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A SOIL-SITE STUDY OF WESTERN LARCH
(*Larix occidentalis*, Nutt) ON A
WAITS STONY LOAM SOIL

by

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INTRODUCTION

A knowledge of site productivity is an essential tool in forest management. As management becomes more intensive a need will develop for better methods of site quality prediction based on a more intimate knowledge of the growth characteristics of the crop and the site factors controlling growth. With this knowledge, decisions can be made as to the proper species, the type of stand treatment necessary, and the length of time required to produce a merchantable crop.

Height growth has been widely used as a measure of site productivity. From height growth data, a series of curves are prepared representing the growth of trees on all sites. Using these curves the height growth of any tree can be measured and compared to others by selecting the proper curve and using an index such as the height at a given age.

This approach can, however lead to considerable error in site quality prediction. Investigations involving several species have shown that height growth trends vary on different soils. When this is true, height growth curves drawn from an average curve will not represent growth on all sites.

A series of height growth curves have been developed for western larch (*Larix occidentalis* Nutt.) (Cummings, 1939). These curves were drawn from an average curve based on data from 142 plots over a wide range of sites on many different soils. More specific information is now needed about growth characteristics of western larch.

This study investigated the height growth of western larch on one soil series, Waits, in an area of relatively uniform climate, the Swan Valley. The objectives of this study were:

1. To develop a height growth curve on the Waits soil series.
2. To compare this curve to the average curve drawn by Cummings to see if a difference exists in their shapes.
3. To test by multiple regression analysis the influence of soil, physiographic, and vegetational variables on site quality for western larch.

DESCRIPTION OF STUDY AREA

Location

The study area is located in the Swan Valley of northwestern Montana, about 75 miles northeast of Missoula. It is bounded on the north by the end of the valley at Bigfork and on the south by Seeley Lake—a distance of about 75 miles. It is within the northeastern half of Missoula County and the eastern half of Lake County.

The valley is oriented in a north-south direction. The southern half is drained by the Clearwater River, a tributary of the Blackfoot River, while the northern half is drained by the Swan River, a tributary of the Flathead River. The east boundary is the precipitous west face of the Swan Mountains, while the west boundary is the gentler east face of the Mission Mountains. Elevations of the valley bottom range from 4100 feet at Seeley Lake, to a high of 5200 feet on the Clearwater-Swan divide and to a low of 3600 feet at Bigfork. Elevations of the Swan Mountains remain fairly constant for the full length of the study area, with a high of about 9800 feet. The Mission Range reaches a maximum elevation of about 10,200 feet about 30 miles north of Seeley Lake. Elevations decrease from this point until the range ends at Bigfork. The valley maintains an average width of about 10 miles for its entire length.

Climate

The only weather records maintained in the Swan Valley are those at Seeley Lake at the extreme southern end of the study area. The average annual temperature and precipitation at this station are 41.0°

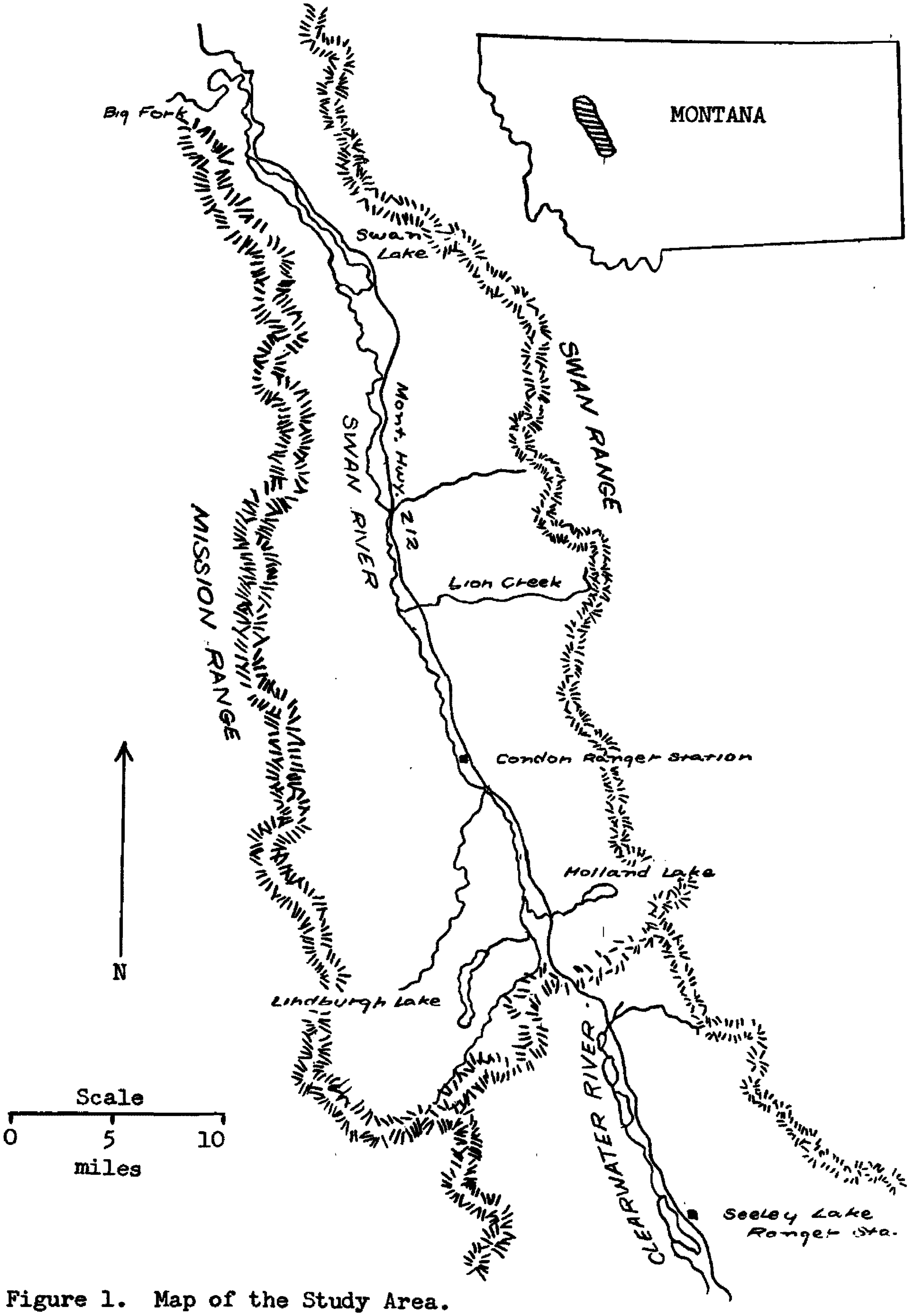

Figure 1. Map of the Study Area.

