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A Study of Root Biomass in an Engeimann Spruce-Subalpine Fir Stand in Northern Utah

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A STUDY OF ROOT BIOMASS IN AN ENGELMANN SPRUCE-SUBALPINE FIR

STAND IN NORTHERN UTAH

by

Larry O. Gadt

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Larry O. Gadt

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by

Larry O. Gadt, Master of Science

Utah State University, 1970

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Department: Forest Science

Biomass of roots in the top 6 inches of soil profile was measured. This weight was then used in a stepwise multiple regression to test correlations between root biomass and above ground mensurational parameters.

Total biomass of all roots was 9822 ± 2810 pounds per acre oven dry. Spruce roots weighed 4417 ± 997 pounds per acre; of this spruce roots less than 0.125 inch diameter weighed 2023 ± 347 pounds per acre and biomass of spruce roots greater than 0.125 inch diameter was 2394 ± 853 pounds per acre. Total fir roots weighed 5156 ± 2687 pounds per acre; of this roots less than 0.125 inch totaled 869 ± 181 pounds per acre and biomass of fir roots greater than 0.125 inch diameter was 4287 ± 2653 pounds per acre.

Low r^2 (0.11 to 0.17) values were found and the parameters which showed the greatest predictive value were $(dbh)^2$, dbh, basal area, $(\text{basal area})^2$, and height.

The sampling design involved the pairing of trees over 4 inches diameter. Point density expressed as basal area was not useful in relating to root biomass with this sampling design.

(57 pages)

INTRODUCTION

Purpose and Scope of Study

The above ground productivity of different forest types has been studied by foresters for many years. Emphasis has been placed on trying to correlate this productivity with certain environmental factors. Except for studies of seedling root: top ratios, little has been done to correlate underground productivity with biomass above ground. In Europe root studies have been pursued rather vigorously, especially in Germany, Finland, and Russia. Some of these studies have been concerned with *Picea* and *Abies* but only a few have been translated into English.

This study has two principal objectives: 1) to determine how much root biomass is in the upper 6 inches of the soil profile in selected portions of an Engelmann spruce-subalpine fir stand in northern Utah, and 2) to determine what, if any, correlations exist between root biomass and certain above ground mensurational parameters including height, age, diameter at breast height (dbh) and basal area.

Description of Species

The Engelmann spruce (*Picea engelmannii* Parry) - subalpine fir (*Abies lasiocarpa* (Hook) Nutt.) association is considered by some ecologists to be the western counterpart of the boreal spruce-fir association of eastern and northern North America (Alexander, 1958a). The natural range of this association is extensive. It reaches from the central interior valleys of British Columbia southward through the Rocky Mountains and out-lying mountainous tracts to Mexico. Locally its distribution as a forest type is generally restricted because both species require a cool, moist habitat (LeBarron and Jemison, 1953). Precipitation is generally 25 inches or more and the majority of this comes in the winter as snowfall, especially in the northern regions. In many parts of the Intermountain region summer rainfall is scant. This often results in the occurrence of a moisture deficiency in the upper portion of the soil horizon.

At higher elevations this forest type is found on all aspects and at lower elevations it is generally restricted to cool, moist pockets such as north slopes and valleys.

Engelmann spruce

Engelmann spruce is one of seven species of *Picea* native to the United States. It is a widely distributed species; extensive stands are found in nine western states and two Canadian provinces. Its range extends from British Columbia and Alberta, south to New Mexico and Arizona (Fowells, 1965). Engelmann spruce is rated as "tolerant" by foresters (Baker, 1949). It is a slow growing species especially in the early stages of development. Root penetration may be as slow as 1 to 3 inches the first year with shoot growth just as slow depending on locality, condition of seedbed, and climatic factors (Fowells, 1965). This spruce is a long-lived tree maturing in about 300 years. Trees over 500 years old are not uncommon. Engelmann spruce has the capacity to grow well at advanced ages--it will continue to grow steadily for 300 years if given adequate growing space (LeBarron and Jemison, 1953).

Engelmann spruce is characterized by a shallow root system which renders trees highly susceptible to windthrow. Where trees grow in bogs or heavy soils underlain by impervious rock or clay subsoils, a weak, superficial root system common to the seedling stage may persist to old age. But when spruce grows on deep, porous soils, vertical sinker roots arising from the lateral roots may penetrate deeper than 8 feet (Alexander, 1958a).

Subalpine fir

Subalpine fir is one of nine species of Abies native to the United States. It is the smallest as well as the most widespread of the true firs native to the United States, and is found in widely scattered stands from southeastern Alaska to southern Arizona. In Utah, it occurs in the Uinta and Wasatch Mountains but rarely on the Colorado plateaus (Fowells, 1965).

Subalpine fir is considered to be "very tolerant," more so than Engelmann spruce (Baker, 1949). Its seed will germinate and survive on a wider range of seedbeds than will seed of Engelmann spruce. It will survive on duff layers, dry soil, and other places where spruce has failed to become established, presumably because fir has a larger seed and can more quickly produce a vigorous root system. Establishment and early survival of subalpine fir are favored by relatively deep shade and the species cannot compete successfully with Engelmann spruce in areas where light intensity exceeds 50 per cent of full sunlight (U. S. Forest Service, 1944). Little is published about the rooting habits of subalpine fir, but the majority of foresters consider it a shallow rooted species much like the spruce (Preston, 1966).

The long lived characteristic of Engelmann spruce and the ability of subalpine fir to maintain growth in a shaded understory has resulted in a definite forest structure. Frequently old growth Engelmann spruce-subalpine fir forests are structured with nearly pure spruce in the overstory and fir predominating in the understory. Oosting and Reed (1932) found that in old growth spruce-fir forest in southern Wyoming, Engelmann spruce never made up less than 70 per cent of the total basal area and often more than 90 per cent. Both species can reproduce by layering.

REVIEW OF LITERATURE

Weaver and Kramer (1932) made perhaps one of the first significant research efforts to measure roots quantitatively and compare these data with above ground volume. Although they did not measure the finer roots and they were not concerned with developing predictive equations, their study resulted in a better understanding of the amount of roots produced by trees. The species studied was bur oak (Quercus macrocarpa Michx.).

In the past 30 years considerably more effort has been made toward gaining a more thorough understanding of the rooting habits of forest grees. Hopkins and Donahue (1939), in a study of spruce and balsam fir roots, found relationships which were useful in understanding root ecology. They worked mostly with soil morphology and found that organic matter and soil moisture were the most important factors influencing root distribution. An above ground parameter they analyzed was tree height, but they found no correlation between this parameter and root length.

Ovington (1962) noted that relatively few records of root weights are available and although they give similar results on the whole, experience in root sampling indicates that these may be seriously in error due to the difficulty of ensuring that all roots are collected in a sample and no soil is included in the weight calculations. More recent refinements in root sampling techniques, as well as development of more accurate laboratory procedures, have helped to eliminate a considerable amount of this error. Many studies since 1960 have contributed much to the knowledge about individual species of forest trees. Statistical methods in analyzing root data have aided considerably in expressing the significance of results, especially when an evaluation of correlation with other parameters is desired (Kozak and Smith, 1965).

Bray (1963) credits the increased interest in roots to studies in Eurasia, North America, and Africa. These studies greatly increased the knowledge of roots and helped to dispel the reluctance to sample below ground systems of plants because of their assumed great depth.

