon and summed for total profile content. Analyses performed included organic matter, total carbon, total nitrogen, bulk density, textural analysis, available phosphorous and exchangeable potassium, calcium and magnesium.

Plant biomass and nutrient evaluation of understory vegetation was performed on a milacre basis. Chemical analyses included total nitrogen, phosphorous, potassium, calcium and magnesium.

Field sampling for tree component analysis was performed on the basis of a predetermined stand table. Three trees for the lower, mid and upper heights of each diameter class (up to six classes) were sampled. Pseudotsuga menziesii trees were sectioned into thirds and subdivided into components, i.e., foliage by age classes, bark, wood and live and dead branches. Tsuga heterophylla (Raf.) Sarg. and and Thuja plicata (Donn.) were separated by thirds and subcomponents of current (1968) and older foliage, wood, bark and live and dead branches. Aggregated samples were analyzed for nitrogen, phosphorous, potassium, calcium and magnesium content.

Per hectare plant biomass and nutrient estimates were prepared using the following formula and a stand table.

$$w = a + b(x) \qquad \text{where} \quad w = \text{component weight}$$

$$x = D^2H$$

Evaluation of variable combinations of diameter and height showed that D^2H was the best independent variable for predicting plant biomass and nutrient content. Estimation of plant biomass and nutrient weight per hectare yielded higher r^2 for total tree analysis. r^2 for section analyses were lower.

Plant biomass and nutrient distribution patterns varied among and within ecosystem components. Larger quantities of nitrogen and phosphorous were found in the soil than in vegetative material, whereas

for calcium, magnesium and especially potassium, the reverse was true. The understory component contribution was variable but minimal at all times.

Plant biomass and nutrient distribution within the tree component showed two basic patterns, one unique to *Pseudotsuga menziesii*, the other common to *Thuja plicata* and *Tsuga heterophylla*. In considering the tree component in the total ecosystem, its greatest influence lies in the distribution of calcium, magnesium and particularly potassium.

The results of this work indicate that the approach used is valid for estimating plant biomass and nutrient distribution; however, in order to expand to other ages, sites and species, a modification of sampling intensity and procedure is necessary.

Plant Biomass and Nutrient Distribution in a Young *Pseudotsuga menziesii* Forest Ecosystem

by

Bruce Douglas Webber

A THESIS
submitted to
Oregon State University

in partial fulfillment of
the requirements for the
degree of
Doctor of Philosophy

June 1973

APPROVED:

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Date thesis is presented January 16, 1973

Typed by F. Douglas for Bruce Douglas Webber

ACKNOWLEDGMENTS

The author expresses his gratitude to the many persons who gave assistance during the course of this study. He is indebted to his major professor, Dr. C.T. Youngberg, for review of the manuscript and assistance given during residence at Oregon State University. He also thanks Dr. N. Hartman, Dr. D. Moore and Dr. W. Chilcote for their critical reviews, and Mr. J. Taylor, Mr. D. Taylor and Miss Joan Ralston, summer assistants, for their help in field and laboratory analysis. Special appreciation is expressed to Mr. Kevin McCullough, technician, for his extensive and capable assistance over the past four years. Appreciation is extended to the Canadian Forestry Service for the opportunity of attending graduate school and to Dr. V. Marshall and Mr. A. MacEwan for their critical review.

The extensive time and patience required for typing by Mrs. F. Douglas and Mrs. S. Lee, and for statistical analysis is greatly appreciated.

The author, on behalf of himself, wife and family, thanks his fellow graduate students and the faculty and staff of the soils department for the hospitality and friendliness extended during their stay in Oregon.

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PLANT BIOMASS AND NUTRIENT DISTRIBUTION IN A YOUNG *PSEUDOTSUGA MENZIESII* FOREST ECOSYSTEM

I. INTRODUCTION

"A forest is not, as is often supposed, a simple collection of trees succeeding each other in long perspective, without bond of union and capable of isolation from each other; it is, on the contrary, a whole, the different parts of which are interdependent upon each other, and it constitutes, so to speak, a true individuality" (Clave, as cited by Lutz, 1963, p.565).

Inherent in this statement is that man is one of the facets regulating powers and inducing longeval changes. Man is becoming more conscious of his well being and is instilling an internal conflict between materialistic comfort and a desire for environmental purity. He desires both the *status quo* and reduced environmental deterioration. As man becomes more conscious of his environment, he requires a sounder knowledge of factors affecting natural systems (42, 164).

Present population trends are inducing radical changes in utilization and allocation of forest resources, with greater emphasis being placed on recreational, conservational and ecological uses. These, combined with rising production costs, decreasing land base and increased value of forest products, make maximal utilization of forest resources inevitable (116, p.105-193; 160).

Forests are no longer wild crops subject to periodic harvesting and self-regeneration; they are a natural resource suitable for intensive and selective management practices (117, p.76-89). Concomitant with intensification in forestry practices and environmental concern will be greater demands for knowledge in all facets of the forested environment, including the influence of man. The most incessant desire will be for greater productivity, achieved by such techniques as fertilization, tempered by the spectre of pollution. As a result, environmental concern is now an integral cog in forest research.

To balance increased productivity and environmental quality, one must first determine productivity. Odum (100) has suggested several methods of measuring productivity, including biomass sampling which, despite the complexity and massiveness of the system, is the most practical. Productivity, in terms of the variable of interest, is measured within defined limits as dictated by desire and personal interest.

Biomass analysis provides information on many topics, including nutrient distribution and, in time, nutrient cycling. This technique can potentially provide qualitative and quantitative information that is basic to a more complete comprehension of natural ecosystems. Biomass measures will evaluate silvicultural treatment effects, determine forest cover influencing hydrological properties, and provide information on yield and stand growth and on quantity and quality of potential fire fuel. An indication of the potential food supply for insects, diseases and wildlife is also possible.

As voiced by Ovington and Young, there is a need to re-orient classical forestry concepts to encompass a more complete entity - the whole tree concept (117, 160, 161). This concept is a restrictive definition of biomass or "...that part of a given habitat consisting of living matter, expressed either as the weight of organisms per unit area... of habitat" (138). Man's concept of himself and his environment is simplicity oriented; an orientation being manifested through structuring habitat into hierarchial systems followed by analysis of any level of interest. Granted that the whole tree concept is a more relevant approach to many forestry problems, it still needs to be augmented by a nutritional input, which is of physiological importance for living matter. Evaluation of nutritional status has been instituted by many authors (31, p.37-60; 79-86; 102-119; 120, p.4-31; 121; 122; 123; 126; 128, p.1-288, 127; 140; 155); however, due to differing methodologies, care must be exercised in interpreting and extrapolating results.

Augmentation of biomass of whole trees and nutritive concepts results in an ecosystem approach. An ecosystem is a quasi-organism "...including not only the organism complex, but also the whole complex of physical factors forming what we call the environment of the biome - the habitat factors in the widest sense" (56). Odum (100) further elaborates on the ecosystem concept by stating:

> Living organisms and their non-living (abiotic) environment are inseparably inter-related and interact upon each other. Any entity or natural unit that includes living and non-living parts interacting to produce a stable system in which the exchange of minerals between the living and non-living parts follows circular paths is an ecological system or ecosystem.

A more applicable ecosystem definition is that conceived by Hills (38).

> A forest ecosystem is a biological productivity system in which the forest as a group of organisms utilizes the energy of its environment to produce matter...is an open dynamic system which for convenience of study may be subdivided into four subordinate systems - ecoclimate, soils, ... vegetation and macrofauna. Intermixed with this complex of local systems are extensions of four systems of continental or global extent. The physical environment may be grouped into two-macroclimate and landforms. The systems of living organisms may be grouped into the human, socio-economic system and the biosystem consisting of all other organisms, both plant and animal, ranging from microscopic to macroscopic dimensions.

Inherent within these definitions are all the forces and functions of an ecosystem, including nutrient cycling, energy flow relationships, hydrologic cycles, organic matter distribution and decomposition (13). To fully evaluate any of these aspects is a mammoth task in itself (114).

It has become increasingly apparent that evaluation of forestry practices must go beyond the standard economic response concept. The significance and effects of manipulative practices on forest ecosystems is an accountable item. The pertinent questions revolve around the 'why and how' of sampling. Since one of the more promising practices is fertilization, it follows that evaluation of nutrient and biomass distribution and nutrient cycling is logical. Before cycling can be tackled, a knowledge of nutrient and biomass distribution is essential. This therefore became the governing concept behind this work.

The objective of this thesis was to procure information on nutrient distribution patterns in a young *Pseudotsuga menziesii* ecosystem. Such information is basic to further expansion of programs centered on nutrient cycling - distribution and effects of management practices on them.

II. LITERATURE REVIEW

Biomass Distribution

1. General Remarks

The collection, accumulation and interpretation-description of data on biomass production is complex and varied, particularly in the realm of interpretation-description. A systems analysis approach, based on a hypothesis derived from real-world processes, has resulted in expressing biological productivity in modular terms (22, 28, 95). The approach "...involves the description of a system...by means of a flow diagram that enhances the different components of the system together with the possible pathways which connect the various components" (28). The application of system descriptions and simulation models should put silvicultural management on a scientific basis. Basic formulations of rudimentary modular cyclic descriptions have been formulated by Cole and his collaborators (19), but more elaborate models have been postulated by Fortescue and Marten (28), Curlin (22), Bormann and Likens (12, 13) and Whittaker and Woodwell (152, 156).

Irrespective of methodology, there is a common dependency on sampling methods and inherent natural variability. Many of the sources of variation are common to both plant biomass and nutrient distribution.

2. Factors Affecting Biomass Production

J.L. Keays, in evaluating the potential of full-tree utilization, has made a detailed analysis of critical factors affecting biomass production, the conclusions of which are summarized in Table 1

TABLE 1. FACTORS AFFECTING BIOMASS PRODUCTION

Component	Factors			
	Critical	Major	Minor	Unknown
Unmerchantable top of bole	Species Top limit Dbh Stump height Tree height			
Foliage	Species Tree height Stand density	Site Crown ratio Season Taper	Stump height	Others
Branches	Species Tree height Stand density	Tree age Dbh Season	Stump height	Site Others-dominance Taper, genetics
Crown and Slash	Species Top limit Tree height Stand density	Dbh Tree age Site Crown ratio Season	Stump height	Dominance (maybe major)
Stump, roots and stump-root	Stump height Species Taper Dbh Stand density	Tree height Type and compaction of soil Water Nutrients Dominance	Wind-throw	Others

(46, p.1-98; 47, p.1-94; 48, p.1-67; 49, p.1-79; 50, p.1-62; 51) and discussed below.

a) Environmental

Environmental factors such as light, temperature, moisture, nutrition, insects and diseases influence forest production. Rodin and Bazilevich (128, p.1-288; 129) have stressed the importance of environmental conditions in the evaluation of world biomass production. With increasing average temperature and moisture, biomass production is higher and more diversified (tundra versus tropics). However, they and others (12; 13; 14, p.78-87; 102-124; 155) stress that species differences do exist in the relative proportions of individual tree components (Table 2).

TABLE 2. BIOMASS PRODUCTION OF MAJOR VEGETATION TYPES

CHARACTERISTIC	VEGETATION TYPE					
	Arctic Tundra	North Taiga	South Taiga	Oak	Sub-Tropical Forest	Tropical Rain-Forest
Biomass (ton hectare^{-1})	5	100	330	400	410	500
Green Parts (%)		8	6	1	3	8
Above ground	30	70	73	75	77	74
Roots	70	20	22	24	20	18

b) Site

A reduction from macroscopic to microscopic dimensions focuses attention on site, which is of major importance for foliage, crown and slash and stump-root production (47, p.1-94; 49, p.1-79; 50, p.1-62). Hydrologic site properties influence both total and proportionate biomass production since, with more xeric conditions, the percent decrease in tree biomass is greater than that for other ecosystem components (153). Ovington (118) also stresses that component weights vary by species and region while Switzer (141), in working with loblolly pine, found that site modified rate, but not pattern, of dry-matter accumulation.

c) Stand Density

There are two main theories on density effects on productivity - Assman and Mar:Moller. Mar:Moller contends that production increases with increased stocking up to the point of full occupancy. Within wide limits beyond full occupancy, any further increments in stocking do not significantly affect annual growth, only its distribution among stand components (21, 89). Support for Mar:Moller's concepts is found in the work by Weetman and Harland (146), Keays (47; 48; 49; 50), Ovington (106) and Singer (134).

Assman purports that "...growth per unit area increases with increased stocking until optimum production is reached at some definite density. Beyond this point production decreases" (8). Support for this theory is found in the work by Loomis _et al_. (68), with additional partial support by Baskerville (7; 8; 9; 10). In studying density changes in balsam fir from 700 to 5000 stems per acre, Baskerville (7; 8; 9; 10) found that bole wood increased from 57.1

to 67.1 percent, whereas branches and foliage both decreased (17.4 to 10.1 and 16.4 to 12.8 percent, respectively). Unanimity of opinion regarding decrease in foliage production relative to total biomass exists; however, there is disagreement over the concept of constant foliage weight per unit area regardless of stocking (8; 88; 134; 146).

Support for Baskerville's contention that a biologically meaningful measure of stand density and physiological explanation of tolerance is required can be gained from the diversity of opinions found in the literature. Switzer (141) further indicates the care necessary in interpreting differences between stand and sample tree accretion patterns since stands have a fixed land base, whereas variable area is associated with a sample tree.

Some of the concepts discussed above, particularly those of constancy in foliage production, are illustrated in the following figures;

d) Age

When discussing density effects, the age variable is impossible to eliminate since age is associated with competition, mortality and changing density, yielding changes in time, of form, weight and productivity. It is of utmost importance to consider successional effects since, in the earlier stages of stand development, the understory vegetation may contain a majority of nutrients in an ecosystem.

Figures 1 and 2 illustrate time changes which are further supported by the work of Ovington on Pinus sylvestris (Table 3).

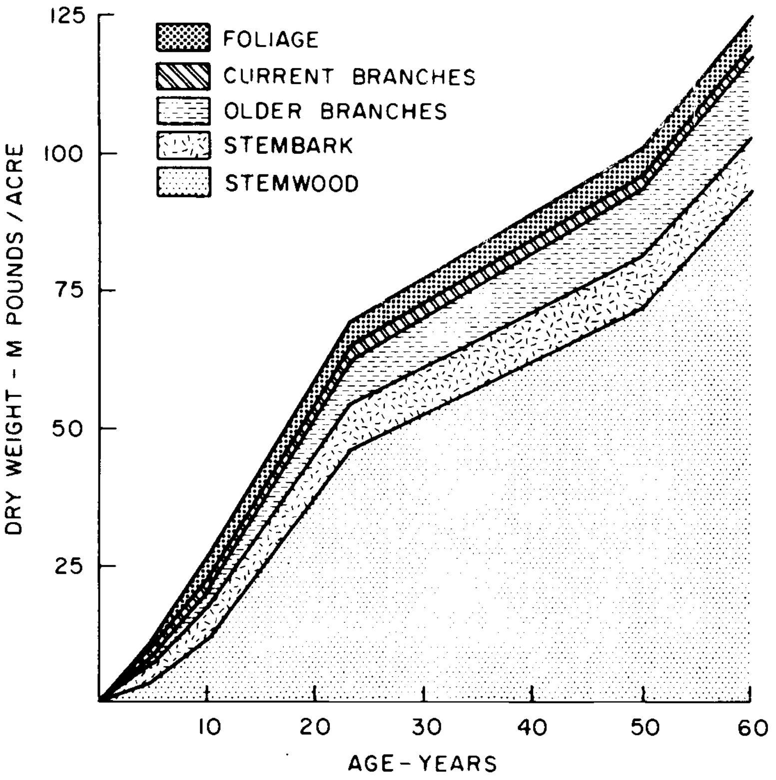

Fig. 1. Dry matter accumulation in the standing crops of even-aged loblolly pine (Switzer *et al.*, 141).

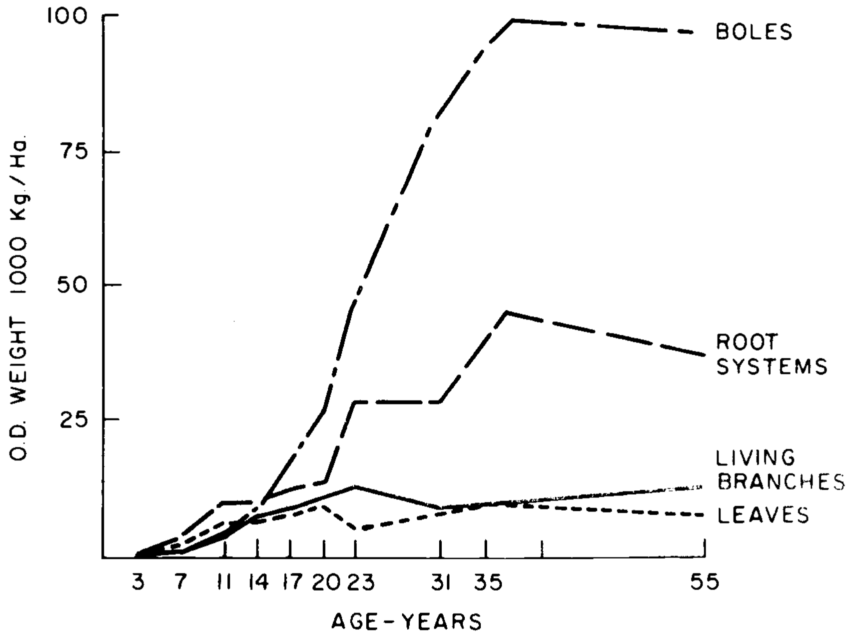

Fig. 2. The weights of the plantations of *Pinus sylvestris* (Ovington, 109).

TABLE 3. THE AVERAGE DRY MATTER PRODUCTION OF SAMPLE TREES EXPRESSED AS A PERCENTAGE OF WEIGHT OF AERIAL SHOOT PRODUCED (OVINGTON, 109).

			Component	
Age	Cones	Branches	Leaves	Bole
3	0	20.0	40.0	40.0
11	0	26.2	48.1	25.7
17	1.8	28.6	47.3	22.3
23	4.3	32.6	24.4	33.7
35	5.0	24.2	25.0	47.8
55	5.5	12.7	34.7	47.6

Satoo (132), working with Pinus densiflora, and Zavitkovski (166), working with aspen, support the concept of time-induced changes, with net production dependent on age as well as stand density and site quality.

Detailed analysis of an age series (0-12 years) of a young Pinus radiata stand by Forrest and Ovington (27) led to the conclusion that tree crown development was most rapid after five years, and at seven years was almost constant at 112,000 kg/lha. General conclusions based on very young stands can be problematic as biomass distribution patterns can be affected by competition.

Apparently, age effects are really of a successional nature and stand development is of consequence when a long time-period or stand dynamics is under consideration. Conclusive works on age effects

(122, 125, 144) support the general concept of constant foliage production after some definite age. Of more immediate concern in sampling is the variation introduced by tree size and form.

e) Tree Size and Form

Although dry matter increases with tree size, the relative distribution among components is not constant. Keays (47, p.1-94), in evaluating foliage distribution, found its percentage to generally decrease with an increase in diameter with a wide variation due to species effects, e.g., Picea jezoensis 4" to 12" had 67 to 15 percent foliage and Larix decidua, 6 to 4 percent. Changing the base of expression, i.e., as a percent of bole weight to full-tree weight, only affected percentage values, not trends. Accepting that the absolute amount of foliage per acre is relatively constant in a fully stocked stand, one must distinguish between percentages based on a sample tree and the amount of a component per unit area. Further analysis by Keays (48, p.1-67) on branch material yielded similar trends to those of foliar analysis. Ovington and Madgwick (122) found, with Scots pine, that leaf weight was constant, branch and root weight increased, and bole weight decreased with tree size. Baskerville (7) obtained similar results with Abies balsamifera for a 1- to 10-inch diameter range, with the one exception of constancy in percentage of bark.

f) Species

Species differences in biomass production have been well documented by Ovington (118) and Whittaker et al. (153), from whom Tables 4 and 5, respectively, are taken.

TABLE 4. ANNUAL INCREASE IN BIOMASS (1 x 10^3 kg. oven dry per ha.) FOR THE FIRST 46 - 47 YEARS AFTER AFFORESTATION AT A GOOD SITE IN ENGLAND. (Ovington, 118).

	Pseudotsuga taxifolia	Larix decidua	Pinus sylvestris	Pinus nigra	Picea abies	Castanea sativa	Quercus robur
boles of standing trees	4.3	3.2	2.8	4.6	3.9	2.3	2.3
boles and crowns of standing trees	5.4	4.1	3.3	5.3	5.6	2.5	2.7
litter layers	0.1	0.7	0.2	0.4	0.5	0	0
boles, crowns and litter layers	5.5	4.8	3.5	5.7	6.1	2.5	2.7
boles removed in harvesting	4.4	1.9	4.5	4.0	3.8	1.3	1.2

Because of site preference, morphological and physiological variations, differences in biomass productivity, branching, form and crown structure exist between coniferous and deciduous species. Coniferous species have greater foliar biomass, more branches per unit length of stem, more branches and greater branch weight, whereas deciduous species are more efficient biomass producers.

g) Season

Seasonal accretion in biomass occurs due to variation in patterns over a year. Sampling during accretion periods will lead to erroneous results, particularly in younger and smaller size classes. Stability in biomass thus becomes a crucial factor in sampling for both biomass and nutrient content and one is advised to sample after growth has ceased.

TABLE 5. RELATIVE DISTRIBUTION OF BIOMASS AMONG COMPONENTS OF THREE SPECIES OF DIVERSE FORM (Whittaker *et al.*, 153).

	SPECIES		
Component	*Liriodendron tulipifera*	*Quercus alba*	*Pinus echinata*
	Biomass distribution (%)		
Stemwood	76.9	58.5	30.1
Stem bark	9.2	12.5	8.9
Branch wood and bark	12.	26.9	7.5
Current twigs and leaves	1.9	2.1	1.5
2nd-year leaves	-	-	1.8
3rd-year leaves	-	-	.2
Fruit	.3	.02	.01

Nutrient Distribution

1. Variables Affecting Nutrient Distribution

Nutrient content varies considerably depending upon many factors, including: (83) season, crown position, age, crown class, physiological state, disease and insects, environmental and soil properties, the three most important being season, age and crown position.

a) Season

Seasonal effects vary according to species and growth characteristics, resulting in different periods of constant nutrient concentration (40, 60, 92, 149, 150). For uninodal coniferous species such as Douglas-fir and black spruce, nitrogen, calcium and magnesium concentrations are maximum in winter, whereas potassium and phosphorous maxima occur in the fall (69, p.1-36; 70, p.1-21). An analysis of loblolly pine (1949) and potassium deficient Pinus strobus (150) foliage yielded similar results in that:

i) in new foliage nitrogen content reached a stable level in the fall and continually decreased thereafter;

ii) calcium and magnesium content continually increased throughout growth and maturation (loblolly pine only), and

iii) potassium and phosphorous decreased to relatively constant levels.