F. and 22.24 inches, respectively.

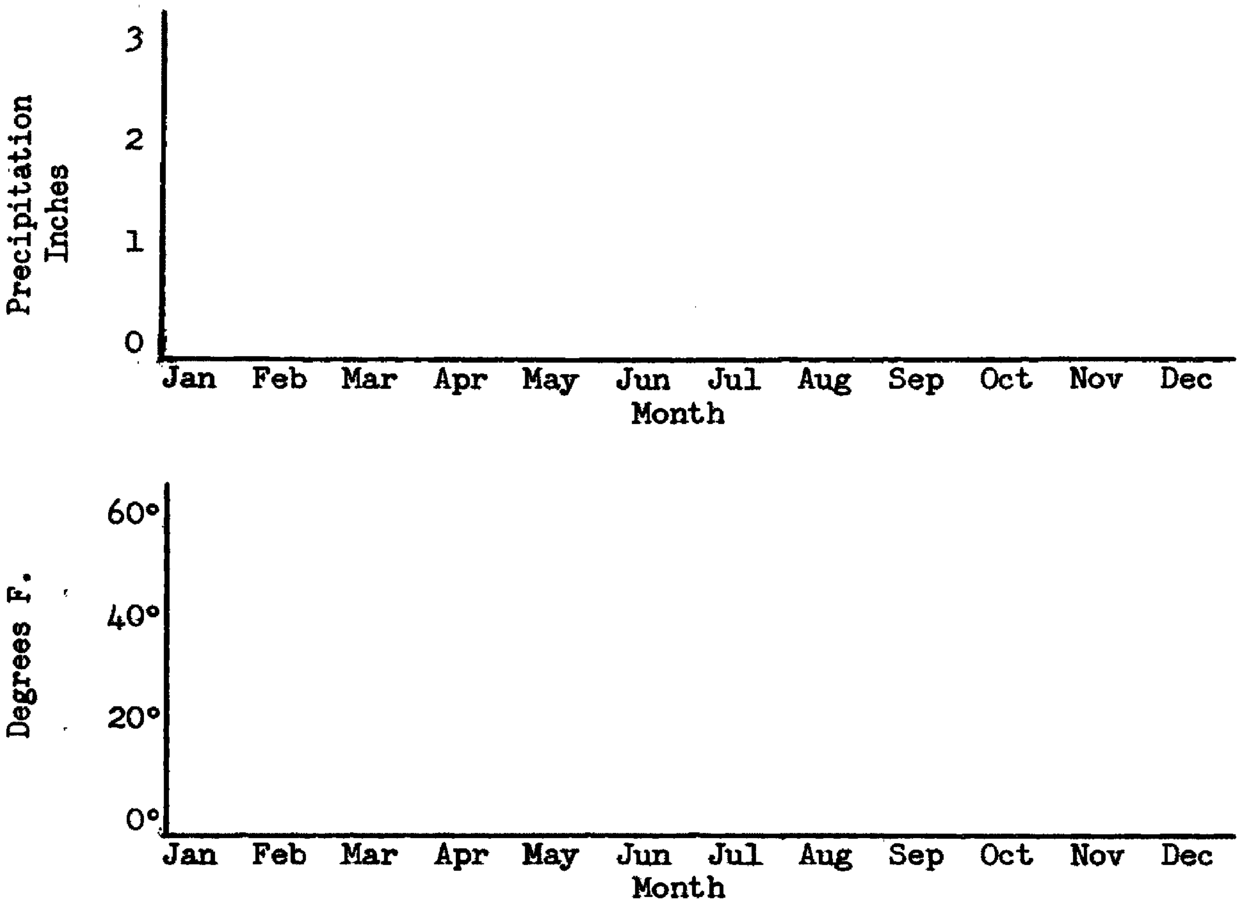

Figure 2. Mean monthly and mean annual temperatures and precipitation for Seeley Lake Ranger Station (U. S. Weather Bureau 1937-1963).

Partial records at Swan Lake for two years indicate that the northern part of the valley is slightly warmer and more mesic than the southern part.

Vegetation

Considerable variation exists in the vegetation types of the Swan Valley. In the Seeley Lake area and the valley bottom from Holland Lake to Lion Creek the Pinus ponderosa-Pseudotsuga menziesii type is predominant with an understory of Calamagrostis rubescens, Festuca idahoensis, and Symphoricarpos alba. Throughout the rest of the valley bottom up to an elevation of about 5500 feet the Larix occidentalis-Pseudotsuga menziesii type occurs with an understory of Xerophyllum terax, Vaccinium spp., and Pachistana myrsinites. Intermixed with this type are the Pinus contorta type occupying burned-over areas and the Thuja occidentalis-Abies amabilis type in the moist drainage bottoms of the northern part of the valley. Above 5500 feet the subalpine forests of subalpine fir, Engleman spruce and lodgepole pine are found.

Western larch occurs in all types except the subalpine but reaches its greatest importance when associated with Douglas-fir (Pseudotsuga menziesii) and lodgepole pine (Pinus contorta). The most extensive stands occur as even-aged mixtures of larch and lodgepole pine that have developed on old burns.

Geology

The Swan Valley was formed as a result of the uplift of the Mission and Swan Ranges which are composed of rocks of the belt series. Argillites and quartzites predominate on the east slope of the Mission Range while the west slope of the Swans is almost entirely impure argillitic limestone.

The valley was extensively glaciated during the Wisconsin Age by mountain glaciers. The entire valley was filled with ice to a depth of about 1,000 feet (Alden, 1953). Most of the glaciation originated on the gentler east slopes of the Mission Range and flowed north and south from the Clearwater-Swan divide.

As a result of glaciation the valley is filled with a mantle of till. In some areas the till is shallow and is underlain by clays that are possibly the result of glacial lakes. Ice movement appears to have been greater north of the Clearwater-Swan divide where the glacial features are more pronounced. South of the divide, more evidence of reworking by water is present in the tills and landforms.

Soils

The soils of the Swan Valley are mainly Grey Woodeds and Brown Podsolics formed over the till mantle. The study series, Waits, is a field identification of an established series. It is a bisequa Brown Podsolic over a Grey Wooded soil formed in quartzite and argillite till with subrounded coarse fragments up to 4 feet in diameter. A typical soil profile is as follows:

Soil Profile: Waits Stony Loam

O_1	2-0"	Leaf litter and organic mat.
A_2	0-¼"	Grey; discontinuous.
Bir	¼-10"	Light yellowish brown (10YR 6/4) loam; 10YR 5/6 moist; very weak, fine, subangular blocky structure; very friable, fluffy, nonsticky and nonplastic; about 20% coarse fragments; pH 6.0; abrupt, wavy boundary.
II A_2	10-16"	Light grey (7.5YR 7/2) gravelly silt loam; 7.5YR 6/2 moist; weak, medium subangular blocky; brittle, hard, nonsticky and nonplastic; about 45% coarse fragments; pH 5.5; clear boundary.
II A_2B_2	16-30"	Pinkish grey (7.5YR 7/2) gravelly silt loam; 7.5YR 5/4 moist; brittle, hard, nonsticky and nonplastic; few thin, discontinuous pores; about

45% coarse fragments; pH 5.5; gradual boundary.

II B_2A_2 30-60+" Brown (7.5YR 6/2) gravelly silty clay loam; 7.5YR 5/4 moist; weak, medium subangular blocky; brittle, hard, slightly sticky and slightly plastic; many thin discontinuous clay films; many large discontinuous pores; about 45% coarse fragments; pH 5.5.

Variation in the Waits series in the study area lies mostly in the depth and texture of the various horizons. The Bir varies from 8 to 14 inches in thickness. Moist colors range from 7.5YR 5/3 to 10YR 6/3. The II A_2 may or may not be present. The lower horizons vary in sequence but are always composed of A_2 and B_2. They commonly contain clay pockets and bands. Silt and clay films vary from very few and fine to many and moderately thick, particularly on top of coarse fragments. Clean gravels generally occur below the coarse fragments. Hues range from 5YR to 10YR depending on the color of the parent material. In some profiles a B_2t horizon is found below 48 inches. Textures range from gravelly clay loams to very gravelly sandy loams. In profiles formed in very gravelly sandy loams there is generally no evidence of development below 50 inches. The percentage of coarse fragments in the profile varied from 30 to 85 per cent.

The Waits soil series as described in the Swan Valley appears to differ somewhat from profile descriptions in other areas. While the horizon sequence is similar, the Waits series as described by Carlson (1964) in western Sanders County has heavier textures and more clay bridging.[1] Also, this soil was formed in outwash material rather than till. The Soil Conservation Service (1960) described a Waits profile just north of the study area as being a Bir over a C horizon. However, the description of the C horizons is similar to the A_2-A_2B_2 sequences described in this study. Apparently the difference is that more recent descriptions have noted development to a much greater depth.

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[1] Nimlos, T. J. 1965. Personal communication.

LITERATURE REVIEW

Site Factor-Quality Relationships

Site factor-tree growth relationship studies have been extremely popular. The results of at least 65 studies of the soil-site relationships for various tree species throughout the United States have been published in the last 30 years (Della-Blianca and Olsen, 1961). These studies indicate that over large areas and between different species the relationship between site factor-tree growth is not constant. Coile (1952) has presented a comprehensive review of the factors of site and their effects on tree growth throughout the United States.

Soil Chemical Properties

Correlations between the soil's chemical characteristics and site productivity are wanting in the literature. Tarrant (1949) found nutrient levels too high in the soils of western Washington to be a limiting factor in the growth of Douglas-fir. Auten (1945a, 1945b) could not find any significant correlation between site index for yellow poplar (Liriodendron tulipifera) and black oak (Quercus velutina) and the calcium, magnesium, and potassium content of the soil. Holmes (1960) found a correlation between total nitrogen and height growth of lodgepole pine but it was minor compared to the physical properties influencing soil moisture. Coile (1948) recognized that chemical properties affect site productivity but were generally not as limiting as the physical characteristics. Voigt (1958) points out that in soils the same factors that regulate, or are related to, the availability of nutrients are often the same as those that govern the availability of water. Therefore, in some cases, growth responses attributed to one variable may be the result of several other variables.

Failure to show relationships between soil chemical properties and site productivity has been attributed to similar levels of fertility (Voigt, 1958). Some variation of the variable in question is certainly necessary in order to obtain significant results. Spatial variability of the soil under forest stands may also account for some of the confusion in interpreting chemical data (Klemmedson and Murray, 1963). Zinke (1962) and Zinke and Crocker (1962) have shown the magnitude of the variation of soil properties under forest stands to be large. Where soils are variable, close attention to the spatial distribution of soil properties is a must in sampling for a functional analysis of sites (Klemmedson, 1959).

An inability to measure the nutrient supplying capacity of the soil may be responsible for much of the failure to correlate chemical data to site productivity (Klemmedson and Murray, 1963). While some correlations have been found using total or exchangeable amounts, the results have been only fair and methods of determining the available nutrients need to be developed.