The use of above ground parameters in the prediction of underground weight of roots has obvious merits. If the necessary statistical parameters and root weight are established, estimates of root weight can be made without harvesting the roots. Ovington (1962) and Baskerville (1966) developed regression equations using diameter at breast height for predicting root weights.

Young, Strand, and Attenberger (1964) and Monk (1966b) also developed regression equations; however, they included height as well as dbh. All of these studies were conducted by excavating the complete root systems of a number of trees and correlating root data with selected parameters. Results of these studies will be discussed in more detail later.

RESEARCH AREA

This study was carried out on a one-fourth acre circular plot located on the Utah State University College Forest. A one-tenth acre plot is located within the quarter acre plot. These plots lie in the Southeast one-fourth of the Northeast one-fourth, Section 21, Township 13 North, Range 4 East, Salt Lake Base Meridian. The one-quarter acre circular plot is identified as plot D-10 of the permanent study plots which were established in the summer of 1950 to evaluate growth, mortality, and other parameters on the College Forest (List, 1959). Table 1 contains data which aid in understanding the species composition of the plots.

Table 1. Summary information from the one-fourth and one-tenth acre plots[a]

Plot	Number of stems		Average height (ft.)		Average diameter (in.)		Basal area (sq. ft.)		Per cent of total basal area	
	F[b]	S	F	S	F	S	F	S	F	S
one-fourth acre	34	12	50	69	10.4	16.8	23.95	22.84	51.2	48.8
one-tenth acre	12	7	48	71	9.4	17.2	7.54	14.15	34.8	65.2

[a]Includes trees 4.0 inches dbh and larger.

[b]F= subalpine fir; S= Engelmann spruce.

Aspect of the plots is east and the slope is 6 to 8 per cent. The elevation of the site is approximately 8,000 feet. This higher elevation along with aspect and soil profile result in this site being classified by Pflugbeil (1960) as "best" with the following categories: best, good, fair, and poor.

Soils information from the College Forest is limited; however, the study plot is considered an alfisol. The soils are coarse to gravelly in texture and have clays intermingled. They can be compacted easily if moist.

METHODS

In the late spring and early summer of 1969 the study plot was mapped by means of a plane table with an open sight alidade. All stems above 1 foot in height were mapped. Figure 1 is a stem map of the plots. The outer circle includes the one-quarter acre plot and the inner circle is the one-tenth acre sampling plot. A complete list of stems is found in Table 6 in the Appendix. Each stem was tagged as it was mapped to prevent double coverage.

Diameter at breast height measurements were made with a tape. Height data were collected using an Abney level for stems over 8 feet high and for stems shorter than 8 feet measurements were made directly. Dbh measurements were not taken on trees shorter than 8 feet tall.

Because relatively few trees on the plot were larger than 4 inches dbh, the most efficient and accurate way of age determination was by direct boring of trees on the plot. Complete increment cores were taken on all trees on which the center could be reached with an 8-inch borer. On larger trees, a core was taken as deep as penetration was possible, and then extrapolation was used in determining age of tree. Admittedly there is a source of error using the extrapolation method. The cores were taken to the laboratory and rings were counted using a stereozoom microscope. The age thus determined was the age at breast height and not the total age of the tree. Oosting and Reed (1952), in a closed forest in Wyoming, found that Engelmann spruce trees 4 to 6 feet tall were 45-75 years old. Subalpine fir trees in the same height range were 35-50 years old.

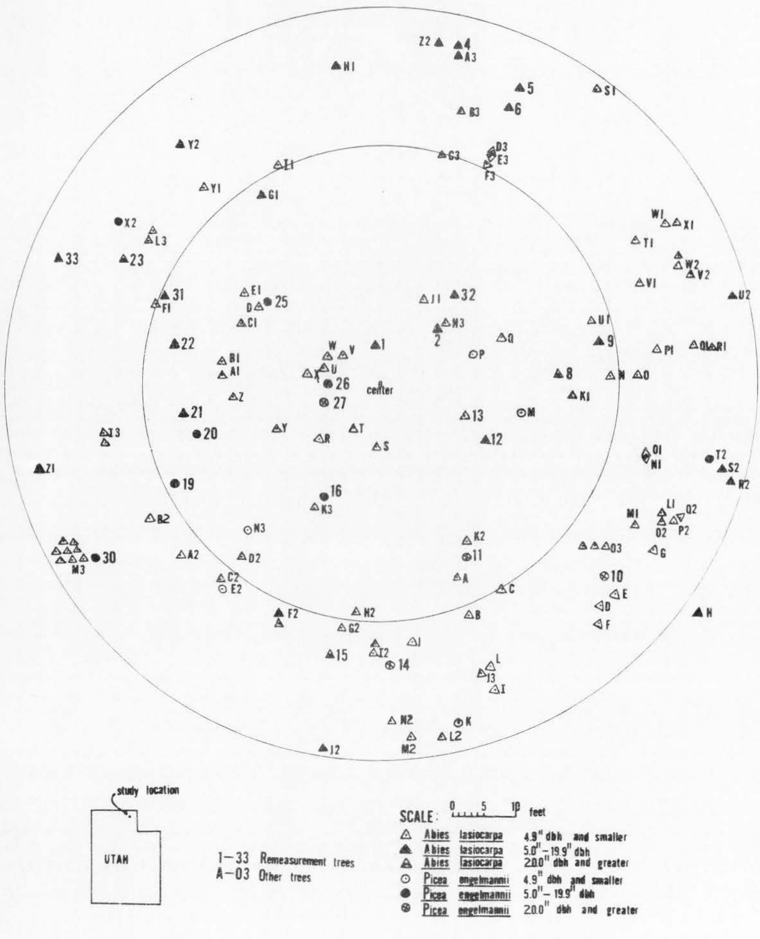

Figure 1. Stem map.

Field Sampling Procedure

Sampling of roots generally is done by one of four methods: 1) hydraulic excavation of entire root systems, 2) excavation of a monolith or soil block, 3) injection of radioactive isotopes or tracers, and 4) collection of soil cores. The fourth method was the one chosen for this study. This method has possibly the most versatility of all the methods used in collecting quantitative data. The soil core procedure in root sampling was developed by agricultural and range scientists (Schuurman and Goedewaagen, 1965), and it is particularly useful in the surface layers of the soil profile with which this study was concerned. It represents a fast and efficient means of obtaining root samples. Finer roots are not lost and this alone can represent a considerable amount of weight in the upper horizons of the soil profile.

The sample core used was 6 inches in depth and 6 inches in diameter (0.1 cubic foot), and it was attached to a "T" handle. This sampler was forced into the soil to the desired depth and then a shovel was forced underneath to cut off any roots which were below the core and to leave only those roots which were contained within the core. The entire core was then lifted and placed in a plastic bag for transporting to the laboratory. If an obstruction prevented the core from penetrating deeper, the shovel was used to find the obstruction. If the obstruction was a rock or other non-living root material it was pulled out and the core forced the remainder of the 6 inches. If the obstruction was a large root, then a pair of ordinary pruning shears was used to sever the root so that the core could pass by and include that portion of the root which was inside the core. In this manner the top 6 inches of the ground surface were included in the sample whether it consisted of rock, soil, or roots.

Field Sampling Design

In the majority of root studies the problem of where and how to sample is difficult to solve. Because of the uniqueness of the sampling design used in this study a rather detailed description will be given.

