SOIL-SITE RELATIONSHIPS IN SECOND GROWTH DOUGLAS-FIR STANDS IN THE CENTRAL OREGON COAST RANGE

by

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A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1959

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Date thesis is presented July 22, 1958

Typed by Betty Bryant

ACKNOWLEDGEMENTS

A word of appreciation is due to Dr. C. T. Youngberg for his aid in introducing me to the soils of the Douglas-fir region. I am also indebted to Dr. Ellis G. Knox for his assistance in classifying some of the soils which were most troublesome and for helpful suggestions concerning organization of results. I wish to thank Dr. R. G. Petersen for his assistance with the statistical analysis of the data.

Funds for this study were made available through the Forest Protection and Conservation Committee.

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INTRODUCTION

The ability to predict future returns on an investment benefits any business enterprise. Forest management is particularly dependent on such predictions since investments made in the establishment of a timber stand are not repaid by harvested products until the end of a long rotation period. The rate of forest growth varies widely from one area to another according to the site quality of each particular locality. Techniques of measuring this rate of growth and predicting the harvest yield have been applied to timber stands of intermediate ages for many years. Forecasting yields on lands which are not now supporting timber stands of the desired species is not as easily accomplished.

At the present time large areas of forest land in Oregon are unstocked as a result of fire or clearcutting operations which did not provide for adequate reforestation. Selection of the areas which will repay investments in reforestation requires that the forest manager be able to recognize the higher quality sites. Experience in forest areas elsewhere in the United States and in those few site studies which have been conducted in the Douglas-fir region has shown that the soil profile, a permanent feature of the environment, together with other surface environmental features, provides a reliable guide to the site quality of a given locality. Soil features may have a direct influence on growth or they may serve as an indicator for other growth modifying factors. When correctly interpreted, they may be used to predict the potentiality of unstocked lands with useful accuracy.

The purpose of the present study was to determine the soil and site features which are related to the rate of growth of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco.) in the central Coast Range of Oregon. This area was chosen both for its convenience as a field laboratory and for the rather simple climatic and soils patterns which exist here. Rates of growth on different soil and site conditions for established stands of this species were determined. The relationships found can be applied to similar habitats which are not currently supporting timber stands of sufficient age or density to permit direct measurement of site quality by conventional mensurational means. Forest site classes may be mapped from soils information obtained from field operations or soils maps may be interpreted to obtain timber site quality by utilizing the relationships between soil series and depth phases as mapped and the growth of Douglas-fir.

THE SITE INDEX CONCEPT

Fundamentally, site evaluation is the prediction of the amount of salable timber products which can be grown on a particular area of land in a given amount of time. There are many difficulties which make the measurement of productivity in terms of yield impractical. Changing market conditions and specifications for products alter the portion of the tree which is to be utilized. The many man-made and natural disasters which alter the final production cannot be considered to be a part of the real ability of the site to grow timber. Moreover, yields are not commonly used to measure site quality because a history of production is needed to determine average yields. In the United States we do not have such production records for most of our forests.

The height growth of most conifers and many hardwoods has been shown to correlate with the total volume growth of fully-stocked stands. Most timber species show little variation in the rate of height growth with different degrees of stocking. The height of the average dominant and codominant trees has been utilized as an easily measured index of site quality. Curves of the average height over the range of ages for many species have been determined. Curves for Douglas-fir as grown in the Pacific Northwest were developed by McArdle and Meyer. (33, p. 13)

Families of harmonized curves drawn at regular intervals through the total range of growth data make it possible to predict the expected height of a stand at any given age. In the Northwest the height at 100 years of age is used as a common reference point. The predicted height of any given stand at 100 years of age is the "site index" of that stand. The range of possible site indices for a species is often broken into 3 to 5 groups called "site classes". In Douglas-fir stands five site classes are recognized. The height at 100 years for trees in each class are as follows:

Site Class I	over 185 feet
II	155 to 185
III	125 to 155
IV	95 to 125
V	less than 95

Spurr (41, pp. 80-85) has criticized the use of one set of curves for all stands of the same species because the growth pattern differs with various habitat conditions. He has also pointed out that use of standard curves can result in overestimation of site index when young stands are measured even though older trees growing on the same area will indicate that the pattern of height growth is not as predicted. Carmean (7, pp. 242-250) investigated the average growth rates of Douglas-fir on several soils groups. On poorly-drained soils he found that young stands grow at a slow rate but that this rate is maintained beyond the age when most site curves indicate a lower annual increment. On sandy soils this species makes rapid growth during the early years but growth decreases markedly in later life. Use of the curves of average Douglas-fir height growth results in an underestimation of the site quality of young stands growing on poorly drained positions. These same curves would result in an over-estimate of the site index of stands on sandy or coarse textured soils.

The use of the site index curves facilitates the interpretation of information concerning the influences of site factors on tree growth, permitting the comparison of stands of different ages. Site index curves used for this purpose should represent the normal pattern of growth for the locality being studied. One of the first steps in analysis of data from the present study was the determination of the proper site curves for the stands within the study area.

REVIEW OF PREVIOUS SOIL-SITE INVESTIGATIONS

Attempts to classify forest land according to productivity by use of soil characteristics were made by nineteenth century European foresters. Cajander (5, p. 6), in his review of different approaches which have been made to useful identification of forest types, mentions the use of a subjective classification of soils into five grades or broad soil classes which were established from empirical production data. Most subsequent work in "locality classification" has been related to either the use of the plant indicator species and vegetation types (3, no. 140), or to the mensurational techniques of site index determination from the height growth rates of trees on the land in question. Heiberg and White (24, p. 7) refer to these two approaches as direct and indirect methods of site evaluation. The direct mensurational techniques are used in most soil-site studies to determine the applicability of such indirect measures as vegetation and soil features.

Soil-Site Research in Other Areas of the United States.

The study of relationships between soils and forest growth in the United States has had a relatively brief history. About 1924, Haig (21, p. 28) reported that a correlation existed between the growth of red pine (*Pinus resinosa* L.) and various types of Connecticut soils.

The range of soils considered was relatively limited. The young ages of the plantations studied resulted in an emphasis on surface soil characteristics, such as surface soil texture. This property alone was a sufficient site indicator to place an area within the correct site class. Within the loam and sandy textured soils, the only textural groups covered by this study, Haig found the percentage of silt-plus-clay in the A horizon to be positively related to the rate of height growth of the pine. When the soil series and type were determined and correlations between these mapping units and site computed, these relationships made a slightly better estimation of site quality possible than that obtained by using surface texture alone.

Similar relationships between surface soil texture and red pine growth were found by Hickock and coworkers. (25, pp. 732-749) The nitrogen content of the A horizon was also found to increase with increasing site value. Nearly all factors tested showed some correlation with site quality in the lower site index range. Correlation was either low or lacking between higher site values and these soil factors.

Turner (46, p. 10) related the rate of growth of trees in Arkansas to the recognizable quantitative group combinations of soil and site factors which could be summarized in a specific soil type of specific slope and exposure. Characteristics which were related to the growth rate of trees were primarily those which influenced the amount of water available to plants.

The Southern Pine Region has been the most thoroughly studied of all United States forest areas. It is here that the relationships between site productivity and soil factors have been most clearly established. Coile (8, p. 729) found that no single physical characteristic of the soils gave a well defined correlation with site index of shortleaf pine (*Pinus enchinata* Mill.). The ratio of silt-plus-clay percent of the B horizon to the depth of the B horizon was a reliable guide to site quality on soils with light textured surface and clayey subsoils. To evaluate site quality on a more general basis Coile advised the consideration of aspect, relative topographic position and slope, texture and thickness of the A and B horizons, and the nature of the substratum or soil parent material. The depth of this substratum to impermeable layers should also be considered if the soil is relatively shallow (9, pp. 65-66).

In a later work (10, p. 39), Coile adapted the use of the xylene equivalent, the difference between the moisture equivalent and the same test with xylene used in place of water, as a method for evaluating the imbibitional water value of clayey subsoils. This value was utilized to characterize the physical properties of the subsoil as an environment for root growth. Utilization of this value enabled him to relate the imbibitional water values to the height growth of shortleaf and loblolly pines (*Pinus taeda* L.).

Further studies with these species resulted in the development of methods for the prediction of site quality by use of depth to the subsoil and the imbibitional water value of this subsoil. (12, p. 739) The standard error of site index estimates made on the basis of these two variables was approximately 9 feet, a level of accuracy comparable to that of estimates based on height measurements interpolated by height-age curves to the reference age. The field application of tables constructed from the results of multiple regression analysis of the depth, imbibitional water value, tree height and age, requires only the use of a soil auger to evaluate the necessary soil properties. (12, p. 741) Plasticity of the subsoil is used as an estimate of the imbibitional water value for field purposes.

Ralston and Barnes (35, pp. 84-85) have applied these findings to slash pine (*Pinus elliottii* Engelm.) productivity. Their study showed that on poorly drained flatlands typical of the habitat of this species the depth of the strongly mottled horizon or a fine textured (clayey) horizon served as a reliable guide to the rate of future height growth. Other work by Ralston (34, p. 407) utilized a modification of Schumacher's "fundamental growth curve" of the form:

$$\text{Log}_{10}\ \text{Volume} = a_o + b_o \frac{1}{\text{Age}} + a_1 S + b_1 S \frac{S}{\text{Age}}$$

S = Site Index (38, p. 20)

The modified form of this equation as utilized by Ralston was as follows:

$$\text{Log}_{10}\ \text{Height} = b_o + b_1 \frac{1}{\text{Age}} + b_2 x_2 + \dots + b_k x_k$$

x_2---x_k = numerical equivalents for site factors to be tested. Use of this multiple regression formula has been applied to soil and site variables as they affect growth of southern pines (loc.cit.) and Douglas-fir (30, p. 326).

Zahner (51, p. 448) separated loblolly pine sites in the Gulf Coastal Plain into two drainage classes and determined a separate prediction formula for each class on the basis of surface soil depth and the imbibitional water value of the subsoil horizons. For this species the site index was found to be higher on the soils with impeded drainage. The seeming inconsistency of this relationship, since impaired drainage would be expected to hinder root development, appears to reflect the increased moisture availability where the water table is maintained near the surface. This species is adapted to stream bottoms and other areas of moist soils. (23, p. 90)

Gaiser (17, p. 274) investigated loblolly site in the coastal plains of Virginia and the Carolinas. He found that three similar shaped curves of height over age were necessary to plot the growth of this species on soils of three different stages of drainage. Since the soil series of the region were established with drainage classes as one of the differentiating characteristics, Gaiser was able to tabulate sites according to soil series by also considering variations in depth to subsoil horizons.

Hodgkins (27, p. 66) demonstrated the necessity for local adaptations of such site tables as were developed by Coile and others. His tests of general tables on three pine species in Alabama indicated that the local conditions considerably altered the site values which would be expected from the strict application of the generalized tables.

In aspen (Populus tremuloides Michx.) stands of the Lake States, Kittredge (30, pp. 210-213) has shown that soil profiles can be used, within limits to predict height growth. One of the profile features, development of a strong A_2 horizon, was associated with better aspen growth. Donahue (13, p. 39) listed the soil characteristics associated with the best growth of hardwoods in the Adirondacks of New York State. These were a fine mull A horizon with no noticeable development of a bleached A_2, a pH above 5.0, deep, dark brown B horizons, the presence of slight to moderate amounts of rocks in the profile, and a thin accumulation of organic matter. He also noted that the best sites occurred on southerly slopes where a perched, moving water table existed.

Studies of the growth of various oaks in the Midwest have shown the following soil factors to be related to site quality: slope position, (18, p. 4) (2, p. 1); aspect and exposure; drainage and depth of the A horizon, (loc. cit.). Youngberg and Scholz (50, pp. 331-332) studied the effects of soil fertility factors on the growth of understocked oak stands in Wisconsin. On deep soils the content of exchangeable bases, soil reaction and content of organic matter were directly related to site quality.

Growth of tulip poplar (Liriodendron tulipifera L.) was found to be inversely related to the clay content of the A horizon. A_2 horizons with high clay content were found to be capable of retaining more water at maximum moisture levels. Poor growth was attributed to inhibition of root aeration and a reduction in effective rooting depth. (39, pp. 34-38)

Conifer stands in Maine have been investigated by Young (48, p. 86) who has reported negative correlation between the depth of the A horizon and the height growth of eastern white pine (Pinus strobus L.). This decrease in site quality with increasing depth of the A horizon presents a reverse relationship to that demonstrated in the Southern Pine Region. Young suggests that this may be due to the recent glacial origin of the New England soils studied. The author further demonstrated lower site quality for white pine where there is a high content of stones in the B horizon. A horizons with high imbibitional water values were found to be associated with poor spruce-fir sites.

Aird and Stone (1, p. 426) considered a simple regression of site index on either depth of the soils or on soil drainage class to be the most useful site prediction tool for European and Japanese larch (Larix decidua Mill. and L. leptlepis Sieb. and Zucc.) as grown in plantations in New York State. They also reported that soil type groups provided a suitable site indication if appropriate depth separations were made.

Soil-Site Research in the Douglas-fir Region.