Soil Physical Properties

Correlations of tree growth to the physical properties of the soil have generally met with greater success than those with soil chemical properties. These factors are generally indexes of soil water availability. Coile (1948) states, "It has been fairly well established that physical soil properties which allow for rapid infiltration and good water storage and low evaporation loss are associated with good forest sites." White (1958) maintains that available water is the key factor in forest site evaluation and that most site classification schemes are attempts to characterize indirectly the soil moisture regime.

Soil texture was important in determining site quality for Douglas-fir in western Washington (Gessel and Lloyd, 1950) and ponderosa pine in eastern Washington (Holtby, 1947). Depth of the surface horizon has been correlated to site index for loblolly pine (*Pinus taeda*) (Coile, 1948; Coile and Schumacher, 1953; Gaizer, 1950), shortleaf pine (*Pinus echinata*) (Coile, 1935), white oak (*Quercus alba*) (Gaizer, 1951), eastern white pine (*Pinus strobus*) and red spruce (*Picea rubens*) (Young, 1954), and yellow poplar (Auten, 1945a). Depth to an impermeable layer, such as clay pan or bedrock, appears to be extremely important and has been correlated to Douglas-fir (Hill *et al.*, 1948; Schlots *et al.*, 1956; Lemmon, 1955; Zinke, 1959), western white pine (*Pinus monticola*) (Coupland, 1958), loblolly pine (Gaizer, 1950), longleaf pine (*Pinus palustris*) (McLurkin, 1953), ponderosa pine (Cox *et al.*, 1960; Zinke, 1959), lodgepole pine (Holmes and Tackle, 1962), black walnut (*Juglans nigra*) (Hansen and McCoumb, 1958), yellow poplar (Auten, 1945b) site quality. Carlson (1964) suggests that depth to the first heavy-textured horizon may influence site productivity for western larch and other conifers by holding excess water in the zone of root activity. Other authors have correlated such physical properties as imbibitional value of the surface horizon (Young, 1954; Coile, 1952), the presence of mottling (Auten, 1945b;

Hansen and McCoumb, 1958) and the depth of the litter layer (Godman and Gregory, 1953) to site quality.

Physiography

Physiography has been the factor most frequently used in site quality studies, presumably because of the widespread knowledge of its influence on climate and soil formation (Klemmedson and Murray, 1963). However, as the above statement implies, it is mainly an indirect factor which expresses the more difficultly measured microclimate and care must be taken in interpreting results from climatic data. While a truer picture of the effect of site factors on productivity could be obtained by quantifying the microenvironment, the procedure would be considerably more difficult (Jackson, 1962).

Some investigators have found that as slope gradient increases, site productivity declines (Meyers and Van Deusen, 1960; Einsphar and McCoumb, 1958; Zahner, 1958; Lemmon, 1955), while others have found the relationship not statistically significant (Gaizer, 1951, Hill _et al_., 1958). Site index generally decreases with increased distance upslope (Meyers and Van Deusen, 1960; Einsphar and McCoumb, 1958; Doolittle, 1957). Some writers, however, have recognized that quite often physical soil factors, especially depth, are confounded with topographic position (Coile, 1948; Jackson, 1962). Zinke (1958) found slope position to be significant when considered by itself but not significant when the other variables were held at their means. Meyers and Van Deusen (1960) found that slope position alone accounted for 46 per cent of the total variation in ponderosa pine site index, but due to the correlation between soil depth and slope position, it accounted for only an additional 7 per cent of the total variation. Aspect was significant in determining the site index for Douglas-fir in western Washington (Hill et al., 1948) and oaks (Einspahr and McCoumb, 1951), but not significant for slash pine (Pinus caribaea) (Jackson, 1962) or Douglas-fir (Lemmon, 1955) in the Willamette Basin of Oregon. Site index decreased with increasing elevation for Douglas-fir (Lemmon, 1955; Hill et al., 1949; Carmean, 1954).

Climate

Little use of climatic data has been made in site productivity studies because records are generally not reliable or available. Where adequate records are available the results are generally good. McClurkin (1953) found precipitation during the first six months of the year correlated to the height growth of longleaf pine more than any soil variable. The interaction of precipitation and depth to the least permeable horizon, and the average diurnal range of temperature from March to June were correlated to the annual increment in height of slash pine (Jackson, 1962). Annual precipitation has been correlated to Douglas-fir site productivity (Hill et al., 1949; Carmean, 1954).

Stand Factors

Considerable attention has been given in the literature to the effect of stocking on height growth with several different results being reported. Holmes (1960) has reviewed the literature thoroughly and concluded that:

1. Root competition on poor sites and under conditions of dense stocking may retard height growth of trees.
2. Height-density relations vary by species and age.

3. The ability to express dominance varies by species.
4. Pretreatment density and time can affect the relation of density to height after treatment.
5. No generalization applicable to all species, age classes, and sites can be formulated.

Methods of Predicting Site Quality

Vegetational Composition

Site productivity can be predicted on a qualitative basis from species composition. Proponents of this system argue that vegetation is the product of the total site and should provide a better basis of classification than isolated site factors. Cajander developed the system in the early 1900's and much of the current work in this area has been a natural outgrowth (Westveld, 1954). Rowe (1956) has presented a classification of sites in the boreal forests of Manitoba and Saskatchewan on the basis of moisture regimes using understory vegetation. Daubenmire (1961) recently found that habitat types could be used to predict height-growth of ponderosa pine, while Gagnon and McArthur (1959) classified white spruce (*Picea glauca*) sites on the basis of ground vegetation even after agricultural cropping.

The system is best applied to the less complex communities of the northern forests (Doolittle, 1963). In the southern forests, the practice of using the presence or absence of a few species of narrow ecologic amplitude has not been possible. Hodgkins (1960) considered this and developed a system for evaluation of longleaf pine sites based on the relative dominance of a large number of species. The system, however, still has its drawbacks in that it is a qualitative assessment of site quality which is only indirectly related to actual production (Coile, 1959). In addition, the use of indicator species may be difficult in those areas where cropping, fire, or grazing have disturbed the sites (Doolittle, 1963).

Soil Series-Site Relations

Many investigations have predicted site quality on the basis of soil series or related soil groups. Most of these studies have been conducted in the east because soil survey work is much further advanced. Results have differed considerably, with good correlations found for some soils and species (Van Eck and Whiteside, 1959; Broadfoot and Krinard, 1959; Broadfoot, 1960; Carlson, 1964; Hill _et al_., 1948; Doolittle, 1957; Gessel, 1949; Gessel and Lloyd, 1950; Schlots _et al_., 1956) and poor correlations for others (Zinke, 1959; Lemmon, 1955). In most cases where a correlation was found, it was on groups of related soil series and even then some investigators warned that considerable variation may exist on a single group of soils. The predictability of site productivity on the basis of soil series appears to be related to the growth characteristics of the species, the environmental variation encountered on the series, and the nature of the soil series (Carlson, 1964).

Stand Parameters

The use of a height-age relationship to express site quality was first proposed in the early 1900's (Rith, 1916; Watson, 1917; Frothingham, 1918). It is simple, relatively independent of stand factors, and represents a measure of productivity for the individual species. The value of height growth has been argued but has been widely accepted and used. Studies since then have shown that it is not always independent of density and other stand factors (Holmes, 1960). Although it should not be regarded as a cure-all, it is probably the best single measure of site (Spurr, 1952; Vincent, 1961).

Height is usually expressed as average dominant or dominant and codominant heights. Recent work, however, points out that generally dominant height is more satisfactory (Ker, 1952; Spurr, 1952). It is generally easier to classify and measure dominants and they are less likely to drop out of a stand as it ages.

Volume growth has been proposed as a measure of site quality (Bates, 1918; Mader, 1963; Sammi, 1965) because it is more closely tied to the productive capacity in terms of value. It is difficult to measure and subject to variation with stand density and utilization standards. While volume growth expressed in terms of mean annual yield for normally stocked stands at the culmination of growth has long been considered the ideal measure of site, it is rarely used in North America because of these disadvantages (Spurr, 1952).

Construction of Height/Age Curves

Several methods have been used in the construction of height/age growth curves. Perhaps the oldest and most widely used is the anamorphic curve method developed by Bruce (1926). With this method the heights and ages from a series of plots covering the range of sites and ages are plotted and a curve fitted to the distribution by trial and error. A family of anamorphic or proportional curves is drawn from the average curve to represent growth on all sites. The "average" curve can be developed by a regression analysis of some transformation of height and age that will give a curve of the proper shape.