All of the samples were taken with the one-tenth acre plot shown in Figure 1. The outer circle representing the one-quarter acre plot contained trees from which data were obtained in order to evaluate different parameters in the regression analysis. All trees within the one-tenth acre which had a diameter at breast height of 4 inches or greater were paired in as many combinations as possible. The number of trees was 19 and this resulted in 171 pairings. Each of the 171 pairings was then given a number and 60 numbers were randomly selected to determine where the samples would be taken. The sample selected, representing a pair of trees, was then taken midway between these two trees. A sample point that fell within two times the diameter of any tree was moved perpendicular to a line drawn between the trees until it was outside this area. The elimination of an area which is within two times the diameter of a tree, from the center of that tree, was done to avoid the very large superficial, lateral roots. Future studies may determine the biomass of such roots. A considerable amount of time and money will be needed to measure accurately the root biomass in the spruce-fir forest association. Figure 2 is a map showing the location of the 60 sample points and the trees used in the pairing.

Laboratory Methods

After the samples were taken and transported to the laboratory in plastic bags they were placed in containers. A 2 per cent solution of

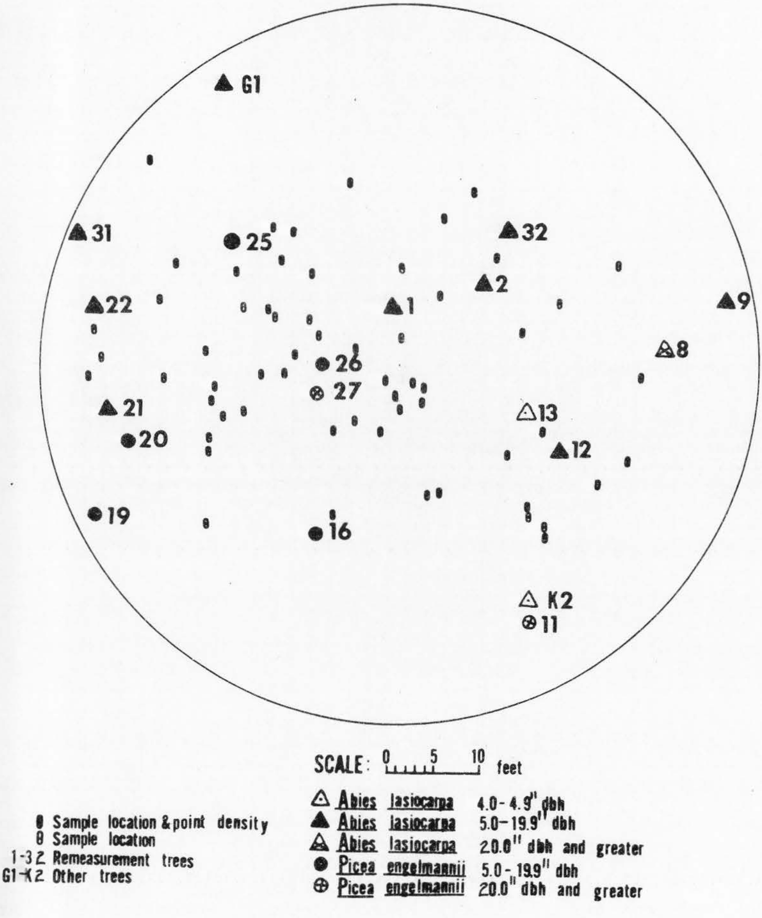

Figure 2. Paired trees and sample points.

calgon (sodium hexametaphosphate) was then added and the mixture allowed to soak for 12-18 hours. The variation in soaking time was necessary in order that samples which contained more clays could be separated easily. Calgon aids in the separation of soil particles from the roots and the clay particles were difficult to separate from the roots. If longer soaking time was allowed the roots started to decompose and this made identification difficult.

Following soaking, the container and its contents was placed on a shaking table and allowed to agitate on the low cycle for 1 minute. When a longer agitation was allowed the gravel particles in the mixture acted as an abrasive and removed the outer bark, resulting in identification being difficult if not impossible.

When agitation had been completed the mixture was next placed in a sink on a series of screens: 4, 6, and 8 squares to the inch. Water was gently flushed over this mixture until the soil particles had been removed and only the coarser gravel particles and roots remained. The roots were then separated from the rocks with a pair of tweezers. In this manner the roots were separated with a minimum of damage and loss. Although a few of the very fine roots were undoubtedly lost, the loss was held to a minimum. Roots were placed in a beaker of water for identification and size differentiation.

Identification was carried out with the aid of a sterozoom microscope. Gilbertson, Leaphart, and Johnson (1961) developed a key for identifying roots of the major conifers of the Inland Empire. Their key was useful in this study for macroscopic purposes because only two tree species were present. The microscope was not used for microscopic work but rather for a more detailed examination of macroscopic characteristics. The following characteristics were used to differentiate species: outer bark, resin ducts, and annual rings. Engelmann spruce has an outer bark which is conspicuously scaly with broad linear to platelike scales; resin ducts are present in the wood; and annual rings are indistinct. On the other hand, subalpine fir has an outer bark which is smooth or with narrow shredlike scales; it has conspicuous resin pockets; resin ducts are not present in the wood; and annual rings are more distinct (Gilbertson, et al., 1961). Because only two species were involved the outer bark characteristics were the ones most used. Care exercised in the separation of soil from the roots resulted in the majority of the finer roots remaining attached to the larger roots. This aided in the identification and any roots which could not positively be identified were placed in the category "other."

Only live roots were identified and later weighed. Characteristics used to differentiate the dead from live roots were: elasticity, color, and ease of separating cortex. Live roots are elastic enough so that they do not break easily while dead roots break off easily when handled. Live roots are greyish in color especially when the outer cortex is separated from the inner bark or cambium; dead roots are generally dark brown in color throughout the root. The outer cortex separates or can be peeled from the cambium on live roots while it is difficult to separate the outer cortex from inner cells on dead roots.

Following separation and identification of the roots by species they were sorted into two size classes, those less than 0.125 inch in diameter and those 0.125 inch and greater. In this manner a clearer picture of the biomass of smaller roots is possible. The roots were then placed in an oven and dried for 48 hours at 70 C. After drying, the roots were immediately weighed to an accuracy of one hundredth gram. A complete listing of the samples along with the weight of each size class is included in Table 7 in the Appendix.

Methods Used in Obtaining Data for Regression Analysis

Since it was desirable to evaluate different mensurational parameters in the stand and their relation to root biomass, data were collected from the trees surrounding each sample point. Because all of the sample points were mapped as well as the location of all stems, the data were assembled, using the map, in the laboratory. A circle representing a 30-foot radius was drawn around each sample point and all trees 4 inches dbh and greater included within this area were recorded. A smaller circle representing a 15-foot radius was then drawn and all stems smaller than 4 inches dbh were recorded. The data were then taken from the field sheets for individual trees and recorded on the sheet representing each sample. An example of the data sheet used for each sample is given in Figure 4 in the Appendix. Because it was desirable to have the results in a form that could be reviewed, all calculations on the sample sheets were performed on a manual calculator.

Methods Used in Obtaining Data for Point Density

So that the effects of different trees on a point within the stand could be evaluated a different method was used in obtaining data. An optical wedge with a basal area factor (BAF) of 20 was used to count the number of trees included within the acceptable distance around 20 randomly selected sample points. The number assigned to each tree was noted and the dbh was later recorded. Point density was measured by a method discussed by Spurr (1962). Because this method takes into consideration not only the size of the tree but also the distance from the sample point, it is considered responsive to changes within a small area. The distance from the sample point to the individual trees was found by taking measurements off the sample point map shown in Figure 2.