Hanzlik (22, pp. 440-441) made a survey of the volume, height and basal area measurements of Douglas-fir stands on various site locations in 1912. He noted that the best growth occurred on slopes rather than level land where poor soil drainage often occurred. The first systematic investigation of the site conditions which affect the rate of growth of Douglas-fir was made in 1929 by the Pacific Northwest Forest and Range Experiment Station. (33, pp. 8-9) McArdle and the other authors reported the effects of slope, aspect and other surface conditions on the yield and rate of height growth of this species. This comprehensive survey of the stands of western Washington and Oregon showed that 90 per cent of the Site I plots were located below 1500 feet elevation and that none were found above 2000 feet. The authors attribute these findings to the effects of shorter growing seasons and lower mean temperatures at these higher elevations. North and east aspects were found to be superior to south and west slopes. The variability of the latter aspect group was much greater but all the Site V stands measured were either on these southerly slopes or on level ground. The best stands were found in regions which received 60 or more inches of rainfall per year. Shallow soils and poor soil drainage were found to reduce site quality even in favorable precipitation zones. Deep, well-drained soils of sandy loam texture were found to be the most productive, while clay soils ranked second where other conditions were favorable. Soils with high gravel content were generally low in productivity. Soils on steep slopes produced higher total yields per acre but this was largely due to the presence of larger numbers of trees on the greater surface area and the fact that the inclined soil permitted a greater portion of the crowns to be exposed to the light.

Hill, Arnst and Bond (26, pp. 837-841) concluded from studies of site classes in relation to soil mapping units used by the Soil Conservation Service that practical prediction of site indices could be made from profile groupings and land capability classes. Soil depth and other factors affecting the ability of the soil profile to retain and store moisture for tree growth were considered to be of primary importance. These workers found the superiority of northern aspects to be evident only on heavy textured soils which were deep to bedrock. On such soils the site index for south slopes was 20 per cent lower than for equivalent conditions on other aspects.

Tarrant (44, p. 719) studied Douglas-fir stands ranging from Site Class I to IV at five locations in Washington and Oregon. He found no statistical relationship between productivity and levels of total nitrogen, available phosphorus and K_2O, or content of organic matter in the surface horizon. The author concluded that the nutrient content of forest soils in the Douglas-fir region appears to be too high to constitute a limiting factor in tree growth. Subsequent trials with nitrogen fertilization have shown height growth response in young Douglas-fir stands growing on glacial outwash and shallow residual soils. (20, p. 100) Growth response to fertilization has not yet been demonstrated on deep residual soils.

The use of standard soil mapping units as a basis for site prediction has been further investigated by Tarrant (45, pp. 723-724), Schlots, et al (37, pp. 101-105), and by Gessel and Lloyd (19, pp. 407-410). The first of these papers suggests that mapping phases of soil types according to topographic position improves the accuracy of the delineations for site differentiation purposes. The author found lower slopes, valleys and basins to be consistently higher sites than ridge tops and upper slopes. Gessel and Lloyd noted that seasonal rainfall over 40 inches per year was of little value for the improvement of site quality. Coile (11, p. 361), in reviewing this paper, suggested that the interpretation of the precipitation effect may have been confused by subsurface moisture movement to lower slopes.

Schlots and coworkers reported that the highest site index was found on areas with deep friable soils of moderate to high fertility levels. Progressively lower quality timber sites were correlated with increasingly pronounced profile development as indicated by the degree of horizonation. These workers found a close relationship to exist between timber site quality and soil depth on those soils which were underlain by claypan, fragipan and hardpan horizons. Parent material differences did not affect site if similar soil profiles had developed. The summation of factors which determine soil type were concluded to be the most important (or indicative of other factors which were important) in determining productivity. Carmean (6, pp. 330-334) divided the Douglas-fir soils of southwestern Washington into five parent material classes for analysis of the significance of various site factors. For residual soils from basalt bedrock he found elevation, average moisture equivalent, and average per cent gravel to be correlated with site index. On the other hand, soil depth was the only factor found to be important in residual soils formed from sedimentary rocks. When all soils were considered together "soil compaction" and the product of gravel content multiplied by moisture equivalent were correlated with site index. Use of prediction formulae form these multiple factor relationships resulted in errors of estimate of 13.2 per cent for all plots. Use of the soil depth variable alone was sufficient to predict site index on the sedimentary rock parent material group of soils with an error of only 5.4 per cent.

Lemmon (32, pp. 324-328) analysed forest soils of the Willamette Valley. Use of the fundamental growth curve as modified by Ralston and others showed that soil depth was the factor which most influenced height growth on north aspects and level areas. On south slopes the degree of slope, elevation and total annual precipitation were significantly related to the rate of growth. Depth of soil alone could be used to predict site index on a given slope, aspect and soil series within plus or minus 22 site index points. The author posed the question as to whether or not the presence of suitable stands of timber may be necessary to determine site index more accurately since there are so many interacting factors affecting the rate of height growth.

Spilsbury and Smith (40, pp. 1-46) have applied a different approach to the identification of Douglas-fir sites in British Columbia. They reasoned that the correct interpretation of the interactions of environmental factors which affect the productivity of a given area can be accomplished only through consideration of the response of natural vegetation. The use of tree height growth as normally utilized in site index determinations has the disadvantage that only the rate of growth of the particular species now present on the land can be evaluated. These authors investigated the use of characteristics of the subordinate vegetation to identify the site-types which represent the various productivity classes of the region. Their results, and those of Becking (4, pp. 438-441), are based on the assumption that natural vegetation, after a period of competition, becomes in equilibrium with the growth factors. If subordinate vegetation characteristics are readily discernible in the field and if these features are stable, or at least recognizable, in areas which are not presently stocked with the desired timber species, then these types afford a reliable means for identification and classification of lands according to their productivity potential.

DESCRIPTION OF THE STUDY AREA

The field data for this study were collected from even-aged stands of Douglas-fir between 30 and 150 years of age in Polk and Benton Counties, Oregon. All sample plots were confined to soils which were formed on residual materials weathered in place from igneous and sedimentary rocks of the Coast Range. Only the areas which are part of the Willamette River drainage were sampled, thus the study area was confined to the eastern portion of the Coast Range and the bordering foothills. Over the entire study area there was a general increase in rainfall and elevation from east to west.

Topography

The western part of the study area is typified by narrow valley floors and V-shaped canyons rising sharply to narrow irregular ridges. Slopes are moderate to steep on most of the forested area, while more gentle slopes are common only along the ridge-tops in the mountainous sections. The terrain is more subdued in the eastern zone bordering the Willamette Valley; here the foothills are rounded and the bottomland areas of the stream channels are broader. Elevations range from 400 feet to about 2000 feet, although there are a few peaks rising above this level.

Climate

Temperatures in the region are moderate due to the ocean influence. Mean summer temperatures in the mountains are 4 to 6 degrees lower than those in the central part of the Willamette Valley. At Falls City near the center of the study area the mean July temperature is 64° F. and the mean January temperature is 38° F. Total annual precipitation ranges from a low of 40 inches along the western edge of the Willamette Valley floor to approximately 70 inches in the deep valleys in the central parts of the counties. At higher elevations on northwestern and northern aspects, local areas may receive as much as 80 inches per year. Rainfall for the months of July, August and September is restricted; this ranges from 2.5 inches in the east to about 3.4 inches at the western extremes of the study area. (47, pp. 1075-1078)

Soils

The forested soils of the region are Reddish Brown Latosols. At higher elevations in the western part of the area some soils exhibit many of the features characteristic of the Brown Latosols. (31, p. 28) On exposed southern slopes of the foothills and on some high ridge-lines of the eastern extremities of the Douglas-fir zone there are shallow soils developed which possess some characteristics of the Non-Calcic Brown soils of dry, warm regions. The soils are developed on basalt and tuffaceous sandstone and shale parent materials. In some regions the overflow of basalt and gabbro has altered the adjacent sedimentary rock layers to metamorphosed forms which are difficult to separate from the overlying basalt. (14, pt. II, pp. 30-35) The soil series utilized in the study are not yet clearly defined and described according to present soils survey standards. Characteristic profile descriptions and the differentiating features applied in identification of the soils studied in the present study are listed in Appendix I.

Forests

A large portion of the western hills and mountain regions of the two counties covered by this study is forested with even-aged stands of Douglas-fir. These forests range in age from less than 40 years to over 300 years. There are a few regions where there is evidence that older stands of Douglas-fir have occupied the land prior to the development of the present stands. Most of the old age, "relict" fir is located in deep valleys and small canyons on north slopes and in protected positions. The younger stands seem to have been established from these seed sources. The wide expanses of bare or grass covered land that must have been present when these forests became established could have been the result of wild fires, as these were doubtless common in the region prior to settlement of the Valley. The continued encroachment of conifer forests into the grass-white oak (Quercus garryana Dougl.) areas of the low rainfall, low elevation south slopes seems to indicate that Douglas-fir is reclaiming areas from which it was barred by former conditions.

Associated timber species of the Douglas-fir include grand fir (Abies grandis Lind.) which is a common understory seedling and sapling in most of the older Douglas-fir stands. The grand fir also occurs in equal age classes with the Douglas-fir at higher elevations. Western hemlock (Tsuga heterophylla Sarg.) is another tolerant species which becomes more common as the Douglas-fir stands mature. Along moist stream banks and on north slopes red alder (Alnus rubrum Bong.) are found in all age classes. Following clear-cutting operations this species often becomes a serious competitor to reestablishment of Douglas-fir on these moist, cool sites. Bigleaf maple (Acer macrophyllum Pursh.) occurs as a scattered tree in most Douglas-fir stands, becoming common where remnant maples are left to restock clear-cut areas. Western red-cedar (Thuja plicata D. Don.) occurs as a scattered tree in the western extremes of the study area. Pacific dogwood (Cornus Nuttalli Aud.), madrone (Arbutus menziesii Pursh.) and yew (Taxus brevifolia Nutt.) are small trees which are commonly found in certain areas. Chinquapin (*Castanopsis chrysophylla* (Dougl) A.DC.) is a relatively rare tree in this area; none were noted on any of the sample plots taken.

METHODS AND PROCEDURES

Field Study Methods

During the fall of 1956, approximately 20 sample plots were established in the Corvallis vicinity. Most of these initial trial plots were located on the McDonald Forest of the Oregon State College School of Forestry. These plots were distributed to cover as wide a range of soil, topography and forest growth conditions as was possible. Later, the limits of the study area were enlarged to include the eastern drainages of the Coast Range in Polk and Benton Counties. Additional plots were then located in such a manner as to give coverage of the entire area. (Figure 1)

A total of 76 plots were located in a subjective manner under the same restrictions as were used on the initial trial plots; i.e., that a wide range of conditions be included. To secure additional information on selected plots and to provide a measure of the variability in site quality and in the various edaphic factors over a very short distance within forest stands growing on what superficially appear to be similar environmental conditions, a random method was used to select 20 plots from the 76 already sampled. On these locations duplicate plots were established. (See underlined plots, Figure 1) The single Site I plot which was found in the original sample was purposely selected as one of the 20 plots to be duplicated. To avoid undue bias of the mean values for all plots a Site V plot was also selected; this plot also represented a rather uncommon soil condition on which more information was desired. Selection of Douglas-fir stands suitable for the location of sample plots was strongly influenced by the past cutting history of the forests within the study area. Throughout most of the region stands which were in the right age class for accurate site estimation were found to exist only as isolated patches of uncut timber in cut-over areas. In only a few localities were there extensive stands in which it was possible to locate a number of study plots on different slope, aspect and soils conditions. An attempt was made to sample a wide variety of such conditions and to distribute the study plots in a roughly uniform coverage of the area to be sampled. Actual location of the plot in a particular drainage or township was all too often dictated by the location of the few remnant stands of timber remaining.

The first requirement for a tentative sample plot was the existence of at least an acre of well-stocked Douglas-fir between 30 and 150 years of age. In these stands a soil pit location and plot center was chosen where slope, aspect and surface terrain features seemed relatively uniform over a space large enough to permit the placement of a circular one-fifth acre plot. The soil pit was

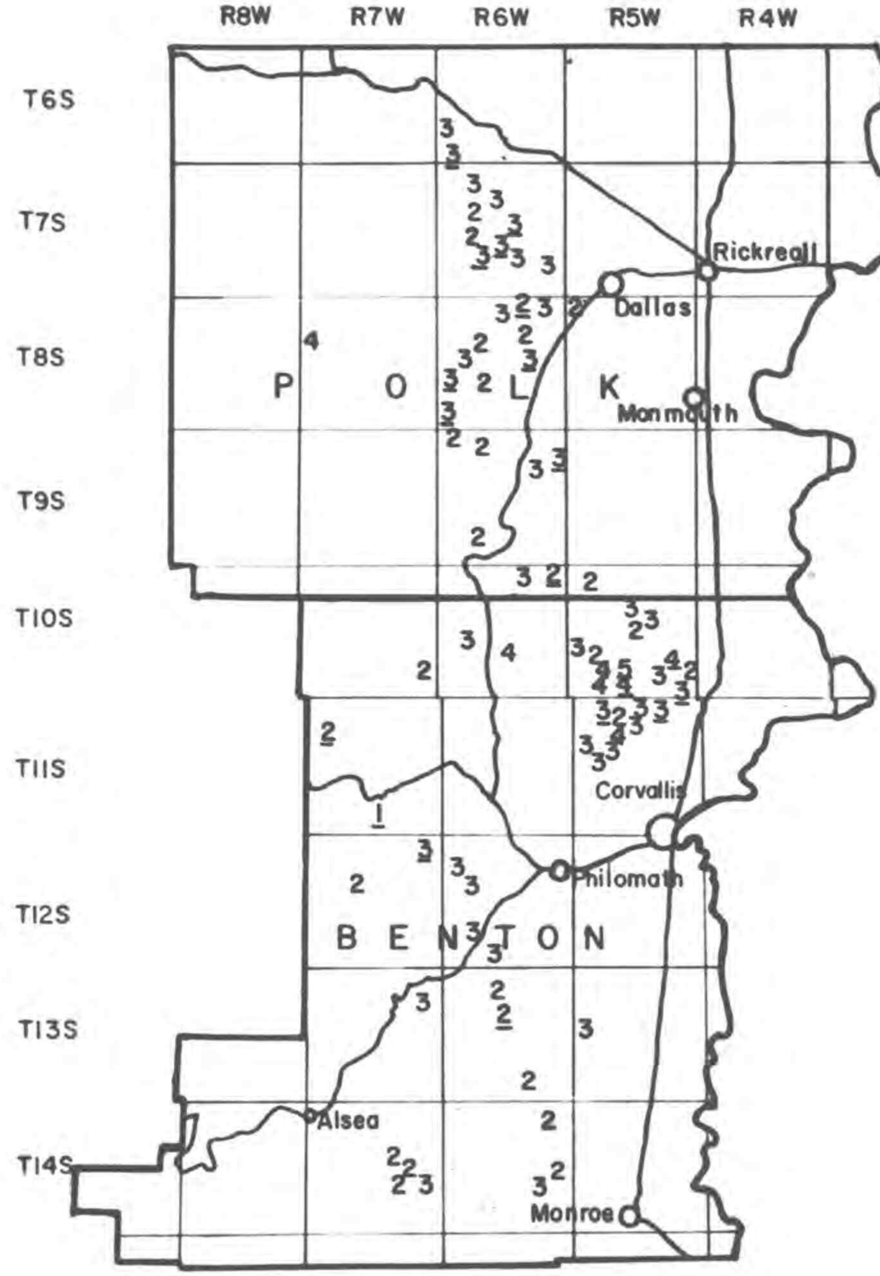

Figure 1.