Several sources of error are inherent in this method. The pronounced vertical dispersion of the data, which covers the entire range of sites, does not define the relationship well (Curtis, 1964). An assumption is made that the distribution of site index is independent of the age of stands sampled. The most serious weakness is the assumption that the shape of the curve is the same for all sites. Several studies have shown that this is not always true. Spurr (1955), in comparing permanent growth plot records to standard site index curves, found that three groups of data had different trends and all deviated from the standard curves. Carmean (1956), working in the Douglas-fir type of the Pacific Northwest, and Zahner (1962), working with loblolly pine, found that the regression equations for height growth on different soil groups differed significantly.

Other methods of height-growth curve construction are based on the development of individual tree or plot curves. Permanent growth plots provide the best method but require long periods of measurement (Spurr, 1956). The growth intercept method, where the height growth for successive five or ten year periods is obtained by measuring the distance between branch whorls, is of use chiefly in young stands and plantations where the whorls are easily distinguishable. The technique has been used by Ferree, *et al*. (1958) and Van Eck and Whiteside (1963) in developing anamorphic and polymorphic or nonproportional curves, respectively, based on soil series for red pine (*Pinus resinosa*) plantations.

Stem analysis, where trees are sectioned and ages determined at given heights, has been used rather widely in recent years. Anamorphic curves have been developed by stem analysis for red alder (Alnus rubra) (Bishop et al., 1958), even-aged northern hardwoods (Curtis and Boyd, 1962) and lodgepole pine (Lemmon et al., 1955). Polymorphic curves have been developed (Stage, 1963) for grand fir by diameter growth classes and sugar maple by soil series (Farnsworth and Leaf, 1965). Stem analysis has been used by Foster (1959) to compare growth curves for white pine and red maple on the same site.

The methods based on individual growth curves for trees or plots generally give better results than height/age determinations. These methods are free of any bias due to an association of age and site quality. It should also be easier to combine the data into groups of polymorphic curves and identify site properties which materially affect the characteristics of the curve (Curtis, 1964). They are not without limitations, however, and Bruce (1926) rejected stem analysis on the basis that the present dominants may not be representative of past dominants. Although this point may well be valid, the possible error introduced appears to be minor when compared to those associated with the conventional height over age method (Curtis, 1964). Dahms (1963) has developed a method to reduce this error by sectioning a number of trees and using the tallest tree at any given stand age. Also, with stem analysis data, the independent variable is height rather than the true, biologically independent variable, age (Curtis, 1964).

Growth of Western Larch

Two soil site studies have been made in the western larch type. Embry (1960), in studying the type throughout its range in western Montana, measured the following variables on 45 plots:

A. Soil variables

1. Total depth to parent material
2. Effective soil depth (total depth corrected for volume of coarse fragments)
3. Depth of rooting
4. Silt plus clay in the B horizon
5. Clay in the B horizon
6. Available moisture in the effective depth
7. Organic matter in the B horizon

B. Physiographic variables

1. Elevation
2. Average slope
3. Aspect

C. Stand variables

1. Reciprocal of stand age
2. Stand density

The final equation developed by regression methods for the prediction of growth on the 45 plots was: $Y = 2.187 - 14.669X_1 - 0.0000522X_2 + 0.0000577X_3 + 0.17546X_{11} + 0.11293X_{12}$ in which Y is the logarithm of height and X_1, X_2, X_3, X_{11}, X_{12} are, respectively, the reciprocal of age, density in stems per acre, elevation, the product of effective depth and the reciprocal of age, and the product of available moisture and the reciprocal of age. The equation yielded a multiple correlation coefficient of .92 which was significant at the 99 per cent level. By holding four of the variables constant at their means and varying the fifth, Embry found that:

1. Height growth varies inversely with stand density.
2. Height growth varies inversely with elevation.
3. Height growth varies directly with effective soil depth.

Carlson (1964) studied the relationships between site index and soil series for five tree species, including western larch, on five soil series in the Clark Fork River Valley of northwestern Montana. Significant differences in site index between soil series could not always be found. However, those soils on which there was no significant difference generally coincided with the soil associations as mapped in that area by the Soil Conservation Service. The mean site index for western larch on the Waits soil series was 63.

Roe (1965) found that site index for western larch differed significantly between Daubenmire's ecological habitat types. The lowest site indexes were found in the *Picea-Abies/xerophyllum* type while the highest were in the *Thuja-Tsuga/Pachistima*, *Thuja/Pachistima* and *Abies grandis/Pachistima* types. A covariance analysis of the data suggested that height growth curves may possibly have different slopes and shapes by individual habitat types.

One other study has yielded some limited information on the growth of western larch. Brewster (1918) found that the annual increment in the height growth of saplings was greatest when the three weather factors of adequate and well distributed rainfall, little cloud cover and high mean monthly temperature were combined.

METHODS

Plot Selection

The first criterion in the selection of plots was that the stands must be at least 50 per cent larch and on Waits soil. The second criterion required that the plots be located in areas of uniform physiographic features and suitable stand density. No plots were located on areas of obvious disturbance within the life of the stand nor were diseased stands included. Only upland stands away from depressions were used.

One plot was located within each stand sampled. A stand as defined in this study consists of any area of homogeneous vegetation and soils. Therefore, in some instances, two or more plots were located in close proximity under the same vegetation type and age class but on different physiographic sites. Such locations gave a test of the effect of physiographic site on site index.

Thirty plots were sampled, representing age classes from 30 to 200 years. Although the stem analysis method gave all points on height-growth curves up to the total age of the stand, younger stands were also sampled to give a better control on stand density at the younger ages. In the older age classes, only present density could be measured, the assumption being that the density-growth curve approximated the height-growth curve in form so that the stand remained within acceptable density limits throughout its life.

Stand Measurements

Site index was measured by stem analysis on the five dominant trees closest to plot center. Each sample tree was felled and a disc cut at the stump and 10-foot height intervals from the ground level. Each disc was marked with the tree number, plot number, and height in tree. Annual ring counts on all discs were made in the laboratory under a dissecting scope or magnifying glass. Tree age at any given height was determined by subtracting the number of annual rings at that height from the total age of the tree. An additional sample for each tree was added by using the total height and total age.

Stand density was measured as basal area per acre at d.b.h.[1] and stems per acre. The d.b.h. was measured to the nearest inch on all trees taller than 4½ feet on a one-tenth acre circular plot in stands where the average dominants were 11 inches or less in d.b.h. and on a one-fifth acre circular plot in stands with larger average dominants. Density was recorded by species and 1-inch diameter class.

Soil Measurements

A soil profile was described on each plot according to standard procedures (Soil Conservation Service, 1951) to a depth of 5 feet. Notations of depth, color, texture, structure, consistence, clay films, roots, pores, volume of coarse fragments and boundary were made for each horizon.

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[1] Abbreviation for diameter breast height; the diameter of a tree 4.5 feet above average ground level.

A sample of each horizon was collected and marked with plot number, location, horizon and depth. The samples were sieved through a two millimeter screen and the fine material stored in quart Mason jars. The jars were randomized and numbered consecutively. Throughout the analysis these numbers were used to identify the samples rather than horizon and plot numbers, so that in no case would all of the samples from a single profile be analyzed at once. pH (thin paste method), per cent silt and clay (modified Bouycouos method), and the 15 atmosphere wilting point (pressure membrane apparatus method) were determined for each sample according to standard procedures (Nimlos, 1961). All soils information was recorded on a modification of the standard Soil Conservation Service soil description form.

Physiography

Elevation, aspect, slope gradient, and slope position were determined for each plot. Elevation was determined to the nearest 25 feet with a Thommen pocket altimeter which had been periodically checked against known elevations at either Seeley Lake Ranger Station, Condon Ranger Station, or the Clearwater-Swan River divide. The azimuth of exposure was recorded to the nearest 5 degrees using a hand compass while slope gradient to the nearest per cent was measured with an Abney level. All plots were classified by their position on slope in relation to local topography into one of the three classes: top, middle or bottom. General notes describing the landform and topography were also made.

Understory Vegetation

The understory vegetation on each plot was sampled by recording species presence in ten 50 by 100 centimeter quadrats. Two lines of three plots each were placed parallel to the slope 25 feet on either side of plot center. A third line of four quadrats was placed in the same direction through plot center. Since ten quadrats were used, the total number of quadrats in which a species occurred was equal to its simple frequency in ten per cent classes.

RESULTS AND DISCUSSION

Development of the Growth Curve

The ages at each height in the five trees were averaged for each plot and a regression equation was developed for the height over age relationships using these plot values. The analysis was one on an IBM 1620 computer at the University of Montana Computer Center using a program which would yield regression equations of all combinations of independent variables. Seven transformations of age (age, age^2, age^3, $\log_{10}$ age, 1/age, $(1/\text{age})^2$, $(\text{age}-20)^3$) were entered as independent variables with the dependent variables of height and logarithm of height. Site index (dominant tree height at 50 years age) and logarithm of site index were also entered as independent variables so that individual site curves could be developed.