STATISTICAL ANALYSIS

Biomass data from the 60 root samples were analyzed so as to detect the amount of variance. Variance of total weight was analyzed as well as variance for roots less than 0.125 inch diameter. The total weight of roots per acre for each size class was determined with stated confidence level and error.

A stepwise multiple regression was run with the different parameters selected as independent variables and root weights as dependent variables. This program (SMRR) was in the FORTRAN language and was already present in the Utah State University Computer Center in the IBM 360 computer. The data and format cards were punched so that this program could be utilized. The dependent variables selected were:

dbh	dbh x age	age
$(dbh)^2$	height	basal area
dbh x height	$(height)^2$	$(basal\ area)^2$
$(dbh)^2$ x height	age x height	

The dependent variables used in the regression were: spruce, fir, and total root biomass less than 0.125 inch diameter; spruce, fir, and total root biomass 0.125 inch and greater; total spruce root biomass, total fir root biomass, and total root biomass.

RESULTS AND DISCUSSION

Sample Variation

Ten preliminary samples were taken early in the study to aid in understanding the amount of variation present in the population of roots. These samples, along with the 60 study samples, indicated that the variation was large and many samples would be necessary to predict root weight with the accuracy that is associated with studies involving above ground biomass. Table 2 shows the variation encountered in this study. The largest statistical error encountered was in the biomass of subalpine fir roots greater than 0.125 inch diameter. Only 32 of the 60 samples had roots of this size class. These roots had a mean weight of 8.77 grams. Several weighed over 30 grams, and one sample weighed over 131 grams. The variation from this low mean was large. Roots of Engelmann spruce which were larger than 0.125 inch diameter varied in their weight distribution up to 36.17 grams. Engelmann spruce roots larger than 0.125 inch diameter were present in 39 of the 60 samples. It was noticed both during the sampling and identification of the roots that the Engelmann spruce had a greater range of root diameters than did the subalpine fir. Many sizes of Engelmann spruce roots were observed in the same sample, while subalpine fir generally had one size or the other present. Thirty-seven of the 60 samples contained both size classes of spruce while 30 contained both size classes of fir. These characteristics may indicate that Engelmann spruce has a more uniform and extensive branching habit than subalpine fir. Hopkins and Donahue (1939) found similar results in working with balsam fir and an unspecified species of spruce. Many very

Table 2. Summary of mean root biomass data and variance

Size class	Mean of 60 samples in grams	Variance in grams	Standard error of the mean in grams[a]	Per cent of the mean
Total biomass of all roots[b]	20.10	709.22	5.75	28.6
Biomass of all spruce and fir roots greater than 0.125 inch dia.	13.51	725.00	5.80	42.9
Biomass of all spruce and fir roots smaller than 0.125 inch dia.	5.92	19.42	0.95	16.0
Biomass of all spruce roots	9.04	90.19	2.04	22.5
Biomass of all fir roots	10.55	650.47	5.50	52.1
Biomass of spruce roots greater than 0.125 inch dia.	4.90	67.23	1.77	36.7
Biomass of fir roots greater than 0.125 inch dia.	8.77	633.44	5.43	61.9
Biomass of spruce roots less than 0.125 inch dia.	4.14	11.52	0.71	17.1
Biomass of fir roots less than 0.125 inch dia.	1.78	3.02	0.37	20.8

[a] 95 per cent confidence level

[b] Includes roots other than spruce and fir.

small subalpine fir roots were found branching directly off much larger roots while Engelmann spruce roots were generally connected to a root only slightly larger. Table 3 is a tabulation of the amount of roots present in the upper 6 inches of soil in this forest association on a per acre basis. These data apply to a limited area but they illustrate how the weights of roots of the two species are distributed in the top 6 inches of the soil.

Table 3. Root biomass and standard error of the mean in the top 6 inches of soil profile[a]

Species and size class	Biomass in pounds per acre oven dry	Standard error of the mean in pounds per acre oven dry
Total biomass of all roots	9822	2810
Total biomass of roots less than 0.125 inch dia.	2904	464
Total biomass of spruce roots	4417	997
Spruce roots less than 0.125 inch dia.	2023	347
Spruce roots greater than 0.125 inch dia.	2394	853
Total biomass of fir roots	5156	2687
Fir roots less than 0.125 inch dia.	869	181
Fir roots greater than 0.125 inch dia.	4287	2653
Other	249[b]	

[a]95 per cent confidence level

[b]Mean and standard error of the mean were not calculated.

Although the standard error of the mean is large in some of the estimates in Table 3, a comparison can be made with other studies concerned with root biomass.

Rodin and Bazilevic (1966) estimated the root biomass in the coniferous forest of the temperate zone to be between 19,000 and 53,000 pounds per acre. This large variation can be accounted for by the many different species which are included in this broad classification. Baskerville (1966), studying a mixed stand of balsam fir and white birch, estimated the fir root biomass at between 23,800 and 39,000 pounds per acre depending on the number of stems. With both species included, the biomass varied between 34,600 and 41,000 pounds per acre. Baskerville did not measure roots smaller than one-sixteenth inch diameter but estimated their biomass at between 3,860 and 5,260 pounds per acre. Box (1968) estimated the root weight of loblolly pine at 12,906 pounds per acre. Loblolly pine is considered a shallow rooted species with 83 per cent of its total root biomass occurring in the upper 18 inches of the soil. Few roots reach a depth of 48 inches. Box also found the majority of the root biomass occurred in the 0 to 0.125-inch size class nearest the surface. Engelmann spruce and subalpine fir possibly produce larger lateral roots and this would be a greater contribution to biomass, particularly around the base of the tree. This area was not measured.

The great amount of variation encountered in this study can be used as an indication of the number of samples needed at designated confidence levels. If a 95 per cent confidence level is desired plus or minus 10 per cent, then 494 samples are necessary to sample the total root biomass. If only the information from roots less than 0.125 inch diameter is wanted, then 154 samples are necessary. The tremendous difference in the number of samples required for the different sizes of roots may warrant the development of different sampling procedures for larger roots. The amount of labor involved in one sample of the size used in this study was about one to one and one-half man days. The use of pressurized water or air may prove to be a more useful and efficient method for studying the larger roots.

Regression Analysis

A stepwise multiple regression was run on the different dependent variables against a set of eleven independent variables. In this program the first regression was run on all eleven independent variables. The regression was next run on ten independent variables, and the one eliminated was the variable which contributed least to the previous equation. This process was continued until only one variable was left. Coefficients are given for each regression as well as the r^2 value. In order to test for significance an "f" test was run on each variable. The set of variables, which had the highest significance along with an r^2 value which was compatible, was selected as the most efficient equation for predicting root weight of that particular dependent variable. Table 4 is a summary of these equations.