Seasonal effects are more noticeable in deciduous than in coniferous species due to elemental migration prior to leaf abscission. Hoyle (40), working with yellow birch, found evidence of several seasonal patterns which resulted in doubt as to the realiability of percentage values for use in evaluation of nutritional seasonal gains and losses. In earlier works, Leyton (64, 65) concluded that seasonal effects reflected the importance of the time factor, since there is variation in both requirements and time of nutrient absorption.

b) Age

Age effects have been acknowledged for some time (64, 65) with consistent common trends. Nitrogen, potassium and phosphorous content decreases with age (59; 60; 69; 70; 71; 81; 93; 149; 150); calcium content increases with age, whereas magnesium is inconsistent. The explanation of these trends would be found in the nature and mobility of the nutrient element and its specific physiological role.

c) Crown Position

Wells and Metz (149) found that in loblolly pine, nitrogen, calcium and magnesium content increased and potassium and phosphorous decreased going from upper to lower crown positions. Results of Lavender and Carmichael (60) were different in that nitrogen, potassium, phosphorous and magnesium had maximal concentrations in upper crown positions. Many other results support Lavender and Carmichael's findings (34; 65; 69, p.1-31; 70, p.1-21; 81).

In their use of mineral composition of Scots pine foliage as a potential indicator of growth or tree height, Leyton and Armson (65) found that another influence of crown position was to accentuate differences among trees of different heights. White, *et al*. (151) found height and site to be significantly related to potassium, aluminum and manganese concentrations in the inner bark of loblolly pine. In addition to their findings on crown position, Wells and Metz (149) found that there were twofold and threefold differences in foliar calcium and magnesium contents, depending on soil type.

d) Other

Jurgenson and Leaf (43) found a soil moisture-fertility interaction in red pine stands affecting height growth, nutrient contents and response to potassium fertilization. Madgwick (81) showed that the effect of poorly-grown versus well-grown red pine trees was to accentuate crown position effects. Lavender (59) found that with increasing dominance, nutrient concentrations were increased and sampling intensity could be reduced. Earlier, Leyton (64) stressed possible influence of site quality, time of day and developmental stage as other variables.

Due to the influence of the above factors and the differing characteristics of nutrient elements, optimum sampling procedures may not be the same for all nutrients (149). Lowry (70, p.235-259; 71, p.1-21) postulated that techniques are either available or can be developed that could permit sampling at more convenient times with no loss in validity of results.

Sampling Methods

1. General Remarks

Sampling for nutrient and biomass distribution involves two crucial steps which limit the confidence in and reliability of results, i.e., selection and sampling of trees. Any nutrient and/or biomass sampling methods is simply an attempt at determining weight per unit area. The best method would be to sample all trees in a stand; however, because of time to sample, cost of sampling and destructive nature of sampling, other methods have been developed.

2. Methodology

a) Allometric Approach

Of the two main methods (41, p.1-139), the allometric approach is more popular. It involves the development of a mathematical relationship between component weights and some quantifiable stand parameter and the application of a stand table to compute weight per unit area. Kittredge (53) developed this method in 1944 and since then it has been used by many others (2; 5; 16; 20; 39; 46; 54; 63; 66; 75; 87; 94; 120; 121; 131; 136; 167).

This method assumes that the relationship developed in one stand is applicable to other stands, and intercept and slope constants will be constant over a variety of conditions (16; 132). Kittredge (53) believes that the relationship between leaf weight and diameter at breast height is applicable to stands of varying sizes, densities, crown classes and ages up to growth culmination and even beyond for tolerant species in all-aged stands. Zavitkovski (166) disagrees, and believes that different allometric relations may exist in trees from young and old stands or in trees from different areas. Satoo (131) also found that the slope and intercept values would change as stand density affected branch biomass. Madgwick (85) found that the relationship between diameter and leaf weight was affected by stand structure, season and genotype. For optimum sampling conditions, he feels that the amount of data collected on each component should be related to its importance, variability and ease of collection.

Statistical criticisms have been raised by Schreuder and Shank (133), Crow (20) and Madgwick (83-87) in three areas:

1) Fitted regressions equations provide an estimate of geometric rather than arithmetic relationships.
2) Regression models introduce bias.
3) There is a possibility of over-estimation of biomass.

Kozak (55), expressing concern over the additivity of regression equations, proposes fitting the same model to all components even if some terms are not significant.

b) Mean Tree Approach

This method, which entails multiplying the component weights of a mean tree by the number of trees per unit area, has received extensive use and review (3; 5; 6; 20; 21; 41; 85; 87; 88; 120; 132); the most pertinent criticism was that an individual tree which is "average" in one respect is not necessarily so in all, or any other respects. The mean tree method results in higher precision, higher bias, less accuracy and little information on stand structure or time induced changes (85; 87). Accuracy and precision both depend on the closeness between assumed and real relationships. Precision will be higher for the mean tree method because of detailed sample tree analysis. Since average trees are statistically rather than biologically defined, and variation in weight distribution within one size class is high, accuracy will be greater with a more systematic sampling system (79).

c) Comparison of Methods Used

A comparison is only possible if total stand data are given (87). Baskerville (9) made one of the more detailed comparisons for a 43-year-old balsam fir stand on a .2 ac. plot (Table 6.).

As the results show, short-cut techniques, i.e., based on average trees, can lead to unacceptable errors, particularly when considering nutritional relationships.

Ovington, Forrest and Armstrong (120) compared unit area sampling, average tree sampling and regression analysis to total tree summation for a plot of 100 8-year-old Pinus radiata trees. Unit area sampling was inadequate, with regression analysis and average tree

TABLE 6. ESTIMATES OF STAND BIOMASS BY SEVEN DIFFERENT METHODS EXPRESSED IN KILOGRAMS PER ACRE (Baskerville, 9).

Base of estimation	Foliage	Branches	Cones	Stemwood	Stem bark	Total above-ground	Roots	Total tree
1. Every-tree summation	5,029	4,738	188	19,376	2,823	32,154	9,260	41,414
2. Tree of mean height	1,833 (-63.5)[1]	1,692 (-64.3)	77 (-59.0)	10,617 (-45.2)	1,480 (-47.5)	15,699 (-51.2)	4,861 (-47.5)	20,560 (-50.2)
3. Tree of mean diameter	2,835 (-43.6)	2,622 (-44.6)	119 (-36.7)	14,626 (-24.5)	2,051 (-27.3)	22,253 (-30.8)	6,779 (-26.8)	29,032 (-29.8)
4. Tree of mean basal area	3,816 (-24.1)	3,488 (-26.4)	158 (-16.0)	17,993 (-7.1)	2,550 (-9.7)	28,805 (-12.9)	8,357 (-9.8)	36,362 (-12.2)
5. Stand table	4,946 (-1.6)	4,641 (-2.0)	183 (-2.6)	18,894 (-2.5)	2,807 (-0.6)	31,471 (-2.1)	9,532 (+2.9)	41,003 (-1.0)
6. Tree of mean volume	4,392 (-12.7)	4,132 (-12.8)	183 (-2.6)	20,210 (+4.3)	2,878 (+1.9)	31,795 (-1.1)	9,636 (+4.1)	41,431 (+0.1)
7. Average co-dominant tree	7,136 (+42.4)	7,078 (+49.4)	298 (+58.5)	28,780 (+48.5)	4,178 (+48.0)	47,497 (+47.7)	13,772 (+48.7)	61,269 (+47.8)

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[1] Values in parentheses are the deviations from estimate 1 expressed as a percentage of estimate 1.

being the best methods. In all cases there was a decreasing error associated with increasing sample size. Regression analysis with a restricted choice of trees based on bole cross sectional area gave the lowest error terms (7% crown for total tree, 2% for leaves and 3% for boles).

Attiwill and Ovington (6) concluded from a literature review that it is necessary to sample over a range of tree sizes. They found that using the average weight of four trees in each of five girth classes multiplied by the number of trees in each girth class gave better results than using four weighted trees of average girth or the average tree, as predicted by regression equations, times number of trees per acre.

Sampling for nutrient distribution will, by necessity, be imposed within a framework of biomass sampling. Care and attention, however, will have to be given to season, crown position, age and number of samples, and what particular trees to sub-sample.

3. Field Sampling

Fractionation will require a balance between considerations vital to the successful completion of the analysis and Rennie's three factors of consideration (127).

a) Non-commercial and commercial components should be separated for practical evaluation, while subsequent grouping would be possible for theoretical considerations.

b) Fractions should be of reasonable anatomical and physiological homogeneity.

c) Fractionation should be practical.

Sampling for nutrient studies will be centered mainly in the canopy but as Crow (21) points out, it is totally unreliable to regard the crown as a homogeneous solid because of the variation in nutrient concentrations due to age and crown position. Heilmann (37, p.1-14) has proposed a framework for nutrient sampling, including the following:

a) Sample foliage of conifers during the dormant season.

b) Sample dominant and codominant trees.

c) Sample 15-20 trees preferably grouped into forest-type sub-divisions.

d) Obtain foliage from the upper portion of the crown.

e) Avoid sampling foliage on twigs bearing cones.

Other authors such as Ovington and Neubold (124), Lowry (69, p.1-51; 70; 71, p.1-21), Kawahara and Tsutsumi (44), Metz et al. (90), recommend specific sample sizes for the confidence limits desired for their species. For Douglas-fir, Lavender (59) has shown that 3.6 dominant, 6.1 co-dominant or 6.8 suppressed trees are required to estimate nutrient contents to ±10 percent of the mean. Thus it can be concluded that sampling technique and size are not too well defined.

Forest Soils Evaluation

1. Forest Soil Variability

"The degree of variability and its effect on accuracy of mean plot values for soil properties is an important problem needing evaluation for soil-site studies (78)." Not only is soil variability (142) a problem, but the reliability of common soil-testing procedures is also questionable. There are additional problems due to soil heterogeneity, lack of knowledge concerning nutrient uptake from different parts of the soil, and yearly variation due to vegetation, weather and silvicultural treatment (61). Mader (78) further emphasizes the problem when he states that " ...the surface soils are not well mixed and homogenized by frequent cultivation but rather are characterized by more accentuated microtopography and non-uniformity. A further problem is encountered if the entire rooting zone is to be investigated since it generally is several feet in depth and variability in the vertical plane is compounded with horizontal changes."

Gessel and Balci (32) did an early evaluation of the causes of variability, and recently Beckett and Webster (11) published an updated evaluation of lateral variability in soils. The latter point out the necessity of differentiating between inconsistency and variability. Inconsistency is caused by poor workmanship or differing techniques, while variability differs, depending on such factors as landscape. Variability in natural landscapes is caused by differences in parent material, climatic effects, topography, weathering and physio-chemical processes. All of the agents have some influence in cultivated landscapes but there are additional contributory effects due to human effects.

Forests are unique and have peculiar operative variables (32), including: (i) distribution of trees compounded by heterogeneity in age and species composition, (ii) macro- and micro- topographic irregularities, (iii) past disturbances, (iv) occurrence of decay-resistant debris, and (v) random location of sample plots in a heterogeneous population.

2. Sampling Procedures

Hammond, Pritchett and Chew (36) approached the problem of soil variability by comparing the cost efficiencies of simple random and multi-stage sampling. Although more samples were required for three-stage sampling over random, the total costs were much lower due to the effect of grouping.

Procedures for sampling forest soils are well defined (37), with two basic approaches being used, i.e., describing the soil and sampling by genetic horizon or a sampling based on known cross-sectional area and volume. In the first instance, a larger number of samples may be required. The total nutrient content can be summed for the entire profile but, due to rooting characteristics, careful interpretation is necessary. Further difficulties can be encountered because of diffuse and irregular boundaries and thicknesses of horizons.

The second method has the two-fold advantage of fewer samples and the feasibility of multi-sampling of sample plots. Estimation of nutrient content, however, is only feasible down to the sampling depth.

Heilman (37) commented on the location of sample plots and the influence of irregular stand features (wind-throw, stumps, etc.). Characterization of the profile for a given stand usually requires one to four pits per plot. Due to the importance of the upper horizons, sampling of these can be more intense with an estimate of 30 samples on a 1-acre plot for an accuracy of ±10 percent of the plot mean at 95 percent confidence interval.

Biomass and Nutrient Distribution in Forest Ecosystems

Comprehensive works on this subject are those by Rodin and Bazilevich (128, p.1-288; 129) and Art and Marko (3). They discuss biomass and nutrient distribution in major world vegetation types. Rodin and Bazilevich (128) are also concerned with many facets of nutrient cycling.

Nutrient distribution and accumulation has been determined in *Pinus virginiana* and *Pinus resinosa* by Madgwick (80; 81; 83; 84; 85; 86; 87; 88), in Scots pine and birch by Ovington (102 to 119; 120; 121), in deciduous mixed forests by Duvigneaud and Denaeyer-Desmet (23; 24), in *Abies sachalinensis* by Yamamoto and Sanada (159), in Maritime pine by Keay and Turton (45), in red spruce and white pine by Young (161; 162), in Douglas-fir by Cole *et al*. (19) and in black spruce by Weetman *et al*. (146; 147). In addition to the above, Rennie prepared summaries of early European literature (126), and Gessel reviewed the problems associated with mineral nutrition of forest trees (30).

Rennie's intent was to prepare estimates of possible nutrient depletion or demands on moorland sites used for reforestation or afforestation purposes. The greatest demand of the trees was for calcium, followed by potassium and phosphorous. Species site exploitation was particularly evident when comparing the demands of hardwoods to pines. The results dispelled the theory that afforestation or reforestation implied site replenishment or improvement. The trees may actually deteriorate the site by concentrating mineral elements in tissue which is removed from the site by harvesting.

A further comparison of nutrient demand to available supply showed a potential depletion of the site when considering potassium, phosphorous and calcium. In these instances, the ratio of demand to supply was very high. The seriousness of the situation depends on the rate of mineral weathering, organic matter decomposition, and nutrient replenishment by such agencies as precipitation and airborne particles.

Wright and Will (158) evaluated the nutrient status of Scots and Corsican pine growing on sand dunes (ages 18-64 years for Scots and 18-46 for Corsican) and concluded that:

a) the most significant seasonal variation was a rise in bark nitrogen content in autumn, especially in young trees;

b) dominant trees have lower levels of phosphorous, potassium and magnesium in needles, branches and bark than suppressed trees;

c) at age 46, the total nutrient content in Corsican pine is still increasing but, at age 64, the total content of nitrogen, phosphorous and potassium in Scots pine is beginning to fall. Calcium content, however, is still rising due to heartwood formation, and

d) depending on age, the bark and stem contain one-third to one-half of the total nutrients in a tree.

The work by Cole and his associates on a 36-year-old second growth Douglas-fir stand is summarized in Tables 7, 8 and 9. Stand component analysis is based on ten sample trees - one suppressed, three intermediate, four co-dominant and two dominant - on a .004 ha. plot.

TABLE 7. DISTRIBUTION OF N, P, K, Ca, AND ORGANIC MATTER (kg/ha) IN A SECOND-GROWTH DOUGLAS-FIR ECOSYSTEM (Cole *et al.*, 19).

Component		N	P	K	Ca	Organic matter
TREE						
Foliage	current	24	5	16	7	1,990
	older	78	24	46	66	7,107
Branches	current	4	1	3	2	513
	older	40	9	32	65	13,373
	dead	17	2	3	39	8,145
Wood	current	10	2	10	4	7,485
	older	67	7	42	43	114,202
Bark		48	10	44	70	18,728
Roots		32	6	24	37	32,986
Total tree		320	66	220	333	204,529
SUBORDINATE VEGETATION		6	1	7	9	1,010
FOREST FLOOR						
Branches		5	1	4	8	1,423
Needles		35	4	5	27	3,005
Wood		14	2	8	17	6,345
Humus		121	19	15	85	11,999
Total forest floor		175	26	32	137	22,772
SOIL						
0-15 cm		809	1,167	79	313	38,372
15-30 cm		858	1,195	66	196	36,935
30-45 cm		761	980	52	152	28,290
45-60 cm		371	536	37	80	7,955
Total soil		2,809	3,878	234	741	111,552
TOTAL ECOSYSTEM		3,310	3,971	493	1,220	339,863

TABLE 8. DISTRIBUTION OF N, P, K, AND Ca BETWEEN THE MAJOR COMPONENTS OF THE SECOND-GROWTH DOUGLAS-FIR FOREST (Cole *et al.*, 19).

Ecosystem component	N		P		K		Ca	
	kg/ha	% of total	kg/ha	% of total	kg/ha	% of total	mg/ha	% of total
Foliage	102	31.9	29	43.9	62	28.2	73	21.9
Branches	61	19.1	12	18.2	38	17.3	106	31.8
Wood	77	24.0	9	13.6	52	23.6	47	14.1
Bark	48	15.0	10	15.2	44	20.0	70	21.0
Roots	32	10.0	6	9.1	24	10.9	37	11.2
Total	320		66		220		333	

TABLE 9. DISTRIBUTION OF N, P, K, AND Ca WITHIN THE MAJOR COMPONENTS OF THE ECOSYSTEM (Cole *et al.*, 19).

Ecosystem component	N		P		K		Ca	
	kg/ha	% of total	kg/ha	% of total	kg/ha	% of total	kg/ha	% of total
Forest	320	9.7	66	1.7	220	44.6	333	27.3
Sub vegetation	6	0.2	1	0.1	7	1.4	9	0.7
Forest floor	175	5.3	26	0.6	32	6.5	137	11.2
Soil	2809	84.8	3878	97.6	234	47.5	741	60.8
Total	3310		3971		493		1220	

In addition to evaluating the present nutrient status of the stand, interpretation of uptake and cycling quantities, the authors made the following observations:

a) There was a large variation in dry weight and elemental composition, reflecting normal crown-class development of Douglas-fir. Since this was a plantation, variation was less than in natural stands.

b) The largest variation occurred in subordinate vegetation.

c) Careful interpretation of the importance value of quantities of nutrients present is needed because of the time factor and the effect of organic matter decomposition, variation in uptake rates and addition of elements to the system in ionic form, e.g., fixation, mineral solubility and precipitation additions.

In the estimation of total nutrient content in soils, the main cause of variation is estimation of horizon thickness. Mcfee and Stone (74) found that between 50 and 100 samples were required to reduce error to ±10 percent. This was a severe limitation since they worked only with deep, relatively homogeneous sandy soils which considerably reduced estimation errors.

Metz _et al_. (90) found that the variation in soil properties necessitated a differing number of samples to estimate mean values to ±10 percent at 95 percent probability. For 0- to 3- inch depth, only one sample and one plot was required to measure pH, whereas 132 plots of one sample each or 95 plots of 16 samples were required to determine magnesium.

Characterization of forest soil properties, other than in soil survey reports, have been carried out in the Pacific Northwest by Woon (157), Woolridge (156), Youngberg (165), Cole (19), Keser (52, 299 p.) and others. Representative analysis of forest-floor chemical properties are given in Table 10.

Comparable chemical analysis of mineral soils in southern Vancouver Island are given in Table 11 (101). The soils in this region are characteristically low in base saturation, due to high leaching and increase in exchangeable hydrogen and aluminium.

TABLE 10. CHEMICAL PROPERTIES OF FOREST FLOORS IN THE PACIFIC NORTHWEST

Source	pH	Available P ppm	Exchangeable Cations K	Ca meg/100g	Mg	Total N	P	K	Ca	Mg
						percent				
1. Youngberg-Oregon	4.0-6.0	36-146	1.5 - 5.4	6.5-23.5	.5-12.8	.71-1.52	.09-.21	.12-.32	.33 -1.05	.15 -.33
2. Keser - BC.										
				Ca & Mg						
a) Glacio fluvial	5.2-5.62	12.5-16.4	2.25	18.69		.16-.61	-	-	-	-
b) Marine Sediment	4.58	10.4	.66	17.41		.51	-	-	-	-
c) Glacial Till	3.81-5.10	18.6-19.7	.61- 1.65	5.02 - 12.15		.30-.47	-	-	-	-
d) Sands	3.93	19.7	.59	10.01		.39	-	-	-	-
3. Woon - Literature Review						.75-1.35	.07-.21	.09-.28	.32 -1.05	-
4. Woon -	4.73-5.61	3.0-31.0	27-14550 (ppm)	Ca only, 110-4200 ppm.		.8-1.88	.01-.12	.03-.11	.16 -1.21	

1. Douglas-fir - Western Oregon.
2. Douglas-fir - Sayward Forest, Vancouver Island.
3. Douglas-fir Forest - Pacific Northwest.
4. Douglas-fir Forest - Haney Research Forest, British Columbia.

TABLE 11. CHEMICAL PROPERTIES OF SOILS ON SOUTHERN VANCOUVER ISLAND (Oswald, 101).

HORIZON	pH (H_2O)		Exchangeable Cations meg./100g				CEC. Meg./ 100g	Total Nitrogen %
			Ca	K	Mg	Na		
A	4.4-5.5	min	1.03	.14	.27	.06	11.20	.08
		max	8.43	.43	.69	.52	21.61	.14
B_1	5.7	min	.52	.11	.07	.04	8.74	.06
		max	1.30	.12	.36	.08	14.65	.06
B_2	5.8	min	.31	.06	.05	.04	7.44	.05
		max	.41	.07	.07	.05	9.98	.060
BC	5.4-5.7	min	.13	.04	.02	.04	6.99	.03
		max	3.80	.13	1.38	.14	12.14	.05
C	6.4	min	.13	.02	.02	.05	5.08	.02
		max	4.74	.17	1.75	.37	19.10	.06

Application of Findings

Justification of research is becoming more important and is used as a means of setting research priorities. Ecosystem studies of the nature being undertaken, or those already in progress, are justified in many respects. The results obtained will continually add to the pool of knowledge, and with an ever-increasing public awareness and concern about the environment, such knowledge can be used to defend or evaluate current silvicultural practices. For example, the work by Weetman and Webber in Quebec (148), in which harvesting effects upon the nutrient cycle were studied showed, under boreal conditions, the disturbing possibility of depletion of nutrient capital in the ecosystem.

Forest fertilization is a silvicultural technique of great potential but of unknown long-term consequences. In western Canada, investigations are in progress to determine fertilization effects upon the total ecosystem. Intensification of forestry practices will lead to more complete utilization of individual trees and stands. The beneficial effects of such procedures have been evaluated by biomass studies (35; 59-63). Associated with this concept would be a requirement to determine the detrimental effects of fuller utilization on the nutrient regime. It thus becomes obvious that studies of this nature are fully justified.

III. METHODS

Area Description

1. Geology

The region under discussion lies in the south-east portion of Vancouver Island within the Coastal Trough, one of the three major physiographic divisions of Coastal British Columbia. In the Douglas-fir region there are four physiographic subdivisions of the Coastal Trough: Seymour Plateau, Seymour Arch, Georgia Depression and the Fraser Lowland. The study area is located in the Georgia Depression at approximately 1000 feet above sea level.

Most of Vancouver Island is underlain by dark fine-grained volcanic rocks which weather into loamy and clayey soils. There are subordinate amounts of limestone and more resistant sedimentary rocks (Upper Cretaceous and Tertiary) such as chert, argillite, tuff and greywacke which do not greatly modify the soil characteristics. Granitic rocks make up a sizeable portion of the Island and weather into sandy textured soils.

The deposits upon which the soils of Vancouver Island have developed are much younger than the above-mentioned bedrocks. These deposits were influenced by events that took place between the last two glacial invasions, during the last glaciation and post-glacial times (Pleistocene and recent epochs). The oldest material of importance originated before the last glaciation period, during which time glacial ice eroded much of the existing materials and left a blanket of glacial till varying from a few feet to more than 100 feet in thickness on the lowlands, floors and valley sides. As the glaciers retreated, the land gradually rose, leaving marine deposits below 500 feet and glacial till above that elevation. These elevational distinctions vary with location on the island, since submergence and emergence varied. The till related to the last glaciation of the region is the most widespread parent material on Vancouver Island.

