THE INFLUENCE OF TIME OF ESTABLISHMENT AND COMPETITION ON THE COMPARATIVE HEIGHTS OF SECOND GROWTH DOUGLAS-FIR TREES

by

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INTRODUCTION

Once considered only in the aggregate, the individual forest tree is today receiving much attention. Comparative size differences that may possibly reflect inherent differences in growth rate are under close scrutiny by the forest geneticist. In his selection of these individuals for breeding purposes, a quantitative estimate of the size variation contributed by each of the many influences involved would be a distinct aid.

The size of any particular individual in an even-aged stand[1/] depends upon its genetic capacity for growth, the amount of competition upon it and other physical factors of its immediate environment (figure 1). In an even-aged stand, however, small differences in age may also exist between individuals and contribute to variation in size. This study was made to measure the variation in heights of associated second growth Douglas-fir trees (*Pseudotsuga menziesii* (Mirb.) Franco) attributable to differences in age and the modifying effects of neighboring trees.

1/ Even-aged is defined as a stand in which relatively small age differences exist between trees, the maximum difference being usually 10 to 20 years. Society of American Foresters. Forest Terminology. Washington, Society of American Foresters, 1958. 97 p.

Figure 1. Can the height superiority of the tallest Douglas-fir be attributed largely to greater age?

REVIEW OF THE LITERATURE

Even before a stand closes there may be some variation in size of individuals due to inherent differences in growth rate and local variations in site factors. When stand closure takes place and competition for crown space or root space occurs, the stand begins to differentiate regardless of how favorable conditions may be (67, p. 325). This division of even-aged stands into size classes as a result of an unequal growth rate by the individuals has been termed an "expression of dominance" (21, p. 1).

Selection for the most vigorous trees in timber marking or for scientific purposes today consists mainly of choosing the largest individuals consistent with quality. These are trees that have made superior volume growth in comparison with average trees on the same site. Need for a more sound basis is obvious. It is through studies of natural variation that the range of variation for traits of economic importance can be established in commercial species, and the proportion contributed by the environmental factors as opposed to genetic factors be learned (22, p. 2). Information on the nature and extent of the variability throughout the range of a species is an initial step in a tree improvement program (52, p. 225). As an example of this approach, it has been concluded that the rate of growth in Norway spruce (<u>Picea</u> <u>abies</u> (L.) Karst.) is due less to genetic constitution and more to environmental factors than previously supposed (40, p. 185).

The size of each particular individual composing an even-aged stand depends upon: (1) its inherent capacity for growth, (2) the degree of competition, and (3) the favorableness of its particular location (67, p. 324). Once in a dominant position in the stand, the height of individuals in relation to their neighbors has been found to be maintained or increased by a high proportion of those trees studied (30). Supporting observations have been made over a six year interval in young Scotch pine (Pinus sylvestris L.) (72) and over twenty years in second growth Douglas-fir (73, p. 47). Diameter growth rate is much higher on these larger diameter trees (62, p. 567) and the economic considerations of this point to the forest manager have been pointed out (23, p. 1). The primary thinning agent in natural stands is mutual competition which seldom causes loss of the dominant trees (73, p. 46). The two factors of age variation and stocking which contribute to an early expression of dominance and hence to an early concentration of growth on the larger individuals have been studied in Eastern white pine (Pinus strobus L.). On low quality sites, it was found that small age differences between individuals may contribute to a poor expression of dominance. On better sites of higher fertility, there was normally good stand differentiation irrespective of age variation. High densities of stocking were likewise not inhibitory on site qualities greater than 60. High density was detrimental if site was low and where it affected all stems alike, stagnation sometimes occurred (21, p. 12-13).

Although other factors may be involved, an interplanting experiment in slash pine (Pinus elliottii Engelm.) seems to demonstrate that age differences as small as one year may work to the detriment of the younger trees (10, p. 1). A wide spacing seems indicated for Douglas-fir if complete suppression of interplanted individuals is to be avoided (41, p. 8).

Age differences between trees may vary widely among stands of Douglas-fir in the Northwest. On the Yacolt burn in south central Washington, 60 to 70 percent of the trees in 10-year-old stands were found to be the same age. This was apparently due to the large amount of seed which germinated the first year after the fire (34, p. 19-20). On an area in the University of British Columbia school forest which had reburned one year after it had been logged and burned, age differences of dominant and codominant trees on plots (size unspecified) range up to 16 years (61, p. 427). In this latter case, there would probably be little difficulty in determining the older trees by their greater size, but in less extreme examples it is only speculatory whether the small age differences among naturally established Douglas-fir would contribute to stand differentiation in favor of the older trees. Data from many plots over western Washington and Oregon indicate that dominants are almost invariably older (38, p. 1). This observation is based on rather inexact age determinations however. If the advantage of greater age is to be maintained, uninterrupted growth would seem requisite. Results of investigations into the progress of growth after open-growing Douglas-firs reached 4.5 feet showed that it was very regular on some areas but highly variable on others. Graphic portrayal of total height over actual age (to 15 years) for areas of regular growth gave a very smooth curve when the points were connected (27, sub. 7.24, proj. 1).