The low r^2 values found in this study illustrate that the independent variables used for each equation account for very little of the total variation present in the root biomass. Since most of the independent variables used were measurements which are easy to take and are relatively standardized, it is assumed that a large amount of the variation was not measured rather than there being significant errors in the collection of data. If indexes could be developed for factors such as above ground or underground competition it is probable that the r^2 values could be increased significantly. Ferrill and Woods (1966) found that a competition index in regression analysis increases the precision. This indicates that root

Table 4. Summary of regression analyses

Dependent variable	Prediction equations	r^2
Biomass of spruce roots less than 0.125 inch dia.	$\hat{Y}=5.42 + 0.00016\,[(dbh)^2 x\ ht.]^{**} + 0.00029\,.(dbh\ x\ ht.)^{**} - 0.433(BA)^{2**} - 0.010(dbh)^{2**}$	0.12
Biomass of spruce roots greater than 0.125 inch dia.	$\hat{Y}=6.41 - 11.75(BA)^{***} + 0.063(dbh)^{2***}$	0.17
Biomass of all spruce roots	$\hat{Y}=10.54 - 10.26(BA)^{**} + 0.055(dbh)^{2**}$	0.11
Biomass of fir roots less than 0.125 inch dia.	$\hat{Y}=1.38 + 0.00005\,[(dbh)^2 x\ ht.]^{***} - 0.00009\,(age\ x\ dbh)^{**} - 0.00009(age\ x\ ht.)^{**}$	0.17
Biomass of fir roots greater than 0.125 inch dia.	$\hat{Y}=-6.24 + 0.480(dbh)^{***} - 0.040(BA)$	0.14
Biomass of all fir roots	$\hat{Y}=-5.27 + 0.47(dbh)^{***} - 0.037(BA)$	0.13
Biomass of all roots greater than 0.125 inch dia.	$\hat{Y}=-5.50 - 0.20\,[(BA)^2]^{**} + 0.0004\,[(dbh)^2 x\ ht.]^{**} + 0.0004\,(dbh\ x\ ht.)$	0.15
Biomass of all roots	$\hat{Y}=-10.32 - 0.02\,[(BA)^2]^{**} + 0.0004\,[(dbh)^2 x\ ht.]^{**} + 0.0004\,(dbh\ x\ ht.)$	0.14

* Significant at the 90 per cent level
** Significant at the 95 per cent level
*** Significant at the 99 per cent level

interference by adjacent trees is important in determining root extension. Their work was performed in a longleaf pin plantation. The all-aged structure of the Engelmann spruce-subalpine fir forest may result in this competition index being more difficult to develop; however, its importance may be greater.

According to Smith (1964), dbh and crown width were significantly correlated with lateral root spread. Since roots occupied only 20 per cent of the area studied, he considered crown competition more important than root competition. Perhaps this is true of even-aged, uniform stands of intolerant species; but, in an all-aged forest where different sizes and ages of trees compete for the same moisture and nutrients, root competition may be more severe.

When all eleven independent variables were used to predict the dependent variables the highest r^2 value found was 0.27 with only two of the variables having significance of 0.90 or better. The extra amount of work necessary to collect and manipulate the data is hardly justified. Twenty-nine independent variables were used in predicting the eight dependent variables. Of these 29, $(dbh)^2$ and height accounted for 14. The only field measurements necessary for 27 of the 29 are dbh and height. Age was the other variable and it was then in combination with the variables height and dbh. This situation is similar to that described by Smith (1964). He found very little additional accuracy obtained by including variables other than crown width and dbh.

With the low r^2 values a fluctuation in the plus or minus value of the same coefficients for predicting root weight of the same species can be explained. With such a small amount of variation being explained the fluctuation in values can result in the same independent variable having a different value when it is being used to predict weight of the same species. An example of this is that $(dbh)^2$ has a minus value when used in predicting biomass of spruce roots greater than 0.125 inch while it has a plus value in predicting biomass of spruce roots greater than 0.125 inch. Another possible explanation of this change is that the predictive value of a variable can change when used to predict different sizes of roots of the same species. Young, Strant, and Attenberger (1964) found this latter explanation in their study of red spruce and balsam fir in Maine. They found the value of height changed when it was used to predict biomass of large roots and fine roots in both species.

Interpretation of data of this nature must be handled with care. The high significance of most of the independent variables used in the final predictive equations is shown in Table 4. These highly significant values must not be interpreted without looking at the r^2 values associated with each equation. The significance value is the level of significance each independent variable has in that particular equation, even though a very small amount of the variation is being measured. The r^2 value must be taken into consideration in these equations to prevent misinterpretation.

Point Density

Spurr (1962) discusses the value of measuring density, expressed in basal area, at a point in the stand rather than the density of the stand as a whole. A brief description will be given here of the angle summation method and if more detailed information is desired the reader is referred to Spurr's article.

The use of the Bitterlich angle count method of determining basal area is a fast and efficient way of obtaining information which is adequate for timber cruising purposes, etc. However, this method is not responsive to changes within a small plot that might be reflected on a particular point in the plot. The angle count method counts the trees which exceed an angle determined by the diopters of the wedge which is being used. This method does not tell how far each tree exceeds the angle, only that it does exceed the angle. The following example illustrates the deficiency of this method. If ten trees each had an angle greater than the wedge and the trees were all within a few feet of the wedge, their effect on the point being measured is considerably different than if the trees were on the periphery of the maximum distance acceptable using that wedge. The angle count method would show that the basal area at that point is the same in both instances although the influence of the trees on that point would be considerably different in the two situations.

The angle summation method takes into consideration the distance of the trees from the point being measured as well as the size of these trees. Table 5 illustrates the steps performed in the calculations. These calculations were made on each of the 20 sample points selected to measure point density. Actual estimate of basal area is obtained by summing column nine and dividing by n number of trees.

How many trees to use in the calculation of the basal area in point density is a problem that is different with each species used. Spurr (1962) found in working with Douglas-fir in New Zealand that eight was the proper number to use. If too many trees are used the results are indicative of stand density rather than point density. If too few trees are used the results are so erratic that a very inaccurate basal area may be chosen. After a certain number of trees is included the basal area has a tendency to gradually increase or decrease depending on the particular situation. Spurr suggested that the point of tapering off be chosen as the number of trees to use. If more trees are included the extra work would not be warranted and the results may be indicative of stand density and not point density. Of the 20 sample points at which point density was measured, 16 showed a definite tapering off of basal area at six or seven trees. A lesser number of trees showed the typical erratic results. At the points where the results were the most erratic it was observed that a tree was very close to the sample point. This results in a very large basal area

Table 5. Angle summation estimate of point density

1	2	3	4	5	6	7	8	9
Rank n	Dbh (in.)	Dist. (ft.)	$\frac{\text{Dbh}}{\text{Dist.}}$	$\left(\frac{\text{Dbh}}{\text{Dist.}}\right)^2$	Col. 5 X $n-\frac{1}{2}$	Col. 6 commul.	$\frac{\text{Col. 7}}{n}$	BA (sq.ft.)
1	34.3	12.0	2.858	8.168	4.084	4.084	4.084	311
2	7.0	6.5	1.077	1.160	1.740	5.824	2.912	222
3	26.1	26.5	0.985	0.970	2.425	8.249	2.750	210
-	--	--	--	--	--	--	--	--
-	--	--	--	--	--	--	--	--
-	--	--	--	--	--	--	--	--

expressed by that tree on the point. The remaining trees were much lower in basal area and more trees were needed to observe the tapering off effect.

Although it was found that a characteristic tapering off was evident, the relationship between point density (basal area) and root biomass was not clearly illustrated. Figure 3 shows how unstable the relationship between point density and root biomass is when the individual estimates of point density at the 20 sample points are plotted against the weight of roots at the same 20 points.

Because of the greater variation in total root biomass, the biomass less than 0.125 inch was also plotted. Both sets of these biomass data showed no relationship to point density.