No combination of more than four independent variables was considered. Of those with less than four variables, 15 were selected on the basis of their low residual sums of squares and plotted. The final four equations used were selected by inspection because all of the equations had similar residual sum of squares. These curves are presented in Figures 3 to 7.

Cummings' (1939) height and age data were analyzed using the same program and transformations so that the two sets of data would be comparable. Both sets were combined and an average regression run to obtain a total sum of squares. Differences in the b coefficients for the two sets of data were tested by comparison to the average regression with a covariance analysis (see Snedacor, 1946).

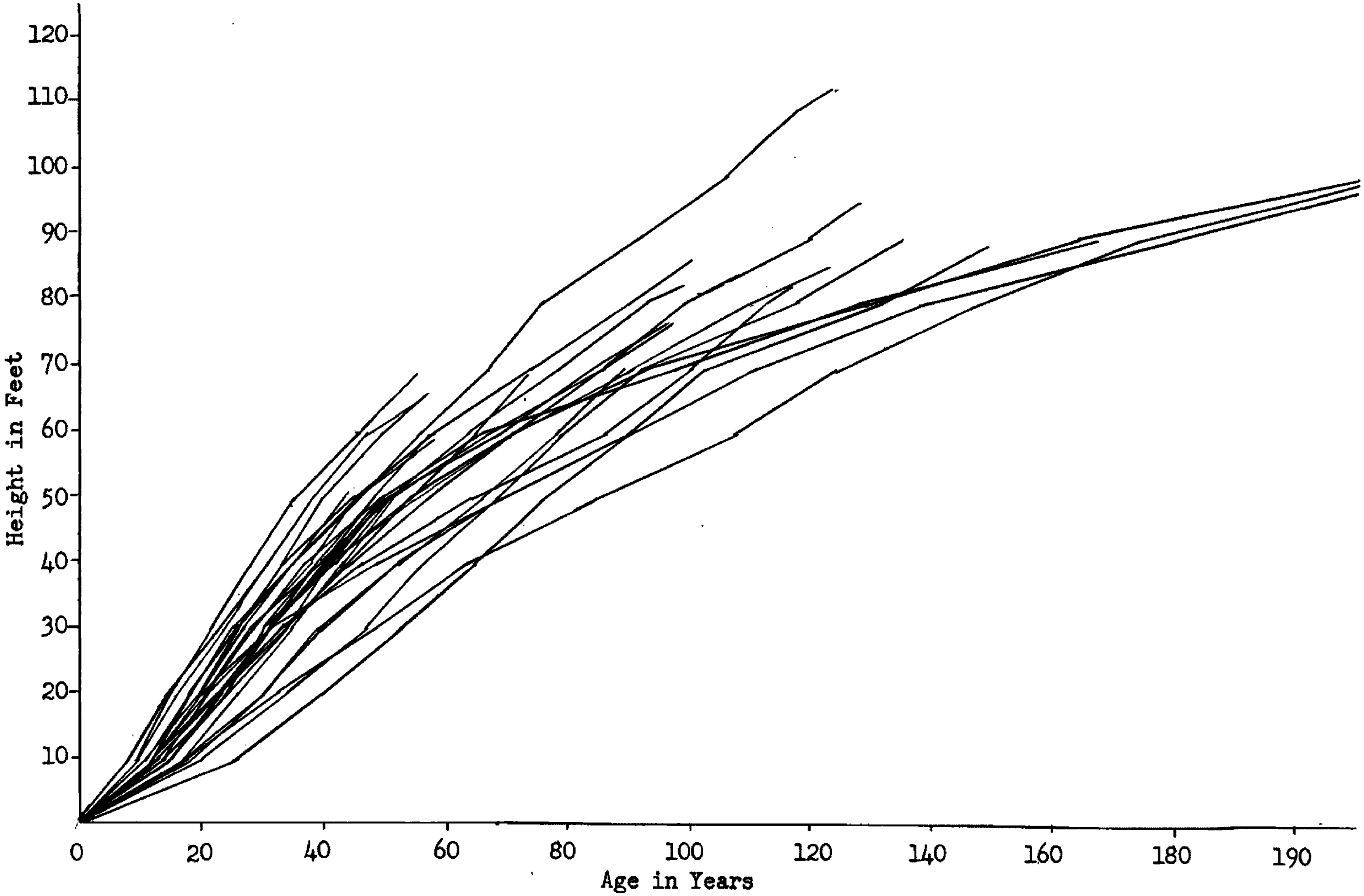
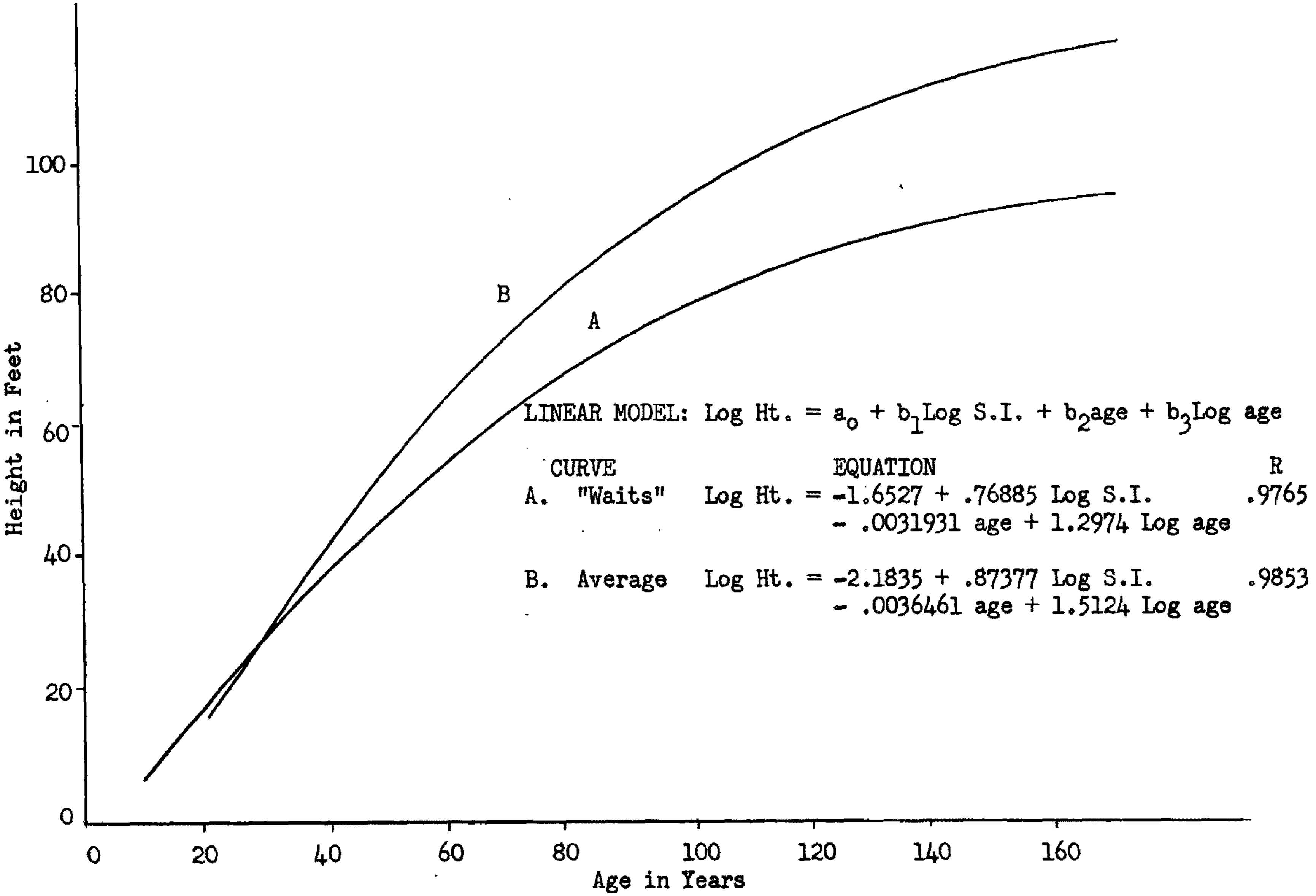