2. Soils

The soils of Vancouver Island are developed on many kinds of unconsolidated parent materials, most of which are of glacial, lacustrine or marine origin (26). Most of the soils found on unmodified tills are stony or gravelly and of sandy loam to loam texture. Only those soils that are of agricultural importance have been classified and mapped (26); areas of forested soils are usually classified as rough mountainous land. The soils of this region have been placed in the Brunisolic and Podzolic orders. Great groups include Sombric Brunisols (Acid Brown forest), Dystric Brunisols (Acid Brown wooded), Concretionary Browns, Ferro-humic Podzols and Humo-ferric Podzols. The soils of the study area are classified as mini humo-ferric podzols, with the following typic description (17):

> These soils have podzolic B horizons in which organic matter, iron and aluminum are the main accumulation products. The upper four inches of the B horizon contain less than 10% organic matter, and the oxalate-extractable iron and

aluminum exceeds that of the C horizons by .8% or more except in heavy sand or soils with coarser textures.

Under undisturbed conditions, these soils have an organic surface horizon (L-H) usually of the mor or moder type. The L-H horizon is directly underlain by a mineral-organic Ah horizon or Ae (thin, discontinuous, indistinct or simply missing) or a podzolic B horizon. The B horizons have a chroma of 4.0 or more in hues of 10YR or redder.

The Humo-Ferric Podzols have developed under mixed coniferous types over a wide range of climatic conditions but they are dominant in the well-drained sites in moist cool regions in coarse, non-calcareous material; or on materials from which free base has been removed.

3. Climate

Vancouver Island has a maritime climate which is quite variable as a result of topographic and latitudinal influences. It is characterized by cool, relatively dry summers and mild, wet winters. The climate of the east and southeast portion of the island is influenced by the Olympic and Insular mountains, resulting in the development of an inner coast climate. The plots are located in the transitional climatic type, i.e., transitional between the cool mediterranean climate and the maritime climate. Precipitation averages 50 inches a year, with a noticeable moisture deficiency during the vegetative period. The latter lasts for about 250 days, the remainder having only a few days of frost or snow. A climatic record is given in Appendix A.

4. Native Vegetation

Pseudotsuga menziesii (Mirb) Franco is the dominant forest species in this area. *Pseudotsuga menziesii*, *Tsuga heterophylla* (Rafn.)

Sarg. and Gaultheria association, considered to be the climax type for this area, indicate well-drained conditions. Under extremely dry conditions or on shallow, stony or gravelly soils, Pinus contorta (Dougl.) is frequently a feature of the association. Other associations are found under conditions of more abundant soil moisture and finer textured soils; however, the above association dominates the sample area.

Sampling Site

1. Selection of Sample Area

The sample area, located on the Greater Victoria Watershed, was selected in conjunction with a proposed research project on the fertilization of Pseudotsuga menziesii and Tsuga heterophylla. This area was to meet design specifications for the fertilizer project in that site index was to be 110 to 140, with approximately 5200-11,600 trees per hectare. Average diameter was to be about 1.3 inches and height 19-24 feet. This plot contains a 15- to 20-year-old Pseudotsuga menziesii stand (at least 75% Pseudotsuga). In this stand, a one-tenth-acre sample plot was located, within which all sample measurements (trees, lesser vegetation and soil) were made. For the purpose of sampling understory vegetation, mil-acre subplots were established.

2. Sampling Procedure

a. Mensurational Data

All trees on the one-tenth-acre sample plot were measured for diameter at breast height to the nearest one-tenth inch and for total height to the nearest foot, using a graduated height pole.

b. Tree Sampling

On the basis of a stand table constructed for the sample plot, three trees from each of a selected combination of height (nearest foot) and diameter (nearest inch) were selected for sampling (Table 2 of Appendix C).

All trees, except for very small ones, were divided into three sections - upper, middle and lower. In each section, the branches and foliage were cut off; branches were grouped into one sample and the foliage was grouped by age classes. The stem was likewise divided into sections. For the upper section, division into stem and terminal branch was made on the basis of presence or absence of foliage. Fresh and dry weight of all components (foliage by ages, branches, stem bark and stem wood) were recorded. Dry weight was obtained by oven drying at $70^{\circ}C$ to a constant weight.

c. Lesser Vegetation

Milacre samples were randomly located in the study plot. In ten of these, the understory vegetation was removed by species, and fresh and dry weights were determined. Trees less than .5 inch in diameter were classified as being part of the understory structure.

d. Soil Samples

The soils in the study area were classified according to the soil classification scheme used in Canada (17). In each of two pits, approximately 50 feet apart, the soil profiles were described and samples were taken from each horizon.

e. Sampling Time

Samples of vegetative material were taken in late summer and early fall of 1968. Soil samples were originally taken in the fall of 1968 and additional samples in May and June, 1971.

3. Sample Analysis

a. Sample Pretreatment

All vegetative samples were weighed fresh, oven-dried to 70°C., reweighed, ground in a Wiley mill and stored in glass containers until needed, at which time they were redried at 70°C. Where the vegetative material was too massive to handle, smaller subsamples were taken.

Soil samples were air-dried, sieved to pass a 2 mm sieve, then dried to 70°C and stored in glass bottles until chemically analyzed. Prior to analysis, they were redried at 70°C and moisture content was determined. Samples for pH determinations were used as taken from the field.

b. Vegetative Samples

Tree samples for each height-diameter class combination were combined for the purposes of chemical analysis. This was a necessity because of the large number of samples and a desire to reduce tree-to-tree variation. For each component, the oven-dry material was blended together and duplicated samples were obtained for chemical analysis. Chemical analyses were as follows:

i) Total nitrogen: In vegetative samples (plants and surface organic matter), total nitrogen was determined using a modified micro-Kjeldahl procedure (76).

ii) Total phosphorous: In vegetative material, total phosphorous was determined colorimetrically using the molybdenum blue method (76).

iii) Total potassium, calcium and magnesium: Cation content in vegetative samples was determined by dry ashing duplicated samples and determining ion content using a Varian atomic absorption spectrophotometer.

Total sample tree nutrient content was obtained by multiplying concentration values by component dry weight. The total weight in any class was obtained by multiplying individual sample tree content by the appropriate number of trees per hectare. The same procedures were used for determination of total nutrient content in understory vegetation.

c. Soil Samples

Soil samples were analyzed as stated below. All results were expressed as concentration and total content for the soil profile.

i) Organic matter and carbon: These two constituents were determined simultaneously using the Walkley Black method and converting percent carbon to percent organic matter. Carbon content was also determined on a Leco Induction furnace (77).

ii) Cation exchange capacity (CEC) and exchangeable cations: Duplicate 10-gram samples were analyzed for cation exchange capacity and exchangeable cations using neutral normal ammonium acetate extraction. Exchangeable cations were determined on a Varian atomic absorption spectrophotometer (77).

iii) pH: Fresh soil samples were obtained from the field and pH determined in a soil:water paste.

iv) Particle size: This was estimated using the hydrometer method and a 40-second and 2-hour reading.

v) Available phosphorous: The amount of available phosphorous was determined by using acid fluoride extraction and a molybdenum blue colorimetric determination (76).

vi) Bulk density: Known volumes of soil were collected in the field. These samples were air-dried, oven-dried $70^{o}C$ and weighed. The samples were then sieved to determine particle distribution for calculation of nutrient content on a volume basis.

vii) Moisture content: Duplicate samples of dry soil ($70^{o}C$) were weighed and dried for 24 hr at $105^{o}C$ and the percent moisture content was calculated.

IV. RESULTS

For determining nutrient distribution in an ecosystem, a systematic or definitive procedure must be followed. First, a soil analysis is made and the quantity of available or total nutrients determined. This is relatively uncomplicated and entails quantifying nutrient levels on a volume-area basis. Second, the understory vegetation is examined and its biomass and nutrient weight calculated. Third, biomass and nutrient weights must be determined for the tree strata of the ecosystem, a task both complex and time-consuming. It will be helpful to examine the results in terms of these separate but intertwined components.

Soil Strata

The conventional means of expressing soil nutrient capital is on the basis of exchangeable or available quantities per unit weight of soil. The expression of nutrient capital, in quantifiable terms, for distribution analysis requires bulk density determinations and the subsequent expression of such capital on volume/unit area basis. Physical and chemical determinations made on this soil are summarized in Tables 12, 13 and 14. A typical description for a mini-humoferic podzol was given earlier and the descriptions for the two profiles considered are given below.

TABLE 12. STUDY SITE SOIL PHYSICAL AND CHEMICAL PROPERTIES.

HORIZON	PHYSICAL				CHEMICAL										
	BULK DENSITY gm/cc.	PARTICLE SIZE			pH	EXCHANGEABLE CATIONS			C.E.C. meq/100g	O.M. %	$\%C_1$	$\%C_2$	%N	AVAILABLE P ppm	LOSS ON IGNITION %
		SAND	SILT	CLAY		K	Ca meq/100g	Mg							
PIT 1			PERCENT												
L-H	.23				5.6	.66	21.17	3.52	42.42	59.7	34.6	-	.69	134.6	
BF_1	.84	36.8	49.8	13.3	5.6	.15	1.13	.19	12.25	5.6	3.2	3.5	.12	11.9	14.1
BF_2	.72	34.4	53.8	11.7	5.5	.09	.18	.05	8.82	4.3	2.5	2.7	.10	4.2	10.5
B - C	1.21	35.2	51.7	13.1	5.2	.07	.19	.04	8.40	3.7	2.1	2.8	.09	7.9	10.2
C	1.20	52.4	37.1	10.5	5.5	.03	.20	.04	4.33	1.3	.8	.6	.03	33.4	3.9
PIT 2															
L-H	.36				5.6	.40	4.43	.95	43.75	63.1	36.6	-	.31	39.6	
BF_1	.77	46.1	41.9	12.0	5.8	.13	4.27	.38	12.08	6.0	3.5	3.8	.10	9.7	10.8
BF_2	.71	50.1	39.2	9.7	5.6	.07	1.59	.13	9.03	4.2	2.4	2.7	.09	10.7	7.9
B - C	1.36	60.5	27.3	12.2	6.0	.07	1.47	.24	8.15	3.2	1.8	2.0	.08	21.6	5.9

C_1 - determined by Walkley-Black method.

C_2 - " " Leco Induction Furnace.

Pit 1 Profile Description

HORIZON	DEPTH INCHES	DESCRIPTION
L - H	2-0	Black (10 YR 2/1 m) semi-decomposed organic matter; abundant fine and medium roots; abrupt, irregular boundary; ½ to 1½ inches thick, pH 5.6
BF_1^a	0-7	Reddish brown (5 YR 4/5 m), silt loam to loam, structureless single grain; loose, friable, zone of root accumulation - fine and medium roots, irregular boundary; 7 inches thick; pH 5.6
BF_2	7-16	Yellowish red (5 YR 4/8 m); silt loam; structureless, friable; some gravel and large rocks; gradual wavy boundary; 9 inches thick, pH 5.5
B - C	16-22	Dark brown (7.5 YR 4/4 m); silt loam; structureless; friable, few large roots; some gravel; clear and smooth boundary; 6 inches thick; pH 5.2
C	22 +	Dark greyish brown (10 YR 4/2.5 m); sandy loam; firm-compact; some mottling; structureless - amorphous; pH 5.5

Pit 2 Profile Description

L - H	1½-0	Black (7.5 YR 2/0 m); semi-decomposed to undecomposed organic matter; few fine roots; abrupt boundaries; 0 to 1½ inches thick, pH 5.6
BF_1	0-7	Dark reddish brown (5 YR 3/4 m); structureless - single grained; friable; fine roots; streaks of organic matter in horizon; gradual wavy edges; 7 inches thick; pH 5.8
BF_2	7-18	Yellowish red (5 YR 4/8 m); loam; structureless - single grained; friable loose, fine and medium roots, diffuse wavy boundary; 11 inches thick; pH 5.6
B - C	18-23	Dark brown (8.75 YR 4/3 m) sandy loam; loose friable, structureless - single grained; abrupt irregular boundary, not mottled; roots present on top of underlying bed rock; 5 inches thick, pH 6.0

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[a] An F horizon is one enriched with hydrated iron.

TABLE 13. ELEMENTAL CONTENT OF FOREST FLOOR IN STUDY AREA.

			ELEMENT	
PIT	K	Ca	Mg -Percent-	N
1.	.070	.920	.347	.69
2.	.077	.377	.533	.31

Since physical and chemical determinations were made on the basis of less than two-millimeter size fraction, the relative proportion of that size fraction in a given quantity of soil must be known. With bulk density values (Table 12), and this figure (Table 14), total nutrient quantities on a per hectare basis can be calculated (Table 28).

TABLE 14. SIZE FRACTION DISTRIBUTION IN SOIL OF STUDY AREA.

		SIZE FRACTION	
PIT	HORIZON	<2mm	<2mm
1.	BF_1	50.0	50.0
	BF_2	71.4	28.6
	BC	86.7	13.3
	C	94.5	5.5
2.	BF_1	64.6	35.4
	BF_2	68.1	31.9
	BC	46.6	53.4

Understory Strata

Twenty milacre sample plots were randomly established in the stand and ten of these were used for sampling understory vegetation. All vegetation in these plots was removed and weighed. For biomass and nutrient evaluation, the samples were combined into five random sets of two and subsequently analyzed. The biomass and nutrient evaluation by sets are presented in Appendix B; Table 15 summarizes the frequency of species occurrence and Table 17 summarizes the determinations on a per hectare basis.

TABLE 15. FREQUENCY OF OCCURRENCE OF UNDERSTORY VEGETATION

SPECIES		PLOT									
		3	18	8	11	6	1	15	10	5	4
					Number/milacre						
<u>Pseudotsuga</u> <u>menziesii</u>[1]											
	live			3			9			2	2
	dead	5	2		6	2	14		2	5	3
<u>Gaultheria</u> <u>shallon</u> (Pursh)	live	131	131	137	24	61	19	133	27	44	9
	dead	8			13	11			13	17	12
<u>Thuja</u> <u>plicata</u>					5		6	2	5	2	6
<u>Berberis</u> <u>aquifolium</u> (Pursh)		12	4	71		5				2	11
<u>Rosa</u> sp.		9	4	30							
<u>Polystichum</u> <u>munitum</u> (Kaulf)			8						17		

[1] For both Pseudotsuga and Thuja, a tree had to be less than ½-inch dbh to be considered part of the understory.

Variation in the frequency of occurrence and density is reflected in both biomass and nutrient weights (Table 17) and in nutrient concentrations (Appendix B). The range in nutrient concentrations for each understory species is summarized in Table 16.

TABLE 16. VARIATION IN NUTRIENT CONCENTRATION FOR UNDERSTORY VEGETATION.

	PERCENT-NUTRIENT CONTENT				
SPECIES	N	P	K	Ca	Mg
<u>Pseudotsuga</u>					
Live	.18 -.33	.03 - .04	.05 -.16	.26 - .43	.04 -.07
Dead	.13 -.26	.01 - .03	.01 -.12	.14 - .34	.03 -.0[illegible]
<u>Thuja</u>	.33 -.44	.03 - .04	.10 -.22	.28 - .74	.04 -.05
<u>Gaultheria</u>					
Live	.37 -.60	.04 - .04	.31 -.40	.43 - .91	.09 -.16
Dead	.24 -.37	.02 - .03	.01 -.05	.32 - .66	.04- .06
<u>Berberis</u>	.85 -.93	.06 - .11	.38 -.77	.64 - .89	.04 -.11
<u>Rosa</u>	.49 -.51	.06 - .11	.29 -.31	.63 - .82	.09 -.11
<u>Polystichum</u>	1.16 -1.25	.13 - .15	.72 -1.38	.56 - .58	.19 -.21

TABLE 17 BIOMASS AND WEIGHT OF NUTRIENTS

FOR UNDERSTORY VEGETATION.

SPECIES		O.D. Weight	N	P	K	Ca	Mg
		Kg/ha			gm/ha		
Thuja	Min	0	0	0	0	0	0
	Max	515	2107	206	1108	3787	247
	Avg	336	1317	117	487	2025	163
Pseudotsuga							
- live	Min	0	0	0	0	0	0
	Max	1306	2338	339	692	3395	548
	Avg	399	869	115	317	1214	191
Pseudotsuga							
- dead	Min	83	165	21	15	284	36
	Max	3325	4222	332	299	4655	1197
	Avg	1030	1496	129	137	2006	368
Gaultheria							
- live	Min	667	4010	294	2389	4597	1067
	Max	3485	12965	1359	10770	18298	3276
	Avg	1729	7670	706	6082	9842	1932
Gaultheria							
- dead	Min	31	89	6	6	167	19
	Max	446	1298	116	232	2422	241
	Avg	196	724	55	81	1269	121
Berberis	Min	0	0	0	0	0	0
	Max	499	4412	419	3564	3873	454
	Avg	136	1196	111	908	1032	123
Rosa	Min	0	0	0	0	0	0
	Max	351	1786	393	1018	2863	316
	Avg	77	390	82	224	614	70
Polystichum	Min	0	0	0	0	0	0
	Max	25	308	37	341	143	51
	Avg	10	119	14	104	56	20
TOTAL / ha		3913	13781	1329	8340	18058	2988

In most instances there was consistency in concentrations for most species in that a particular set, which had the lowest concentration for one element, usually had the lowest concentration for other elements as well. This relationship did not hold for the highest concentrations, resulting in more variation at this end of the scale. Further manifestations of the inherent variation in sampling understory vegetation are illustrated in Table 17, showing maximum, minimum and average weight values on a per hectare basis for each species.

Tree Strata

An initial field survey was carried out in the study area early in 1968, at which time all trees on the one-tenth-acre plot were measured for height and diameter, and a stand table was prepared (Table 1 of Appendix C). On the basis of this table, 56 trees representing the range in species, heights and diameters were selected for biomass-nutrient sampling.

The approach used introduced some bias but a partially systematic sampling was required for development of regression equations relating component weight to some measureable stand parameter. Although ranges of size were sampled, the particular sample trees within any height-diameter combination were randomly chosen, when possible. As could be expected, for the upper extremities of height-diameter, there were only one or two trees available in the plot and therefore random selection was not possible.

For the purpose of chemical analysis and nutrient evaluation, it was necessary to aggregate sample trees into even height-diameter combinations (Table 2 of Appendix C). Regression analysis for weight relationships was performed on the basis of the "raw" height-diameter combinations (for all three species), whereas, for nutrient analysis, it was necessary to use even diameter-height combinations.

In the tree strata of this ecosystem, three main species were encountered - Pseudotsuga menziesii, Thuja plicata and Tsuga heterophylla. Regression equations were developed for each component (1968 foliage, old foliage, live branches, dead branches, wood, bark, see Appendices D, E and F) within each species and the developed stand weights were based on these equations. The development of regression relationships was performed on a Hewlett-Packard 2114A Computer, in consultation with Canadian Forestry Biometrics Service, using the equation:

$$Y = a + bX$$

where Y = Component Weight
X = Independent Variable

A more detailed analysis was performed on Pseudotsuga because of its dominance in the tree strata.

Since three different species were present in the tree strata, each must be discussed separately before species comparisons or nutrient biomass evaluations on an ecosystem basis can be given.

1. Tsuga heterophylla

Biomass and nutrient analysis results are presented in the following Tables and Appendices.

Appendix D - TABLE 1. TSUGA HETEROPHYLLA SAMPLE TREE CHEMICAL ANALYSIS.

2. COEFFICIENTS OF DETERMINATION FOR TSUGA HETEROPHYLLA WEIGHT REGRESSION ANALYSIS.

3. COEFFICIENTS OF DETERMINATION FOR TSUGA HETEROPHYLLA BIOMASS-NUTRIENT CONTENT REGRESSION ANALYSIS.

4. TSUGA HETEROPHYLLA FULL TREE REGRESSION ANALYSIS.

TABLE 18. TSUGA HETEROPHYLLA BIOMASS AND NUTRIENT WEIGHT PER HECTARE.

TABLE 19. NUTRIENT CONCENTRATION RANGES IN TSUGA HETEROPHYLLA.

TABLE 20. TSUGA HETEROPHYLLA BIOMASS AND NUTRIENT DISTRIBUTION BY SIZE CLASS.

Although regression analyses have been performed on every section (Tables 2, 3 and 4 of Appendix D) the only important regressions are those for the whole tree. The analyses for each component are given in Table 3 of Appendix D, while those for the complete tree are given in Table 4. The importance value of these regressions and the resultant plant biomass and nutrient content calculations must be carefully interpreted since, for biomass evaluation, there were only four sample trees and, for nutrient content, there were three samples. More samples would have been desirable; however, neither time nor the relative importance of this species warranted it.

TABLE 18. TSUGA HETEROPHYLLA BIOMASS AND NUTRIENT WEIGHT PER HECTARE.

A. BIOMASS - KILOGRAMS/HECTARE

COMPONENT	DIAMETER CLASS			TOTAL
	*1	2	3	
68 Foliage	1.5	1.6	4.1	7.2
Older Foliage	9.0	4.9	11.2	25.1
Total Foliage	10.5	6.5	15.3	32.3
Live Branches	6.7	5.4	13.3	25.4
Dead Branches	2.9	1.7	3.9	8.5
Wood	55.4	14.8	25.2	95.4
Bark	8.9	2.6	4.7	16.1
TOTAL TREE	84.3	31.0	62.4	177.7

B. NITROGEN - GRAMS/HECTARE

COMPONENT	1	2	3	TOTAL
68 Foliage	24.4	17.9	43.2	85.5
Older Foliage	80.0	46.6	107.5	234.1
Total Foliage	104.4	64.5	150.7	319.6
Live Branches	18.8	16.3	40.5	75.6
Dead Branches	3.5	4.2	10.7	18.4
Wood	37.2	9.6	16.1	62.9
Bark	40.9	11.0	18.6	70.5
TOTAL TREE	204.8	105.6	236.6	547.0

* 1" = .5 - 1.49
2" = 1.50 - 2.49
3" = 2.50 - 3.49
4" = 3.50 - 4.49
5" = 4.50 - 5.49
6" = 5.50 - 6.49

TABLE 18. CONT'D.

C. PHOSPHOROUS - GRAMS/HECTARE

COMPONENT	1	2	3	TOTAL
68 Foliage	3.4	2.0	4.5	9.9
Older Foliage	23.3	6.6	11.7	41.6
Total Foliage	26.7	8.6	16.2	51.5
Live Branches	2.0	3.5	9.4	14.9
Dead Branches	.3	.3	.3	.9
Wood	5.5	1.5	2.5	9.5
Bark	5.5	1.5	2.7	9.7
TOTAL TREE	40.0	15.4	31.1	86.5

D. POTASSIUM - GRAMS/HECTARE

COMPONENT	1	2	3	TOTAL
68 Foliage	13.6	6.2	15.0	35.4
Older Foliage	38.3	14.8	30.2	83.3
Total Foliage	51.9	21.6	45.2	118.7
Live Branches	17.2	8.6	19.1	45.9
Dead Branches	.1	.3	.8	1.2
Wood	26.2	7.7	13.9	47.8
Bark	36.2	8.6	12.7	57.5
TOTAL TREE	131.6	46.8	91.7	270.1

TABLE 18. CONT'D.