Discussion of Field Sampling Design

Root sampling points were selected randomly in order to eliminate any bias in trying to avoid certain areas within the one-tenth acre plot. It is not meant that 171 samples is the maximum number of possible sample locations. That number, however, is the maximum for the particular design

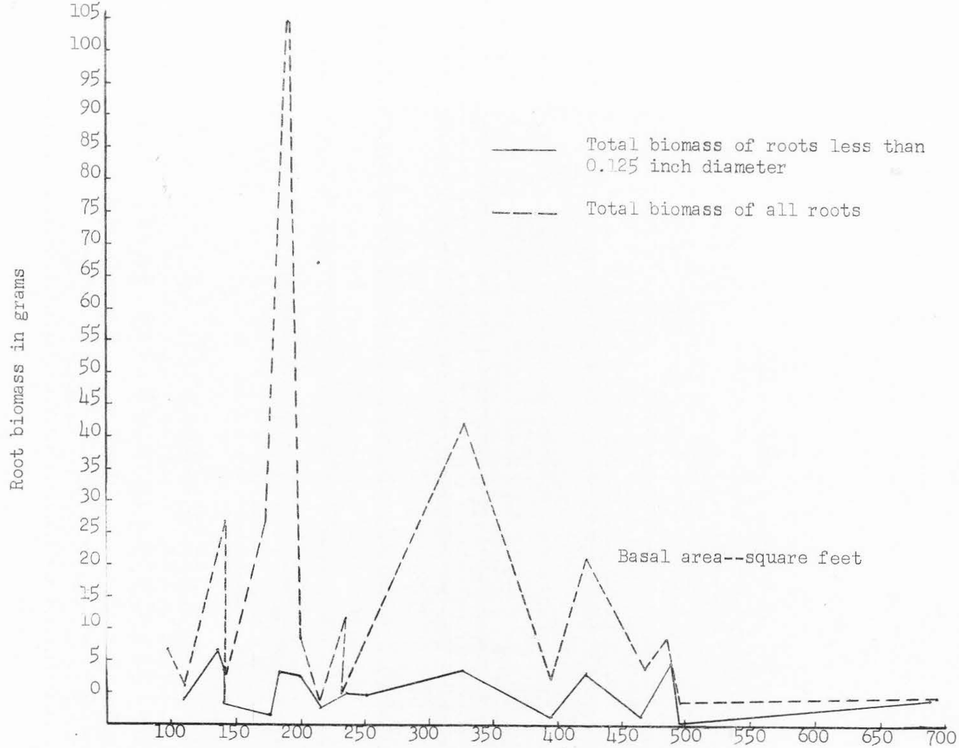

Figure 3. Relationship between root biomass and point density.

chosen. Many variations of this method, such as systematic placement of sample points along a line drawn between the paired trees, could be used if a large sample size (n) were desirable. A list of the 60 samples, the trees paired, and the number assigned to each pairing is included in Table 8 in the Appendix.

In Figure 2, it can be seen that with the pairing of trees in sampling certain areas of the plot might be excluded from sampling. This is particularly evident around tree number 11 which is the largest tree on the plot. Also the periphery of the plot is generally eliminated because of the circular shape of the plot and few trees being on this outer boundary.

Wherever the largest concentration of trees is located is where the largest number of samples is located. This will prevent a large number of samples being taken in an area where no trees are located, such as would be the case if sampling were done on a stratified areal basis. However, each tree resulted in an equal number of possible pairings regardless of its size and this resulted in many samples being taken where a larger number of smaller trees was located, and fewer samples were taken where the few large trees were located. The exclusion of an area around the base of the tree resulted in a small per cent (1.9) of the total sampling area being eliminated. This would fluctuate according to the number and size of stems per acre that are present for the species studied.

CONCLUSIONS AND RECOMMENDATIONS

Although it is difficult in preliminary studies to develop definite ideas about a particular ecosystem, many answers can be found which can add to an understanding as well as to the development of guidelines for future studies.

The variation encountered in the root biomass of this Engelmann spruce-subalpine fir association is relatively large if considered on a total basis. If the variation is analyzed according to root size however, the distribution of this variation is better understood. The large number of samples required for total root biomass, 494, is more than three times the 154 required for roots less than 0.125 inch diameter. Both of these sample numbers are at the 95 per cent confidence level plus or minus 10 per cent error. If the confidence level was dropped to 90 per cent, the number of samples required for total biomass would be reduced to 298 for total biomass; and, for roots less than 0.125 inch, the number is 93. With such large variations encountered in root biomass, future studies may be forced to accept lower than the usual 95 per cent plus or minus 10 per cent error so that the sampling task is not as large. With the variation distributed as it is, there is a need to use a different sampling procedure for the roots larger than 0.125 inch diameter.

In order to reduce loss of the fine roots, the core method appears to be the best method for extracting these roots. However, for the larger roots, particularly around the base of the tree, a different method wherein forced air or water are used to dislodge soil from roots would be more advantageously used. Stoeckeler and Kluender (1938), McMinn (1963), and Singer and Hutnik (1965) used pressurized water to excavate roots of Douglas-fir, red pine, and other plants. Because there are no large bodies of water present on the College Forest to supply water, the use of pressurized air might be the most efficient means. If this were done in late summer the soil moisture would be at a low point and clay soils could be separated from roots more easily.

Of the 11 parameters analyzed for their correlation with root biomass, five showed a slight relationship and six were found to be insignificant. The five found were $(dbh)^2$, dbh, basal area, $(basal\ area)^2$, and height. With these five parameters only two field measurements are necessary--height and dbh. Young, et al. (1964) found that height and dbh were the most important parameters in predicting root weights of seven species of Maine hardwoods and softwoods. The r^2 values found in this study were low in comparison to those of Young, et al. (1964), Baskerville (1966), and Monk (1966a, 1966b). Their r^2 values ranged between 0.50 and 0.96; however, their studies involved the removal of as much of the roots as possible by excavation. The greatest variation may be in the top 6 inches. Complete removal of entire trees results in higher r^2 values, but the disturbance is such that this method may have limited usefulness.

Total root biomass found in the top 6 inches of soil in a stand of Engelmann spruce-subalpine fir was 9822 $\pm$ 2810 pounds per acre at the 95 per cent confidence level, with the exclusion of the area around the base of the tree and all roots below the 6-inch depth. The total spruce root biomass was 4417 $\pm$ 997 pounds per acre. Spruce roots less than 0.125 inch were 2023 $\pm$ 347 pounds per acre. The total fir root biomass was 5156 $\pm$ 2687 pounds per acre. Fir roots less than 0.125 inch were only 869 $\pm$ 181 pounds per acre.

The great difference observed in the biomass of small spruce and fir roots can have competitive significance. Small roots are very important in absorbing moisture and nutrients. Because of their small size, the absorptive surface is large in comparison with the weight. Kramer (1946) found that the larger suberized roots of shortleaf pine absorb moisture but only during periods of moisture stress and slow growth of new root hairs.

Because root biomass is so variable (Figure 3) point density expressed as basal area is not sufficiently sensitive. Sixteen of the 20 sample points showed a tapering off of basal area at six or seven trees. Point density may have value in expressing ecological situations pertaining to other aspects of tree growth, but it had limited usefulness with the sampling design used in this study.

The sampling design and procedure used in this study appear to be adequate and adaptable to many forested situations. Any number of samples desired may be taken. Pairing of the trees results in the elimination of bias in the exact location of the sample so that unfavorable sampling points are included.