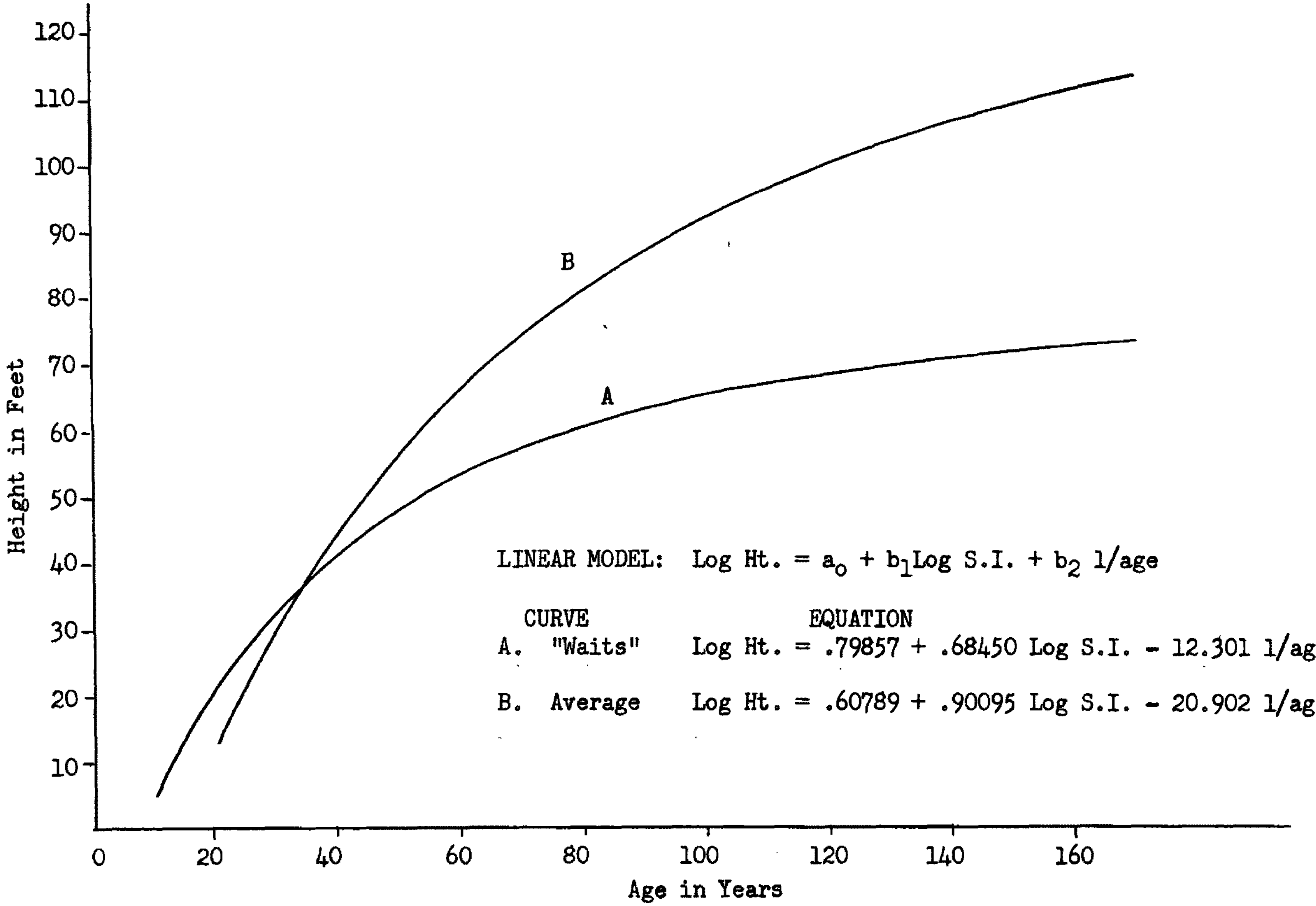
Figure 3. Individual plot height growth curves.



LINEAR MODEL: Log Ht. = a_0 + b_1Log S.I. + $b_2$age + b_3Log age

CURVE		EQUATION	R
A.	"Waits"	Log Ht. = -1.6527 + .76885 Log S.I. - .0031931 age + 1.2974 Log age	.9765
B.	Average	Log Ht. = -2.1835 + .87377 Log S.I. - .0036461 age + 1.5124 Log age	.9853

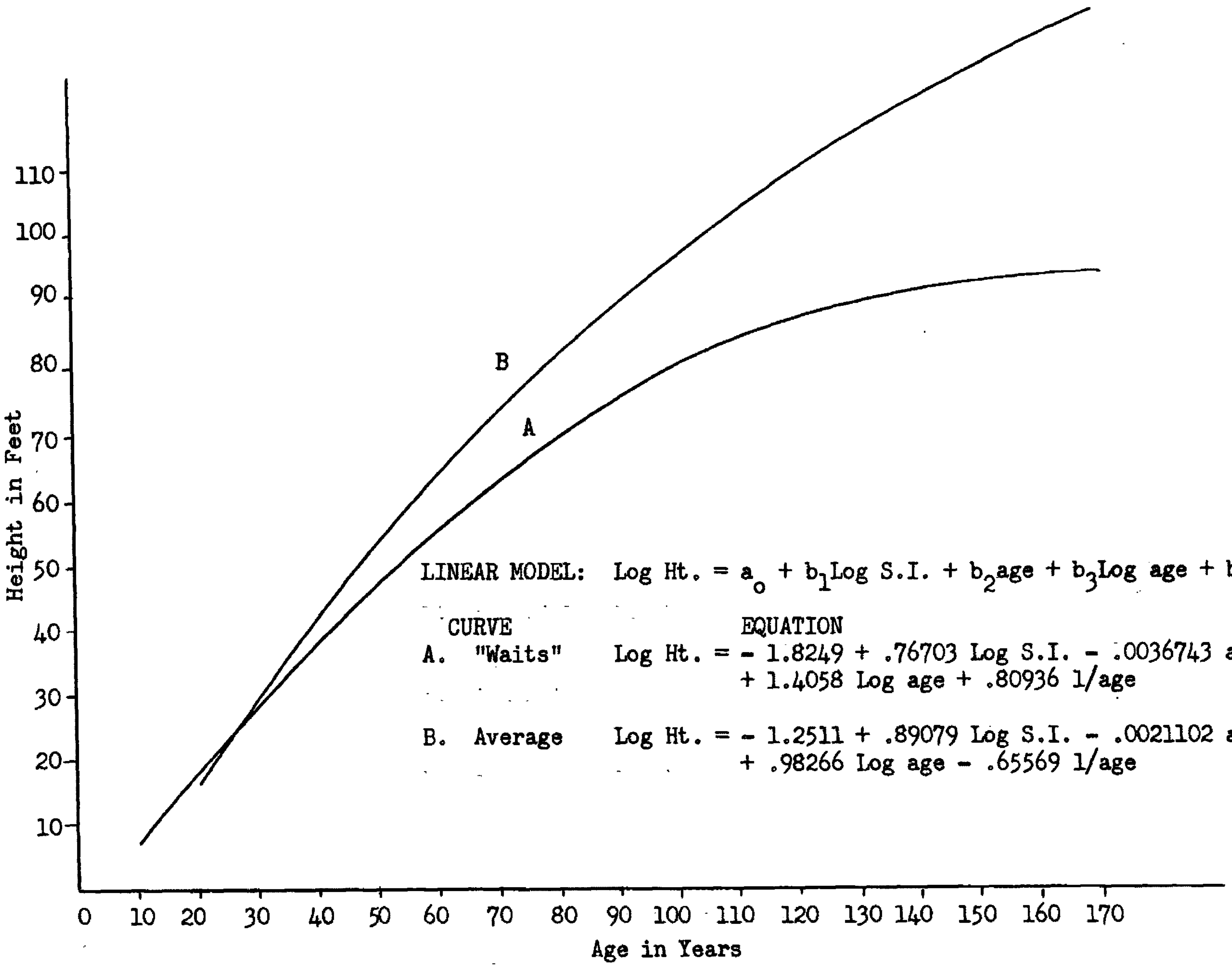
Figure 4. Height growth curves for Waits soil series and average site, as defined by Cummings using log height and 1/age transformations.



LINEAR MODEL: $\text{Log Ht.} = a_0 + b_1 \text{Log S.I.} + b_2 \text{ 1/age}$

CURVE		EQUATION	R
A.	"Waits"	Log Ht. = .79857 + .68450 Log S.I. - 12.301 1/age	.9426
B.	Average	Log Ht. = .60789 + .90095 Log S.I. - 20.902 1/age	.9853