Although it would seem comparatively easy to go into an "even-age" stand and by means of systematic measurements and age determinations select those trees in the stand largest for their age, after field trial this method was judged not feasible for Ponderosa pine (Pinus ponderosa Doug.). An increment boring into the tree center at ground line did not give exact age due to difficulty in counting the rings near the center (6, p. 293). The presence of distinct zones or false rings between true annual rings of conifer seedlings has been reported to cause considerable difficulty in estimations of age with a hand lens. To determine seedling ages under these circumstances, examination of thin sections with a microscope or low power photomicrographs is useful (16, p. 220). One must avoid suppressed trees if accurate age counts are desired since even vigorous species like Eastern white pine may sometimes fail to show evidence of annual ring formation. This was found only if there had been a period when growth of the tree was greatly suppressed (68, p. 418).

Studies have indicated the impossibility of using ring counts other than those made at ground level to determine total age. Wider variations in age are found as the height of the sampling is increased (13, p. 31). This eliminates the possibility of adding a constant age to a determination made at an easily accessible point. Basal sections or V-cuts have been made to determine total ages (35, p. 698), but where the felling of the study trees is impossible, cores containing the tree center must be taken with an increment borer.

One conceivable source of error in age determination could be the formation of a false ring in young trees during the mid-summer bursting of buds. This is often referred to as "lammas" growth. It has been found, however, that growth of lammas shoots is not accompanied by formation of a half-year's wood. Only in the case of shoot growth after a true dormancy is a false ring boundary formed (14, p. 13). Douglas-fir near Oxford, England, continued radial growth for seven to eight weeks after winter buds had formed in June or July (17, p. 14). This would indicate some independence of the two growth actions.

The advantage of a small age difference might largely be negated over a span of time if the detrimental effect of surrounding trees on the growth of individuals compared was unequal. Such an influence is commonly termed "competition."

Competition can be said to be in effect when there is a combined need in excess of supply of such factors as water, nutrients, or light. Competition usually begins when the immediate supply of a single necessary factor falls below the combined needs of the plants. The outcome is usually indicated by the relative size of the contestants, although the direct action of physical factors may quite independently determine the outcome (19, p. 317-330).

Light is popularly credited as the principal factor in competition determining dominance between trees in the forest stand although the relations between light and height growth are very complex (8, p. 317-318). Moreover, some foresters believe that root competition for minerals and moisture may be as significant as light since the quantity and quality of light falling on an area is about the same regardless of the site quality (2, p. 639).

Whether light or root competition or both is involved, decreased competition resulting from wider spacings in plantations of red pine (Pinus resinosa Ait.) (15, p. 565) (65, p. 317), jack pine (P. banksiana Lamb.), pitch pine (P. rigida Mill.) and Eastern white pine (4, p. 14) has brought about greater height growth of these species. Opposing these observations, greater height has been related to more dense stands for red pine (58, p. 370) and for short leaf (P. echinata Mill.) and loblolly pine (P. taeda L.) (69, p. 766). In Douglas-fir spacing tests, trees at wider spacings began to show height growth superiority at an age of 12 years (37, p. 6). The difference between the average height of trees at the extreme spacings (4 x 4 and 12 x 12 feet) continued to widen (50, p. 3), (24, p. 17), and at a total age of 34 years the average tree height at the 12 x 12 spacing was 20 feet or 153 percent greater than the 4 x 4 spacing. A difference of nearly the same magnitude was shown when the average height of dominants and codominants at the two spacings was compared (56, p. 2).

Although a great deal has been learned from this spacing study, the question remains as to the growing space a given size Douglas-fir tree under given site conditions requires to be free from competition. The inability of soil moisture to move through soil at high moisture tensions indicates that the extent of a tree's root system must be the limit of its influence on water and soil nutrients. Shape of the tree's root system then also determines the area over which it receives and exerts competition. Although competition for light may under some circumstances extend to greater distances, competition measurements in the present study were made with root competition in mind. The horizontal root system has been credited with deciding the underground struggle between trees (44, p. 210).

Four stages of root development have been pictured in a forest tree stand, the first stage being "free growth." This is followed by "root invasion" when root systems begin to intermingle and invade adjacent tree root areas. The third stage is "root competition" when the "root capacity" of the soil is reached and one or more vital components becomes scarce. The fourth stage is the release from competition as some competitors die (25, p. 161). In even-age stands it is during this third stage of competition when large differences in the size of trees appear, probably reflecting cramped growing space, and it is probably then that foresters are inspired to devise "measures of competition" to evaluate the effects of the differential stocking which they observe. If the competition area is assumed to be circular, such a measure must be influenced by the extent and symmetry of the trees' root systems.

Soil, biological, and physical factors combine to determine the shape of a conifer root system. Studies of the root systems of black spruce (Picea mariana (Mill.) B.S.P.), tamarack (Larix laricina (Du Roi) Koch), white spruce (Picea glauca (Moench) Voss), and jack pine on both clay and sandy soils in Manitoba indicate the general character of these conifer root systems is rigidly controlled in some species but has more flexible habit in others (54, p. 233).