Location of Sample Plots by Site Index Class,

Benton and Polk Counties, Oregon.

(Underlined figures indicate duplicated plots) excavated in the center of this area to a depth of 60 inches, to relatively unweathered subsoil, or to underlying bedrock, whichever was shallowest. A worm auger was used to determine the nature of the deeper solum when necessary and to test for the existence of bedrock. Since "floater" rock fragments are common in those soils developed on basalt residuum, the use of the auger was severely limited as a means of evaluating soil depth, both below the depth of the pit and in auxiliary locations scattered around the plots.

Horizon boundaries were marked in each profile and the features and properties of each horizon recorded according to the standard methods outlined in the U.S.D.A. Soil Survey Manual. (43, pp. 123-146) Soil reaction was determined by use of the Hellige Truog soil reaction kit. Additional information was taken on the abundance of tree roots at various depths and on the volume of stones in each horizon.

Seven soil series were identified. (Appendix I) The various soil series are closely related morphologically so that some profiles were found to exhibit features characteristic of two different series. Final assignment of series classification was made by comparison to known examples of the different series.

All brownish and yellowish-brown soils with strong B structure and shallow profile development which were found on basalt residuum were assigned to the Dixonville series.

5 plots were located on soils similar to the Dixonville series which were found to have distinctly mottled subsoil horizons. These were included in the Dixonville series since there have been no series developed for the imperfectly drained soils in the area.

Soil samples from each of the horizons differentiated were composited from a slice of soil of uniform depth taken vertically from the top to the bottom of the horizon. Large aggregates of unbroken soil peds were included where possible for use in determining bulk density.

Site index data were taken on the ten dominant and co-dominant trees nearest to the center of each plot. Total height measurements were made by use of the Abney hand level and a surveyor's tape. The age of five of these trees was determined by counting annual rings on an increment core taken from each tree at a height of four feet. An age correction of eight years for the growth from seed to a height of four feet was added to the ring count. (33, p. 61)

Determination of the proper number of height and age measurements required to provide a reliable estimate of the mean value for each stand was made by computation of the standard error of the sample means for each type of measurement taken on the initial 20 sample plots. Ten age measurements were made on these plots but the statistical evaluation showed that the variance of the height values was so much greater than that of mean age that the additional age measurements contributed little to the overall accuracy of the site index estimate. Johnson and Carmean (28, p. 27) have shown that more than six height measurements are necessary to obtain a reliable estimate of average height.

Additional stand information was taken on the 40 randomly selected plots (20 original plots plus the duplicate for each). A one-fifth acre circular plot was outlined around the soil pit location. A 100 per cent cruise of all trees on this plot over two inches in diameter was made in which the species, diameter at breast height and crown class were recorded. On these plots the two dominant trees nearest to the center of the plot were selected for measurement of the 10 year height growth increments as indicated by the positions of the branch whorls. Since Douglas-fir normally produces one terminal shoot and one new whorl of lateral branches each growing season, the scars of the branches which may be seen on the bark may be used to estimate the height of the tree at any given age. The errors which arose when an attempt was made to measure the growth within the live crown of older trees were sufficient to limit the range of the reliable data to no more than 50 or 60 years of growth. The Abney level was used to take these measurements. As with the age determination, an arbitrary correction of eight years was added to the internode occurring at four feet above the ground. The use of a constant age for the four foot on all sites regardless of the different rates of early growth may introduce a slight error in absolute height at a given age. Differences in growth rates at early ages are more often due to differences in the degree of shrub competition and other temporary factors than to the effects of soil and climatic variables.

An estimation of the tree canopy cover and the percentage of crown cover contributed by each shrub and principal forb species to its respective crown stratum was recorded for all 96 sample plots. Herbaceous cover varied with the season, both in total cover provided and in species composition. Since the field work extended from the autumn of 1956 to the late summer of 1957 a comparison of the various plots was considerably handicapped by these variations. Shrubs and trees remained relatively unchanged and provided a basis for general comparisons, especially as crown cover of the tree stratum was related to the cover of the shrubs for the different site classes.

Laboratory Procedures

The soil samples were air dried, the clods to be used in the bulk density measurements selected, and the remainder of the sample ground to pass a 2 mm. screen. The bulk density measurements were made by weighing the soil clods in water according to the method outlined in the Sampling Procedures and Methods of Analysis for Forest Soils. (15, pp. 12-13) Particle sized distribution of the samples was determined by the modified Bouyoucous hydrometer method. (loc. cit., pp. 15-17) The method of dispersion recommended for soils of the Reddish Brown Latosol group by Youngberg (49, pp. 655-656) was utilized; both sodium hydroxide (1 Normal) and Calgon (5%) were used as dispersing agents. A 12 hour period of agitation in a reciprocating shaker was utilized rather than the mechanical stirrer. Forty second and six hour readings were taken for silt-plus-clay and clay respectively.

Two moisture retention levels were determined. Moisture equivalent values were determined on all samples. (15, pp. 13-14) Fifteen atmosphere moisture levels were obtained for all horizons of the 76 original plots by use of pressure extraction. (36, pp. 95-112) The 15 atmosphere values for the 20 plots chosen to be duplicated were applied to their counterparts to obtain an estimate of the range of available moisture as described below.

An approximation of the available moisture which could be held in the surface 50 inches of each profile sampled was computed using the difference between the moisture equivalent value and the per cent moisture retained at 15 atmospheres pressure. Total available water in the profile in inches was computed using the bulk density figures obtained from the clod samples and the recorded depth of each horizon. These values were corrected for the volume of gravels and stones in each horizon as estimated in the field. Those profiles which had less than 50 inches of soil available for free root development, whether due to the existence of a high water table in the poorly drained soils or to the presence of impervious bedrock, were considered to have available water held only to the depth of the restricting layer. For the poorly drained soils the depth at which mottles became prominent was considered the limit of root penetration; this limit corresponded well with the actual depth of abundant root penetration as noted from field observations.

ANALYSIS AND INTERPRETATION OF DATA

Evaluation of Site Index Curves

Site index curves constructed from data covering a major portion of the Douglas-fir region were published in 1929, (revised 1949). (33, p. 13) These curves have since been used generally throughout the region, therefore, they will be referred to as the "standard curves". Carmean has shown that Douglas-fir growing on different soil conditions vary in their patterns of height growth but that the stands growing on residual soils followed the standard curves very closely. (7, pp. 242-250)

The pattern of height growth exhibited by the trees measured in the present study was compared to these standard curves by three methods. A curve of the mean height of dominant and codominant trees plotted over the average age of the individual stands by five year age classes was constructed. (Figure 2a) These data were compared to the standard curve representing the average of all individual plot site indices as determined from a family of standard curves. Younger stands were found to fall generally above this average curve while plots over 80 years of age fell below the standard curve.

The internodal growth increments from 80 sample trees on 40 randomly selected sample plots were utilized to construct a second growth curve. (Figure 2b) The mean height of all trees at each ten year interval showed a pattern of height growth somewhat more linear than the standard curve representing the average site index of the 40 plots. The limitations of the field technique made it impossible to secure data to extend the computed curve beyond the 60 year limit.

A coefficient for the regression of the logarithm of average height on mean age was determined from a modification of the equation:

$$\text{Log}_{10}\text{ Height} = \text{Log}_{10}\text{ Site Index} + b\left(\frac{1}{\text{Age}} - 0.01\right) \quad (1)$$

(7, pp. 242-250)

The modified form of this curve passing through the point of average height and average age for all plots:

$$\text{Log}_{10}\text{ Height} = \text{Log}_{10}\text{ 120.3 ft.} + b\left(\frac{1}{\text{Age}} - \frac{1}{72.4\text{ yrs.}}\right) \quad (2)$$

is the equation for the plot data illustrated in Figure 2a. The resulting regression coefficient was $b = -11.4294$. The curve of equation (2) was plotted against the standard site index curve passing through the same coordinates (120.3 feet, 72.4 years). The computed curve shows a much less rapid rate of height growth after about 50 years of age. The trees which are 40 to 60 years old are growing, on the average, at a rate which would indicate site indices higher than the average for all plots while the older age classes are below the standard curve. A similar pattern

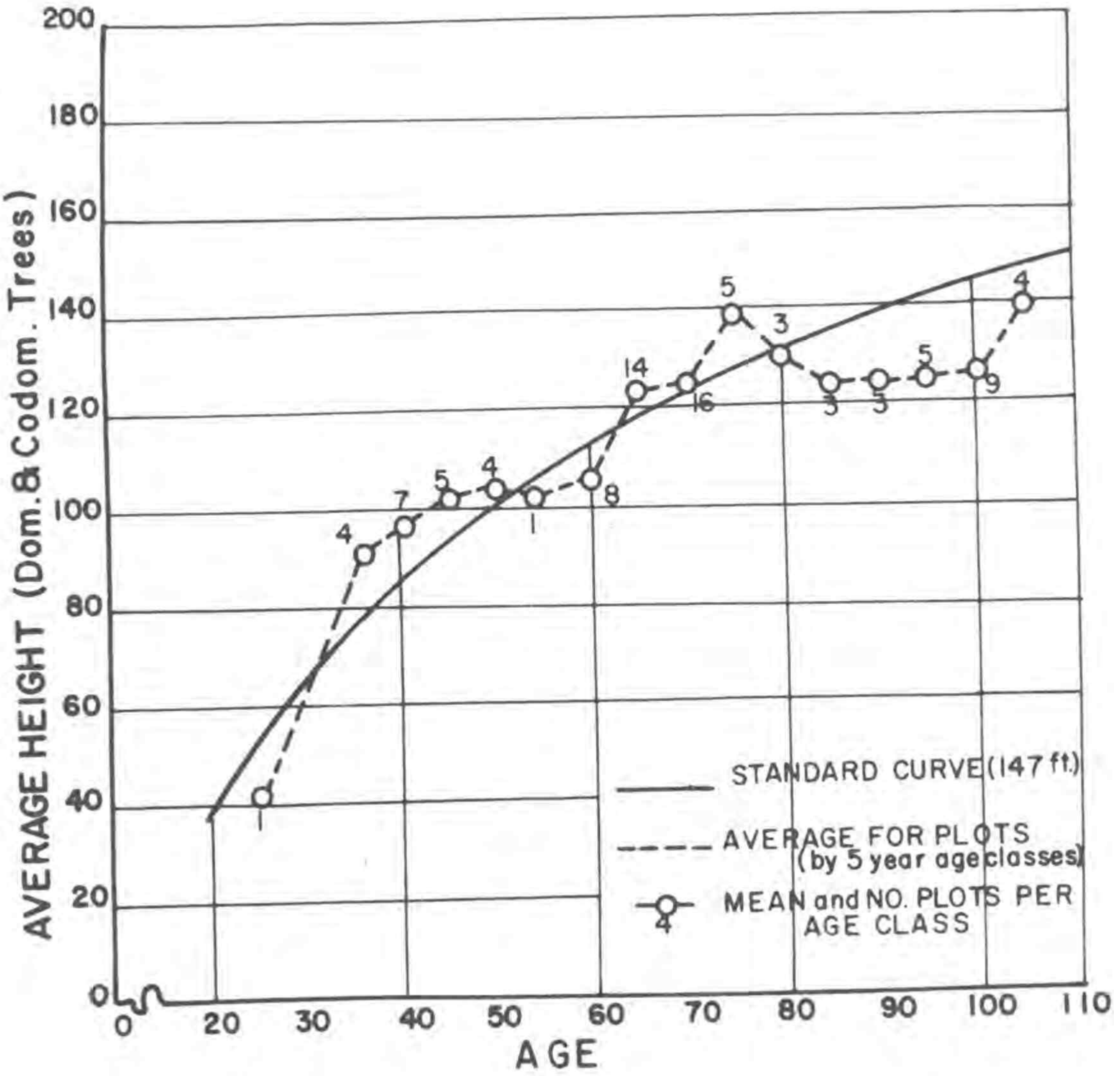

Figure 2a.

Average Total Height over Age for all Plots by 5 year age classes compared to Standard Site Index Curve for the Average of the Site Indices of all Plots (147 ft.)

would emerge if there were unequal representation of the better sites in the older age classes. The distribution of age classes of the different site classes was investigated by a regression of site index over age. This analysis showed a significant decrease in average site quality in the older age classes. Since the standard curves were used to derive the site index values this analysis is not entirely free from the possible effects of a different pattern of height growth if this should exist in the area. A consideration of the cutting history in the study area makes it seem probable that the poorer sites are those which are as yet uncut.