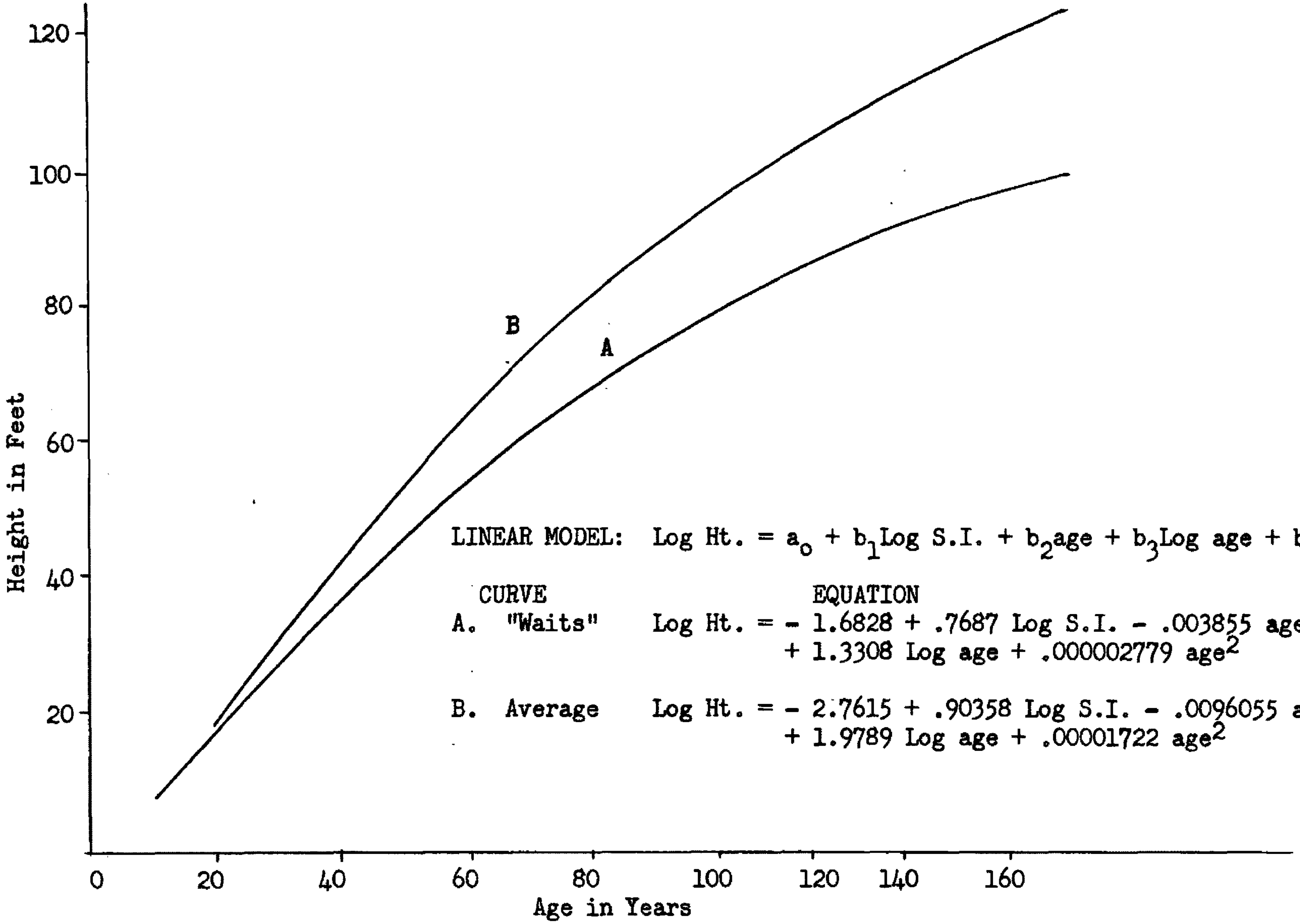
Figure 5. Height growth curves for Waits soil series and average site, as defined by Cummings using log height and log age transformations.



LINEAR MODEL: $\text{Log Ht.} = a_0 + b_1 \text{Log S.I.} + b_2 \text{age} + b_3 \text{Log age} + b_4 \, 1/\text{age}$

CURVE		EQUATION	R
A.	"Waits"	Log Ht. = $- 1.8249 + .76703$ Log S.I. $- .0036743$ age $+ 1.4058$ Log age $+ .80936$ 1/age	.9765
B.	Average	Log Ht. = $- 1.2511 + .89079$ Log S.I. $- .0021102$ age $+ .98266$ Log age $- .65569$ 1/age	.9963

Figure 6. Height growth curves for Waits soil series and average site, as defined by Cummings using log height, log age, and 1/age transformations.



LINEAR MODEL: $\text{Log Ht.} = a_o + b_1\text{Log S.I.} + b_2\text{age} + b_3\text{Log age} + b_4\text{age}^2$

CURVE	EQUATION	R
A. "Waits"	$\text{Log Ht.} = -1.6828 + .7687\ \text{Log S.I.} - .003855\ \text{age} + 1.3308\ \text{Log age} + .000002779\ \text{age}^2$	.9765
B. Average	$\text{Log Ht.} = -2.7615 + .90358\ \text{Log S.I.} - .0096055\ \text{age} + 1.9789\ \text{Log age} + .00001722\ \text{age}^2$	.9969

Figure 7. Height growth curves for Waits soil series and average site, as defined by Cummings using log height, log age and age^2 transformations.

TABLE I

SUMMARY OF COVARIANCE ANALYSIS BETWEEN AVERAGE AND "WAITS" SITE CURVES

Transformation: $\text{Log ht.} = A_o + b_1 \text{ Log S.I.} + b_2 \text{ 1/age}$

Category	D.F.	Resid. S.S.	M.S.	F ratio
Average regression	356	2.9537		
Sum of indiv. regressions	353	2.2587	0.00639	
Differences	3	0.6950	0.23160	36.24**

Transformation: $\text{Log ht.} = A_o + b_1 \text{ Log S.I.} + b_2 \text{ age} + b_3 \text{ Log age}$

Category	D.F.	Resid. S.S.	M.S.	F ratio
Average regression	355	0.99687		
Sum of indiv. regressions	351	0.92720	0.002641	
Differences	4	0.06967	0.017417	6.594**

Transformation: $\text{Log ht.} = A_o+b_1\text{Log SI}+b_2\text{age}+b_3\text{Log age}+b_4\text{1/age}$

Category	D.F.	Resid. S.S.	M.S.	F ratio
Average regression	354	0.99513		
Sum of indiv. regressions	349	0.91439	0.002620	
Differences	5	0.08074	0.016148	6.163**

Transformation: $\text{Log ht.} = A_o+b_1\text{Log S.I.}+b_2\text{age}+b_3\text{Log age} + b_4\text{age}^2$

Category	D.F.	Resid. S.S.	M.S.	F ratio
Average regression	354	0.99513		
Sum of indiv. regressions	349	0.90917	0.002605	
Differences	5	0.08956	0.017910	6.875**

Significant differences at the .05 level in all four of the transformations selected were found, indicating that the growth curve for western larch is different on the Waits soil series from an average curve.

While this study was being conducted, several limitations in the development of the growth curve and sources of error became apparent. It seems appropriate to elucidate these here so that the conclusions can be drawn in the light of them.

1. The curve only applies to the Waits soil series in the Swan Valley. The applicability of it outside the sampling area is unknown.

2. The transformation yielding the best fit is only the best in terms of the others used. It is quite probable that others exist which may describe the actual shape of the growth curve better. However, many of the other transformations are considerably more complicated and little would be added by their use.

3. The assumption that the shape of the curve is controlled within genetic limits by the soil and its associated climate may not be entirely correct. It does not take into account the effect of past stand history. Inspection of the individual plot curves constructed from the stem analysis shows that curve shapes vary considerably even on this one soil series. (See Figure 2). Also, plots that were located in close proximity and within the same type and age class had very similar curves. These stands probably had similar past histories.

4. These data may be biased towards some trend that is

characteristic of the plots sampled and not the population on the whole. The individual plot curves showed that the plots in the older age classes were considerably below the average curve. While this would have no effect in the lower parts of the curve, the upper end could be biased toward a lower site because the individual curves for the higher sites did not reach this age. Some of the effect of this bias was removed by rejecting all data for ages above 170 years. However, an examination of the results indicates that there may still be some present. A downward trend is evident at the upper end of the curves of some of the trial transformation. In a graph of site index over present stand age there was a correlation for ages above 150 years. More of the bias could have been removed if data above this age were rejected. This was not done in this study because it was felt that the bias between 150 and 170 years was not sufficiently great to warrant it and it would necessitate extrapolation of the curves.

5. The variance is not homogeneous along the curve. As the trees increase in age differences in growth rate cause greater and greater differences in heights. Variance will be zero at germination of the seed (origin of the curve) and will increase to a maximum in the older ages. Non-homogeneous variance has the effect of weighting the importance of stands in the upper part of the curve because of their greater probability of having a higher squared deviation. Weighting techniques are available which remove the influence of non-homogeneous data. However, in

this study it was decided to forego these techniques because of the difficulty in selecting the proper weighting and the possibility of adding bias to the curve.

6. Each height within a plot was used as an independent sample in the "Waits" curve giving a total of 227 observations. However, in reality these are pooled into only 30 truly independent observations since each height within the stem analysis is dependent upon the previous heights and all are dependent upon the same site factors. In the statistical analysis, all of the observations were considered as independent since it was these points that defined the curve.

7. In order to compare the "Waits" curve to the average curve to determine if they were significantly different in shape, an average regression for the combined data was computed to obtain the total residual sum of squares. The hypothesis states that the growth curve of western larch on the Waits soil is significantly different than the average growth curve. Forcing the two sets of data through one transformation and into the same curve contradicts this hypothesis because it assumes that the curves for the two are different. While this weakens the statistical test somewhat, lack of a better technique necessitates its use.