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APPENDIX

Table 6. List of trees on one-fourth acre plot

Tree number[a]	Species[b]	Dbh (inches)	Height (feet)	Age (years)	Basal area (sq. ft.)
11	S	34.3	108.0	320	6.414
A	F	3.1	14.0	---	0.052
B	F	---[c]	3.8	---	---
C	F	---	4.4	---	---
D	F	1.6	5.4	---	0.014
E	F	2.7	13.8	---	0.040
F	F	---	2.2	---	---
10	S	26.1	81.0	174	3.719
G	F	3.7	---	---	0.075
H	F	5.7	26.0	---	0.177
I	F	3.6	7.3	---	0.071
14	S	23.1	95.0	150	2.910
J	F	4.0	16.0	45	0.087
	F	2.4	12.0	---	0.031
K	S	1.5	6.5	---	0.012
L	F	---	2.4	---	---
12	F	7.0	23.0	59	0.267
M	S	2.9	---	---	0.046
8	F	21.1	103.0	120	2.428
9	F	15.5	99.0	81	1.310
N	F	---	2.8	---	---
O	F	3.3	6.5	---	0.059
13	F	4.0	22.0	60	0.087
2	F	13.1	69.0	52	0.936
1	F	6.3	26.0	59	0.216
P	S	2.2	---	---	0.026
Q	F	2.5	---	---	0.034
	F	1.7	---	---	0.016
16	S	17.9	80.0	130	1.748
20	S	19.0	83.0	115	1.969
21	F	12.6	63.0	45	0.866
R	F	---	3.3	---	---
27	S	21.4	87.0	131	2.498
S	F	---	4.0	---	---
T	F	---	3.5	---	---
U	F	2.2	4.6	---	0.026
V	F	---	3.1	---	---
W	F	---	4.3	---	---
X	F	---	3.4	---	---
Y	F	---	2.9	---	---
Z	F	---	2.8	---	---
A1	F	---	3.0	---	---
	F	---	1.8	---	---
B1	F	2.8	10.0	---	0.043
C1	F	---	3.1	---	---
D1	F	1.6	6.2	---	0.014

Table 6. Continued

Tree number[a]	Species[b]	Dbh (inches)	Height (feet)	Age (years)	Basal area (sq. ft.)
E1	F	1.8	5.7	---[c]	0.018
F1	F	1.2	5.4	---	0.008
26	S	7.0	25.0	49	0.267
25	S	8.4	48.0	67	0.385
G1	F	5.9	24.0	46	0.190
H1	F	8.9	47.0	---	0.432
I1	F	3.4	18.5	---	0.063
J1	F	1.0	10.0	---	0.006
32	F	5.0	20.0	39	0.136
K1	F	2.2	8.8	---	0.026
L1	F	4.4	22.0	37	0.106
M1	F	0.8	5.2	---	0.0003
N1	F	2.6	4.7	---	0.037
O1	F	2.8	6.4	---	0.043
P1	F	1.8	7.5	---	0.018
Q1	F	6.0	25.0	40	0.196
R1	F	4.2	22.0	33	0.096
S1	F	3.8	---	---	0.079
T1	F	11.1	54.0	49	0.672
U1	F	2.6	10.0	---	0.037
V1	F	3.1	13.0	---	0.052
W	F	3.6	---	---	0.071
	F	2.8	---	---	0.043
X1	F	4.9	22.0	44	0.131
Y1	F	1.3	9.1	---	0.009
19	S	12.6	69.0	96	0.866
30	S	14.9	77.0	111	1.211
Z1	F	8.5	31.0	36	0.394
A2	F	0.9	5.1	---	0.0043
B2	F	---	2.2	---	---
C2	F	---	2.8	---	---
D2	F	1.3	9.0	---	0.009
E2	S	3.9	9.0	---	0.083
F2	F	7.2	33.0	32	0.283
	F	3.0	10.0	---	0.049
G2	F	---	3.0	---	---
H2	F	2.1	9.0	---	0.024
15	F	22.1	100.0	114	2.664
I2	F	3.2	12.0	---	0.056
	F	2.4	5.6	---	0.031
J2	F	7.2	51.0	---	0.283
K2	F	---	4.3	---	---
L2	F	---	2.5	---	---
M2	F	---	4.4	---	---
N2	F	---	1.2	---	---
O2	F	3.1	20.0	---	0.052

Table 6. Continued

Tree number[a]	Species[b]	Dbh (inches)	Height (feet)	Age (years)	Basal area (sq. ft.)
P2	F	1.5	7.6	---[c]	0.012
Q2	F	4.9	19.0	43	0.131
R2	F	10.2	56.0	---	0.568
S2	F	11.5	66.0	50	0.721
T2	S	7.6	42.0	66	0.315
U2	F	7.3	39.0	---	0.219
V2	F	3.5	17.0	---	0.067
W2	F	2.6	13.0	---	0.037
--	F	2.0	---	---	0.022
22	F	12.1	60.0	67	0.799
31	F	6.0	24.0	59	0.196
23	F	24.3	82.0	144	3.221
X2	S	9.9	33.0	77	0.535
33	F	16.0	53.0	95	1.396
Y2	F	11.9	70.0	49	0.772
Z2	F	11.9	68.0	---	0.772
4	F	14.2	78.0	---	1.100
A3	F	10.7	54.0	---	0.625
5	F	17.4	76.0	---	1.651
6	F	16.6	74.0	---	1.503
B3	F	2.7	13.0	---	0.040
C3	F	2.5	8.5	---	0.034
D3	F	3.1	9.5	---	0.052
E3	F	2.3	7.5	---	0.029
F3	F	2.2	3.5	---	0.026
G3	F	3.0	8.0	---	0.049
H3	F	1.0	6.0	---	0.006
I3	F	3.1	18.0	---	0.052
--	F	3.3	15.0	---	0.059
J3	F	---	3.0	---	---
K3	F	---	2.9	---	---
L3	F	---	3.1	---	---
--	F	---	2.9	---	---
M3	F	---	3.6	---	---
--	F	---	2.8	---	---
--	F	---	4.3	---	---
--	F	1.7	7.6	---	0.016
--	F	1.6	7.4	---	0.014
--	F	---	1.7	---	0.016
--	F	---	2.1	---	0.024
--	F	---	2.9	---	0.046
N3	S	---	3.3	---	---
O3	F	---	4.0	---	---

Table 6. Continued

Tree number[a]	Species[b]	Dbh (inches)	Height (feet)	Age (years)	Basal area (sq. ft.)
--	F	---	3.4	---[c]	---
--	F	---	2.5	---	---

[a]Trees were numbered consecutively starting with the letter "A."

[b]S = spruce; F = fir.

[c]No observations were obtained for this variable.