In view of the considerations discussed above and the fact that early rates of growth very nearly coincide with the standard curves, it seems unwise to attempt any modification of the standard curves to more nearly suit local conditions. The curve for the 10 year height increments is relatively free of the bias caused from the overabundance of poor sites in the older age classes. A frequency curve of the site classes represented by all plots shows a relatively normal distribution around the mean site index value. These data were also free of the effects of total stand age as it would influence the prediction of the form of the height growth curve since each increment was based on the independent measurement of age to that branch whorl. Since the curve from the average of these measurements approximated the standard curve throughout the extent of the data, it appeared that any error arising from the use of the standard curves would be negligible. The fact that these standard curves are already in general use throughout the Douglas-fir region is another argument for the interpretation of soil-site data in terms of these theoretical patterns of growth as long as no substantiated improvements can be made.

Single Factor Analysis of Soil and Site Factors

The relationships between site index ratings and single site and soil variables were examined initially by plotting scatter diagrams. Those factors which appeared to have sufficient influence on the rate of height growth to result in a definite pattern of site values were tested further by linear regression analysis.

The depth of soil available for root development appeared to be the most obvious feature affecting the productivity of the various plots. A linear regression of site index values for all plots over the soil depth in inches resulted in a very significant regression coefficient of 0.95. (Table 1) (Figure 3a) Separate analysis of the effects of soil depth on growth for non-stony soils

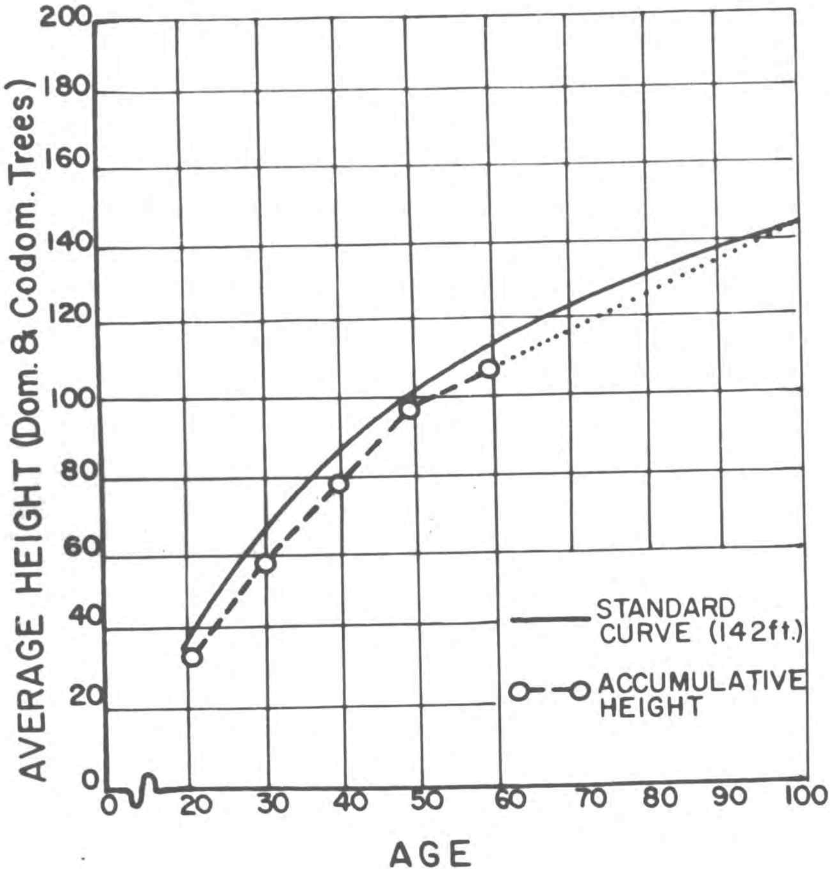

Figure 2b.

Average accumulated 10 year Height Increments for 80 Trees, representing 40 plots VS. Standard Curve for Mean Site Index of these plots.

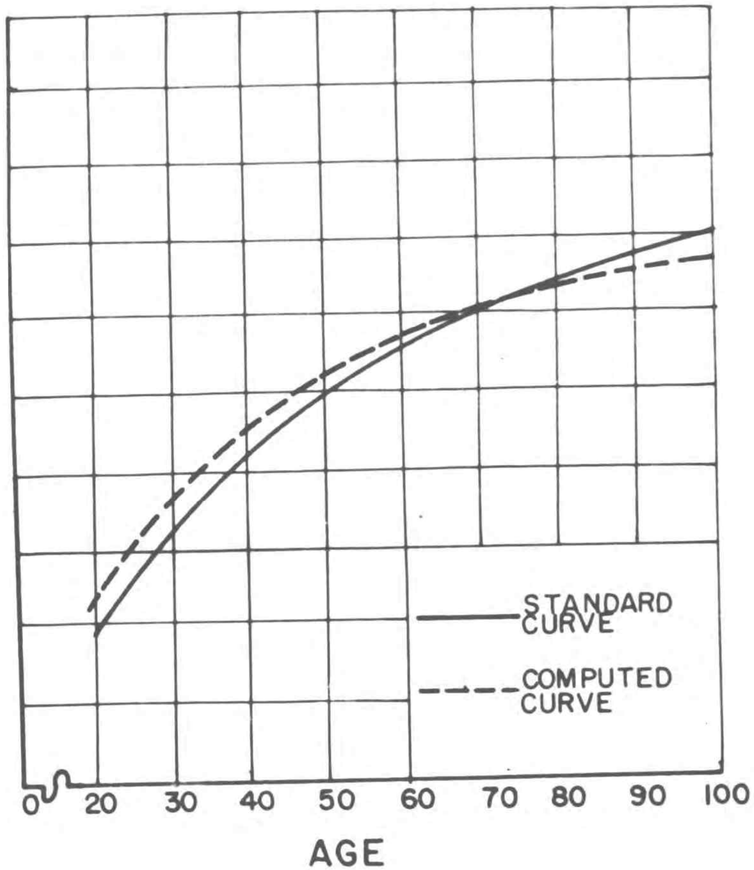

Figure 2c.

Computed Site Index Curve (Log Ht. = Log Ave. Ht. + b (1/Age − 1/Ave. Age) VS. Standard Curve passing through intercept Ave. Age, Ave. Ht. (72.4 yrs., 120.3 ft.).

of the two parent material groups were made using the formula:

$$\text{Log}_{10} \text{ Site Index} = a + bx$$

x = numerical code for 6 inch soil depths 12" to 66" +

The slopes of the two regression lines for the basalt and sedimentary rock parent material groups are shown in Figure 3b. When stony soils are included the effects of restricted depth appears to be lessened. Errors in the estimation of true soil depth available to tree roots results in a non-significant relationship between the soil depths of stony soils as estimated in the field and the site index values of these plots.

It was noted during the field operations that many soils with clayey, strong structured B horizons did not have the deep root penetration characteristic of the soils with more friable subsoils. Quantitative evaluation of the nature of the maximum textural B horizon was made by three methods; bulk density, moisture equivalent and mechanical analysis. Scattergrams indicated that site index values decreased with increasing bulk density of the subsoil horizons. Separate regression analysis for the non-stony soils showed that this relationship was significant for the basalt parent material group. (Table 2) Poorly drained soils tended to have higher site values where there is a greater bulk density in the B horizons.

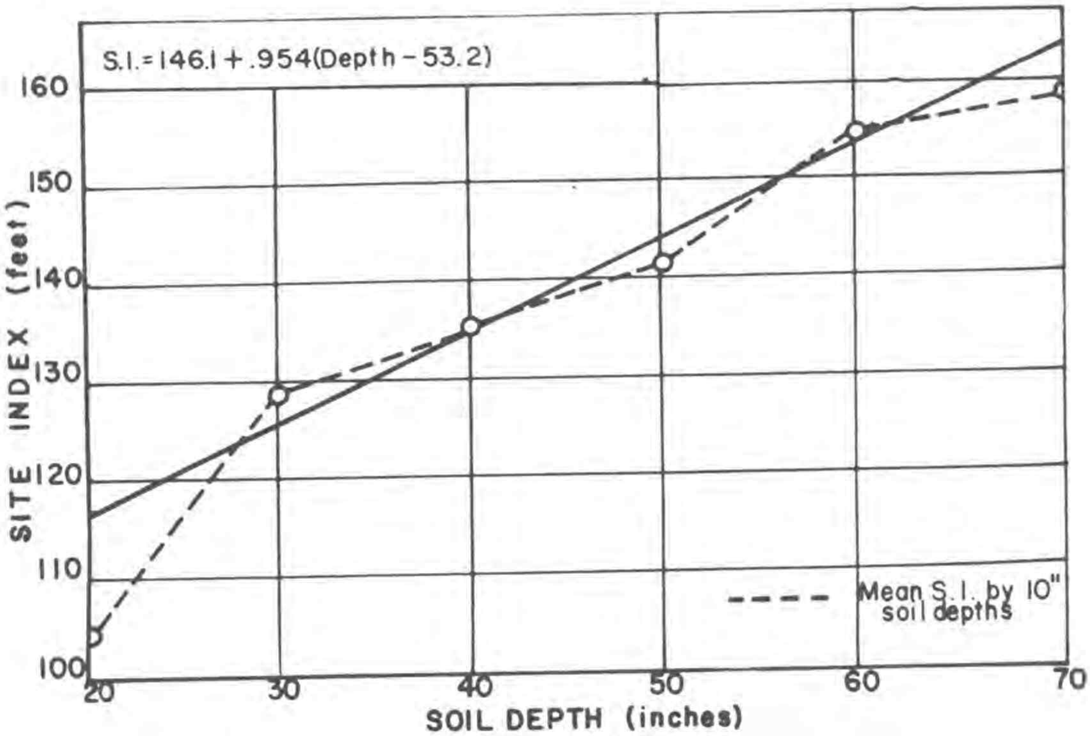

Figure 3a.
Relation of Site Index to Soil Depth.

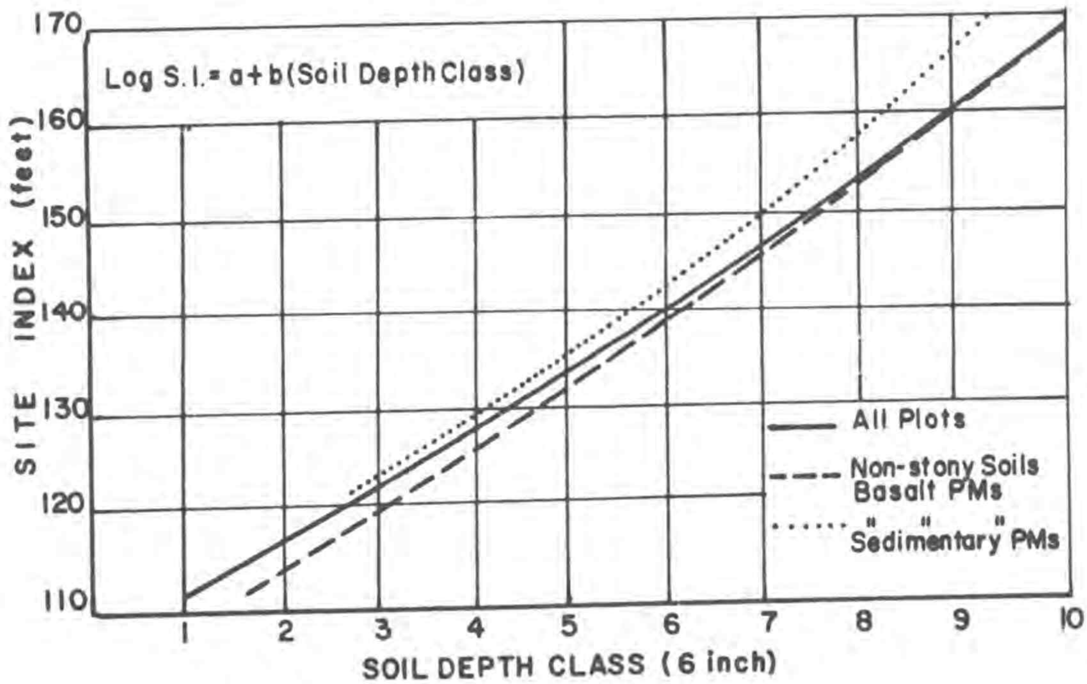

Figure 3b.
Relation of Site Index to Soil Depth Class by Parent Material Group.

There were not enough plots in this soil group to determine whether the depth to mottled horizons was significantly related to the bulk density of the subsoil but the few plots in this group indicated that such a relationship may exist. When all plots were considered together there was a significant decrease in site quality with increasing density of the B. (Figure 4)

Moisture equivalent values of the B horizons were significantly related to site quality for all well-drained soils and for the non-stony soils from igneous parent materials. Poorly drained soils were not included in this analysis since the horizons with maximum clay content in this group were often the A_3 horizons.

Scattergrams of the clay content of the B_2 horizon as it affected height growth suggested that a curvilinear expression would best indicate the effect of this soil variable. Results of the analysis were not significant when the clay factor was considered alone. (Table 2) Investigation of the effects of the clay factor by multiple regression analysis will be discussed later.

The effect of slope on site index values was tested separately for different aspect classes. (Figure 5) (Table 3) On north and south aspects steeper slopes were significantly associated with better site quality. This relationship also held for all plots considered together.