E. CALCIUM - GRAMS/HECTARE

COMPONENT	1	2	3	TOTAL
68 Foliage	16.3	7.7	16.6	40.6
Older Foliage	127.9	41.1	77.3	246.3
Total Foliage	144.2	48.8	93.9	286.9
Live Branches	24.4	12.8	28.8	66.0
Dead Branches	6.9	5.5	13.5	25.9
Wood	44.1	10.7	16.8	71.6
Bark	49.0	12.0	19.2	80.2
TOTAL TREE	268.6	89.8	172.2	530.6

F. MAGNESIUM - GRAMS/HECTARE

COMPONENT	1	2	3	TOTAL
68 Foliage	2.5	1.7	4.2	8.4
Older Foliage	15.5	6.9	14.7	37.1
Total Foliage	18.0	8.6	18.9	45.5
Live Branches	4.2	2.2	5.0	11.4
Dead Branches	.6	.5	1.1	2.2
Wood	7.2	2.2	4.1	13.5
Bark	3.2	1.1	2.2	6.5
TOTAL TREE	33.	14.6	31.3	79.1

TABLE 19. NUTRIENT CONCENTRATION RANGES IN *TSUGA HETEROPHYLLA*

COMPONENT	ELEMENT				
	N	P	K	Ca	Mg
68 Foliage	.89 -1.29	.09 -.18	.32 -.62	.33 -.81	.07 -.13
Older Foliage	.82 -1.09	.08 -.27	.22 -.47	.43-1.53	.10 -.16
Live Branches	.23 - .57	.03 -.07	.12 -.30	.21 -.36	.03 -.07
Dead Branches	.22 - .28	.02 -.03	.01 -.03	.34 -.35	.03 -.04
Wood	.05 - .12	.01 -.02	.03 -.08	.06 -.08	.01 -.02
Bark	.28 -.57	.05 -.11	.20 -.66	.37 -.48	.03 -.05

TABLE 20. TSUGA HETEROPHYLLA BIOMASS AND NUTRIENT DISTRIBUTION BY SIZE CLASS.

A. BIOMASS - Percent

COMPONENT	DIAMETER CLASS			TOTAL [1]
	1	2	3	
68 Foliage	1.8	5.2	6.5	4.1
Older Foliage	10.6	15.9	17.9	14.1
Live Branches	7.9	17.4	21.2	14.3
Dead Branches	3.5	5.4	6.2	4.8
Wood	65.7	47.6	40.4	53.7
Bark	10.4	8.4	7.6	9.1
TOTAL FOLIAGE	12.4	21.1	24.4	18.2
TOTAL TREE	47.4	17.5	35.1	100.

B. NITROGEN - Percent

COMPONENT	1	2	3	TOTAL
68 Foliage	11.9	16.9	18.3	15.6
Older Foliage	39.1	44.2	45.5	42.9
Live Branches	9.2	15.5	17.1	13.8
Dead Branches	1.7	3.9	4.5	3.3
Wood	18.2	9.1	6.8	11.5
Bark	20.0	10.4	7.8	12.9
TOTAL FOLIAGE	51.0	61.1	63.8	58.5
TOTAL TREE	37.5	19.3	43.2	100.

---

[1] Mean percent values for diameter class and component.

TABLE 20. CONT'D.

C. PHOSPHOROUS - Percent

COMPONENT	1	2	3	TOTAL [1]
68 Foliage	8.5	12.7	14.6	11.4
Older Foliage	58.1	42.9	37.5	48.0
Live Branches	5.0	23.0	30.3	17.3
Dead Branches	.8	1.8	1.0	1.1
Wood	13.8	9.6	8.1	11.0
Bark	13.7	10.0	8.7	11.2
TOTAL FOLIAGE	66.6	55.6	52.1	59.4
TOTAL TREE	46.3	17.8	35.9	100.

D. POTASSIUM - Percent

COMPONENT	1	2	3	TOTAL
68 Foliage	10.3	14.4	16.3	13.1
Older Foliage	29.1	31.6	32.9	30.8
Live Branches	13.1	18.5	20.9	16.7
Dead Branches	<.1	.6	.8	.4
Wood	19.9	16.5	15.1	17.7
Bark	27.5	18.4	13.9	21.3
TOTAL FOLIAGE	39.4	46.0	49.2	43.9
TOTAL TREE	48.7	17.3	34.0	100.

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[1] Mean percent values for diameter class and component.

TABLE 20. CONT'D.

E. CALCIUM - Percent

COMPONENT	1	2	3	TOTAL [1]
68 Foliage	6.1	8.6	9.7	7.7
Older Foliage	47.6	45.8	44.7	46.4
Live Branches	9.1	14.3	16.7	12.4
Dead Branches	2.6	6.1	7.8	4.9
Wood	16.4	11.8	9.7	13.5
Bark	18.2	13.4	11.1	15.1
TOTAL FOLIAGE	53.7	54.4	54.4	54.1
TOTAL TREE	50.5	16.9	32.6	100.

F. MAGNESIUM - Percent

COMPONENT	1	2	3	TOTAL
68 Foliage	7.5	11.9	13.4	10.6
Older Foliage	46.6	46.9	47.0	46.8
Live Branches	12.7	15.2	16.1	14.5
Dead Branches	1.9	3.2	3.6	2.8
Wood	21.7	15.2	13.0	17.1
Bark	9.6	7.6	7.0	8.2
TOTAL FOLIAGE	54.1	48.8	60.4	57.4
TOTAL TREE	42.0	18.5	39.5	100.

[1] Mean percent values for diameter class and component.

2. Thuja plicata

The same statistical analytical procedure was used on this species as Tsuga heterophylla and, consequently, results are given in a similar form, i.e.:

Appendix E - TABLE 1. THUJA PLICATA SAMPLE TREE CHEMICAL ANALYSIS.
2. COEFFICIENTS OF DETERMINATION FOR THUJA PLICATA BIOMASS-NUTRIENT CONTENT REGRESSION ANALYSIS.
3. THUJA PLICATA FULL TREE REGRESSION ANALYSIS.

TABLE 21. THUJA PLICATA BIOMASS AND NUTRIENT WEIGHT PER HECTARE.
TABLE 22. NUTRIENT CONCENTRATION RANGES IN THUJA PLICATA.
TABLE 23. THUJA PLICATA BIOMASS AND NUTRIENT DISTRIBUTION BY SIZE CLASS.

"Diameter^2 x Height" was the independent variable, and component weight was the dependent in a linear untransformed regression equation ($Y = a + bX$). The results of the regression analyses are given in Appendix E.

TABLE 21. *THUJA PLICATA* BIOMASS AND NUTRIENT WEIGHT PER HECTARE.

A. BIOMASS - KILOGRAMS/HECTARE

COMPONENT	DIAMETER CLASS			TOTAL
	1	2	3	
68 Foliage	21.0	39.9	10.7	71.6
Older Foliage	89.8	257.4	71.0	418.2
Total Foliage	110.8	297.3	81.7	489.8
Live Branches	94.2	80.4	19.1	193.7
Dead Branches	10.1	6.0	1.3	17.4
Wood	437.3	327.3	75.2	839.8
Bark	81.5	52.6	11.6	145.7
TOTAL TREE	716.9	762.1	189.2	1686.4

B. NITROGEN - GRAMS/HECTARE

COMPONENT	1	2	3	TOTAL
68 Foliage	171.7	385.8	104.7	662.2
Older Foliage	268.5	1810.0	495.1	2573.6
Total Foliage	440.1	2195.8	622.4	3258.3
Live Branches	149.2	106.6	24.3	280.1
Dead Branches	7.8	4.8	1.0	13.6
Wood	245.4	158.6	34.9	438.9
Bark	249.0	146.4	31.1	426.5
TOTAL TREE	1063.7	2602.2	713.7	4394.9

TABLE 21. CONT'D.

C. PHOSPHOROUS - GRAMS/HECTARE

COMPONENT	1	2	3	TOTAL
68 Foliage	0	65.9	21.5	87.4
Older Foliage	7.3	176.7	52.3	236.3
Total Foliage	7.3	242.6	73.8	323.7
Live Branches	21.1	10.0	1.9	33.0
Dead Branches	.3	.3	.1	.7
Wood	20.8	16.2	4.0	41.0
Bark	52.7	20.5	3.5	76.7
TOTAL TREE	102.2	289.6	83.3	475.1

D. POTASSIUM - GRAMS/HECTARE

COMPONENT	1	2	3	TOTAL
68 Foliage	31.1	155.9	44.1	231.1
Older Foliage	262.8	631.5	172.2	1065.5
Total Foliage	293.4	787.4	216.3	1297.1
Live Branches	94.9	39.4	7.1	141.4
Dead Branches	.5	.3	.1	.9
Wood	72.1	103.5	25.7	201.3
Bark	376.7	145.4	24.9	547.0
TOTAL TREE	837.7	1076.0	275.2	2188.9

TABLE 21. CONT'D.

E. CALCIUM - GRAMS/HECTARE

COMPONENT	1	2	3	TOTAL
68 Foliage	283.0	401.1	104.0	788.1
Older Foliage	1763.0	2913.2	768.8	5445.0
Total Foliage	3047.5	3314.3	872.8	6234.6
Live Branches	487.2	360.8	82.7	930.7
Dead Branches	26.2	26.3	6.5	59.0
Wood	278.7	173.2	37.6	489.5
Bark	1409.3	670.8	130.1	2210.2
TOTAL TREE	4248.8	4545.5	1129.6	9922.5

F. MAGNESIUM - GRAMS/HECTARE

COMPONENT	1	2	3	TOTAL
68 Foliage	11.4	46.0	13.8	71.2
Older Foliage	81.7	228.0	62.8	372.5
Total Foliage	93.1	271.5	76.1	440.7
Live Branches	34.2	20.8	4.5	59.5
Dead Branches	1.4	1.3	.3	3.0
Wood	33.0	31.4	7.6	72.0
Bark	26.9	21.6	4.8	53.3
TOTAL TREE	88.6	350.4	93.3	631.5

TABLE 22. RANGE OF NUTRIENT CONCENTRATIONS IN *THUJA PLICATA* .

COMPONENT	ELEMENT				
	N	P	K	Ca	Mg
68 Foliage	.58-1.15	.05 -.17	.20 -.61	.87 -2.16	.11-.16
Older Foliage	.56-1.03	.04 -.13	.16 -.45	1.22 -1.9	.10-.12
Live Branches	.14- .30	.01 -.03	.02 -.14	.52 - .69	.03-.05
Dead Branches	.12- .14	.01 -.01	.01 -.01	.49 - .91	.03-.04
Wood	.03- .11	<.01 -.03	.01 -.08	.07 - .11	.01-.02
Bark	.27- .52	.04 -.06	.24 -.42	1.26 -2.03	.04-.08

TABLE 23. *THUJA PLICATA* BIOMASS AND NUTRIENT DISTRIBUTION BY SIZE CLASS.

A. BIOMASS - Percent

COMPONENT	DIAMETER CLASS			TOTAL
	1	2	3	
68 Foliage	2.9	5.2	5.7	4.3
Older Foliage	12.5	33.7	37.6	25.1
Live Branches	13.1	10.6	10.1	11.6
Dead Branches	1.4	.8	.7	1.0
Wood	61.0	42.9	39.8	50.3
Bark	11.4	6.9	6.1	8.7
TOTAL FOLIAGE	15.4	38.9	43.3	29.4
TOTAL TREE	42.9	45.6	11.3	10.0

B. NITROGEN - Percent

COMPONENT	1	2	3	TOTAL
68 Foliage	16.1	13.8	14.7	15.1
Older Foliage	25.2	69.6	69.3	58.6
Live Branches	14.0	4.1	3.4	6.4
Dead Branches	.7	.2	.1	.3
Wood	23.1	6.1	4.9	10.0
Bark	23.4	5.6	4.4	9.7
TOTAL FOLIAGE	41.3	83.4	84.0	73.7
TOTAL TREE	24.3	59.4	16.2	100.0

TABLE 23. CONT'D.

C. PHOSPHOROUS - Percent

COMPONENT	1	2	3	TOTAL
68 Foliage	0	22.7	25.7	18.4
Older Foliage	7.2	61.0	62.8	49.8
Live Branches	20.6	3.4	2.3	6.9
Dead Branches	.3	.1	.1	.1
Wood	20.3	5.6	4.8	8.6
Bark	51.6	7.1	3.9	16.2
TOTAL FOLIAGE	7.2	83.7	88.5	68.2
TOTAL TREE	2.5	61.0	17.5	100.

D. POTASSIUM - Percent

COMPONENT	1	2	3	TOTAL
68 Foliage	3.7	14.5	16.0	10.6
Older Foliage	31.4	58.7	62.6	48.6
Live Branches	11.3	3.7	2.6	6.5
Dead Branches	.1	<.1	<.1	<.1
Wood	8.6	9.6	9.4	9.2
Bark	45.0	13.5	9.1	25.0
TOTAL FOLIAGE	35.1	73.2	78.6	59.5
TOTAL TREE	38.3	49.2	12.6	100.

TABLE 23. CONT'D.

E. CALCIUM - Percent

COMPONENT	1	2	3	TOTAL
68 Foliage	6.7	8.8	9.2	7.9
Older Foliage	41.4	64.1	68.1	54.9
Live Branches	11.5	7.9	7.3	9.4
Dead Branches	.6	.6	.6	.6
Wood	6.6	3.8	3.3	4.9
Bark	33.2	14.8	11.6	22.3
TOTAL FOLIAGE	48.1	72.9	77.3	62.8
TOTAL TREE	42.8	45.8	11.4	100.

F. MAGNESIUM - Percent

COMPONENT	1	2	3	TOTAL
68 Foliage	5.8	13.1	14.8	11.2
Older Foliage	42.1	65.1	67.3	58.4
Live Branches	17.5	5.9	4.8	9.4
Dead Branches	.7	.4	.3	.4
Wood	17.0	9.0	8.2	11.4
Bark	13.8	6.2	5.2	8.4
TOTAL FOLIAGE	47.9	78.2	82.1	69.6
TOTAL TREE	30.7	55.0	14.6	100.

3. Pseudotsuga menziesii

Because of its numerical and biomass dominance, Pseudotsuga menziesii was analysed in the greatest detail. Regression equations were evaluated and, on the basis of the accepted form, biomass and nutrient calculations were made. The tables used or produced by linear regression were:

Appendix F - TABLE 1. COEFFICIENTS OF DETERMINATION FOR PSEUDOTSUGA MENZIESII REGRESSION ANALYSIS.

2. COMPARISON OF COEFFICIENTS OF DETERMINATION FOR PSEUDOTSUGA MENZIESII DRY WEIGHT USING RAW DATA AND EVEN INCH DATA.

3. COEFFICIENTS OF DETERMINATION FOR PSEUDOTSUGA MENZIESII BIOMASS-NUTRIENT CONTENT REGRESSION ANALYSIS.

4. PSEUDOTSUGA MENZIESII FULL TREE REGRESSION ANALYSIS.

TABLE 24. PSEUDOTSUGA MENZIESII BIOMASS AND NUTRIENT WEIGHT PER HECTARE.

TABLE 25. NUTRIENT CONCENTRATION RANGES IN PSEUDOTSUGA MENZIESII.

TABLE 26. PSEUDOTSUGA MENZIESII BIOMASS AND NUTRIENT DISTRIBUTION BY SIZE CLASS.

It was observed, during chemical analysis, that the accuracy in measuring nitrogen content was much higher than for the other elements. As a result of this, a regression analysis was run for nitrogen content for several different components, using different stand parameters as the independent variable. Table 27 illustrates a generally poor correlation between the independent variable and nitrogen concentrations. The initial thought behind this probe was to use a regressed concentration and biomass weight to estimate component nutrient content. Because of relatively poor results from this approach, an evaluation using component nutrient content for regression purposes was utilized.

When deciding upon the regression equation to be used, several criteria were considered. Simplicity and ease in measuring stand parameters for the independent variable was essential. The same equation form and independent variable had to be employed for all components to ensure additivity of the calculated figures. The form of the equation and independent variable had to have some biologically meaningful basis for its use. The equation decided upon has already been stated where "X" is the independent variable of choice. Since diameter and height were the only stand parameters measured, varying combinations of these were tried (Appendix F), the final observation being that "diameter^2 x height" was the most appropriate.

Since the per hectare weight spread for Pseudotsuga was substantial, the question arose as to whether or not a logarithmic transformation would result in a significant improvement in r^2 values.

A summary of the regressions run for raw diameters (field diameters and heights) and even inch diameter - height combinations, and a transformation of both was carried out (Tables 2 and 3 of Appendix F). Such treatment of the data did not greatly improve accuracy and, as a result, was not expanded. The independent variable used for all further computations was "diameter^2 x height" in an untransformed linear relationship. This independent variable and the linear regression model was applied to the other two species.

TABLE 24. PSEUDOTSUGA MENZIESII BIOMASS AND NUTRIENT WEIGHTS PER HECTARE.

A. BIOMASS - KILOGRAMS/HECTARE

	DIAMETER CLASS						
COMPONENT	1	2	3	4	5	6	TOTAL
68 Foliage	681.	781.	614.	412.	70.	138.	2696.
Older Foliage	1161.	2206.	2054.	1468.	256.	510.	7655.
Total "	1842.	2987.	2660.	1880.	326.	648.	10351.
Live Branches	3453.	3698.	2820.	1867.	316.	621.	12775.
Dead "	215.	741.	737.	546.	96.	123.	2458.
Total Wood	9705.	11799.	9530.	6467.	1106.	2183.	40790.
Total Bark	2395.	2459.	1835.	1204.	200.	398.	8491.
TOTAL TREE	17610.	21684.	17590.	11964.	2044.	3973.	74865.

B. NITROGEN - GRAMS/HECTARE

68 Foliage	12778.	10141.	6340.	3800.	616.	1183.	34858.
Older Foliage	44376.	36238.	23194.	14089.	2298.	4427.	124622.
Total "	57155.	46379.	29534.	17887.	2913.	5610.	159478.
Live Branches	11210.	12156.	9311.	6181.	1048.	2059.	41966.
Dead "	1921.	1897.	1391.	903.	152.	297.	6561.
Total Wood	14267.	10103.	5672.	3172.	497.	937.	34648.
Total Bark	11373.	8651.	5210.	3056.	489.	934.	29703.
TOTAL TREE	95924.	79186.	51116.	31199.	5099.	9838.	272358.

TABLE 24. CONT'D.

C. PHOSPHOROUS - GRAMS/HECTARE

	DIAMETER CLASS						
COMPONENT	1	2	3	4	5	6	TOTAL
68 Foliage	2840.	2024.	1145.	644.	101.	190.	6944.
Older Foliage	11711.	8167.	4515.	2498.	389.	731.	28011.
Total "	14550.	10191.	5660.	3142.	490.	921.	34954.
Live Branches	2350.	2488.	1873.	1234.	208.	409.	8561.
Dead "	82.	166.	163.	119.	21.	42.	593.
Total Wood	2089.	1424.	767.	417.	63.	120.	4880.
Total Bark	1245.	1489.	1194.	808.	138.	272.	5146.
TOTAL TREE	20312.	15751.	9654.	5718.	921.	1764.	54136.

D. POTASSIUM - GRAMS/HECTARE

68 Foliage	6195.	5907.	4213.	2708.	453.	884.	20360.
Older Foliage	15774.	15505.	11262.	7300.	1225.	2396.	53462.
Total "	21969.	21408.	15465.	10008.	1678.	3280.	73808.
Live Branches	8684.	8582.	6184.	4059.	682.	1334.	29525.
Dead "	0.	55.	185.	164.	30.	63.	497.
Total Wood	2843.	2466.	1651.	1029.	170.	323.	8482.
Total Bark	9252.	8201.	5581.	3503.	580.	1126.	28243.
TOTAL TREE	42748.	40716.	29076.	18764.	3130.	6126.	140569.

TABLE 24. CONT'D.

E. CALCIUM - GRAMS/HECTARE

	DIAMETER CLASS						
COMPONENT	1	2	3	4	5	6	TOTAL
68 Foliage	7288.	5128.	2861.	1594.	249.	467.	17589.
Older Foliage	47449.	37521.	23389.	13992.	2266.	4350.	128966.
Total "	54738.	42649.	26250.	15586.	2515.	4818.	146555.
Live Branches	12236.	18115.	15735.	11054.	1898.	3745.	62785.
Dead "	1036.	3595.	3730.	2737.	487.	975.	12560.
Total Wood	5751.	4898.	3237.	2002.	329.	636.	16852.
Total Bark	13848.	10579.	6408.	3759.	603.	1153.	36349.
TOTAL TREE	87609.	79836.	55360.	35138.	5832.	11326.	275101.

F. MAGNESIUM - GRAMS/HECTARE

68 Foliage	1886.	1312.	723.	388.	62.	117.	4488.
Older Foliage	8524.	5704.	3010.	1608.	246.	457.	19549.
Total "	10410.	7016.	3733.	1996.	308.	573.	24036.
Live Branches	928.	1663.	1526.	1085.	189.	376.	5767.
Dead "	389.	451.	357.	240.	41.	81.	1559.
Total Wood	1159.	1154.	786.	494.	82.	159.	3834.
Total Bark	1673.	1296.	793.	470.	74.	145.	4451.
TOTAL TREE	14559.	11580.	7195.	425.	694.	1334.	39648.

TABLE 25. NUTRIENT CONTENT RANGES IN

PSEUDOTSUGA MENZIESII.

COMPONENT	ELEMENT				
	N	P	K	Ca	Mg
			Percent		
I - 68 Foliage	.88-1.01	.11- .21	.41-.81	.26- .39	.06-.12
67 "	.98-1.15	.12- .19	.37-.66	.42- .67	.07-.14
66 "	.89-1.05	.12- .21	.39-.60	.51- .76	.07-.12
65 "	.80- .98	.13- .20	.32-.62	.51- .89	.07-.11
64 and less	.80- .87	.13- .19	.21-.48	.49-1.11	.06-.11
Live Branches	.28- .48	.06- .11	.24-.41	.28- .63	.05-.11
Wood	.07- .12	.01- .12	.01-.06	.03- .06	<.01-.02
Bark	.36- .55	.06- .11	.32-.78	.40- .78	.05-.11
II - 68 Foliage	.79-1.01	.12- .24	.46-.68	.29- .53	.04-.11
67 "	.90-1.08	.11- .20	.39-.62	.52- .87	.06-.13
66 "	.87- .98	.11- .20	.35-.53	.62- .98	.05-.12
65 "	.81- .97	.10- .18	.34-.57	.71-1.03	.05-.10
64 and less	.75- .86	.09- .20	.30-.48	.76-1.11	.07-.10
Live Branches	.20- .41	.04- .08	.16-.26	.39- .76	.04-.08
Dead "	.20- .31	.03- .05	.05-.10	.47- .62	.04-.06
Wood	.04- .11	<.01- .01	.01-.02	.03- .06	.01-.02
Bark	.37- .53	.06- .12	.36-.69	.40- .80	.05-.08
III - 68 Foliage	.81- .96	.17- .21	.50-.63	.36- .50	.08-.11
67 "	.80-1.02	.09- .18	.34-.65	.62- .92	.08-.14
66 "	.77- .99	.13- .18	.28-.52	.78-1.25	.07-.16
65 "	.71- .84	.12- .25	.29-.58	.80-1.38	.06-.15
64 and less	.70- .86	.12- .25	.31-.63	.81-1.45	.06-.13
Live Branches	.17- .34	.04- .07	.10-.20	.42- .69	.05-.07
Dead "	.16- .21	.02- .03	.02-.05	.44- .60	.04-.06
Wood	.04- .09	<.01- .01	.01-.03	.03- .06	<.01-.01
Bark	.20- .45	.03- .11	.12-.32	.26- .67	.03-.05

TABLE 26. PSEUDOTSUGA MENZIESII BIOMASS AND NUTRIENT DISTRIBUTION BY SIZE CLASS.