Table 7. Sample weights in grams

Sample number	Species[a]	Biomass of roots less than 0.125 inch dia.	Biomass of other roots 0.125 inch dia. and greater	Biomass of roots
119	S	4.18	16.47	---
	F	1.17	9.89	---
	O	---	---	0.12
72	S	4.18	16.47	---
	F	1.17	9.89	---
	O	---	---	0.12
107	S	5.05	34.96	---
	F	0.55	---	---
	O	---	---	1.93
132	S	1.31	5.73	---
	F	0.11	---	---
	O	---	---	0.02
114	S	0.45	---	---
	O	--	---	0.15
139	S	0.25	---	---
	O	---	---	0.02
156	S	7.05	5.98	---
	F	0.92	---	---
	O	---	---	1.64
84	S	1.03	2.00	---
	F	0.09	33.22	---
	O	---	---	0.26
112	S	7.62	36.17	---
	F	1.18	2.10	---
	O	---	---	0.09

Table 7. Continued

Sample number	Species[a]	Biomass of roots less than 0.125 inch dia.	Biomass of other roots 0.125 inch dia. and greater	Biomass of roots
128	S	4.23	10.36	---
	F	.58	---	---
	O	---	---	0.02
75	S	9.54	3.17	---
	F	2.02	2.26	---
	O	---	---	0.54
59	S	7.71	17.82	---
	F	0.30	---	---
	O	---	---	2.64
97	S	1.86	0.53	---
	F	2.08	---	---
	O	---	---	0.01
125	S	0.44	---	---
	F	2.46	69.29	---
	O	---	---	0.01
123	S	1.88	---	---
	F	2.39	4.61	---
	O	---	---	0.05
14	S	4.96	1.56	---
	F	3.58	99.77	---
	O	---	---	0.22
2	S	3.28	6.89	---
	F	2.55	1.55	---
	O	---	---	0.05
82	S	7.95	0.53	---
	F	3.15	---	---
	O	---	---	0.42

Table 7. Continued

Sample number	Species[a]	Biomass of roots less than 0.125 inch dia.	Biomass of other roots 0.125 inch dia. and greater	Biomass of roots
127	S	15.54	0.31	---
	F	1.98	---	---
	O	---	---	0.12
160	S	8.35	---	---
	F	1.41	---	---
	O	---	---	0.32
31	S	2.01	0.64	---
	F	0.56	0.69	---
	O	---	---	---
16	S	1.45	---	---
	F	1.14	---	---
	O	---	---	0.78
58	S	0.39	0.18	---
	F	0.63	---	---
	O	---	---	0.96
21	S	4.81	---	---
	F	2.35	1.04	---
	O	---	---	0.02
166	S	0.83	6.65	---
	F	0.17	---	---
	O	---	---	0.07
120	S	0.12	0.12	---
	F	0.21	1.70	---
	O	---	---	0.13
24	S	4.33	2.07	---
	F	4.68	3.42	---
	O	---	---	0.02

Table 7. Continued

Sample number	Species[a]	Biomass of roots less than 0.125 inch dia.	Biomass of other roots 0.125 inch dia. and greater	Biomass of roots
129	S	0.90	---	---
	F	1.14	4.62	---
	O	---	---	0.20
60	S	1.20	1.77	---
	F	1.30	---	---
	O	---	---	0.55
70	S	15.51	6.57	---
	F	5.89	0.31	---
	O	---	---	0.53
39	S	9.62	3.76	---
	F	0.34	---	---
	O	---	---	0.15
67	S	4.73	---	---
	F	2.07	0.52	---
	O	---	---	0.86
53	S	0.08	6.77	---
	F	1.31	0.77	---
	O	---	---	0.22
94	S	2.67	2.49	---
	F	4.47	5.87	---
	O	---	---	0.03
116	S	6.47	---	---
	F	3.40	---	---
	O	---	---	0.04
74	S	4.61	13.79	---
	F	1.17	131.05	---
	O	---	---	0.10

Table 7. Continued

Sample number	Species[a]	Biomass of roots less than 0.125 inch dia.	Biomass of other roots 0.125 inch dia. and greater	Biomass of roots
57	S	3.81	---	---
	F	2.63	---	---
	O	---	---	0.61
13	S	0.64	---	---
	F	2.37	---	---
	O	---	---	0.03
32	S	4.92	1.55	---
	F	0.24	1.47	---
	O	---	---	0.21
105	S	3.00	0.35	---
	F	0.24	---	---
	O	---	---	1.85
159	S	3.35	---	---
	F	0.43	---	---
	O	---	---	0.02
146	S	3.78	---	---
	F	0.55	---	---
	O	---	---	0.92
56	S	3.49	---	---
	F	1.46	2.90	---
	O	---	---	2.70
140	S	2.69	0.53	---
	F	2.22	11.10	---
	O	---	---	0.68
63	S	3.80	23.78	---
	F	0.32	---	---
	O	---	---	0.21

Table 7. Continued

Sample number	Species[a]	Biomass of roots less than 0.125 inch dia.	Biomass of other roots 0.125 inch dia. and greater	Biomass of roots
158	S	5.92	2.64	---
	F	1.17	0.20	---
	O	---	---	0.28
135	S	3.01	2.88	---
	F	0.31	---	---
	O	---	---	1.85
69	S	1.65	4.98	---
	F	---	2.51	---
	O	---	---	0.02
104	S	0.28	33.31	---
	F	0.16	0.68	---
	O	---	---	0.33
96	S	0.05	3.24	---
	O	---	---	0.68
6	S	1.20	---	---
	F	0.56	84.92	---
	O	---	---	0.03
27	S	5.71	---	---
	F	7.76	0.44	---
	O	---	---	1.69
45	S	6.12	---	---
	F	5.96	---	---
	O	---	---	0.81
5	S	4.70	---	---
	F	5.84	0.89	---
	O	---	---	0.54

Table 7. Continued

Sample number	Species[a]	Biomass of roots less than 0.125 inch dia.	Biomass of other roots 0.125 inch dia. and greater	Biomass of roots
7	S	6.81	5.79	---
	F	3.71	35.10	---
	O	---	---	0.30
87	S	3.20	---	---
	F	1.90	---	---
	O	---	---	0.35
167	S	6.20	6.65	---
	F	1.80	1.10	---
	O	---	---	0.30
89	S	8.10	---	---
	F	4.00	0.15	---
	O	---	---	0.15
25	S	2.46	6.10	---
	F	2.02	1.88	---
	O	---	---	0.21
61	S	8.30	12.46	---
	F	3.19	---	---
	O	---	---	0.11

[a]E = Engelmann spruce, S = Subalpine fir, O = other

Table 8. Sample number corresponding to trees paired for location of root samples

Sample number	Trees paired
2	9-12
5	9-32
6	9-G1
7	9-31
13	9-1
14	9-26
16	9-11
21	8-G1
24	8-20
25	8-21
27	8-19
31	8-11
32	12-13
39	12-21
45	12-11
53	13-22
56	13-26
57	13-27
58	13-11
59	2-32
60	2-G1
61	2-31
63	2-20
67	2-1
69	2-27
70	2-11
72	32-31
74	32-20
75	32-21
82	G1-31
84	G1-20
87	G1-19
89	G1-26
94	31-21
96	31-19
97	31-1
104	25-19
105	25-1
107	25-27
112	20-1
114	20-27
116	21-22
119	21-26
120	21-27
123	22-1
125	22-27

Table 8. Continued

Sample number	Trees paired
127	19-1
128	19-26
129	19-27
132	1-27
135	26-11
139	K2-12
140	K2-13
146	K2-20
156	16-12
158	16-2
159	16-32
160	16-G1
166	16-19
167	16-1

DATA SUMMARY SHEET

Plot # ___ Root Biomass--Sp.___ Fir ___ Total ___

Tree #	Spec	Age	Ht.	dbh	BA	BA^2	Age X ht	Dbh x ht	Dbh^2 X ht	Age x Dbh	Ht^2	Dbh^2	
TOTALS													

Figure 4. Data summary sheet.

VITA

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Master of Science

Thesis: A Study of Root Biomass in an Engelmann Spruce-Subalpine Fir Stand in Northern Utah

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