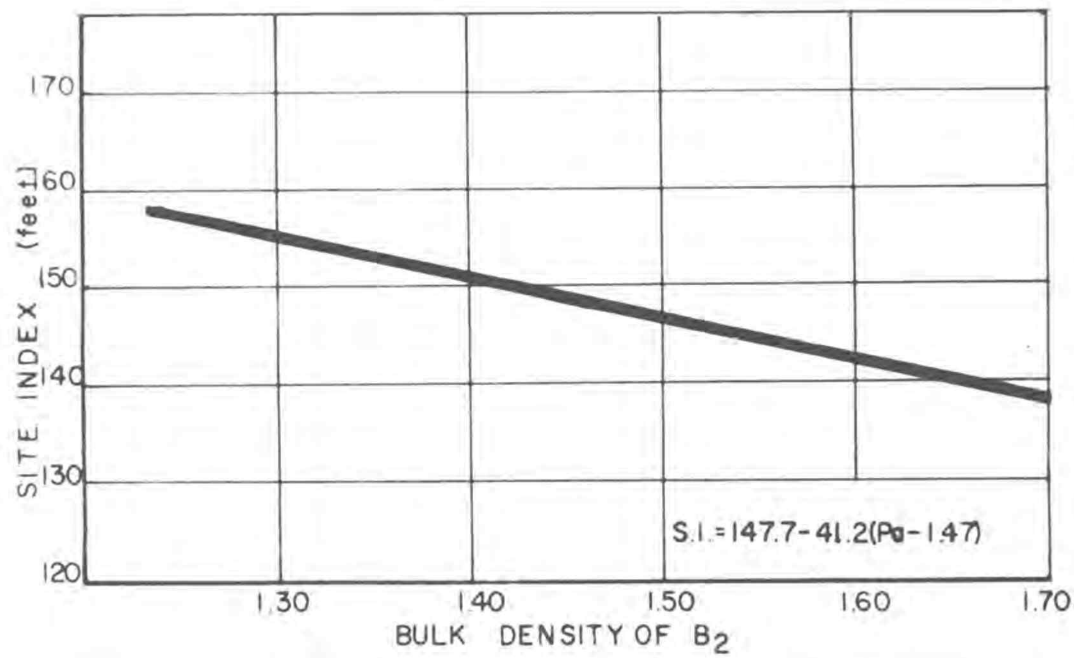

Figure 4.

Relation of Site Index to Bulk Density of B_2 Horizon.

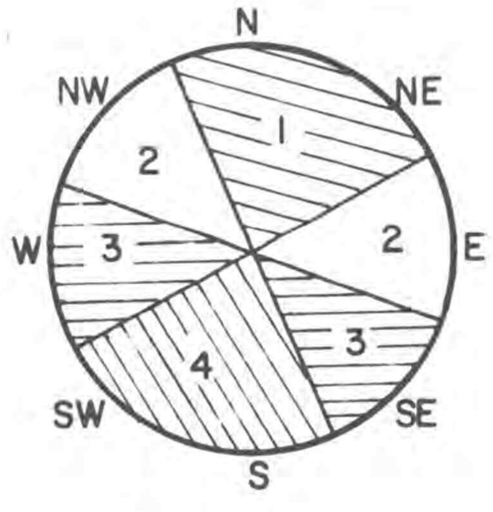

Figure 5.

Designation of Numerical Aspect Classes for use in regression analysis.

Table 1

Results of Regression Analysis of Site Index as Affected by Soil Depth

Regression Equations:

1: Site Index = a + b(soil depth in inches)

2: Log_{10} Site Index = a + b(soil depth class)

Soils Group	d.f.	b	r	F
(Regression Equation 1)				
All Plots	94	0.95	0.62	59.22**
(Regression Equation 2)				
All Plots	91	0.020	0.68	75.80**
Non-stony Soils Sedimentary PMs	29	0.022	0.63	17.5 **
Basalt PMs	38	0.020	0.76	5.07**
Stony Soils	24	0.003	0.08	0.14

**Significant at the 1% level

Table 2

Results of Regression Analysis of the Effects of Subsoil Properties on Site Index Values

Regression Equations:

1: Site Index = a + b(Bulk density of B_2 horizon)

2: Site Index = a + b(Moisture equivalent of B_2 horizon)

3: Site Index = $b_o + b_1$(% clay in B_2) + b_2(%clay)^{2}X 10^{-2}

Soils Group	b	d.f	r	F
Equation 1:				
All Soils	-41.19	86	-.245	4.39*
Non-stony, Well-Drained Soils Basalt PMs	-67.82	29	-.435	6.75*
Sedimentary PMs	-9.71	27	-.059	0.94
Stony Soils	-42.36	19	-.441	4.58*
Poorly Drained Soils	+15.09	5	-.239	0.305
Equation 2:				
All Well-Drained Soils	-1.53	79	-.390	14.01**
Non-stony Soils Basalt PMs	-1.75	29	-.438	6.83*
Sedimentary PMs	-0.81	27	-.277	2.22
Stony Soils	-0.98	19	-.356	2.60

Equation 3:	b_1	b_2	R^2	R	F
All Soils	-2.90	2.65	0.017	.129	0.73

**Significant at 1% level
*Significant at 5% level

Table 3

Results of Regression Analysis of the Effects of Slope on Site Index, by Aspect Groups. (Fig. 6)

Aspect Group	Mean Site Index	b	d.f.	r	F
1 (N, NE)	164.5	.792	13	.564	6.07*
2 (NW, E)	152.3	.332	24	.407	1.85
3 (W, SE)	145.0	.128	21	.118	0.29
4 (S, SW)	142.7	.791	27	.527	10.36**
All Aspects	147.1	.439	91	.333	11.38**

**Significant at 1% level
*Significant at 5% level

Multiple Regression Analysis of the Effects of Soil and Site Factors

The influence of single soil and site factors on the growth of timber is often obscured by the associated influences which modify the effects of the factor being investigated. A multiple regression technique was utilized to examine simultaneously several of the site variables which appeared to be most closely correlated with site quality. Including stand age as one of the independent variables permitted the use of present tree height as the dependent variable. The analysis was not dependent on use of the standard site curves as were the single factor analyses.

Six site factors were evaluated by this method. Soil depth had been shown previously to be significantly related to site quality. The clay content of the B_2 horizon was used as a measure of the stage of development of the profile. This seemed to be the most quantitative expression of the nature of the subsoil. A scattergram had shown that a curvilinear function most clearly expressed the relationship between the per cent clay in the B_2 and site index. This factor was then entered as per cent clay and as $(\text{per cent clay})^2$. (Table 4) Stony soils and those with a fractured bedrock base at less than 60 inch depths had been shown by preliminary tests to vary markedly from the general relationships found true for non-stony soils.

(Tables 1 and 2) All profiles were grouped into stoniness classes according to the per cent volume of stones estimated for the entire profile. Effects of other profile features on the ability of the solum to store moisture were expressed in inches of "available moisture" to a depth of 50 inches or to some horizon which limited root penetration. Aspect classes were assigned according to Figure 5. Average annual rainfall for each plot was estimated to the nearest 5 inch class from an isohyetal map. (42, map)

Computation of the regression analysis was performed by the Statistical Service, Oregon Agricultural Experiment Station.

Soils depth, available moisture, per cent clay in the B_2 and the stoniness class of the soil were found to be significantly related to the rate of height growth. (Table 5)

The various "b" values for the different independent variables were applied to the data from the individual plots and the standard error of estimate for a single plot determined. The standard error of the logarithm of total height was found to be plus or minus 0.0943 or 2.23 per cent. After conversion to actual height this represents a negative error of 25.4 feet and a positive error of 31.5 feet.

A prediction formula for determining site index from the factors which were shown by the analysis to be

Table 4

Soil and Site Factors Entered in Multiple Regression Analysis

Equation:

$\log_{10}$ Height = b_1 (Aspect class) + b_2 (Annual precipitation)

+ b_3 (Soil depth class) + b_4 (Inches of available H_2O)

+ b_5 (% clay in B_2) + b_6 (% clay) X 10^{-2}

+ b_7 (Stoniness class) + b_8 (1/Age)

x_1 (Aspect class)

1, N, NE 2, NW & E 3, W & SE 4, SW, S

x_2 (Average annual precipitation)

Multiples of 5 inches per year, range 50 to 85 inches.

x_3 (Soil depth class)

Depth class	1	2	3	4	5	6	7	8	9	10
Depth(inches)	12-18-24-30-36-42-48-54-60-66 +									

x_4 (Available moisture in inches)

Inches of available H_2O = Σ (Moist. Equiv. - 15 Atoms. %) X(bulk density) X(depth) of each horizon from 0 to 50 inches

This value corrected for % stones by volume and depth of rooting zone if less than 50 inches.

x_5 (Per cent clay in B_2 horizon)

Value for clay as determined from mechanical analysis.

x_6 $(x_5)^2 X 10^{-2}$

x_7 (Stoniness class of soil profile)

Stoniness class	1	2	3	4	5
% stones in profile (vol.)	10%	25%	50%	75%	

x_8 (1/ Age)

Reciprocal of the average age of 5 dominant and codominant trees.

Table 5

Results of Multiple Regression Analysis of the Relation between Soil and Site Factors and the Rate of Height Growth of Douglas-fir

Source of Variation	d.f.	M.S.	F	Effect (b)
Aspect	1	.00023	N.S.	.0016
Ave. Annual Precipitation	1	.00133	N.S.	.0005
Soil Depth	1	.21311	22.41**	.0252
Available Moisture	1	.03981	4.19*	.0120
% Clay in B_2	1	3.18811	335.50**	.0700
$(\%Clay)^2 x\ 10^{-2}$	1	2.28154	240.52**	-.0642
Stoniness Class of Profile	1	.14134	14.86**	.0417
Age -1	1	.26435	27.79**	-9.3836
Error	85	.00951		

Multiple R^2 = .9980

Multiple R = .9990

**Significant at 1% level
*Significant at 5% level

significantly related to the rate of height growth was constructed:

$$\text{Log}_{10} \text{ Site Index} = -.0585 + .0252 \text{ (Depth)} + .0121 \text{ (Available moisture)} + .0700 \text{ (\% clay in } B_2) - .0006 \text{ (\% clay)}^2 + .0417 \text{ (Stoniness class)}$$

The site index values derived by solving this equation for each plot were compared to the site predictions taken from the standard curves. Of the 93 plots tested 16 were found to deviate widely from the site index values predicted by the standard curves. For several of these plots, located on fractured bedrock, the site index was underestimated due to the incorrect evaluation of soil depth. Soils in high rainfall areas did not show the reduction in height growth rates which was characteristic of the average of all soils where the B horizon contained a high content of clay. The mean deviation between site index values estimated from the two methods was 21.9 feet. The standard deviation of an individual estimate was 24.3 feet. The accuracy with which the formula predicted site index values varied between soils of different series. These variations are discussed in the section Site Quality Variations between Soil Series.

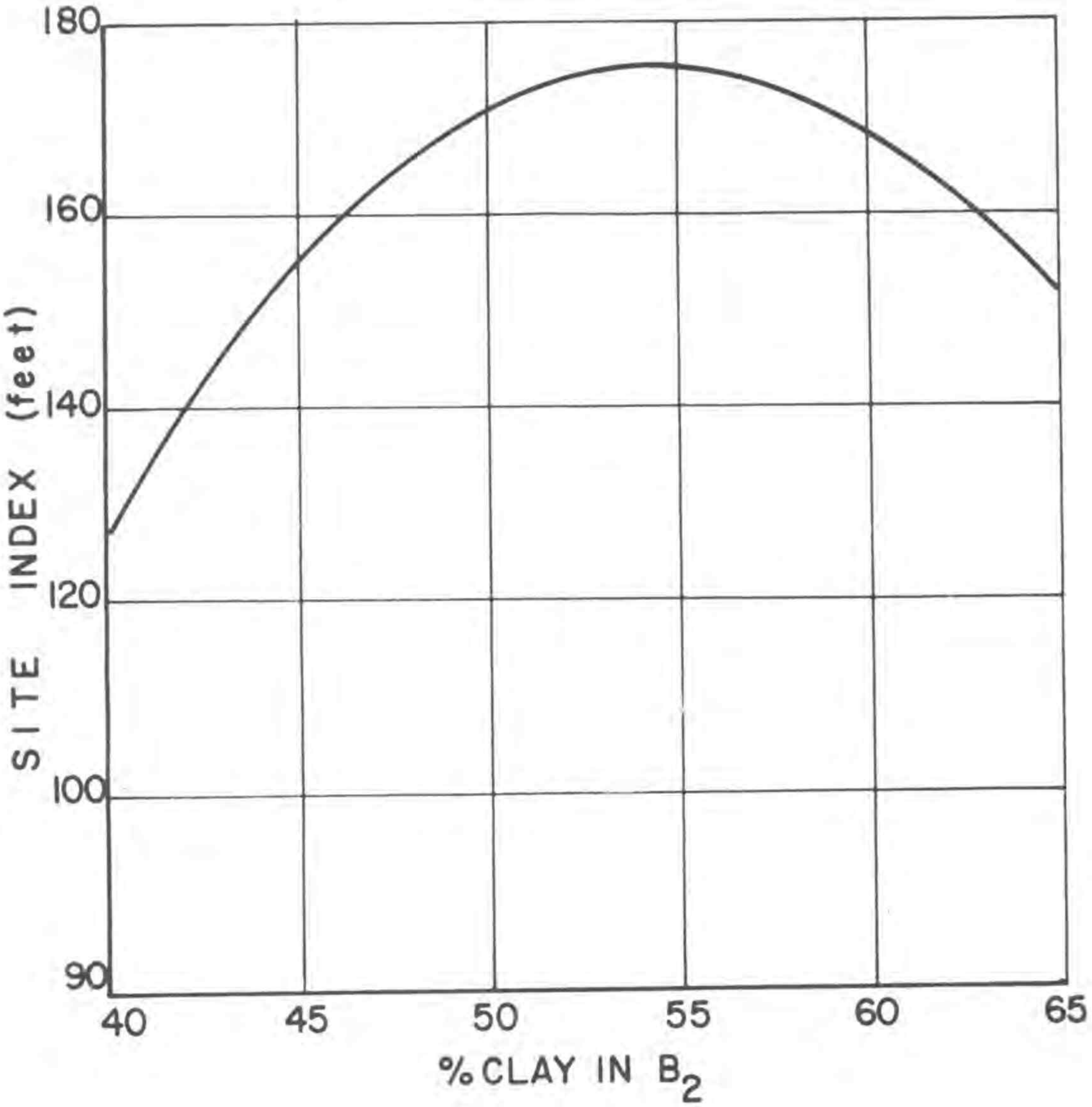

Figure 6.