A. BIOMASS

	DIAMETER CLASS - INCHES						
COMPONENT	1	2	3	4	5	6	TOTAL
			Percent				
68 Foliage	3.9	3.6	3.5	3.4	3.4	3.5	3.6
Older Foliage	6.6	10.2	11.7	12.3	12.5	12.8	10.3
Live Branches	19.6	17.1	16.0	15.6	15.5	15.6	17.1
Dead Branches	1.2	3.4	4.2	4.6	4.7	3.1	3.3
Wood	55.1	54.4	54.2	54.1	54.1	54.9	54.5
Bark	13.6	11.3	10.4	10.1	9.8	10.0	11.3
TOTAL FOLIAGE	10.5	13.8	15.2	15.7	15.9	16.3	13.9
TOTAL TREE	23.5	28.9	23.5	16.0	2.7	5.3	100.

B. NITROGEN

68 Foliage	13.3	12.8	12.4	12.2	12.1	12.0	12.8
Older Foliage	46.3	45.8	45.4	45.2	45.1	45.0	45.8
Live Branches	11.7	15.4	18.2	19.8	20.5	20.9	15.4
Dead Branches	2.0	2.4	2.7	2.9	3.0	3.0	2.4
Wood	14.9	12.8	11.1	10.2	9.7	9.5	12.7
Bark	11.9	10.9	10.2	9.8	9.6	9.5	10.9
TOTAL FOLIAGE	59.6	58.6	57.8	47.4	47.2	57.0	58.6
TOTAL TREE	35.2	29.1	18.8	11.5	1.9	3.6	100.

TABLE 26. CONT'D.

C. PHOSPHOROUS

DIAMETER CLASS							
COMPONENT	1	2	3	4	5	6	TOTAL
68 Foliage	14.0	12.9	11.9	11.3	11.0	10.8	12.8
Older Foliage	57.7	51.8	46.8	43.7	42.2	41.4	51.8
Live Branches	11.6	15.8	19.4	21.6	22.6	23.2	15.8
Dead Branches	.4	1.1	1.7	2.1	2.3	2.4	1.1
Wood	10.3	9.0	7.9	7.3	6.9	6.8	9.0
Bark	6.1	9.5	12.4	14.1	15.0	15.4	9.5
TOTAL FOLIAGE	71.7	64.7	58.7	55.0	53.2	52.2	64.6
TOTAL TREE	37.5	29.1	17.8	10.6	1.7	3.3	100.

D. POTASSIUM

68 Foliage	14.5	14.5	14.5	14.4	14.5	14.4	14.5
Older Foliage	36.9	38.1	38.7	38.9	39.1	39.1	38.0
Live Branches	20.3	21.1	21.3	21.6	21.8	21.8	21.0
Dead Branches	0	.1	.6	.9	1.0	1.0	.4
Wood	6.6	6.1	5.7	5.5	5.4	5.3	6.0
Bark	21.6	20.1	19.2	18.7	18.5	18.4	20.1
TOTAL FOLIAGE	54.4	52.6	53.2	53.3	53.6	53.5	52.5
TOTAL TREE	30.4	29.0	20.7	13.3	2.2	4.4	100.

TABLE 26. CONT'D.

E. CALCIUM

	DIAMETER CLASS						
COMPONENT	1	2	3	4	5	6	TOTAL
68 Foliage	8.3	6.4	5.2	4.5	4.3	4.1	6.4
Older Foliage	54.2	47.0	42.2	39.8	38.8	38.4	46.9
Live Branches	14.0	22.7	28.4	31.5	32.5	33.1	22.8
Dead Branches	1.2	4.5	6.7	7.8	8.3	8.6	4.6
Wood	6.6	6.3	5.8	5.7	5.6	5.6	6.1
Bark	15.8	13.3	11.6	10.7	10.3	10.2	13.2
TOTAL FOLIAGE	62.5	53.4	47.4	44.3	43.1	42.5	53.3
TOTAL TREE	31.8	29.0	20.1	12.8	2.1	4.1	100.

F. MAGNESIUM

68 Foliage	13.0	11.3	10.0	9.0	8.9	8.7	11.3
Older Foliage	58.6	49.3	41.8	37.5	35.4	34.2	49.3
Live Branches	6.4	14.4	21.2	25.3	27.2	28.2	14.5
Dead Branches	2.7	3.9	5.0	5.6	5.9	6.0	3.9
Wood	8.0	10.0	10.9	11.5	11.8	11.9	9.7
Bark	11.5	11.2	11.0	11.0	10.7	10.9	11.2
TOTAL FOLIAGE	71.6	60.6	51.8	46.5	44.3	42.9	60.6
TOTAL TREE	36.7	29.2	18.1	10.8	1.7	3.4	100.

TABLE 27. PERCENTAGE OF VARIATION EXPLAINED BY REGRESSION (r^2) FOR NITROGEN CONTENT AGAINST DIFFERENT INDEPENDENT VARIABLES.

$W + N = a + b\,(x)$.

SECTION	COMPONENT	x	a	b	r	r^2 x 100
I - 68	Foliage	D^2H	.941	.0005	.335	11.2
II - 68	"	D^2H	.902	-.00004	-.364	13.2
III - 68	"	D^2H	.991	-.0001	-1.000	100.
I - 68	"	DH^2	.944	.000007	.287	8.2
II - 68	"	DH^2	.907	-.000009	-.397	15.7
III - 68	"	D	.936	.01	.235	5.5
II - 68	"	D	.921	-.012	-.355	12.6
I - 68	"	H	.965	.0002	.027	.1
II - 68	"	H	.993	-.004	-.615	37.8

Ecosystem

Ecosystem results are a reconstruction of the vegetative and soil components into a single unit. Vegetative data have already been summarized on the basis of a weight per hectare. Further computations are required for soils since it is necessary to determine the weight of available nutrients per hectare for each soil horizon. The formula for such a computation is:

Weight of Available nutrients/hectare

= (Square meters/hectare)X Depth (cm)
X Centimeters/sq meter X Bulk Density
X Percent of sample less than 2 mm in
size X Milliequivalents/gram
X Equivalent Weight.

The horizon values are summed to yield available nutrients in terms of kilograms per hectare (Table 28).

The total biomass and nutrients contained in the aerial components of the ecosystem is simply the summation of the species totals (Table 29). The relative importance value of nutrient-biomass distribution is derived by comparisons between the various ecosystem components (Tables 31, 32, 33 and 34). Such a comparison, for example, would be the distribution of biomass and nutrients between the various tree components (Tables 31, 32 and 33). These comparisons are found in the discussion section.

TABLE 28. TOTAL AVAILABLE NUTRIENTS IN EFFECTIVE* SOIL PROFILE OF STUDY SITE.

PIT HORIZON	THICKNESS cm.	ELEMENT					
		N	P	K	Ca	Mg	OM
				- Kg/ha -			
1. LH	2.5	413.	8.0	15.3	252.7	25.5	35,635.
BF_1	17.8	869.3	891.8	44.1	169.4	17.5	41,892.
BF_2	22.	1126.6	495.2	39.8	41.	7.3	49,876.
B-C	15.2	1505.3	1261.9	44.3	6.0	8.0	58,612.
TOTAL	58.4	3914.3	2656.9	143.5	469.2	58.3	186,015.
2. LH	1.3	139.7	1.8	7.0	40.	4.4	28,529
BF_1	17.8	917.4	854.8	44.7	753.5	41.2	53,280.
BF_2	27.9	1160.2	1448.9	36.3	428.2	21.8	56,254.
B-C	12.7	602.3	1731.3	23.2	235.8	23.0	25,295
TOTAL	59.7	2819.6	4036.8	111.2	1457.6	90.3	163,358.
AVERAGE		3366.9	3346.8	127.3	963.4	74.3	174,688.

[*] C horizon not included because of compaction and lack of root penetration.

TABLE 29. BIOMASS AND NUTRIENTS CONTAINED IN AERIAL COMPONENT OF A YOUNG PSEUDOTSUGA MENZIESII ECOSYSTEM.

	ELEMENT					
SPECIES	O.M.	N	P	K	Ca	Mg
			Kg/ha			
Understory						
Thuja	336.	1.32	.12	.49	2.02	.16
Pseudotsuga						
Live	399.	.87	.11	.32	1.21	.19
Dead	1030.	1.50	.13	.14	2.01	.37
Gaultheria						
Live	1729	7.67	.71	6.08	9.84	1.93
Dead	196.	.72	.05	.08	1.27	.12
Berberis	136.	1.20	.11	.91	1.03	.12
Rosa	77.	.39	.08	.22	.61	.07
Polystichum	10.	.12	.01	.10	.06	.02
TOTAL UNDERSTORY	3913.	13.79	1.32	8.34	18.05	2.98
Standing Trees						
Pseudotsuga	74867.	272.36	54.13	140.57	275.10	39.64
Thuja	1686.	4.40	.47	2.19	9.92	.63
Tsuga	178.	.55	.09	.27	.53	.08
TOTAL TREES	76731.	277.31	54.69	143.03	285.55	40.35
TOTAL VEGETATIVE	80644	291.10	56.00	151.37	303.60	43.33

TABLE 30. BIOMASS AND NUTRIENT DISTRIBUTION IN A YOUNG *PSEUDOTSUGA MENZIESII* ECOSYSTEM.

COMPONENT	ELEMENT					
	O.M.	N	P	K	Ca	Mg
			- Kg/ha -			
TREE						
68 Foliage	2775.	35.6	7.	20.6	18.4	4.6
Older "	8099.	127.4	28.3	54.6	134.7	20.0
Live Branches	12995.	42.3	8.6	29.7	63.8	5.8
Dead "	2485.	6.6	.6	.5	12.6	1.6
Wood	41725.	35.2	4.9	8.7	17.4	3.9
Bark	8652.	30.2	5.2	28.9	38.6	4.5
TOTAL TREE	76731.	277.3	54.7	143.0	285.6	40.4
SUBORDINATE VEGETATION	3913.	13.8	1.3	8.3	18.1	3.0
FOREST SOIL						
L-H	32082.	276.4	4.9	11.1	146.9	15.0
BF_1	47586.	893.3	873.3	44.4	461.4	29.3
BF_2	53065.	1143.4	972.0	38.1	234.6	14.5
BC	41953.	1053.8	1496.6	33.8	120.9	15.5
TOTAL	174688.	3366.9	3346.8	127.4	963.8	74.3
TOTAL ECOSYSTEM	255331.	3658.0	3402.8	278.7	1267.5	177.7

TABLE 31. PERCENT BIOMASS AND NUTRIENT DISTRIBUTION IN TREE COMPONENT OF A YOUNG *PSEUDOTSUGA MENZIESII* ECOSYSTEM.

	ELEMENT - PERCENT					
COMPONENT	O.M.	N	P	K	Ca	Mg
68 Foliage	3.6	12.8	12.9	14.4	6.5	11.3
Older Foliage	10.6	45.9	51.7	38.2	47.2	49.4
Live Branches	16.9	15.3	15.7	20.8	22.3	14.5
Dead Branches	3.2	2.4	1.1	.3	4.4	3.9
Wood	54.4	12.7	9.0	6.1	6.1	9.7
Bark	11.3	10.9	9.6	20.2	13.5	11.2
TOTAL TREE	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 32. BIOMASS AND NUTRIENT DISTRIBUTION BY SPECIES AND COMPONENT

		COMPONENT					
ELEMENT	SPECIES	68 FOLIAGE	OLDER FOLIAGE	LIVE BRANCHES	DEAD BRANCHES	WOOD	BARK
				Kg/ha			
N	Ps.	34.8	124.6	41.9	6.6	34.7	29.7
	Th.	.7	2.6	.2	<.1	.4	.4
	Ts.	.1	.2	.1	<.1	.1	.1
TOTAL		35.6	127.4	42.3	6.6	35.2	30.2
P	Ps.	6.9	28.0	8.6	.6	4.9	5.1
	Th.	.1	.2	<.1	<.1	<.1	.1
	Ts.	<.1	.1	<.1	<.1	<.1	<.1
TOTAL		7.0	28.3	8.6	.6	4.9	5.2
K	Ps.	20.4	53.4	29.5	.5	8.5	28.2
	Th.	.2	1.1	.1	<.1	.2	.6
	Ts.	<.1	.1	.1	<.1	<.1	.1
TOTAL		20.6	54.6	29.7	.5	8.7	28.9
Ca	Ps.	17.6	129.0	62.8	12.6	16.8	36.3
	Th.	.8	5.4	.9	<.1	.5	2.2
	Ts.	<.1	.3	.1	<.1	.1	.1
TOTAL		18.4	134.7	63.8	12.6	17.4	38.6
Mg	Ps.	4.4	19.6	5.7	1.5	3.8	4.4
	Th.	.1	.4	.1	<.1	.1	.1
	Ts.	<.1	<.0	<.1	<.1	<.1	<.1
TOTAL		4.6	20.0	5.8	1.6	3.9	4.5
O.M.	Ps.	2696.	7656.	12776.	2458.	40790.	8491.
	Th.	72.	418.	194.	17.	840.	145.
	Ts.	7.	25.	25.	29.	95.	16.
TOTAL		2775	8099.	12995.	2504.	41725.	8652.

Ps. = *Pseudotsuga*
Th. = *Thuja*
Ts. = *Tsuga*

TABLE 33. BIOMASS AND NUTRIENT WEIGHT BY SPECIES AND DIAMETER CLASS

		DIAMETER CLASS - INCHES					
ELEMENT	SPECIES	1	2	3	4	5	6
				- Kg/ha -			
N	Ps.	95.9	79.2	51.2	31.2	5.1	9.8
	Th.	1.1	2.6	.7			
	Ts.	.2	.1	.2			
TOTAL		97.2	81.9	52.1	31.2	5.1	9.8
P	Ps.	20.3	15.8	9.7	5.7	.9	1.8
	Th.	.1	.3	.1			
	Ts.	<.1	<.1	<.1			
TOTAL		20.5	16.2	9.9	5.7	.9	1.8
K	Ps.	42.7	40.7	29.1	18.8	3.1	6.1
	Th.	.8	1.1	.3			
	Ts.	.1	<.1	.1			
TOTAL		43.6	41.9	29.5	18.8	3.1	6.1
Ca	Ps.	87.6	79.8	55.4	35.1	5.8	11.3
	Th.	4.2	4.5	1.1			
	Ts.	.3	.1	.2			
TOTAL		92.1	84.4	56.7	35.1	5.8	11.3
Mg	Ps.	14.6	11.6	7.2	42.7	.7	1.3
	Th.	.2	.4	.1			
	Ts.	<.1	<.1	<.1			
TOTAL		14.8	12.0	7.3	42.7	.7	1.3
O.M.	Ps.	17610.	21683.	17590.	11965.	2045.	3974.
	Th.	717.	762.	189.			
	Ts.	84.	31.	62.			
TOTAL		18411	22476.	17841.	11965.	2045.	3974.

TABLE 34. ECOSYSTEM BIOMASS AND NUTRIENT DISTRIBUTION (PERCENT).

COMPONENT	ELEMENT					
AERIAL	O.M.	N	P	K	Ca	Mg
68 Foliage	1.1	1.0	.2	7.4	1.5	3.9
Older "	3.2	3.5	.8	19.6	10.6	17.0
Total "	4.3	4.4	1.0	27.0	12.1	20.8
Tree	30.0	7.6	1.6	51.3	22.5	34.3
Sub. Veg.	1.6	.4	.1	3.0	1.4	2.5
TOTAL AERIAL	31.6	8.0	1.6	54.3	23.9	36.8
SOIL						
L - H	12.6	7.5	.1	4.0	11.6	12.7
Mineral	55.8	84.5	98.2	41.7	64.4	50.4
TOTAL SOIL	68.4	92.0	98.3	45.7	76.0	63.1

V. DISCUSSION

Soil Analysis

1. Properties of Surface Organic Layers

Variation in surface soil properties in the two soil pits reflects the influence of the aerial component of the ecosystem. Surface depositions (L-H horizons) vary because pit 2, in an open area, received less litter than pit 1. The common influence of natural development is reflected in the nitrogen and organic matter contents, but exchangeable calcium and magnesium reflect differences in soil parent material.

Further manifestations of the differences in parent material and variability in aerial vegetation is reflected in elemental analysis of the surface horizon (Table 12). Calcium and magnesium showed major differences between the pits. The physio-chemical nature of the deposited organic matter will affect the availability of the contained nutrients and should be evaluated in nutrient cycling studies.

2, Physical Properties of Mineral Soil

Due to its glacial origin, soil parent material in this site is varied, as confirmed by chemical and physical analyses. Soil from pit 2 has a higher percentage of material greater than two millimeters in size. These values (Table 14) support a supposition that either the parent materials are different deposits or the material in pit 2 is weathering to a coarser-textured soil than in pit 1. Particle size analysis (Table 12) shows a much higher sand and lower silt content in pit 2.

3. Chemical Properties of Mineral Soil

In evaluating soil chemical-fertility properties, analytical procedures presumably reflect extractive powers of vegetative root systems or availability of nutritive elements, or both. The analytical results from the two pits illustrates some of the natural variation in soils. Moreover, it is possible that the use of available or exchangeable elements per unit soil weight (meg/100 gm) may be misleading unless some total nutritive concept is used (ecosystem discussion).

Analytical procedures used in forest soil evaluation have mainly been adopted from agricultural procedures, and may or may not be satisfactory for forest crops.

Total nitrogen is directly associated with organic matter and carbon and, consequently, these have the same distributional pattern (Table 12). Differences between pits decrease with depth, reflecting diminishing vegetative influence and the occurrence of common resistant nitrogen bearing elements in mineral soils (e.g., humic acid).

Carbon content was determined, using the Walkley-Black (C1) and Leco Induction Furnace (C2) methods. Organic matter content was derived from the Walkley-Black method. The value of carbon determination lies in its use for determining carbon:nitrogen (C:N) ratios. Nitrogen, which is released from plant material by heterotrophic microbial action, can be released via ammonium or nitrate ions and immobilized microbial tissue, leached from the system, or utilized by plants.

The C:N ratio is indicative of which process is more dominant. With a high ratio, microbial requirements will dominate whereas, under low ratio conditions (25 or less), nitrogen becomes more available for plant uptake.

Soil nitrogen content exceeds the .1% quoted by Gessel as the critical level for Douglas-fir growth (30) and is higher than that found by Oswald (101)(Table 11), but within the ranges given by Keser (52) and Bourgeois (15). In pit 1, C:N ratios range from 50 for the surface to 24.2 for the C horizon, and in pit 2, the ratios are 117 to 24.4. These values imply possible nitrogen deficiencies, which may account for the low site index (100-110) in this area.

Phosphorous, another major element in tree nutrition, requires major study before soil phosphorous-plant uptake relationships will be fully understood. Bourgeois (15) found, in his evaluation of two different soil types, that neither the Bray P1 test for available phosphorous nor the use of Morgan's solution for extraction yielded any significant differences between soils. He concluded that for measuring phosphorous availability to Douglas-fir, the values obtained by such techniques are questionable. The distribution of available phosphorous in the two study sample pits was the same, although of differing magnitude. Surface soils were high, followed by a decrease in depth and then increased levels in the B-C and C horizons.

Cation-exchange capacity is a measure of the ability of a soil to hold cations in available forms for plant uptake or retention in the system. CEC is a function of the type and amount of clay and organic matter present. It is determined by saturating the soil with a homo-ionic salt solution which displaces the available cations, then summing up the quantity of displaced cations and exchangeable hydrogen or determining the quantity of replacing cations on the exchange complex via another cationic replacement. The most common technique is to use normal, neutral ammonium acetate; however, Clark (18) has advocated measuring CEC at soil pH values. The ammonium acetate method will, in many cases, give higher values, due to the effect of pH dependent charges.

In both pits, exchange capacities are high (greater than 20 meg/100 grams) in the surface and diminish with depth. For the BF_1 horizon, CEC is classified as being medium (15) while for other depths, it is low. CEC and organic matter have the same distributional pattern until the BF_2 horizon is reached, where the influence of clay minerals appears to become more important and CEC does not diminish as does organic matter content (Table 12).

The use of homo-ionic extraction techniques has been developed in agriculture using, in many cases, a highly manipulated, semi-homogeneous growth medium. Under forested conditions, the crop is long-lived and the soils are very heterogeneous. Forestry situations are compounded by a lack of knowledge concerning nutrient requirements of trees and nutrient availability-uptake relationships.

Of the three exchangeable cations, potassium shows the least difference in pattern or content between the two pits and its values fall well within the ranges for soils in south-eastern Vancouver Island

(Table 11). The largest differences between the two pits lie in the values for exchangeable calcium and magnesium. The values for pit 1, lie within the ranges found by Oswald (Table 11), whereas those for pit 2 are generally much higher.

Forest and Understory Vegetation

1. Chemical Analysis of Understory Vegetation

Chemical analysis of the lesser vegetation (Table 16) showed intra- and interspecific differences. For Pseudotsuga and Thuja (i.e., trees less than .5" dbh), all tissue was ground up into a homogeneous mixture and component separation was not attempted since there would have been insufficient material for analysis.

Similar procedures were used on the other listed species; however, for Gaultheria, differentiation into leaves and twigs is recommended as the significance of this species is much greater than for either of the two tree species, at least in the understory vegetation.

In comparing elemental concentrations in Pseudotsuga and Thuja in the understory and tree components, concentrations were much lower in the former. For understory samples, elemental content is dependent upon the relative contribution of each tree component. Visually, the largest influence was from bark, stem and branches and, consequently, the concentrations found in the understory tree species were closely aligned to those found in these components in the tree strata (Table 16 compared to Tables 22 and 25).

Interspecific differences between *Thuja* and *Pseudotsuga* are of the same magnitude as found in the tree strata (Tables 16, 22 and 25). Other than the obvious differences in elemental constitution, the most evident difference is the smaller range between maximum and minimum values for *Thuja* in the understory (except for calcium).

Intraspecific differences, i.e., those that give rise to the ranges in concentrations, are found in both species and dead *Pseudotsuga.* For both species, the same variables are operative, causing the intraspecific differences, i.e., differing component makeup and age. The supposition that the influence of the woody components is higher in the understory vegetation is supported by the elemental data for dead *Pseudotsuga* since there is little difference, in nutrient concentrations, between live and dead *Pseudotsuga*. There are interplot concentration differences; however, a certain consistency exists in that, for an individual species, the lowest concentrations for each element usually occurs in the same plot.