8. The "Waits" and the average curve are not strictly comparable. The average curve was constructed from the conventional height/age data while stem analysis was used for the "Waits" curve. The average curve data is weakest in the youngest and

oldest ages while the "Waits" data is strongest in the youngest ages. Also height of the average dominant defined the "Waits" curve rather than the dominant and codominant height of the average curve.

The final curve for the Waits series was selected from the four "best" fits by examination. The standard growth curve of Schumacher (1939) Log Ht. = a + b 1/age was not a good fit to the data. The residual sum of squares was relatively high and the curve appeared to be high in the younger ages and low in the older ages. No explanation for this can be offered except that possibly some bias exists in the data that when combined with this transformation yielded a poor fit. The simplest transformation yielding a good fit was Lot Ht. = A_0 + b_1 Log S.I. + b_2 age + b_3 Log age. The residual sum of squares was low. The curve appeared to be a good fit to the raw data and it approximated the slightly sigmoid relationship expressed in the individual plot curves.

While a true difference is present between the "Waits" and the average curve, some doubt is cast upon its validity for site quality prediction. Site index values for the individual plots ranged from 28 to 62 with a standard defiation of ± 9.65 as determined from the individual plot curves. The variation in the shape of the individual plot curves and observations of diameter growth trends suggest that past stand history may be a major influence in the height growth of western larch at least on the Waits soil series. This view is further substantiated by a spacing study conducted on the Waits soil series in the Coram Experimental Forest[1] where in a heavily stocked nine-year-old stand,

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[1] A. L. Roe, 1965, Personal communication.

height growth had been decreased 25 per cent. Western larch appears to overstock quite readily on poorer sites such as those of the Swan Valley and this could enter considerable error into any site determination.

Regression Analysis of Individual Site Factors on Height Growth

The effect of the individual site factors on site index for western larch was tested by multiple regression analysis at the University of Montana Computer Center. Using site index and present rate of height growth as dependent variables, the relationship to the independent site factors took the form $Y = f(X_1, X_2, X_3, \ldots X_n, e)$ where Y is the measure of growth and $X_1, X_2, X_3, \ldots X_n$ are site factors. When expressed as a linear model the form is $Y = a_o + b_1x_1 + b_2x_2 + b_3x_3 \ldots b_nx_n + e$. Sixteen site factors were substituted for the X terms and the equation solved for the a_o and b coefficients describing the best fit to the data.

The results of the regression analysis are summarized in Table II. An analysis of variance on the regressions showed that neither equation was significant in predicting site quality or rate of height growth for western larch in the study area on the Waits soil series. Multiple correlation coefficients with the 16 independent variables for the dependent variables, site index and rate of height growth were .765 and .451, respectively.

TABLE II

SUMMARY OF MULTIPLE REGRESSION ANALYSIS OF SITE VARIABLES ON SITE INDEX AND RATE OF HEIGHT GROWTH

Var. no.	Independent Variable	Y site index		Y rate of height growth	
		Regression Coefficient	T squared[2]	Regression Coefficient	T squared
X_1	Total stand age	-0.0000126	0.05096	-0.00000878	0.29936
X_2	Basal area per acre	-0.0020449	0.00021	-0.05612395	1.97270
X_3X_1	Quotient of X_2 divided by X_1	2.5097807	0.76942	0.81808650	0.99323
X_3	Azimuth of aspect	-0.0226580	0.30489	-0.00010347	0.00007
X_4	Elevation	-0.0033021	0.89813	-0.00109020	1.18939
X_5	Coded position on slope	0.8121051	0.11289	0.02577442	0.13816
X_6	% slope	0.2032876	1.07975	-0.00830141	0.02188
X_7	Chroma of Bir horizon	-4.3925923	2.62138	-0.56618150	0.52912
X_8	% clay in Bir horizon	-1.1820240	2.05512	-0.03955601	0.02796
X_9	% silt plus clay in Bir horizon	0.7173280	1.10197	0.03041231	0.02406
X_{10}	P.W.P. of Bir horizon	-2.0371557	2.40962	-0.26800106	0.50668
X_{11}	% clay in lower horizons[1]	-0.0185836	0.00653	0.01018792	0.23837
X_{12}	% silt plus clay in lower horizons[1]	0.2194808	1.18659	0.01823739	0.15653

TABLE II (Continued)

Var. no.	Independent Variable	Y site index		Y rate of height growth	
		Regression Coefficient	T squared[2]	Regression Coefficient	T squared
X_{13}	P.W.P. of lower horizons[1]	-3.5084630	1.11355	-0.11697750	0.01503
X_{14}	% coarse fragments in profile	-0.0154176	0.03567	-0.00865265	0.13649
X_{15}	% frequency of Xerophyllum tenax	-0.0110524	1.17409	-0.00288742	1.44363
X_{16}	% frequency of Pachistama myersintes	0.1022948	0.27338	-0.01336556	0.05670
	Constant	61.987654		20.714667	
	R^2	76.4		45.1	

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[1] Calculated as a weighted average by horizon thicknesses of the values obtain from each horizon.

[2] T squared equals F for 1 and 12 D. F., 4.75 at 05% level.

TABLE III

ANALYSIS OF VARIANCE OF REGRESSION EQUATIONS

Y = rate of height growth

Source	D.F.	S.S.	M.S.	F.	$F_{.05}$
Regression	17	140.21007	8.35886	.58099	2.38
Deviation	12	170.49703	14.20808		
Total	29	310.70710			

Y = site index

Source	D.F.	S.S.	M.S.	F.	$F_{.05}$
Regression	17	6737.9093	396.3476	2.2960	2.60
Deviation	12	2071.4667	172.6222		
Total	29	8809.3760			

In both equations, no single independent variable was significant when considered in combination with the others with a T test.

Results show that on the plots sampled, none of the physiographic, soil, or vegetative variables used in the equation were significant in predicting the growth of larch. This is probably the result of one or a combination of the following three situations.

1. The factors are truly insignificant in predicting the growth of western larch on the Waits soil series.
2. The variation in the independent variables was not great enough to create a sum of squares large enough to be significant when compared to the error sum of squares.
3. Some factor or factors that are unknown or are not included in this study are influencing the growth of larch enough to create a large error term.

While undoubtedly some of the variables are insignificant because of the first situation, it is doubtful that all of them are. Embry's (1960) soil-site study in western larch showed that at least some of the factors measured in this study were significant when considered over a wider range. Therefore, the second situation is at least partially true and within the narrow range of soils and small sampling area, not enough variation was present in any factor for it to be significant. Under these conditions, the Waits soil series within the Swan Valley can probably be considered a uniform site.

Site index varies considerably between plots. The average S.I. was 47 with a S.D. of ± 9.65 and a range of 28 to 62. Since a non-significant amount of this variation is explained by the independent variables most of it enters the error term which will suppress the significance of the other factors. The large error term may be the result of past stand history and other related factors which have an influence on measurements of site productivity by affecting height growth.

Site indexes on the Waits soil series in the Swan Valley are low, the mean site index being 47. The average site index in Cummings' (1939) data was 55. Roe (1965) found an average site index of 61 in a larch pole study conducted throughout northwestern Montana and northern Idaho. These probably approximate average site index values for western larch. Average site index on the Waits series in Sanders County was 63, one more than the maximum found in the Swan Valley. Site indexes ranged from 57 to 76 on the Waits series. If plots had been included in this study from areas such as this, some climatic gradients would probably have been found significant in influencing the height growth of larch on the Waits soil series.

SUMMARY AND CONCLUSIONS

A growth curve for western larch on the Waits soil series in the Swan Valley was developed from data collected by stem analysis of five trees from each of 30 plots. A curve was fitted to the data by regression analysis using several different transformations. Four of the transformations yielding the best fit were compared to an average curve for all soils and sites developed by Cummings (1939).

In addition, soil, physiographic, and vegetational data were collected on each plot and a multiple regression analysis made of their effect on site index and rate of height. Based on the results of this study the following conclusions can be made:

1. The growth curve for western larch on the Waits soil series is significantly different from an average growth curve for all soils and sites.

2. No soil, physiographic, or vegetational factors used in the multiple regression were significant in determining site index for western larch.

3. The large variations in the shape of the individual growth curves are probably the result of past stand history. This may also be responsible for creating a large error term in the multiple regression which suppressed the significance of the individual site factors.

4. Variation in the soil, physiographic, or vegetational factors was probably not sufficient within the narrow range of soils and small sampling error to cause significant variation in site index. If plots had been included from other areas sufficient variation probably would

have been present in some factors for them to be significant.

5. Site indexes in this study appear to be considerably lower than the average site index for western larch and those sampled on the Waits soil series in other areas.

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