Relation between Site Index and % Clay in B_2 Horizon (after compensating for other soil and site factors).

The Effects of Soil Depth

The significant relationship shown by the multiple regression analysis for the soil depth factor corroborated the results of the single factor analysis. The slope of the regression line for the effect of soil depth represents a difference in site index values of approximately 65 feet between the two extremes in soil depth measured.

Effects of Clay Content of the B_2 Horizon

The multiple regression analysis showed that the clay content of the subsoil was very significantly related to the rate of height growth when other soils variables were considered. The value of this factor in the prediction formula was limited to soils having between 45 and 60 per cent clay in the B_2. Soils with clay values outside this range were erroneously predicted since the effect of this factor was too strong. The variation to be expected in site index with changing clay content of the B_2 horizon between the limits listed above are shown in Figure 6.

The Effect of Stoniness

There was a significant increase in site quality with increasing stoniness of the overall profile. It has been indicated earlier that there is a tendency on the part of the field observer to underestimate the depth of soil available to tree roots when there is an appreciable content of stones in the subsoil. The relationship indicated by the regression coefficient is at least in part a correction of these errors. In clayey soils the presence of a moderate amount of gravels and stones may be beneficial to the development of tree roots through possible improvements in permeability, aeration and the rate at which the soil will warm up in the spring. The last benefit mentioned would be likely to result in longer growing seasons only at the higher elevations in the study area. It would normally be expected that the presence of a large volume of stones in a soil would decrease the volume of soil capable of storing water for use by the vegetation during the dry summer months. In this analysis the available moisture variable was corrected for the effect of stone volume, thus, this aspect of the effect of stones on tree growth was removed.

Aspect and Annual Precipitation Variables

The effects of aspect and precipitation differences are reflected in such soil characteristics as depth and the degree of horizon development. The soil depth, clay content of B_2 and available moisture variables in the formula expressed these characteristics. When the rate of height growth was corrected for the effects of these soil factors the remaining variations were not sufficiently related to aspect and rainfall differences to be significant. The precipitation estimate as taken from a generalized isohyetal map does not include the effects of local topography. There is little doubt that the effects of precipitation would be more clearly related to site quality if a larger geographical area were studied in which there was a wider range in rainfall.

Effects of the Range of Available Moisture

The calculated range of available moisture for each horizon when combined to derive the inches of moisture in each profile includes the effects of the stoniness of the component horizons. As entered in this analysis the depth of the profile was considered to extend only to the limit of common root penetration. Since the regression formula also included a depth variable and a stoniness variable, the exact interpretation of the significant relationship between available moisture and site index is obscure.

Site Quality Variations between Soil Series

A grouping of plots by soil series indicated that a general increase in average site value coincided with the progression from soils typical of low rainfall regions, such as the Dixonville series, to the soils of higher precipitation regions, represented by the Hembre, Astoria and Blachly series. (Tables 6 and 7) A wide variability in site values was evident on all series. Only the Dixonville soils seemed to be distinctly differentiated from the other soils on the basis of series alone.

Many of the subsoil characteristics which are related to the rate of tree growth are also utilized in differentiating soil series. (See Appendix I for differentiating characteristics for series listed) The soils of the Sites and Dixonville series characteristically have firm, strong structured B horizons. The Aiken soils have a less friable subsoil than the Hembre series formed on similar parent materials. Those soils with the more easily penetrated B horizons show deep root system development and are high quality sites. Utilization of the series divisions alone could lead to serious errors in estimation of site quality since several of the series were not adequately sampled in the field study. There is no reason to suspect that the Hembre and Blachly series are generally any poorer Douglas-fir sites than the soils of the Astoria series, although the data from the present study would indicate that this is true. In the case of the Hembre soils, all plots sampled were either shallow soils or on exposed upper slope positions. Where this series is found in favorable slope and aspect positions site index values for deep Hembre soils might reasonably be expected to equal those of the Astoria series.

Table 6

Distribution of Sample Plots by County, Soil Series and Site Class

County	Soil Series	Site Class I	II	III	IV	V	Not Used	Total
BENTON								
	Aiken		8	12	2		1	23
	Hembre			1				1
	Dixonville			8	6	3		17
	Blachly		1					1
	Astoria	2	3					3
	Melbourne		1					1
	(high rainfall) Sites		4	1				5
	Melbourne (low rainfall)		1	1				2
<u>County Total</u>		2	18	23	8	3	1	55
POLK								
	Aiken		3	13			1	17
	Hembre		2					2
	Dixonville			1	1			2
	Blachly		2	3				5
	Astoria		1					1
	Melbourne		3	1				4
	(high rainfall) Sites		1	6	1		1	9
	Melbourne (low rainfall)				1			1
<u>County Total</u>			11	24	3		2	41
<u>All Plots</u>		2	30	47	11	3	3	96

Table 7

Average Site Index Values and Ranges of Site Indices for Sample Plots according to Soil Series, Stoniness and Soil Drainage

Soil Series	No. of Plots	Mean Site Index	Range of Site Index Values
Soils formed on Basalt Residuum:			
Aiken	38	145.3	123-175
Non-stony soils	26	151.7	125-175
Stony soils	11	144.4	126-164
Imperfectly drained	1	123.0	
Dixonville	19	120.4	92-145
Non-stony soils	4	125.0	103-136
Stony soils	9	127.9	109-145
Imperfectly drained	6	107.0	92-132
Hembre	3	155.2	134-175
Non-stony soils	2	154.5	134-175
Stony soils	1	157.0	
Soils formed on Sedimentary Rock Residuum:			
Astoria	6	178.5	164-196
Non-stony soils	5	179.0	164-196
Stony soils	1	176.0	
Sites	13	152.5	125-180
Non-stony soils	12	151.2	125-180
Stony soils	1	168.0	
Melbourne (high rainfall)	5	164.3	138-178
Blachly	6	152.0	130-165
Non-stony soils	4	155.0	145-165
Stony soils	2	147.5	130-165
Melbourne (low rainfall)	3	145.3	123-168
Plots not used	3		
All Plots	96	146.2	92-196

Table 8

Clay Content of the B_2 Horizon for the Average of all Soils by Soils Series compared to Average Site Index Values

Soil Series	Range of % clay in B_2	Average % clay in B_2	Average Site Index
Hembre	41-51%	47.0%	155.2
Aiken	30-65	52.4	145.3
Dixonville	41-59	48.7	120.4
Astoria	43-54	48.0	178.5
Melbourne (high rainfall)	40-51	46.6	164.3
Blachly	37-58	47.2	152.0
Sites	44-76	61.0	152.5
Melbourne (low rainfall)	34-50	44.3	145.3

Table 9

Mean Site Index from Prediction Formula compared to Site Index from Standard Site Curves, by Soil Series

Soil Series	Number of Plots	Mean SI (std. curve)	Mean SI (formula)	Mean Error
Hembre	3	155.2	149.7	23.7
Aiken	38	145.3	141.1	21.6
Dixonville	19	120.4	125.5	15.4
Astoria	6	178.5	164.3	25.5
Melbourne (high rainfall)	5	164.3	150.4	28.4
Blachly	6	152.0	148.0	14.2
Sites	13	152.5	128.7	27.6
Melbourne (low rainfall)	3	145.3	134.7	38.0
All Soils	93	146.2	138.6	21.9
	Standard Error of an Individual Estimate			24.3

Average per cent clay of the B_2 horizons of all soils by series (Table 8) shows that Aiken and Sites soils in the middle range of precipitation, that is, 55 to 65 inches per year, have the highest clay accumulation in the subsoil. The prediction formula developed from the results of the multiple regression analysis gave the best site index estimates on these soils (Table 9) since the majority of the sample plots fell within these soil-rainfall areas. Soils of the Blachly and Hembre series generally showed a high percentage of clay throughout the profile. In these soils the B horizons were friable and deeply penetrated by roots. Additional information on these soils of the high rainfall regions will be required to determine the relationships between subsoil characteristics and the rate of height growth. On the Dixonville and "low rainfall Melbourne" soils of the dry, exposed southern slopes and fringes of the forested area the influence of soil depth is most evident. A few soils of the "low rainfall Melbourne" series with clay loam subsoils were underestimated by the prediction formula due to the very low clay content of the B horizon.

Analysis of Subordinate Vegetation Data

Estimated average crown cover and frequency of occurrence of all shrubs and the most common forb species were calculated. Average cover and frequency percentages were then calculated for all plots within 10 foot site index classes. (Tables 10 and 11) These data were based on the general cover estimates made on each sample plot and, thus, do not represent sufficiently detailed study for more than superficial consideration of the vegetation composition for the various site classes.

A general increase in the per cent cover of all shrub species combined was noted to correspond to decreasing site values. The average cover of each site class interval was plotted. (Figure 7) A regression of site index on the per cent shrub cover resulted in a significant regression coefficient of -.287. The decrease in crown closure of the tree canopy with decreasing site quality (Table 10) may explain the higher density of shrubs found on these poorer sites.

Sword fern (Polystichum spp.) has been reported to be indicative of high quality Douglas-fir sites in British Columbia (40, pp. 35-36) and in Washington and Oregon. (4, pp. 438-441) Salal (Gaultheria Shallon) and Oregon grape (Berberis spp.) are most common on sites of intermediate quality. Data from the present study shows that these relationships are also true of the Polk and Benton Counties area. Forbs which require moist, cool habitats such as wild lily-of-the-valley (Maianthemum bifolium), Vancouveria hexandra and Trillium species are most frequent on plots in the higher site classes. The average per cent cover contributed by grasses and oak increases on dryer warmer locations which usually have low productivity ratings. Poison oak (Rhus diversiloba) is common throughout the study area, appearing on 35 per cent of all plots and on plots of all site classes from I to V. The cover value of this species increases generally on sites of low productivity.

Many of the stands sampled which showed the lowest rates of growth occurred on southern exposures where Douglas-fir stands had become established in the past 40 to 60 years. Several of the characteristic species of the oak-grass vegetation type still are evident on these locations. The effects of the conifer forest overstory are probably not yet complete, therefore, further detailed study of changes in species composition and in the relative importance of these species as the stands become mature and are harvested will be necessary before the permanent vegetation characteristics typical of these sites can be defined.

Table 10

Average Per Cent Cover by Tree and Shrub Species for Sample Plots by 10 Foot Site Index Classes

Species	Site Index Class 180 +	175	165	155	145	135	125	115	105	95
Pseudotsuga menziesii (Mirb.) Franco.	83	82	68	76	65	64	67	65	48	68
Abies grandis Lindl.		1	2	1	4	5	6			
Quercus Garryana Dougl.	tr	tr	1	1	1	1	3		15	1
Acer macrophyllum Pursh.		11	4	2	3	2	1		10	
Alnus rubra Bong.	—	1	1	tr	tr	1	tr	—	—	—
Total Tree Cover	83	95	76	80	73	73	77	65	73	69

Table 10 (cont'd)

Average Per Cent Cover by Tree and Shrub Species for Sample Plots by 10 Foot Site Index Classes

Species	Site Index Class									
	180+	175	165	155	145	135	125	115	105	95
Rubus spp.	2	1	3	1	1	7	3	2	5	12
Corylus rostrata Ait.	7	3	6	4	5	4	6	15	10	12
Symphoricarpos mollis Nutt.	1	1	1	5	1	1	1			1
Holodiscus discolor(Pursh)Maxim.	1	1	1	1	2	1	1	5	2	5
Rosa spp.	1	tr	1	1	1	1	2	10	2	6
Rhus diversiloba T. and G.	1	tr	2	6	1	3	9		20	12
Rhamanus Purshiana DC.	tr	tr	tr	tr			tr			
Amelanchier florida Lindl.						1	1			1
Acer circinatum Pursh.	2	1	2	tr	4	1	3			
Gaultheria Shallon Pursh.	tr	15	8	1	11	13	3	80		
Cornus Nuttallii Aud.		tr	4	1	1	2	2			
Loniceria spp.	tr	tr	1	1	1	1	3	2		1
Berberis aquifolium Pursh.		4	1	1	5	5	tr	5		
Vaccinium parvifolium Sm.		tr	tr	tr	tr					
ALL SHRUBS	13.7	27.6	30.1	21.6	31.8	39.8	33.3	100.0	35.5	51.0

Table 11

Frequency of Occurrence of Herbaceous Species on Sample Plots, by 10 Foot Site Index Classes

Species	Site Index Class									
	180+	175	165	155	145	135	125	115	105	95
Polystichum spp.	100	71	59	62	80	58	67		50	100
Pteridium spp.	100	71	82	69	40	67	42	100		100
Vancouveria hexandra(Hook)Morr. & Dec.	67	14	29	15						50
Adenocaulon bicolor Hook.	67	43	41	23	47	42	33			100
Campanula spp.	33	43	18	31	53	25	8			
Trilium spp.	67	29	12		27	8				
Goodyera dicipiens(Hook)St. J. & Const.	33	14	35	23	27	25	50			
Trientalis europaea L. var. *latifolia* Torr.	33	57	59	38	47	17	50	100		100
Galium spp.	100	71	59	62	80	58	67		50	100
Maianthemum bifolium DC.	67		18	15		8	8			
Fragaria spp.		29	6	23	13		8		50	
Asarum caudatum Lindl.		14	12							
Hieracium spp.		14	29	8	53	33	33		50	50
Lupinus spp.			12	15	20	17	17	100		
Grasses (not differentiated)	67	29	65	77	73	58	58	100	100	100