Intraspecific variations for the other species in the understory vegetation, excluding *Gaultheria*, is less, simply because there are few instances of occurrence. An obvious observation is the high elemental concentration in *Polystichum*, *Berberis* and *Gaultheria*. Because of its scarcity, the importance of *Polystichum* is lessened. *Berberis* is similarly less significant than *Gaultheria*. The high concentration of nitrogen and calcium in *Gaultheria* would be of more significance if sectioning into leaf and stem material had been instituted. For nutrient cycling work, the effect of such species on the rate of leaf decomposition and importance of nutrient tie-up in potentially decay-resistant tissue must be determined.

The potential effects of understory vegetation in nutrient cycling has been emphasized by others (82; 108; 113). Maximum potassium concentrations in live Gaultheria went up to .40%, whereas in dead Gaultheria, .05% was the maximum. Such values would indicate rapid release or, at least, mobility of potassium in the ecosystem. The true impact of a particular species on an ecosystem can only be evaluated when elemental concentrations are applied to biomass and a per hectare estimate is calculated (Table 17).

2. Nutrient Concentrations in Tree Component

There are interspecific differences in nutrient concentrations due to preferential uptake and requirements; however, there are trends common to Tsuga heterophylla, Thuja plicata and Pseudotsuga menziesii. Nitrogen generally increases with height in the crown, as found by others (37; 60; 71; 81; 150). This trend is well established within a single tree; however, attempts at developing regression equations for relating height to concentration were unsuccessful. This phenomena can be attributed to the sampling technique used, as subdivision of a tree into thirds from the base upward results in a comparison of material differing in physiological age. Normally, nitrogen concentrations decrease with age (69; 71); however, in Pseudotsuga, the trend was for an increase in concentration going from current to one-year-old foliage, which has been noted elsewhere (60).

A partial explanation lies in sampling time since, in July and August, when samples were taken, nitrogen accumulation may still be occurring. Additionally, weather and seasonal effects (92), which have been postulated by others, might also have been operative at this time.

Age differences for both Tsuga and Thuja foliage are confounded by the method of tissue treatment. Age separation, used in Pseudotsuga, was not used in either of the other species, resulting in the overwhelming biomass of older foliage and lower nutrient concentrations.

Apart from the effect of the nitrogen content in the second-year tissue, concentration trends were consistent with other reported works (60; 69; 70). With increasing content of older and more woody tissue concentration, values dropped. Nitrogen content diminished and reached a maximum low in stemwood but was higher in bark. Differences in nitrogen content between species was minimal, with Thuja having the lowest values. Lower concentrations in smaller trees are partly attributable to their growth characteristics, since most are slow growers and would have different nutrient uptake characteristics than larger trees.

Phosphorous has basically the same distributional pattern as nitrogen. Previous results (59; 60) indicate that phosphorous is maximum in the fall in upper crown positions and in the current foliage. The results for phosphorous analysis in this study are somewhat irregular. Gross trends would support those distributional patterns, as noted by others (59; 60), with obvious species differences, since Pseudotsuga has the highest concentrations, Thuja the lowest, and Tsuga intermediate (Tables 19, 22, 25). Real significance will only be found in comparing comparable tissue. A decrease in phosphorous concentration with crown position is more obvious with *Thuja* and *Tsuga* than *Pseudotsuga*. The changes in concentration with crown position are indistinct in *Pseudotsuga*; however, the difference between tree components is obvious, *Thuja* having noticeably lower content in wood and dead branches. The ranges encountered for phosphorous content lie well within Heilman's quoted values of .1-.25% (37).

Calcium concentrations generally increase with age and distance from the apex. Species differences are obvious, as *Thuja* is generally the highest. *Tsuga* appears to lie between *Thuja* and *Pseudotsuga* in terms of quantity contained and in the nature of distributional patterns. Calcium concentrations in *Pseudotsuga* wood and *Thuja* wood decrease with distance from the tree apex. This also occurs with *Pseudotsuga* bark but the reverse is generally true for *Thuja*, whereas *Tsuga* lies between these two species.

Magnesium concentrations in all three species have inconsistent trends. This is in contrast to the definitive change in concentration with age and crown position for black spruce observed by Lowry (70). The only really consistent trend in the present data is the increasing concentrations with height in the crown of *Pseudotsuga*. In most instances, magnesium content in foliar material lies well within the ranges found for *Pseudotsuga* in Oregon (59).

In considering potassium concentrations, Madgwick (81) found them to be minimal in mid-crown material, whereas Lowry (70) found them to be correlated to age and crown position. Species differences are indistinct (Tables 19, 22, 25); however, *Thuja* has the most obvious pattern in that concentrations decrease with decreasing height. Patterns in Pseudotsuga are less obvious and quite variable. Once again, the concentration values are well within the values obtained by others (59).

Irrespective of species, there are several general comments that warrant stating. It was originally hoped that some functional relationship between concentration and some measureable stand parameter would be devised. Linear regression analysis among foliar nitrogen content, foliar material and tree height yielded no meaningful relationships (Table 27) because:

a) The sampling method precluded any possible correlations with height since physiologically dissimilar tissue was used for chemical analysis.

b) There was a large magnitude of variation in nutrient content for comparable components due to sampling over a wide range of tree sizes.

c) Sampling may have been carried out at such a time that the more suppressed trees had satisfied their nutrient requirements, whereas larger trees were still taking up nutrients.

d) Year-to-year variation in elemental concentrations may have been severe, and confused any attempts to relate concentrations to height.

Biomass and Nutrient Distribution in a Pseudotsuga menziesii Forest Ecosystem

1. Analytical Procedures

a. Subordinate Vegetation

The evaluation of biomass and nutrient distribution patterns entails three basic determinations. The first is the analysis of subordinate vegetation which, in this study, was only a light sampling. The second is quantification of soil nutrient capital, and the third is the analysis of standing tree crop.

b. Soils

Soils evaluation is fraught with frustration in several plains. The relevance of analytical techniques and nutrient uptake relationships are open questions. The problem is further compounded by soil heterogeneity and large quantities of coarse material ($>$2mm). Soil analytical results were corrected for the contribution attributable to coarse fractions, but even this will yield only approximations because:

i) Relationships between soil testing procedures and tree uptake are ill-defined. Additionally, testing techniques may not have any relationship to dynamics of seasonal nutrient availability.

ii) Effect of mycorrhizae on nutrient uptake in natural stands is poorly understood.

iii) Estimation of nutrient availability in a soil profile is dependent on subjective evaluation of horizon thickness.

iv) Nutrient uptake might occur in a limited soil volume, thus developing localized depletion zones not detectable by conventional analytical techniques.

c. Forest Component

In determining both biomass and nutrient distribution in forest vegetation, a compromise is reached between expediency and accuracy because of ecosystem complexity. In the present study, a compromise was reached in that linear regression techniques were used to estimate component values from the parameters of interest. For all three species, the same regression equation was used ($Y = a + bX$, where $X = D^2H$). The total nutrients contained in the forest component is simply a summation of independent species estimations.

i. Tsuga heterophylla

For each tree component (e.g., 68 foliage), weight and nutrient analysis regressions were determined for each tree section (Appendix D, Tables 2, 3 and 4) and for the total tree. Section I is defined as the upper third of the standing tree, Section II the middle third and Section III the bottom third (using tree base as a starting point). An additional comparison was made, using the "field height-diameter (raw)" values and component weights and comparing these to even diameter-height combinations. The latter technique, implemented to ensure sufficient material for chemical analysis, should reduce variation, a supposition supported by the results of the regression analysis (Tables 2 and 3 of Appendix D). In most cases, there has been improvement in the r^2 values using the grouping technique.

Estimations of section component biomass and nutrient weights were also made, resulting in r^2 generally greater than 90 percent. Poorer results which were obtained (e.g., potassium and calcium in Section II) resulted mainly from procedural errors, since sectioning a tree, as stated, groups tissue of dissimilar physiological age. To partially circumvent this, nutrient and biomass analysis can be performed on a total tree rather than on a component basis which, in most instances, leads to a marked improvement in component estimates (Appendix D, Table 4). For example, Section I - 1968 foliar calcium content has lower r^2 values (65.7) than total tree - 1968 foliar calcium content (99.8). For biomass evaluation, the only determinations of real value are those for total components; however, analytical results for individual tree components can be used for special purposes, e.g., determination of nutrient distribution within a tree.

ii. Thuja plicata

The same statistical procedures as those used on Tsuga heterophylla were used on Thuja plicata; however, tree component r^2 values for dry weight were more variable than those for Tsuga Appendix E, Table 3). As was found before, total component r^2 values were higher than section r^2, the lowest value (46.8) being for dead branches. This was expected since the quantity of dead branches was more a function of competition than D^2H. r^2 values for Thuja are lower than those for Tsuga. However, more confidence can be placed on the results for Thuja since eight diameter height combinations were used for regression analysis.

Nutrient content r^2 were high, especially for total component analysis, most r^2 values falling between 90 and 99% and only bark phosphorous (66.4) and potassium (55.9) being low. In all other cases, r^2 values for nutrient content were greater than those for the component biomass, which would be indicative of differences between biomass and nutrient distribution patterns.

iii. Pseudotsuga menziesii

In terms of number, size and mass, Pseudotsuga is the dominant species, and more extensive analyses were performed on it. On the basis of relevant literature and a desire for simplicity, a straight linear regression model was utilized, the following independent variables being tried (Appendix F):

a. $X = DH^2$ for weight only using raw data values.

b. $X = H^2$ for weight only using raw data values.

c. $X = D^2H$ for weight only using raw data values.

d. $X = D$ for weight only using raw data values.

e. $X = H$ for weight only using raw data values.

f. $X = D^2$ for weight only using raw data values.

g. $X = D^2H$ for weight only using raw data values and logarithmic transformation.

h. $X = D^2H$ for weight only using even diameters and heights and logarithmic transformation.

i. $X = D^2H$ for weight and nutrients using even diameters and heights and untransformed variables.

An independent variable had to be an easily measureable parameter which was related to tree growth. Since height defines the vertical extent of a tree and diameter is a function of photosynthetic efficiency, together they should be a truer measure of tree biomass. This hypothesis was tested, using field diameter and height measurements (raw data) and component dry weights (Tables 2 and 3 of Appendix F).

The stated hypothesis is supported by the statistical results. Diameter as the independent variable yields higher r^2 values for those components most closely associated with it (e.g., foliage) than for those having a less exacting relationship (e.g., bark weight). r^2 values, using height, are less than when diameter is used. The difference is less for those components whose weight is a function of both variables (wood and bark weight versus foliage). Diameter is thus a better measure of component weights than height.

The diameter and particularly weight range for this stand was large and, since a linear relationship was assumed, a large range of X values might increase r^2. This assumption was tested by squaring diameter and height. When diameter and height are squared, r^2 are generally larger.

Once it was established that both diameter and height were measureable parameters reflecting component biomass, the possibility arose that a combination of them might improve r^2. A variable combination of diameter (D), diameter squared (D^2), height (H) and height squared (H^2): D^2H, DH^2, D^2H^2 were tried. The results for the D^2H and DH^2 are given in Table 1 of Appendix F but, during analysis of D^2H^2, the r^2 values were found to be lower than those for D^2H and therefore were not tabulated. There was an improvement in r^2 using both D^2H and DH^2; however, the former was chosen as the independent variable since diameter can be measured more easily in the field and the differences between them were small.

All weight analyses to this point were carried out using field values for diameter and height. Chemical analysis had to be performed on composite samples representing specific diameter-height combinations, and thus it was necessary to compare "raw" data and the even one-inch combinations. The differences between these two independent variables are variable (Appendix F, Table 2), the largest occurring in total component analysis. Logarithmic transformation is commonly used to increase linearity. Both raw data and even-inch combinations were subject to logarithmic transformation (Table 35).

TABLE 35. COMPARISON OF TRANSFORMED AND UNTRANSFORMED DATA AS ESTIMATORS OF COMPONENT WEIGHT.

Component	Transformed	Untransformed
I - 68 Foliage		x
older foliage	x	
live branches	x	
wood		x
bark		x
II - 68 Foliage		x
older foliage	x	
live branches	x	
dead branches	x	
wood		x
bark	x	
III - 68 Foliage		x
older foliage		x
live branches	x	
dead branches		x
wood		x
bark		x
Total 68 Foliage	x	
older foliage	x	
live branches	x	
dead branches	x	
wood	x	
bark		x
Total Foliage	x	
Total Tree	x	

x = best estimator.

Transformation of even-inch diameter and even-foot height combinations improves r^2 values for total components only slightly and, consequently, "raw" diameters were chosen for estimating component weights. In the analysis for nutrient contents, even-inch combinations had to be used; however, in most cases, r^2 values for total components were over .90 (Table 4 of Appendix F). In summarizing regression analysis, the following points are made:

i. In biomass evaluation, r^2 values were better for foliar material in the upper portions of the crown, mainly due to tree growth characteristics.

ii. r^2 values for older foliage and live branches were maximum in mid-crown positions because the amount of older material in the upper third of the tree is variable, but in the mid-third, such biomass has a more functional relationship to the independent variable.

iii. Wood and bark r^2 were highest in the third section of the tree since it was here that the majority of these two components were found.

iv. r^2 for total tree components reflected variation about the regression line (due to tree-to-tree variation), whereas in section analysis, r^2 reflected both variation about the regression line and variation introduced due to growth peculiarities and the nature of sampling.

v. r^2 for total nitrogen is generally lower than those for biomass since analytical error is introduced, including the probability of human error and error inherent in the analytical procedure. The best r^2 for nitrogen is in the current foliage in upper crown positions while the worst was for foliage in lower crown positions. The same trends with nitrogen appeared as were present in biomass evaluation; however, r^2 is generally less than for biomass evaluation.

vi. For phosphorous, the better r^2 were in older foliage but were generally less than those found for nitrogen, mainly due to analytical errors. r^2 for total 1968 foliage was very similar to that found for Section I - 1968 foliage reflecting a strong influence of this component on the total r^2 value; however, with older foliage, Section II was more influential.

vii. Potassium r^2 was generally better than those for phosphorous but poorer than those for nitrogen. r^2 for 1968 foliage continually decreased, with distance from the crown apex, whereas for older foliage, r^2 values were a minimum in Section I. The poorest values were for total wood, whereas the best were for live branches.

viii. Calcium had higher r^2 values than the other elements already discussed but also exhibit the same general trends found before. Total component r^2 values were fairly high for all components except the foliage, which indicates again, the strong influence of the second section. r^2 values of 96.5 for total bark are expected, due to the role of calcium as part of calcium pectate in cellular structure. This is also reflected in the r^2 values for total wood.

ix. Magnesium r^2 values were minimal for total foliar components and very high for woody storage and dead components (>90%). The amount of magnesium in these organs is closely regulated by their biomass, as indicated by the close similarity between r^2 for biomass and magnesium content.

The evaluation of biomass and nutrient distribution in the forest ecosystem is dependent upon the accuracy of regression values used to relate component weights to some measureable parameter. Once these have been evaluated, the last procedure is to apply a stand table and to determine the relative amount of biomass and nutrients contained within each component. As is implied, such determinations were made for each species and then summed to determine ecosystem quantities.

2. Biomass and Nutrient Distribution Patterns

A forest ecosystem consists of three distinct units - soil, understory vegetation and tree cover. Biomass and nutrient distributional patterns are definable among units and within the tree component itself.

a) Soils

The accuracy and values for soil physical and chemical parameters (Tables 12, 13, 15) are influenced by spatial and temporal variation (11; 85; 142) as well as by influences of vegetation and parent material. The problems of sampling and accuracies of soil parameter estimations are still unresolved, with varying recommendations coming from the literature (11; 36; 57; 74; 78; 90; 142) depending on the parameter of interest.

By acknowledging the limitations upon the freedom and latitude of soil interpretations, several worthwhile results can be indicated. The soil component of the ecosystem contains the majority of the nutrient elements, particularly phosphorous, nitrogen and calcium (Table 34). For magnesium and potassium, the picture is somewhat different as a considerable fraction of these elements is contained in the vegetative component.

Considering the soil component as a separate entity, the following distributional patterns are found (Table 36).

TABLE 36. PERCENT DISTRIBUTION OF NUTRIENT ELEMENTS WITHIN SOIL COMPONENT OF A YOUNG <u>PSEUDOTSUGA MENZIESII</u> ECOSYSTEM.

Horizon	Element					
	O.M.	N	P	K	Ca	Mg
L-H	18.0	8.2	.2	8.7	15.2	20.1
BF_1	27.2	26.5	26.1	34.9	47.9	39.5
BF_2	30.4	33.9	29.0	29.9	24.3	19.6
B-C	24.0	31.3	44.7	26.5	12.5	20.9

Two basic trends are evident: one shown by organic matter and nitrogen, the other by exchangeable cations. Phosphorous closely parallels the organic matter and nitrogen pattern except that, in the B-C horizon, results indicate some potential influence of parent material.

The relationship between organic matter and nitrogen is much the same as that found in the earlier evaluation of elemental concentrations. Maximum quantity of organic matter and nitrogen in the BF_2 horizon is due to accumulation of mobile organic fractions in this horizon. Although absolute quantities differ, Cole (19) found similar trends for organic matter, nitrogen and phosphorous in Washington State. Phosphorous, as shown above reflects the influence of organic matter and soil minerals in that there is continually increasing quantities with depth to the B-C horizon. In Cole's data, this enrichment was not found, an occurrence I attribute to differences in parent material.

Exchangeable cations are concentrated in the BF_1 horizon,the mineral horizon with the highest CEC. Both the Washington study (19) and the present study exhibit the same property of having maximum exchangeable cations and organic matter in different horizons. The decomposition of organic matter will release cations which will be adsorbed onto exchange sites. With increasing depth, more resistant organic compounds will accumulate, e.g., lignin, which contain less metallic cations that the original tissue.

Although percentage values indicate similar trends between Cole's (19) soil analysis and mine, absolute quantities are different. This might be accounted for by differences in methodology and parent material. Expressing our results on a volume-area basis and taking into account the influence of coarse fragments resulted in lower values for nutrient content.

b) Understory Component

Biomass and nutrient contents are attributable to three main species - *Gaultheria*, *Pseudotsuga* and *Thuja* - which account for 85-93% of biomass and nutrients in the understory. The importance of *Gaultheria* is evident (Tables 18 and 29). Distributional patterns for biomass and nutrients vary, but the proportion found in *Gaultheria* is always the highest of all species. Percentage biomass is minimal for *Gaultheria* in comparison to its nutrient content (Table 29). The high proportion of potassium in live *Gaultheria* (72.9%) is prominent, as is the low value for dead *Gaultheria* (.9%). A further comparison with live and dead *Pseudotsuga* also indicates low potassium content in dead material. *Berberis*, in comparison to its biomass contribution, has a high potassium content (3.5 to .9%), indicating a high demand or possibly luxury consumption. The same reasoning can be applied to *Gaultheria*.

Other trends that might be attributable to species preference are:

1) High phosphorous content (6.4%) in *Rosa* sp. in comparison to its biomass contribution (2.0%).
2) *Berberis* has a high nitrogen and phosphorous content in addition to potassium.
3) Percentage contribution of *Gaultheria* for calcium,

nitrogen and phosphorous are similar, with a slightly higher value for magnesium.

c) Tree Component

This stand was heavily stocked with over 16,000 trees per hectare, of which 88% were two inches or less in diameter. Of the three species present, Tsuga is the least significant, having only 97 trees (.5%) per hectare. Of these, 88% are two inches or less in diameter. Thuja is more abundant, with 1,381 trees per hectare (8.4%) but with 98% being two inches or less in diameter. Pseudotsuga constitutes 90% (14,885 per hectare) of the total tree species and has 86.9% two inches or less in diameter. Pseudotsuga dominates, since it constitutes from 96.3 to 99% of the total biomass and nutrient weights (Table 33). Intensive discussion of Thuja and Tsuga is unwarranted and the main emphasis should be placed on their respective distributional patterns (Tables 20 and 25). Due to the massive influence of Pseudotsuga, the distribution for the tree component of the ecosystem is essentially that of Pseudotsuga.

i. Total Biomass

Total biomass in Tsuga, Thuja and Pseudotsuga is 178, 1,686 and 74,867 Kg/ha, respectively (Table 29). Biomass distribution over a diameter range varies by species, since the range goes up only to 3" for Tsuga and Thuja and 6" for Pseudotsuga.

As shown by data in Tables 20, 23 and 26, there are differences and similarities among these species. When total production over all diameter class is examined, the largest weight contribution is from wood (50.3 - 54.5%). The second largest contributor for both Pseudotsuga and Tsuga is live branches, but for Thuja, it is older foliage (attributable to difficulties encountered in separation of foliage and branch material). The next largest contributor is bark (Pseudotsuga and Thuja), or older foliage (Tsuga). Although Cole (19) only worked with suppressed, intermediate, co-dominant and dominant samples, his distribution patterns and mine are similar in that wood contribution is highest, followed by bark, branches and then foliage. The trends indicated by my results are well supported in the literature; however, specific values differ because of species differences (see, e.g., 7; 8; 9; 10; 19; 45; 88; 121; 122; 123; 126).

For Pseudotsuga, total foliage percent increases with diameter, an accretion made in older foliage since current foliage was almost constant. In Tsuga and Thuja, all leaf biomass increased with diameter, which may be attributable to competition. Smaller trees of these species are undergoing increasing suppression and, consequently, are producing less new foliage. This leads to an increasing percentage of those components which are accumulated over time, i.e., wood and bark. Such a possibility is indicated in both species since percent wood is highest in the one-inch class.

Detailed size class analysis was not performed by Cole (19) and, consequently, the only exhibited trend is for decreasing percent wood with size. The analysis of Abies balsamifera biomass by Baskerville (10) showed a decreasing contribution attributable to wood, whereas foliage and branches increased with size.

The trends evident in biomass distribution should also be reflected in nutrient distribution. Modification of these trends will occur due to the physiological function and characteristic of each element.

ii) Nitrogen

Of the total 277.31 Kg/ha of nitrogen in the tree component, Pseudotsuga has 98.2%, Thuja 1.6% and Tsuga .2%. These values are only slightly different from the biomass distributions (97.6, 2.2 and .2% respectively). The same basic distribution pattern found for biomass in Thuja and Tsuga is found for nitrogen. Nitrogen is important for photosynthesis and is of highest proportion in the foliage. This is well illustrated for both Thuja and Tsuga since there was 73.7 and 58.5%, respectively, in foliar material. For these species, foliar nitrogen proportions increase with tree size, whereas wood and bark nitrogen proportions decrease. Pseudotsuga, however, has a relatively constant proportion in foliage, live branches and bark over size. Cole's results (19) would indicate increasing foliar and branch and decreasing bark contribution; however, sampling on the basis of dominance can lead to numerous errors (10).

Although there is inherent error in the results, due to the model used, dominance seems to have an effect upon distribution. Treating Pseudotsuga as the dominant species, the most interesting pattern, in addition to those noted above, is the constant proportion found in older foliage. This indicates that nitrogen taken up is redistributed similarly over all sizes (for foliage). Less production in smaller Pseudotsuga may be attributed to genetic differences and/or less efficient foliage being present, but not necessarily to a nitrogen deficiency.

iii) Phosphorous

Phosphorous is distributed differently over all three species, the most obvious eccentricity being the low foliar contribution of small Thuja. This phenomenon was induced by fitting a linear model, resulting in heavy weighting by larger trees and negative values for one-inch trees. This error could be eliminated by using a combination of an exponential and a linear curve.

For Thuja, there is an increasing quantity of phosphorous being contained in the foliage, due to ever-increasing foliar biomass. This acquisition is made at the expense of the branches, wood and bark, all of whose proportions decrease with increasing diameter.

Similar trends are evident for Tsuga; however, the older foliage has a decreasing quantity of phosphorous. This is understandable since, for Tsuga, biomass of the 1968 foliage increased from 1.8 to 6.5% and older foliage increased from 10.6 to 17.9%. Comparable Thuja values were 2.9 to 5.7% and 12.5 to 37.6%, respectively. This indicates a more rapid increase in foliar biomass for Thuja foliage. Additionally, the distinction between Thuja foliar and branch material is difficult and a portion of the "real" branch material could end up in the foliage component, accounting for the higher biomass acquisition. This anomaly would be emphasized in larger trees because of the greater quantity of biomass to contend with. Tsuga is similar to Thuja in having a decreasing quantity of phosphorous in the bark component.

Pseudotsuga is the other extremity from Thuja, since there is a decreasing proportion of phosphorous in foliar tissue and increasing branch and bark contribution with an increase in tree size. The only similarity between these species lies in decreasing phosphorous contribution in woody material.

The differences among the three species lie in distributional patterns and contribution over all sizes. Thuja has a higher foliar contribution, followed by Pseudotsuga and Tsuga; however, the latter species both have high phosphorous content in live branches. Other than those components mentioned, further elaboration and discussion of the data is not warranted.

iv. Potassium.

Thuja and Tsuga are similar in that, with increasing diameter, they have an increasing foliar and decreasing bark contribution. Relative values differ, since Thuja is usually greater than Tsuga. The branch anomaly is maintained, since Thuja contribution decreases with size while Tsuga increases. Wood potassium in Tsuga decreases with size while in Thuja, it remains fairly constant.

In Pseudotsuga, the current year's foliar potassium contribution is constant. In fact, most of the component values are almost constant or have only slight increasing or decreasing trends with increasing size. A possible explanation of these results would be that the potassium requirements of each component is constant regardless of size and that *Pseudotsuga* is inherently better able to extract its requirements than *Tsuga* or *Thuja*. The other possibility is that foliar potassium content of the different components varies with tree size in *Tsuga* and *Thuja*.

v. Calcium and Magnesium

These elements are being considered together since they have essentially the same distributional pattern. In *Pseudotsuga*, the diameter influence is basically the same for both elements in that both current and older foliage show decreasing contributions with increasing diameter. The absolute quantities and proportions are different for both elements, with a much greater weight of calcium present. Considering the influence of size, there is a common trend for calcium and magnesium, since live- and dead-branch proportion increases with diameter while wood contribution decreases. A deviation for *Pseudotsuga* is that wood magnesium proportion increases with diameter whereas calcium decreases (Table 32).

For both *Tsuga* and *Thuja*, the suppression influence is still apparent. This is reflected in a large influence of woody tissue in the one-inch diameter class and increasing influence of foliar tissue with size. *Tsuga* begins to show patterns not unlike those of *Pseudotsuga* in some instances, i.e., increasing elemental proportion in branch material. Both *Tsuga* and *Thuja* show decreasing proportion in wood and bark tissue with an increase in diameter. The proportion of magnesium in foliage is greater than that for calcium.

3. Ecosystem Distribution

An ecosystem study is a means of illustrating the complexity of factors that affect nutrient distribution and cycling. Such studies also serve to bind the two major operative nutrient cycles, i.e., the internal biological and external geological cycles. Human influence is more often felt in the biological than geological cycle. Potential implications of management practices, including nutrient drain and site deterioration, have been pointed out by several authors (125; 126; 148). Before such a drain can be quantified and understood, the nutrient content of the ecosystem has to be determined in detail. Naturally other practices, such as fertilization, can be evaluated in the same light.

It is now appropriate to integrate ecosystem components into a whole (Tables 29, 30, 31 and 32). The distribution of organic matter among ecosystem components varies with stand age and site; with progression toward full site occupancy, the weight of organic matter will increase, accompanied by a change in the distribution pattern (27; 98; 109; 112; 118; 137; 141). Cole (19) found a total ecosystem organic-matter content of 339,863 Kg/ha, which is larger than that (225,329 Kg/ha) for the stand under discussion, a condition attributable to a larger vegetative biomass (205,539 versus 80,643 Kg/ha). This difference is an age-site phenomenon, whereas the difference in soil organic-matter content (111,553 versus 174,539 Kg/ha) can be accounted for by differing soil properties and possibly differing methods of expressing results.

The distributional patterns for both biomass and nutrients will vary within components. Data from other sources would indicate a reduction in foliar and an increase in woody tissue influence with age (27; 109; 122; 137; 141). For Pseudotsuga in Washington, Cole (19) found 2.7% of the ecosystem biomass to be foliage and 60.1% to be total vegetation weight. My study area has 4.2% foliar biomass and 31.6% total vegetation biomass. The differences here are due to age. Component fractionation for the ecosystem under study in terms of biomass and nutrients is given in Table 37.

The time dependency function is operative for nitrogen distribution in that with age there should be an increase in nitrogen in aerial components. The 7.6 and .4% in forest and subordinate vegetation differs from Cole's 9.7 and .2%, mainly due to age effects, since my system has a greater total weight of nitrogen (3658 versus 3 310 kg/ha).

Available phosphorous was determined, using an acid fluoride method, and the phosphorous content in my soil is quite similar to that found by Cole (3346.8 versus 3971 kg/ha), using a total phosphorous determination (19). In consideration of the total vegetation content, mine is less (56.7 versus 67 kg/ha); however, expressed as a percent of the total ecosystem content, they are very close (1.6 versus 1.7%).

Under more rigorous climatic conditions for Picea mariana and Picea rubens - Abies balsamifera, Weetman and Webber (148) found phosphorous to be more concentrated in standing tree crops. For the

TABLE 37. BIOMASS AND NUTRIENT DISTRIBUTION FOR A YOUNG *PSEUDOTSUGA MENZIESII* ECOSYSTEM.

Ecosystem Component	Element													
	OM		N		P		K		Ca		Mg	
	Kg/ha	%	Kg/ha	%	Kg/ha	%	Kg/ha	%	Kg/ha	%	Kg/ha	%
Forest	76,731	30.0	277.3	7.6	54.7	1.6	143.0	51.3	285.6	22.5	40.4	34.3
Subordinate vegetation	3,912	1.6	13.8	.4	1.3	.03	18.1	3.0	18.1	1.4	3.0	2.5
Forest floor	32,082	12.6	276.4	7.6	4.9	.1	11.1	4.0	146.9	11.6	14.9	12.7
Soil	142,604	55.8	3090.5	86.5	3341.9	98.2	116.2	41.7	670.1	64.5	59.3	50.5
Total	255,329	100.0	3658.	100.0	3402.8	100.0	278.7	100.0	1267.7	100.0	117.6	100.0

Picea mariana stand, phosphorous content was 5.8% of the system total (using total soil phosphorous) and 58.3% (using available soil phosphorous). For the Picea abies stand, the values were 19.5 and 89%, respectively. It is thus apparent that depletion via harvesting is a potential problem, a conclusion supported by the earlier European literature evaluation by Rennie (126).

The vegetation component has a higher potassium content than the soil component; this is similar to the condition found by Cole for Pseudotsuga menziesii in Washington (19). His percentages were slightly higher for the soil component (47.5 versus 42.7%). The actual weights of potassium, both in soil and in vegetation, are less in my study area than in Cole's (266 and 227 kg/ha versus 127.3 and 161.3 kg/ha); however, the percentage distribution is quite similar (54.0 and 44.6 versus 45.7 and 51.3%).

Potassium distribution was more favorable for upland Picea mariana than phosphorous (148), with vegetation potassium content still being high (38.0% using exchangeable quantities and <0.5% using total). Potential depletion problems increased in Picea rubens - Abies balsamifera, as potassium content was 71% of the total ecosystem content using exchangeable soil content. Rennie (126) also found high potassium content in vegetative material, up to 67% of the total being contained in vegetative material.

Total and percentage distribution of calcium in this stand bears a close resemblance to that found in Washington (19). The differences between the two areas can be attributed to stand age differences. The level for calcium in the study area, i.e., 23% of the total being in vegetative material, is radically different from both Rennie's (126) 70% for Pinus and Weetman and Webber's 86% for Picea mariana and 75% for Picea rubens - Abies balsamifera stands (148).

A comparison for magnesium is only possible using Weetman and Webber's spruce stands (148). The young Douglas-fir stand has a high proportion of the magnesium contained within the living component (34%), with even larger percentages found in the soil (50.5%).

Before considering nutrient cycling, it is worthwhile to emphasize several assumptions. First, nutrient extraction technique bears some relationship to vegetative nutrient uptake capacity and provides a basis for comparison between areas. This is questionable for forest crops, since our concern is with a perennial slightly manipulated crop whose nutrient extracting capacity is relatively unknown. In addition, the full significance of a nutrient level in foliage is only partially understood due to the possibility of ionic mobility and transfer between tissues.

Secondly, measurement of exchangeable cations can imply that nutrient uptake is mainly from exchange sites. This is a point needing evaluation since the influence of root mycorrhizae and contact exchange in tree nutrition is poorly understood.

In addition, when the question of significance of nutrient levels is raised, particularly when any attempt is made at determination of productivity and foliar nutrient concentrations, it is always relevant to ask if the level determined is physiologically required or if luxury consumption is operative (e.g., potassium). Additional points can be raised as to whether an evaluation should be based on nutrient ratios and/or physiologically active unit content, e.g., amino acids, proteins, organic acids, rather than nutrient levels *per se*.

With these points in mind, a partial discussion on the implications of nutrient distribution can be given. This discussion can really apply only to this particular stand, although certain trends which have been found indicate the potential for extrapolation. Table 38 is a comparison of Cole's results (19) and those from this study. The relative percentages could potentially be the same on both areas if these stands were the same age. The implication of this statement is that the consistency of percentage distribution could well overcome, or at least be used to account for or minimize influences of differing absolute quantities.

For mineral cycling and distribution purposes, it is possible to derive a partial flow sheet based on ecosystem studies. This is a helpful procedure which can be used as a partial means of evaluating mineral cycling. It is only a partial means since the real significance of several of the pathways has not been clearly determined.

Yearly uptake is questionable because of factors such as ionic mobility, effect of surface epiphytes on absorption, and leaching losses from foliar tissue during precipitation. This introduces elements into the soil system whose solubility, translocation and availability differ from those added via vegetation. This predisposes a requirement for a dynamic evaluation of the system; however,

TABLE 38. COMPARISON OF PERCENT BIOMASS AND NUTRIENT DISTRIBUTION AMONG ECOSYSTEM COMPONENTS IN WESTERN WASHINGTON AND VANCOUVER ISLAND.

Ecosystem Component	Element									
	OM		N		P		K		Ca	
	Cole	G.V.W.S.[1]	Cole	G.V.W.S.[1]	Cole	G.V.W.S.[1]	Cole	G.V.W.S.[1]	Cole	G.V.W.S.[1]
Forest	60.1	30.0	9.7	7.6	1.7	1.6	44.6	51.3	27.3	22.5
Subordinate Vegetation	.3	1.6	.2	.4	.1	<.1	1.4	3.0	.7	1.4
Forest Floor	6.8	12.6	5.3	7.6	.6	.1	6.5	4.0	11.2	11.6
Soil	32.8	55.8	84.8	86.5	97.6	98.2	47.5	41.7	60.8	64.5

[1] Greater Victoria Watershed.

an ecosystem approach does provide some initial values and a set of limiting parameters within which it is possible to work.

VI. SUMMARY AND CONCLUSIONS

Biomass and nutrient distribution in a young *Pseudotsuga menziesii* ecosystem, on Southern Vancouver Island, was evaluated in terms of ecosystem components, (i.e., forest, understory and soil). The main objective of this investigation was to evaluate biomass and nutrient distribution patterns. Secondary aims included devising sampling and laboratory methodology for future expansion in this line of research.

For technique development, it was deemed necessary to use the simplest and most biologically meaningful stand parameters, i.e., diameter and height. Linear regression analysis was performed, using variable combinations of these parameters, resulting in the choice of $(\text{diameter})^2$ X height as the most suitable independent variable (X) for use in an untransformed equation. It is probable that for future use the X variable will be volume, thus requiring only a field diameter measurement and a local volume table.

Subdivision of sample trees into sections and components provides information on species differences; however, some revision of this procedure is warranted in that the crown apex should be used as the initial base for sectioning. Fractionation of foliage into age classes may, under some circumstances, be of little significance and entail more time and effort than the results justify.

Evaluation of intercomponent biomass and nutrient distribution served to clarify the importance value of each component. The understory component was of minimal importance with regard to biomass and total nutrient content. A word of caution is needed, since this was a study designed to measure biomass and nutrients at a particular point in time. When attention is focused on nutrient cycling and dynamics of nutrient availability, the importance of understory species may greatly increase. This would be especially true when a management practice such as fertilization is employed. Under this condition understory vegetation may be effective competitors for readily available nutrients.

Further manifestations of the potential importance of understory vegetation is evident in interspecific differences in nutrient concentrations. As the data showed, there were major differences among species which could have a major impact, depending on species composition and density in the understory.

The tree component of the ecosystem was, as expected, the second largest in the ecosystem. Interspecific differences among the three species, Pseudotsuga menziesii, Thuja plicata and Tsuga heterophylla, were evident in nutrient concentrations and in biomass and nutrient distribution. A strong influence of suppression on nutrient distributional patterns was exhibited in the latter two species which was not evident in Pseudotsuga menziesii.

The potential impact of nutrient distribution and quantities in the tree component will be of major consequence when harvesting, or other management practices, are instituted. On the basis of the results found, it is likely that the major impact will be felt in potassium nutrition simply because the tree component contained such a large quantity. Once again, the full impact of the distributional patterns and quantities contained in the tree component will only be known when a full understanding of nutritional requirements of forest crops and the dynamics of availability are understood.

With the exception of potassium, the soil component contains the largest quantities of total and available or exchangeable nutrients, the largest quantities of nitrogen and phosphorous, followed by decreasing proportions of calcium and magnesium and potassium.

In considering the total ecosystem, it is evident that distributional patterns in vegetative tissue are dominated by Pseudotsuga menziesii. The distributional patterns found in this 18-year-old stand will be modified with stand development, resulting in greater proportions being contained in the standing crop.

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APPENDIX A

TABLE 1. CLIMATIC DATA FOR SOUTHERN VANCOUVER ISLAND (Day *et al.*, 25).

Climatic Data for Stations in the Surveyed Area

		Precipitation in Inches			Temperature ^{o}F.			Sunshine Hours
	Elevation	Mean Annual	4 mos. June-Sept.	2 mos. July and August	Mean Annual	4 mos. June-Sept.	2 mos. July and August	Annual
Saanich Peninsula Area -- Cool Mediterranean Climate								
Victoria	228	27.1	3.4	1.1	50	58	60	2192
Dom.Observatory	730	27.2	3.1	1.1	50	62	64	
Cordova Bay	112	32.1	3.7	1.3	49	58	60	
James Island	176	27.5	3.5	1.3	50	60	62	
Pat Bay Airport	53	33.6	4.2	1.6	49	59	61	
Sidney	200	30.7	4.0	1.5	49	60	62	2038
Pender Island	200	30.2	4.2	1.6				
Average		29.8	3.7	1.4				
Range		{27.1-33.6	3.1-4.2	1.1-1.6}				
Saanich Peninsula to Comox Lowland -- Transitional Climate								
South to North								
Sooke	125	46.1	4.7	1.4	49	58	59	
Shawnigan Lake	455	42.9	4.8	1.6	48	60	63	
Cowichan Bay	175	35.5	4.4	1.7	49	61	63	1805
Duncan	28	39.3	4.7	1.8	50	62	65	
Ganges	36	38.0	4.6	1.7	49	60	62	
Chemainus	40	41.4	4.9	1.7	-	-	-	
Nanaimo	100	37.9	5.5	2.0	50	61	64	
Nanaimo Airport	104	42.5	4.9	2.1	47	58	61	1832
Departure Bay	60	33.8	5.3	2.0	50	62	65	
Parksville	300	31.9	5.2	2.2	46	57	59	
Denman Island	180	50.4	5.8	2.0	-	-	-	
Comox Airport	75	46.3	5.9	2.7	48	59	61	
Cape Lazo	125	41.8	5.5	2.2	48	59	62	
Average		40.6	5.1	1.9				
Range		{31.9-50.3	4.4-5.9	1.4-2.7}				

TABLE 1. CONT'D.

Climatic Factors Affecting Plant Growth in Southeast Vancouver Island (Day *et al.*, 25).

	Cool Mediterranean Climate		Transitional Climate						Maritime Climate			
	Sidney	Victoria	Sooke	Shawnigan Lake	Duncan	Ganges	Nanaimo	Cape Lazo	Jordan River	Cowichan Lake	Alberni	Cumberland
Altitude above mean sea level...	100	228	125	455	28	35	85	125	10	545	300	523
Mean annual temp. °F....	49	50	49	48	51	49	50	48	48	49	49	48
Yearly precipitation (inches).....	30.3	26.9	45.4	42.1	38.6	37.3	37.2	42.1	71.2	73.1	67.8	57.6
Beginning of vegetative period.......	Mar. 8	Feb.26	Mar. 6	Mar.22	Mar. 2	Mar. 8	Mar.10	Mar.23	Mar.13	Mar.15	Mar.15	Mar.23
End of vegetative period.......	Nov.22	Dec. 4	Nov.20	Nov.15	Nov.22	Nov.20	Nov.21	Nov. 6	Nov.24	Nov.15	Nov.15	Nov.10
Duration of vegetative period (days)	259	281	259	237	265	257	256	228	256	245	245	232
Mean date last frost in spring.........	Mar.31	Feb.28	Apr.21	May 2	May 4	Apr. 7	Apr.12	Apr.13	Apr. 4	Apr.26	May 12	May 14
Mean date first frost in fall..........	Nov.16	Dec. 7	Oct.27	Oct.17	Oct. 6	Nov. 4	Nov. 3	Oct.24	Nov. 5	Oct.19	Oct.10	Oct.11
Duration of frost-free period (days).....	230	282	189	168	155	211	205	194	215	176	151	150
Day degrees above 42°F in vegetative period.	2976	3014	2723	2815	3434	2995	3269	2795	2263	2970	3376	2837
Precipitation during vegetative period (in.).	14.7	15.6	21.7	16.7	19.6	17.7	18.6	16.1	34.5	31.9	30.2	24.4
Water deficiency during vegetative period (3-in. storage)...	10.2	10.6	8.4	9.3	9.7	9.3	8.6	9.0	3.7	6.0	5.7	5.8
Mean date of drought point-												
(2-in. storage)...	May 26	May 18	June 7	June 7	June 8	June 5	June 8	June 4	July 2	June 26	July 1	Jne.18
(3-in. storage)...	June 8	June 2	Jne.19	Jne.19	Jne.21	Jne.14	Jne.22	Jne.14	Jul.13	July 6	July 9	July 3
(4-in. storage)...	Jne.19	Jne.13	July 1	July 1	July 1	Jne.29	July 3	Jne.24	Jul.24	July 15	Jul.18	Jul.13

APPENDIX B

TABLE 1. MILACRE CHEMICAL ANALYSIS

			ELEMENTAL PERCENTAGE*				
Species	Milacre	O.M.	N	P	K	Ca	Mg
Thuja plicata	4 & 5	371.0	.44	.03	.10	.28	.05
Pseudotsuga menziesii Live	4 & 5	248.0	.33	.03	.09	.43	.07
Dead	4 & 5	260.0	.26	.02	.01	.31	.04
Gaultheria shallon Live	4 & 5	540.0	.60	.04	.36	.69	.16
Dead	4 & 5	119.0	.37	.02	.02	.66	.04
aquifolium	4 & 5	40.0	.90	.06	.38	.89	.08
Gaultheria shallon Live	3-18	2821.	.37	.04	.31	.53	.09
Dead	3-18	233.0	.24	.02	.03	.32	.04
Pseudotsuga menziesii Dead	3-18	2691.0	.13	.01	.01	.14	.04
aquifolium	3-18	98.0	.85	.08	.59	.64	.09
Rosa sp.	3-18	27.0	.49	.06	.31	.63	.11
Polystichum munitum	3-18	20.0	1.43	.15	.72	.56	.21
Pseudotsuga menziesii Live	8-11	309.0	.26	.04	.16	.35	.05
Dead	8-11	102.0	.21	.02	.01	.31	.30
Gaultheria shallon Live	8-11	1391.0	.44	.04	.36	.55	.10
Dead	8-11	224.0	.31	.02	.01	.59	.05
Thuja plicata	8-11	372.0	.36	.04	.14	.77	.04
aquifolium	8-11	404.0	.88	.08	.71	.78	.09
Rosa	8-11	284.0	.51	.11	.29	.82	.09
Pseudotsuga menziesii Live	1-6	1057.	.18	.03	.05	.26	.04
Dead	1-6	1252.	.13	.01	.02	.24	.03
Gaultheria shallon Live	1-6	835	.49	.04	.40	.91	.15
Dead	1-6	25	.29	.02	.02	.54	.06
Thuja plicata	1-6	199	.33	.03	.10	.62	.05
aquifolium	1-6	8	.93	.11	.77	.68	.11
Pseudotsuga menziesii Dead	15-10	67.0	.20	.21	.12	.34	.04
Thuja plicata	15-10	417.0	.41	.04	.22	.74	.05
Polystichum munitum	"	20.0	1.16	.13	1.38	.58	.19
Gaultheria shallon	"						
Live		1408.0	.50	.04	399.	.43	.11
Dead	15-10	361.0	.29	.03	.05	.54	.05

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* Average of duplicate determinations.

APPENDIX C

TABLE 1. NUMBER OF TREES PER HECTARE BY DIAMETER AND HEIGHT.

— = Classes sampled

Dbh / Height	TREES/HECTARE 1			2			3			4	5	6	TOTAL
	Df[1]	Cd[2]	Hm[3]	Df	Cd	Hm	Df	Cd	Hm	Df	Df	Df	
6	49	86											185
7	395	198											593
8	741	210	12										963
9	939	235		25									1199
10	1087	148	12										1247
11	963	86											1049
12	914	74	25	49	37								1099
13	1211	37	12	173	37								1470
14	791	25	12	371	74								1273
15	815			741	37								1593
16	346			667	49		25						1087
17	173			717	12		74	12					988
18	25			642	12		49						728
19				469			222	12					701
20	12			247			173						432
21				99		12	148						259
22				198			222						470
23				37			272			49			210
24							124		12	37			147
25							148			62			136
26							74			86			111
27							25						25
28										99			99
29										49	12		61
30										25			25
31										37	12		49
32										12			12
33										25			25
34										12	25	25	62
35										12		12	24
37												12	12
39												12	12
TOTAL	8511	1099	73	4435	258	12	1334	24	12	505	49	61	16363
				Dbh - inches									
		1											

[1] DF = *Pseudotsuga menziesii*

[2] Cd = *Thuja plicata*

[3] Hm = *Tsuga heterophylla*

TABLE 2. TREES SAMPLED FOR BIOMASS AND NUTRIENT EVALUATION.