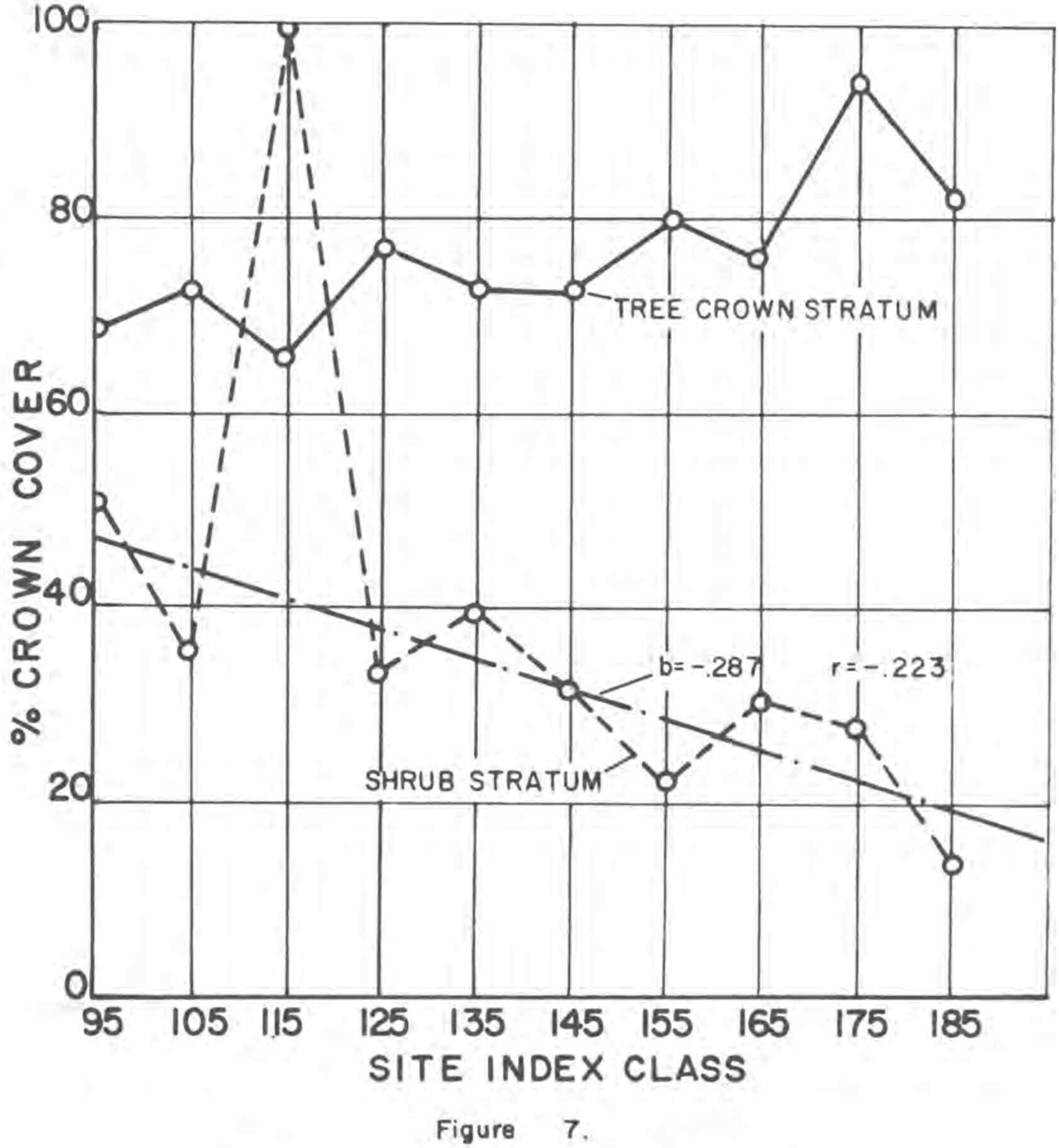

Figure 7.

Average Crown Cover for Trees and Shrubs

(sample plots grouped by 10 ft. S.I. classes).

IDENTIFICATION OF SITE QUALITY UNDER FIELD CONDITIONS

Various soil properties have been shown to have significant relationships to site quality. Some of these properties can be evaluated readily in the field and, thus, are useful indicators of the relative potential of denuded soils as timber sites. Site index has been shown to vary predictably according to changing values of soil depth, stoniness, slope and the characteristic vegetation on each area. Other soil properties such as the amount of available moisture in the rooting zone, the moisture equivalent and bulk density of the sub-soil horizons, while related to the site value, can not be estimated under field conditions except as the observer can relate known values for similar soils to those being investigated. The clay contents of the B horizons have been shown to have a significant relationship to site quality only when the other soil properties mentioned above are also considered.

In practical field use the identification of the soil series would be useful if these series can be identified from soils maps of the area or by identification of the soil from profile characteristics. These characteristics include such soil properties as firmness and distinctness of structure of the B horizon, properties which are related to the bulk density and clay content already shown to be related to site quality. Classification of soils at the series level also considers the climatic differences, which, while not directly related to site quality by the present study, are known to influence productivity of timber stands. The mean site indices for the different series sampled have been shown to be greater on soils which are characteristic of areas of high annual precipitation. Thus, classification of soils upon which potential site quality is to be determined, makes it possible to rate each area, indirectly, according to the effects of some of the separate properties which cannot be considered individually.

The use of soil series classification together with soil depth was concluded to be the best initial step toward evaluation of site potentials for denuded soils. Where depth phases of the soil series are delineated on soils maps, site quality for a given area may be determined directly from such maps. Relationships of soil series and depth classes to site index were calculated using the regression coefficients for the effect of depth determined for each parent material group. (Table 12) When only the series and depth factors are considered the estimation of site index on the 93 sample plots included in the analysis resulted in an average error in site prediction of 10.78 feet. The standard error of a single prediction was plus or minus 13.41 feet; thus, use of these two factors permits estimation of the correct site class in about 70 per cent of the plots.

Modifying factors which will alter the capability of the site include stoniness, aspect, slope and the characteristics of the subsoil which affect root penetration. Stoniness has been shown to result in a common underestimation of the soil depth. It does not seem wise to apply the fixed positive stoniness class regression coefficient determined by the analysis of this variable, since different observers would be expected to vary widely in their estimates of the free rooting depth in soils where stones were common. Perhaps an arbitrary addition of one six inch depth class, when in doubt as to whether the apparent depth to stones is the true limit of rooting space, would result in a nearly accurate depth evaluation for most observers.

Aspect and slope effects become most important where exposed positions are combined with shallow soils to result in low site values. Slight concavities in moderate and gentle slopes and broad ridge-tops with less than 10 per cent slope are areas in which impeded soil drainage might be suspected. These soils usually show mottled sub-soils and increasing pH with depth. Care should be taken in such soils to determine the depth of common root

Table 12

Expected Site Index Value of Soils by Series and Depth Classes

Soil Series	Soil Depth Class 1	2	3	4	5	6	7	8	9	10
<u>Non-stony Soils</u>	Depth	18"	24"	30"	36"	42"	48"	54"	60"	66"+
Hembre					141	148	155	162	170	178
Aiken			121	126	133	139	145	152	160	168
Dixonville	95	103	110	116	121	127	133	139		
Astoria				143	150	158	166	175	184	194
Melbourne (high rainfall)				126	133	140	147	155	163	171
Blachly						136	144	151	159	167
Sites					132	138	146	153	161	169
Melbourne (low rainfall)				120	126	134	140	147		

<u>Stony Soils</u>

Where possible utilize road cuts and windfalls to determine the extent of root penetration into the subsoil. If it is necessary to rely on auger determinations of soil depth, an arbitrary addition of six inches (one depth class) should be made to the average depth to rock of several borings.

Note: Underlined site index values indicate the extent of plot data.

penetration. This depth should be considered to be the soil depth for use of Table 12.

The value of vegetation composition as a means of identifying site quality of cleared land will depend on the disturbance history of the area. Unless there has been repeated burning the shrub species which were present prior to cutting should still be evident. Sword fern is a common species on moist, cool, cutover areas such as would be expected to have high site capability. Grasses and poison oak quickly reinvade areas on hot, dry slopes where moisture in the summer is limited. Lesser vegetation common to the old-growth forest may still be found under dense clumps of shrubs and can serve as a clue to the nature of the original forest. The shrub and forb species found can serve as additional indicators of site value and may be used, together with topographical features, to generalize upon the evaluations of site quality made in specific locations.

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APPENDIX I

SOIL SERIES DESIGNATIONS UTILIZED IN SOIL-SITE STUDY

The forested soils of the Oregon Coast Range have been differentiated into soil series but they are not yet clearly defined. The series recognized at the present time and utilized in the present study are briefly described below. The criteria for separation of the series in each parent material group and a typical profile description for each series are listed.

SOILS FORMED ON IGNEOUS PARENT MATERIALS (BASALT)

Aiken Series

The Aiken series includes soils of a wide range of characteristics from shallow rocky soils with fractured basalt fragments common in the subsoil to deep, clayey soils with moderate B development. The following profile description was made on a soil which supported a stand of Douglas-fir with a site index value of 150 feet. The soil occurred on a 15% slope near a ridge-top at 1280 feet elevation.

A_1 0-6 inches 2.5 YR 3/4 gravelly silt loam texture, containing many shot; strong, fine granual structure; loose consistence when moist, slightly sticky and plastic when wet. pH 5.8

A_3	6-16	Faces of peds 2.5 YR 3/4, interior of peds 2.5 YR 3/6; clay loam texture with common shot; mixed strong, medium and fine subangular blocky and fine granular structure; larger peds firm, granules friable when moist, sticky and plastic when wet; pH 5.2.
B_1	16-24	2.5 YR 3/6, clay texture, shot common; moderate, medium subangular blocky structure, breaking to finer aggregates; friable when moist, sticky and very plastic when wet; pH 4.5.
B_{21}	24-34	2.5 YR 3/6; containing spots of charcoal; clay texture; moderate, medium angular blocky structure; friable when moist, sticky and very plastic when wet; pH 4.5.
B_{22}	34-46	Same as above but with texture becoming more silty with depth; structure also weaker with depth.
B_3	46+	5 YR 4/6; silty clay texture; weak fine blocky structure; friable to very friable when moist, sticky and plastic when wet; pH 4.5.

Hembre Series

The Hembre soils are differentiated from Aiken soils on the basis of more brown and yellowish brown colors, lower pH values throughout the profile, from 5.1 to 5.5 at the surface to about 4.5 in the subsoil. The B horizon is somewhat less firm, the structure being less distinct. This profile was described on a plot which had a site index of 134 feet. There was reason to believe that this did not represent the true capability of the site since the stand showed signs of wind injury. The soil profile was described on a 25% north slope at 1450 feet elevation.

A_1	0-8 inches	5 YR 3/3; loam, with strong subangular blocky and granular structure; friable when moist, slightly sticky and slightly plastic when wet; pH 5.2.
B_1	8-20	5 YR 5/6; silt loam; moderate fine and medium subangular blocky structure; friable when moist, sticky and plastic when wet; pH 5.0.
B_2	20-40	5 YR 5/8; silty clay loam; weak medium platy structure breaking to irregular subangular blocks; friable when moist, slightly sticky and plastic when wet; pH 4.2.
B_3	40-47	5 YR 5/8-6/8; silt loam; weak fine subangular blocky structure; friable when moist, slightly sticky and plastic when wet; pH 4.0.
C	47+	5 YR 6/8; silt loam; very weak structure, very friable.

Dixonville Series

This series has been described in Douglas County, Oregon, where it is found on warm south slopes supporting oak-fir stands. Similar soils in the Benton-Polk county area were assigned to this series. Dixonville soils are differentiated from the Aiken series on the basis of higher pH, more blocky structure of the B horizon, and generally shallow rocky subsoils. Subsoil colors are usually less red than in the Aiken. This profile was described at 1100 feet elevation on a 30% southwest slope. The site index of the Douglas-fir stand was 122 feet.

A_1	0-5	7.5 YR 3/2; silty clay; moderate medium crumb structure; friable when moist, sticky and plastic when wet; pH 6.0.
A_3	5-12	7.5 YR 3/2; silty clay; strong irregular crumb mixed with moderate fine subangular blocks; friable when moist, sticky and plastic when wet; pH 5.8.
B_1	12-20	5 YR 3/3; silty clay; moderate fine subangular blocky structure; friable when moist, sticky and plastic when wet; pH 5.8.
B_2	20-25	5 YR 3/4; gravelly clay; (70% of soil volume basalt fragments); firm when moist, sticky and plastic when wet; pH 5.8.

B_3 25-30 5 YR 3/4; gravelly clay; (75% of soil volume stones) moderate coarse subangular blocky structure, peds becoming less distinct and finer with depth; firm when moist, sticky and plastic when wet; pH 5.6.

SOILS FORMED ON SEDIMENTARY ROCK PARENT MATERIALS

Astoria Series

Soils of the Astoria series are found in the study area only at higher elevations and in protected locations. These soils are very acid throughout the profile, have deep A horizons, are generally yellowish brown in the subsoil and have soft to very friable subsoil consistence. This profile description was written for a soil found at 1700 feet elevation on a 10% northwest slope. A Douglas-fir western hemlock stand on the area showed a 164 foot site index for the fir growth.