SPECIES	HEIGHT-FEET	DIAMETER-INCH
Douglas Fir	9'	1"
	20'	1"
	20'	3"
	27'	3"
	34'	5"
	34'	6"
	39'	6"
Cedar	6'	1"
	14'	1"
	17'	2"
Hemlock	8'	1"
	21'	2"
	24'	3"

APPENDIX D

TABLE 1. <u>TSUGA</u> <u>HETEROPHYLLA</u> SAMPLE TREE CHEMICAL ANALYSIS*

COMPONENT	SECTION I (Upper Third)					II (Middle Third)					III (Lower Third)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
TREE # 773															
68 Foliage	1.29	.13	.44	.60	.10	1.1	.12	.38	.52	.08	-	-	-	-	-
Older Foliage	1.00	.18	.42	.98	.16	.8	.22	.40	1.25	.17	-	-	-	-	-
Live Branches	.39	.06	.20	.34	.07	.2	.06	.15	.29	.07	-	-	-	-	-
Dead "	0	-	-	-	-	-	-	-	-	-	.23	.02	.03	.34	.04
Wood	.12	.02	.06	.08	.02	.08	.01	.06	.08	.01	.07	.01	.07	.08	.01
Bark	.57	.11	.59	.59	.05	.50	.10	.66	.61	.03	.43	.08	.42	.48	.02
TREE # 1125															
68 Foliage	1.21	.15	.62	.64	.13	1.06	.18	.58	.81	.14	-	-	-	-	-
Older Foliage	1.09	.17	.47	.91	.16	.95	.22	.39	1.26	.16	.82	.27	.22	1.53	.16
Live Branches	.44	.06	.26	.35	.06	.32	.05	.30	.36	.06	.23	.05	.13	.29	.05
Dead "	-	-	-	-	-	-	-	-	-	-	.22	.02	.01	.35	.03
Wood	.09	.01	.05	.07	.02	.07	.01	.06	.07	.01	.05	.01	.03	.07	.01
Bark	.53	.08	.47	.54	.05	.50	.07	.40	.50	.04	.39	.05	.33	.54	.04
TREE # 1930															
68 Foliage	1.20	.15	.59	.33	.07	.99	.09	.32	.47	.11	.89	.11	.34	.40	.11
Older Foliage	1.01	.15	.44	.43	.10	.94	.08	.24	.67	.14	.96	.09	.24	.69	.13
Live Branches	.57	.07	.25	.22	.04	.31	.03	.12	.22	.03	.25	.05	.12	.21	.04
Dead "	-	-	-	-	-	-	-	-	-	-	.28	.02	.02	.35	.03
Wood	.11	.01	.08	.07	.01	.07	.01	.06	.06	.01	.05	.01	.05	.06	.02
Bark	.62	.07	.36	.38	.04	.50	.07	.33	.37	.03	.28	.05	.20	.40	.05

* All values average of duplicate samples.

TABLE 2. COEFFICIENTS OF DETERMINATION FOR TSUGA HETEROPHYLLA DRY WEIGHT REGRESSION ANALYSIS. (RAW DATA)

		Weight=a+b(x)	Log Weight=a+blog(x) $x=D^2H$
Section	Component	r^2	r^2
I	68 Foliage	96.9	92.9
	Older Foliage	63.7	73.8
	Live Branches	95.0	90.4
	Wood	98.1	99.5
	Bark	99.6	99.9
II	68 Foliage	98.5	78.9
	Older Foliage	93.4	95.6
	Live Branches	99.0	94.5
	Dead "	-	-
	Wood	3.5	52.2
	Bark	6.1	54.9
III	68 Foliage	97.3	67.1
	Older Foliage	99.1	89.9
	Live Branches	99.0	89.7
	Dead "	98.7	88.8
	Wood	86.5	94.7
	Bark	96.5	96.5

Section I: Upper third of the Sample Tree.
" II: Middle " " " " "

III: Lower " " " " "

TABLE 3. COEFFICIENTS OF DETERMINATION FOR *TSUGA HETEROPHYLLA* BIOMASS-NUTRIENT REGRESSION ANALYSIS.

$\text{Weight} = a + b(x) \qquad x = D^2H$

Section	Component	ELEMENT					
		Nitrogen	Phosphorous	Potassium	Calcium	Magnesium	Dry Weight
I	68 Foliage	97.7	94.2	95.7	65.7	89.8	97.0
	Older Foliage	77.4	70.5	78.0	17.0	35.0	64.4
	Live Branches	99.9	99.8	98.3	91.2	92.6	95.2
	Wood	99.5	99.0	100.0	98.1	82.0	98.2
	Bark	100.0	99.0	98.3	96.9	98.5	99.7
II	68 Foliage	98.2	99.3	99.6	99.1	98.6	98.4
	Older Foliage	92.2	9.2	61.2	43.7	90.2	93.6
	Live Branches	50.2	99.7	.1	7.5	4.1	93.0
	Wood	2.9	3.0	1.4	.1	.2	3.6
	Bark	3.5	2.9	.7	.6	.0	6.4
III	68 Foliage	96.9	96.9	96.9	96.9	96.9	97.1
	Older Foliage	98.5	99.9	98.6	99.9	99.1	98.9
	Live Branches	98.6	98.8	98.8	99.2	99.2	98.9
	Dead "	100.0	99.7	99.5	99.7	99.6	98.9
	Wood	86.7	81.9	99.1	78.6	95.8	86.9
	Bark	92.8	91.6	87.0	92.1	98.3	98.7

TABLE 4. <u>TSUGA HETEROPHYLLA</u> FULL TREE REGRESSION ANALYSIS.

$$\text{Weight} = a + b(x) \qquad x = D^2H$$

A. BIOMASS - KILOGRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	3.13	1.56	.998	99.6
Older Foliage	77.20	3.97	.999	99.9
Live Branches	34.64	4.95	.999	99.8
Dead "	24.03	1.39	.994	98.9
Stem Wood	683.39	6.57	.862	74.3
Stem Bark	104.38	1.34	.967	93.8
ALL FOLIAGE	80.94	5.53	.999	100.0
WHOLE TREE	927.38	19.78	.979	95.8

B. NITROGEN - GRAMS/HECTARE

68 Foliage	.150	.016	.998	99.7
Older Foliage	.654	.038	.999	99.9
Live Branches	.082	.015	.999	100.0
Dead "	.001	.004	.999	100.0
Stem Wood	.463	.004	.871	75.9
Stem Bark	.513	.005	.932	86.9
ALL FOLIAGE	.844	.054	.999	100.0
WHOLE TREE	1.902	.082	.998	99.7

a = y intercept   b = slope   r = correlation coefficient

r^2 = coefficient of determination

TABLE 4. CONT'D.

C. PHOSPHOROUS - GRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	.028	.002	.999	100.0
Older Foliage	.283	.003	.936	87.5
Live Branches	-.015	.004	.998	99.5
Dead "	.002	.0002	.998	99.7
Stem Wood	.069	.001	.899	80.8
Stem Bark	.067	.001	.945	89.4
ALL FOLIAGE	.259	.007	.993	98.5
WHOLE TREE	.380	.012	.995	99.1

D. POTASSIUM - GRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	.128	.0051	.998	99.6
Older Foliage	.412	.010	.991	98.1
Live Branches	.159	.007	.993	98.6
Dead "	-.003	.0003	.997	99.5
Stem Wood	.314	.004	.944	89.1
Stem Bark	.500	.003	.859	73.8
ALL FOLIAGE	.540	.015	.994	98.8
WHOLE TREE	1.513	-.028	.983	96.6

TABLE 4. CONT'D.

E. CALCIUM - GRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	.156	.006	.999	99.8
Older Foliage	1.486	.023	.968	93.8
Live Branches	.218	.010	.997	99.4
Dead "	.037	.005	.998	99.7
Stem Wood	.560	.004	.790	62.4
Stem Bark	.618	.005	.886	78.5
ALL FOLIAGE	1.643	.029	.978	95.6
WHOLE TREE	3.076	.052	.972	94.4

F. MAGNESIUM - GRAMS/HECTARE

68 Foliage	.017	.002	.999	100.0
Older Foliage	.156	.005	.997	99.4
Live Branches	.037	.002	.999	99.7
Dead "	.004	.004	.998	99.6
Stem Wood	.087	.001	.911	83.0
Stem Bark	.036	.001	.959	92.0
ALL FOLIAGE	.204	.005	.994	98.7
WHOLE TREE	.369	.009	.988	97.6

APPENDIX E

TABLE 1. <u>THUJA PLICATA</u> SAMPLE TREE CHEMICAL ANALYSIS

COMPONENT	I					II					III				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
<u>Dbh 1" Ht. 6'</u>							PERCENT								
68 Foliage	.87	.11	.40	1.50	.14										
Older "	.84	.08	.39	1.58	.12										
Live Branches	.23	.03	.14	.68	.05		NOT APPLICABLE					NOT APPLICABLE			
Dead "	0	0	0	0	0										
Wood	.05	.01	.02	.10	.01										
Bark	.37	.04	.31	2.03	.05										
<u>Dbh 1" Ht. 14'</u>															
68 Foliage	1.10	.15	.61	1.49	.16	.81	.07	.37	1.57	.13	.58	.05	.20	2.16	.12
Older "	.91	.09	.38	1.29	.12	.72	.06	.28	1.76	.10	.60	.04	.25	1.88	.10
Live Branches	.22	.03	.14	.68	.04	.27	.02	.07	.69	.04	.15	.02	.04	.56	.04
Dead "	0	0	0	0	0	0	0	0	0	0	.12	.01	.01	.49	.03
Wood	.07	.01	.06	.10	.01	.05	.01	.01	.07	.01	.04	.01	.01	.07	.01
Bark	.39	.05	.30	1.56	.05	.30	.06	.31	1.26	.04	.27	.05	.31	1.73	.04
<u>Dbh 2" Ht. 17'</u>															
68 Foliage	1.08	.13	.59	.87	.15	.83	.10	.36	1.18	.13	.58	.05	.25	1.79	.12
Older "	.94	.09	.39	1.22	.02	.71	.06	.25	1.53	.11	.56	.05	.22	1.91	.11
Live Branches	.23	.03	.12	.52	.03	.16	.02	.08	.57	.04	.14	.01	.03	.55	.04
Dead "	0	0	0	0	0	0	0	0	0	0	.14	.01	.01	.67	.03
Wood	.08	.01	.06	.11	.01	.07	.01	.06	.10	.01	.06	<.01	.03	.09	.01
Bark	.42	.07	.50	1.29	.05	.35	.07	.50	1.53	.05	.30	.05	.45	1.75	.05
<u>Dbh 3" Ht. 19'</u>															
68 Foliage	1.15	.17	.49	.91	.16	1.00	.14	.45	1.01	.13	.81	.10	.38	1.48	.11
Older "	1.03	.13	.45	1.15	.12	.83	.08	.27	1.39	.10	.67	.06	.16	1.75	.10
Live Branches	.31	.03	.14	.64	.04	.18	.01	.05	.53	.03	.14	.01	.02	.64	.03
Dead "	0	0	0	0	0	0	0	0	0	0	.14	.01	.01	.91	.04
Wood	.11	.03	.08	.10	.02	.07	.01	.07	.07	.02	.06	<.01	.04	.08	.02
Bark	.52	<.01	.35	1.58	.08	.43	.04	.30	1.76	.07	.35	.04	.24	1.52	.05

TABLE 2. COEFFICIENTS OF DETERMINATION FOR THUJA PLICATA BIOMASS-NUTRIENT REGRESSION ANALYSIS.

Weight = a + b(x)   x = D^2H

Section	Component	ELEMENT					
		Nitrogen	Phosphorous	Potassium	Calcium	Magnesium	Dry Weight
I	68 Foliage	90.2	89.2	84.2	66.4	88.9	44.9
	Older Foliage	98.4	99.6	99.4	96.2	99.1	81.9
	Live Branches	99.7	99.5	99.8	99.3	98.7	60.5
	Wood	98.0	93.7	99.7	79.6	98.0	7.8
	Bark	98.0	91.1	70.0	83.5	98.4	95.0
II	68 Foliage	89.3	89.2	89.1	89.1	89.5	81.0
	Older Foliage	92.9	91.8	93.1	95.0	94.6	90.1
	Live Branches	48.9	.1	15.1	28.8	25.7	40.9
	Wood	97.2	97.6	99.9	90.3	98.0	91.2
	Bark	95.2	64.4	65.3	94.4	96.8	79.2
III	68 Foliage	92.4	91.0	94.7	88.1	92.9	78.6
	Older Foliage	89.5	90.5	88.7	90.3	90.4	84.8
	Live Branches	92.2	92.8	93.2	91.8	93.2	89.4
	Dead Branches	92.2	98.2	90.2	98.5	97.6	54.8
	Woos	89.9	67.5	93.2	76.5	97.1	80.3
	Bark	91.3	55.7	42.2	75.1	92.5	78.2

TABLE 3. *THUJA PLICATA* FULL TREE
REGRESSION ANALYSIS.

Weight = a + b(x) $x = D^2H$

A. BIOMASS - KILOGRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	-5.88	2.79	.909	82.6
Older "	-86.73	18.81	.963	92.7
Total "	-92.61	21.59	.958	91.7
Live Branches	44.06	4.65	.948	89.8
Dead "	6.61	.29	.684	46.8
Wood	237.85	17.87	.947	89.7
Bark	50.37	2.66	.917	84.2
TOTAL TREE	229.80	47.23	.996	99.2

B. NITROGEN - GRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	-.090	.027	.987	97.3
Older "	-1.030	.139	.973	94.8
Live Branches	.085	.006	.995	99.0
Dead "	.005	.0002	.960	92.2
Wood	.151	.008	.977	95.5
Bark	.164	.007	.977	95.5
FOLIAGE	-1.120	.167	.976	95.3
TREE	-.714	.188	.982	96.5

TABLE 3. CONT'D.

C. PHOSPHOROUS - GRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	-.098	.006	.945	89.3
Older "	-.141	.014	.967	93.6
Live Branches	.016	.0004	.969	93.9
Dead "	.0001	.00002	.991	98.2
Wood	.005	.001	.995	99.0
Bark	.042	.0006	.815	66.4
FOLIAGE	-.239	.020	.961	92.4
TREE	-.176	.023	.971	94.3

D. POTASSIUM - GRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	-.078	.012	.956	91.4
Older "	-.167	.045	.977	95.4
Live Branches	.074	.001	.939	88.2
Dead "	.0003	.00001	.950	90.2
Wood	.004	.007	.994	98.8
Bark	.302	.005	.748	55.9
FOLIAGE	-.245	.057	.973	94.7
TREE	.136	.070	.991	98.1

TABLE 3. CONT'D.

E. CALCIUM - GRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	.019	.027	.940	88.3
Older "	-.175	.199	.978	95.6
Live Branches	.268	.020	.990	98.0
Dead "	.177	.009	.956	91.4
Wood	.177	.009	.956	91.4
Bark	1.040	.027	.945	89.4
FOLIAGE	-.156	.225	.974	94.9
TREE	1.338	.282	.981	96.3

F. MAGNESIUM - GRAMS/HECTARE

68 Foliage	-.021	.004	.955	91.2
Older "	-.074	.017	.978	95.6
Live Branches	.022	.001	.989	97.8
Dead "	.0005	.00007	.988	97.6
Wood	.013	.002	.991	98.1
Bark	.019	.001	.986	97.2
FOLIAGE	-.096	.020	.974	95.0
TREE	-.041	.024	.981	96.2

APPENDIX F

TABLE 1. COEFFICIENTS OF DETERMINATION FOR *PSEUDOTSUGA MENZIESII* REGRESSION ANALYSIS.

$$\text{Weight} = a + b(x)$$

Section	Component	X					
		DH^2	H^2	D^2H	D	H	D^2
I	68 Foliage	87.5	74.4	92.4	82.2	68.0	92.4
	67	81.7	72.5	84.8	81.7	68.4	87.1
	66	72.6	65.4	74.5	71.5	62.2	75.5
	65	55.0	46.1	60.5	57.2	44.0	63.1
	64<	9.7	9.9	8.7	1.5	7.8	7.4
	Live Branches	65.4	62.2	65.8	73.3	61.8	70.8
	Wood	91.3	82.1	88.7	67.0	69.8	79.8
	Bark	89.2	81.1	85.8	63.6	68.6	76.0
II	68 Foliage	71.1	70.0	68.7	70.6	65.4	71.9
	67	74.2	69.5	74.8	76.0	65.2	79.2
	66	73.2	66.9	75.3	76.5	63.2	80.2
	65	50.2	48.5	53.0	64.8	49.9	62.7
	64<	33.1	34.7	34.4	48.8	38.2	43.5
	Live Branches	87.2	79.4	88.2	83.7	73.3	89.7
	Dead "	2.4	.8	2.9	.2	.1	1.7
	Wood	93.7	89.2	91.2	84.3	81.3	90.2
	Bark	52.3	49.2	53.2	55.3	47.3	56.9
III	68 Foliage	14.7	10.2	19.0	16.4	9.5	20.7
	67	79.4	61.3	84.7	61.3	49.8	78.7
	66	81.7	64.4	88.0	67.3	53.9	84.2
	65	76.2	60.0	83.4	66.5	51.3	82.1
	64<	49.3	37.7	57.7	50.4	34.1	61.0
	Live Branches	49.6	41.8	56.1	57.8	40.2	63.4
	Dead "	87.4	75.1	89.0	74.4	65.5	85.7
	Wood	96.8	88.1	96.3	84.0	78.6	93.6
	Bark	93.4	83.9	95.6	86.5	76.9	95.3

D = Diameter.

H = Height.

TABLE 2. COMPARISON OF COEFFICIENTS OF DETERMINATION FOR *PSEUDOTSUGA MENZIESII* DRY WEIGHT USING RAW DATA AND EVEN INCH DATA.

Weight = a + b(x) $x = D^2H$

Section	Component	1" Classes	Log. Raw Data	Log. 1" Classes
I	68 Foliage	94.8	93.4	93.7
	Older "	86.5	92.0	90.5
	Live Branches	67.1	89.3	81.9
	Wood	83.3	49.5	42.2
	Bark	80.9	51.0	50.4
II	68 Foliage	58.0	84.5	87.7
	Older "	65.5	49.5	90.0
	Live Branches	86.1	90.3	91.6
	Dead "	15.7	2.0	1.6
	Wood	85.8	87.8	90.7
	Bark	67.1	92.9	87.7
III	68 Foliage	25.8	12.3	14.0
	Older "	95.8	75.4	86.1
	Live Branches	54.0	72.3	80.2
	Dead "	85.8	91.6	88.8
	Wood	92.6	97.7	92.6
	Bark	96.7	95.9	93.1
TOTALS	68 Foliage	88.9	-	95.2
	Older "	88.8	-	94.9
	Live Branches	85.8	-	93.0
	Dead "	85.7	-	89.5
	Wood	89.2	-	91.3
	Bark	92.7	-	91.3
	FOLIAGE	90.8	-	96.6
	TREE	93.8	-	94.7

TABLE 3. COEFFICIENTS OF DETERMINATION FOR *PSEUDOTSUGA MENZIESII* BIOMASS-NUTRIENT REGRESSION ANALYSIS.

$$\text{Weight} = a + b(x) \qquad x = D^2H$$

Section	Component	ELEMENT					
		Nitrogen	Phosphorous	Potassium	Calcium	Magnesium	Dry Weight
I	68 Foliage	93.7	84.2	96.7	95.8	94.8	92.4
	Older "	91.4	93.6	81.1	92.9	90.0	84.8
	Live Branches	73.2	56.7	72.0	75.8	77.3	65.8
	Wood	80.2	74.0	89.1	78.2	86.7	88.7
	Bark	80.8	61.3	82.0	83.8	88.0	85.8
II	68 Foliage	47.0	37.3	48.7	37.8	35.6	68.7
	Older "	56.8	41.9	57.3	47.3	28.5	88.7
	Live Branches	81.7	87.1	89.9	85.4	88.2	88.2
	Dead "	39.7	31.7	13.6	43.6	40.6	2.9
	Wood	91.6	79.7	63.9	85.3	91.4	91.2
	Bark	84.6	74.9	70.4	42.3	76.3	53.2
III	68 Foliage	20.3	20.3	20.2	21.2	19.8	19.0
	Older "	97.6	84.0	92.6	83.0	77.9	84.4
	Live Branches	52.9	51.7	50.3	50.2	51.5	56.1
	Dead "	82.4	85.5	85.2	84.7	86.6	89.0
	Wood	88.1	90.2	90.7	92.5	91.4	96.3
	Bark	95.1	71.3	58.2	97.4	95.7	95.6

TABLE 4. *PSEUDOTSUGA MENZIESII* FULL TREE REGRESSION ANALYSIS.

$$\text{Weight} = a + b(x) \quad x = D^2H$$

A. BIOMASS - KILOGRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	60.24	1.71	.972	94.6
Older "	61.86	6.47	.952	90.6
TOTAL FOLIAGE	122.10	8.18	.962	92.5
Live Branches	317.16	7.66	.941	88.5
Dead "	1.73	2.45	.942	88.7
Wood	826.46	27.15	.980	96.0
Bark	224.86	4.89	.963	92.8
TOTAL TREE	1509.7	50.35	.983	96.7

B. NITROGEN - GRAMS/HECTARE

68 Foliage	1.339	.014	.951	90.4
Older "	4.604	.053	.949	90.1
Live Branches	1.023	.025	.914	83.6
Dead "	.183	.004	.905	82.0
Wood	1.552	.011	.949	90.0
Bark	1.211	.011	.970	94.1
FOLIAGE	5.943	.067	.953	90.7
TOTAL TREE	9.912	.118	.958	91.8

TABLE 4. CONT'D.

C. PHOSPHOROUS - GRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	.308	.002	.902	81.3
Older "	1.280	.008	.862	74.3
Live Branches	.221	.005	.943	89.0
Dead "	.002	.001	.923	85.2
Wood	.230	.001	.953	90.9
Bark	.107	.003	.851	72.5
FOLIAGE	1.588	.011	.883	78.0
TOTAL TREE	2.146	.021	.937	87.7

D. POTASSIUM - GRAMS/HECTARE

68 Foliage	.603	.011	.937	87.7
Older "	1.514	.029	.917	84.1
Live Branches	.832	.016	.949	90.1
Dead "	-.044	.0008	.919	84.5
Wood	.288	.004	.813	66.2
Bark	.930	.014	.924	85.3
FOLIAGE	2.118	.040	.923	85.1
TOTAL TREE	3.269	.074	.949	90.0

TABLE 4. CONT'D.

E. CALCIUM - GRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	.794	.005	.872	76.0
Older "	4.980	.052	.881	77.7
Live Branches	.892	.047	.948	89.9
Dead "	-.030	.012	.919	84.5
Wood	.587	.008	.955	91.1
Bark	1.471	.014	.983	96.5
FOLIAGE	5.775	.057	.883	78.0
TOTAL TREE	8.754	.138	.9674	93.6

F. MAGNESIUM - GRAMS/HECTARE

COMPONENT	a	b	r	r^2
68 Foliage	.206	.001	.880	77.5
Older "	.943	.005	.764	58.4
Live Branches	.054	.005	.967	93.5
Dead "	.035	.001	.929	86.4
Wood	.130	.002	.981	96.3
Bark	.177	.002	.963	92.8
FOLIAGE	1.20	.006	.777	60.4
TOTAL TREE	1.530	.016	.933	87.1