A_1 0-11 inches 7.5 YR 3/2; silt loam, shot very common; strong medium and fine granular structure; friable when moist, slightly sticky and slightly plastic when wet; pH 5.0.

A_3 11-18 10 YR 3/3; gravelly silt loam, shot common; moderate medium and fine granular structure; friable when moist, slightly sticky and plastic when wet; pH 5.0.

B_{21}	18-26	7.5 YR 4/4 silty clay; moderate fine subangular blocky structure; friable when moist, sticky and very plastic when wet; pH 5.0.
B_{22}	26-31	10 YR 5/4; silty clay; weak medium angular blocky structure; consistence as above; pH 4.8.
B_{23}	31-45	10 YR 5.6; silty clay; weak fine blocky structure; pH 4.7.
B_3	45-60+	10 YR 5/6; gravelly, silty clay; very friable; pH 4.7.

Blachly Series

Blachly soils are similar to the Astoria series except that the colors are red, generally in the 5 YR-2.5 YR range of hues. Blachly soils sampled in the present study were differentiated from the soils of the Sites series on the basis of lower pH values, and more friable B horizons with less distinct structure. The following profile description was written for a soil found at 1400 feet elevation on a 50% east slope. The site index for the stand was 165 feet.

A_1	0-8 inches	5 YR 4/3; silt loam with common shot; strong fine granular structure; loose when dry, slightly sticky and slightly plastic when wet. pH 5.6.

A_3	8-15	5 YR 4/4; silt loam, shot common, strong fine granular and weak medium subangular blocky structure; very friable when moist, slightly sticky and plastic when wet; pH 5.3.
B_1	15-34	5 YR 5/6; silt loam; moderate fine granular and weak medium subangular blocky structure; very friable when moist, slightly sticky and plastic when wet. pH 5.0.
B_2	34-43	5 YR 4/6; stony, silty clay loam, (50-60% stones); weak medium subangular blocky structure; very friable when moist, sticky and plastic when wet. pH 5.0.
B_3	43-55	5 YR 4/4; stony silt loam; (75% stones); weak fine angular blocky structure; very friable when moist, slightly sticky and plastic when wet. pH 4.2.
C	53-60+	7.5 YR 4/4; mixed areas of tuffaceous sandstone bedrock and stony loam; other characteristics of soil as above.

Melbourne Series

The Melbourne Series as described and applied in previous mapping operations has included a wide range of brown colored forested soils. Timber site quality was found to range widely over the different soils included in this broad series. The series was divided into two classes on the basis of surface soil characteristics and other features reflecting differences in rainfall. These subdivisions are described below.

(High Rainfall Melbourne)

These soils are similar to the Astoria soils in color but are not as strongly acid and have firmer B horizons with stronger structure. The profile description below was written on a soil found at 425 feet elevation on a 55% northeast slope. The site index of the stand was 166 feet.

A_1	0-3 inches	7.5 YR 3/2-10 YR 3/2; silty clay loam; strong medium granular structure; friable when moist, slightly sticky and plastic when wet; pH 5.8.
A_3	3-15	7.5 YR 3/2; silty clay loam; moderate medium subangular blocky structure; consistence as above; pH 5.2.
B_{11}	15-23	7.5 YR 3/2; silty clay; structure and consistence as above; pH 5.0.
B_{12}	23-32	7.5 YR 3/2; silty clay; moderate coarse subangular blocky structure, friable when moist, sticky and plastic when wet; pH 4.8.

B_2 32-38 10 YR 4/4; silty clay; weak coarse angular blocky structure, slightly firm when moist, sticky and plastic when wet; pH 5.0.

B_3 38-44 10 YR 4/3; gravelly silty clay; weak medium subangular blocky structure; friable when moist, sticky and plastic when wet; pH 5.0.

C 44-60+ 10 YR 5/4; silty clay loam; moderate fine and very fine subangular blocky structure; soft when moist, slightly sticky and slightly plastic when wet; pH 4.8.

(Low Rainfall Melbourne)

The low rainfall division of the series was differentiated on the basis of surface characteristics such as hard A horizons, lack of shot in the surface soil, and pH values similar to the Dixonville soils. The profile described below was examined at 450 feet elevation on a 20% east slope. The site index of the stand was 123 feet.

A_1 0-4 inches 5 YR 3/3; silty clay; strong medium and fine granular structure; slightly hard when dry, slightly sticky and plastic when wet; pH 6.2.

B_1 4-14 5 YR 3/3-3/4; silty clay, moderate medium and coarse subangular blocky structure; hard when dry, sticky and plastic when wet; pH 5.5.

B_2 14-19 5 YR 3/4; gravelly clay; moderate, medium and coarse, subangular blocky structure; firm when moist, very sticky and plastic when wet; pH 5.2.

C-Dr 19-40+ 10 YR 7/6; very stony clay loam; mixed bedrock materials to 40 inches plus (over 75% stones); moderate medium angular blocky structure; very firm when moist, very sticky and plastic when wet; pH 5.0.

Site Series

Soils of the Sites series, like the Blachly soils, are red to yellowish-red in color (mostly 2.5 YR and 5 YR hues). These soils resemble the Aiken soils except for the differences in parent materials. Subsoils of the Sites soils are firm and tend to be appreciably higher in clay content than the surface horizons. These soils are less acid than those of the Blachly series. The following profile description was written for a soil found at 450 feet elevation on a 12% northeast slope. The young stand on this area showed a site index value of 150 feet.

A_1 0-6 inches 5 YR 4/4; silty clay loam; strong fine subangular blocky structure; friable when moist, slightly sticky and plastic when wet; pH 6.0.

A_3	6-13	2.5 YR 4/4; clay loam, moderate medium and fine subangular blocky structure; friable when moist, becoming firm to hard upon drying, slightly sticky and plastic when wet; pH 5.6.
B_1	13-23	2.5 YR 3/6; clay loam; moderate fine subangular blocky structure; friable when moist, sticky and plastic when wet; pH 5.2.
B_{21}	23-30	2.5 YR 4/6; with black streaks of manganese stains; clay; moderate medium subangular blocky structure; firm when moist, sticky, very plastic when wet; pH 5.2.
B_{22}	30-40	2.5 YR and 10 YR 4/6; gravelly clay loam; moderate medium subangular blocky structure; very firm when moist, containing hard granules; pH 5.0.
B_3	40-55+	5 YR 5/6 to 7.5 YR 5/6; silty clay; weak irregular subangular blocky structure; friable when moist, sticky and plastic when wet; pH 5.2.

APPENDIX II

Timber Stand and Soils Information
from Individual Sample Plots

Location	Average Age	Average Height	Effective Depth	% clay in B_2	Aspect-Slope %	Stony[1] Class
AIKEN SOILS:						
S35 T10 R5	70 yrs.	125 ft.	60 in.	45%	SE-25%	2
S21 T10 R5	152	196	60	45	NW-45	1
S3 T11 R5	69	124	33	35	S-10	4
S3 T11 R5	24	43	48	52	W-25	2
S29 T12 R6	49	95	39	60	N-15	1
S4 T11 R5	105	164	45	53	W-40	3
S36 T10 R5	94	146	43	46	SE-75	4
S36 T10 R5	42	99	60	65	NE-10	1
S32 T12 R6	49	107	39	64	E-15	2
S1 T12 R7	73	131	45	62	E-15	1
S4 T11 R5	90	135	38	59	NW-27	1
S9 T13 R6	42	97	60	65	S-40	1
S15 T13 R6	37	94	60	59	E-40	1
S23 T14 R7	79	136	56	32	SE-50	4
S7 T12 R6	72	130	62	60	NE-15	1
S18 T12 R6	75	129	42	59	S-20	3
S26 T7 R6	64	116	50	39	N-30	3
S2 T8 R6	70	133	33	56	E-15	3
S21 T7 R6	63	118	60	57	S-20	1
S22 T7 R6	81	136	62	59	E-20	2

[1]Stony classes as in text: 1 = less than 10%, 2 = 10-25%, 3= 25-50%, 4= 50-75%, 5= over 75% of soil volume composed of stones.

Timber Stand and Soils Information
from Individual Sample Plots

Location	Average Age	Average Height	Effective Soil Depth	% clay in B_2	Aspect-Slope %	Stony Class
AIKEN SOILS (cont'd)						
S21 T7 R6	130 yrs.	157 ft.	45 in.	55%	S-35%	2
S9 T7 R6	68	116	52	32	W-70	3
S5 T10 R5	66	138	55	62	N-15	1
S32 T6 R6	59	103	57	61	NW-15	1
S9 T7 R6	63	135	62	46	NW-40	1
S4 T7 R6	54	104	45	30	SE-60	4
S22 T7 R6	84	135	66	62	NE-15	1
S29 T10 R5	98	165	50	48	E-5	1
S3 T8 R6	61	134	55	55	E-20	1
S21 T7 R6	65	127	50	53	SE-25	1
S21 T7 R6	133	162	45	50	N-20	2
S32 T6 R6	55	94	45	50	N-20	2
S1 T12 R7	75	136	50	62	S-30	1
S15 T13 R6	40	93	45	54	E-40	1
S3 T11 R5	70	127	38	38	SE-15	4
S4 T11 R5	87	118	26	55	NW-20	1
S36 T10 R5	89	122	45	51	SE-40	2

Timber Stand and Soils Information
from Individual Sample Plots

Location	Average Age	Average Height	Effective Soil Depth	% Clay in B_2	Aspect-Slope %	Stony Class
HEMBRE SOILS						
S4 T9 R6	42 yrs.	108 ft.	60 in.	51%	NE-25%	2
S2 T13 R7	107	138	40	49	N-25	2
S30 T8 R6	58	118	60	41	SW-25	2
DIXONVILLE SOILS						
S17 T11 R5	67	113	55	49	W-35	1
S17 T11 R5	39	89	55	43	NE-30	2
S32 T10 R5	100	111	17	59	SW-5	1
S32 T10 R5	99	103	26	53	W-10	1
S9 T11 R5	101	132	50	47	E-15	2
S17 T11 R5	67	100	40	42	SW-30	1
S17 T11 R5	66	111	50	44	NW-30	1
S32 T10 R5	100	92	18	59	Level	1
S32 T10 R5	94	107	32	49	W-35	2
S32 T10 R5	70	104	40	48	S-30	4
S19 T10 R5	96	126	45	50	W-50	4
S9 T10 R5	69	111	55	49	NW-25	2
S18 T10 R6	101	147	45	50	S-15	3
S15 T10 R5	101	140	45	42	SW-50	3
S15 T7 R6	86	121	35	41	SW-15	1
S15 T7 R6	89	117	40	41	Level	4

Timber Stand and Soils Information
from Individual Sample Plots

Location	Average Age	Average Height	Effective Soil Depth	% Clay in B_2	Aspect-Slope %	Stony Class
DIXONVILLE SOILS (cont'd)						
S32 T10 R5	97 yrs	92 ft.	20 in.	49%	Level	1
S32 T10 R5	104	94	17	59	SW-5%	1
S35 T10 R5	69	99	35	45	SW-30	4
ASTORIA SOILS						
S16 T12 R7	96	162	66	54	NW-5	1
S17 T8 R6	67	136	66	54	W-40	1
S27 T11 R7	70	167	66	47	E-55	1
S8 T11 R7	37	97	50	46	S-25	2
S8 T11 R7	36	98	40	44	S-30	3
S27 T11 R7	72	167	66	43	NE-60	2
BLACHLY SOILS						
S19 T8 R6	63	117	60	58	W-20	1
S28 T8 R6	40	99	55	52	NE-10	1
S25 T10 R7	67	145	66	46	SE-65	1
S30 T8 R6	60	123	55	37	SW-25	1
S6 T9 R6	105	167	55	44	E-50	3
S19 T8 R6	58	100	45	46	W-25	3

Timber Stand and Soils Information
from Individual Sample Plots

Location	Average Age	Average Height	Effective Soil Depth	% Clay in B_2	Aspect-Slope %	Stony Class
MELBOURNE (high rainfall) SOILS						
S23 T14 R7	76 yrs.	157 ft.	66 in.	40%	SW-80%	1
S28 T9 R6	38	117	66	41	NE-60	1
S1 T10 R6	69	118	55	51	S-30	2
S1 T10 R6	71	143	66	51	SW-20	1
S1 T10 R6	72	141	50	50	SE-45	1
MELBOURNE (low rainfall) SOILS						
S24 T14 R6	45	109	66	50	SW-20	1
S24 T14 R6	45	93	50	34	W-20	1
S14 T8 R6	101	124	30	49	E-20	5
SITES SOILS						
S19 T13 R5	35	77	55	74	NE-10	1
S11 T14 R6	65	146	66	49	E-15	1
S34 T13 R6	43	100	55	59	N-15	2
S23 T14 R7	52	120	55	64	SE-15	1
S23 T14 R7	73	146	60	76	SE-20	2
S19 T8 R6	80	122	45	50	SW-30	2
S11 T8 R6	45	108	45	46	SE-20	2
S7 T8 R5	66	127	50	61	SE-20	1
S14 T8 R6	98	134	50	53	SE-25	1
S11 T9 R6	70	106	56	69	NW-20	2

Timber Stand and Soils Information
from Individual Sample Plots

Location	Average Age	Average Height	Effective Soil Depth	% Clay in B_2	Aspect-Slope %	Stony Class
SITES SOILS (Cont'd)						
S12 T9 R6	70 yrs.	123 ft.	50 in.	60%	SE-30%	2
S29 T6 R6	47	102	45	44	E-30	1
S12 T9 R6	64	111	56	43	SE-30	2
PLOTS NOT UTILIZED DUE TO POOR STAND DATA						
S27 T10 R6	59	78	45	26	S-60	4
S13 T8 R7	162	127	35	61	SW-30	1
S3 T8 S6	59	100	40	66	NE-20	1