It was found in Germany that soil texture, aeration, and water capacity were the most important factors influencing root form of Douglas-fir from a coastal seed source. On fine-textured soils with poor aeration and high moisture in the upper levels, root systems were shallow and consisted almost entirely of laterals. On coarse-textured soils with good aeration but low moisture capacity, compact, bushy, tap-root systems developed. Where there were medium-textured soils, the root system was intermediate to these two forms. The

10- to 45-year-old plantation trees studied showed a tendency toward the flat lateral system with age (28) (29). Root development in several other species has been found more extensive on sandy soils than on heavy soils (49, p. 1014).

Where influencing factors do not interfere, the horizontal root system of Scotch pine develops symmetrically (45, p. 341). However, such factors as a strong prevailing wind, moisture supply, amount of plant nutrients, and the presence of other plants were found to influence the direction of development. Lodgepole pine (*Pinus contorta* Loud.) trees show little symmetry of development due to their affinity for decaying roots present in the soil and the mechanical obstruction of rocks. They did not appear to modify their symmetry in response to root competition from other plants with only one exception (53, p. 462). The direction of the horizontal roots of one jack pine seemed little affected by the presence of other roots (18, p. 932). Surface roots of Scotch pine, however, develop best in the direction in which the smallest number of strange roots are encountered (45, p. 343).

While root systems are subject to much modification, in conifers the horizontal roots seem to extend some distance beyond the crown spread. Investigation of the roots of five Scotch pine trees ranging in age from 46 to 196 years old showed that the roots had extended beyond the crown at all stages of development, reaching a maximum ratio of four to five times branch length when the tree was of pole size (71). The ratio of root length to branch length in spruce varies from 1.6 to 1.9, being greater on more moist sites; for pine on the best sites the ratio is about two and on poor sites may be two to three (31). A jack pine of 10 inches d.b.h. in a medium dense stand on sandy soil developed a root system with an average maximum horizontal radius of 21 feet (18, p. 930). This would be approximately two times the diameter of the tree expressed in feet. Excavation of the tree of average diameter in a jack pine plantation at spacings of 2 x 2, 4 x 4, 6 x 6 and 8 x 8 feet showed a progressive increase in the average horizontal radius with a single exception when other vegetation was encountered (3, p. 27-29). When the roots of adjacent trees in red pine or jack pine plantations make contact, the lateral roots tend to turn downward (4, p. 2).

The number and size of roots and extent of root development seemed to be in proportion to tree size of jack pine as soon as soil moisture became a limiting factor retarding growth (3, p. 30). Likewise, poor development of tops has been associated with inferior root systems in pitch pine (49, p. 1014). The impact of competition on growth is summed up by the statement of J.H.G. Smith: "We need not examine many natural stands of Douglas-fir to see that the relatively free-growing trees are bigger and healthier than individuals that have endured moderate to severe competition" (60, p. 495).

PROCEDURES

The Study Areas

In choosing stands for study, principal considerations were age, stocking, and site quality. Root expanse in Scotch pine has been found to increase up to 70 years and in Norway spruce to 110 years (39, p. 67), but this is contradicted by the observation that the greatest expanse of dominant and codominant Scotch pine is reached at an early age (apparently about 20+ years) (70, p. 10). In Douglas-firs of the same crown class, root volume appeared to increase with age to at least 60 years which was the maximum age investigated (48, p. 21). With this consideration, stands of Douglas-fir less than 50 years of age were chosen since active and vigorous root growth in a growing stand brings about vigorous competition.

Stands of the same site class were sampled since many additional variables would be introduced if different site qualities were to be compared (47). Unthinned stands near normality on the basis of number of stems per acre served to make the competition measure comparisons between stands more meaningful. Areas sampled were located within the Voight Creek Experimental Forest near Orting, Washington, the Black Rock Experimental Forest near Falls City, Oregon, and the Adair Tract near Corvallis, Oregon. The characteristics of the three areas sampled are shown in Table 1. Although

Table 1. Characteristics of the Sample Areas[1/]

	- Location -		
	Voight Creek	Black Rock	Adair Tract
Site index	136	125	147
Number of plots	6	5	10
Number trees/plot	4	5	5
Average diameter breast high (inches)	9.6	10.2	7.6
Average age of dominants and codominants (years)	45.4	45.0	26.5
Average age all trees (years)	45.2	44.7	26.6
Range in age (years)	8	4	7
Average age range per plot (years)	4.2	3.2	2.3
Average height of dominants and codominants (feet)	89.2	81.2	57.5
Average height all trees (feet)	86.8	77.7	57.1
Standard deviation of height (feet)	12.8	8.4	4.8
Range in height (feet)	28	24	16
Average height range per plot (feet)	19.7	18.2	10.9

1/ For the opportunity to sample on these experimental forests, appreciation is expressed to the Pacific Northwest Forest and Range Experiment Station, the Oregon Forest Lands Research Center, and the Oregon State College School of Forestry.

the Adair Tract stand was younger than the other two, the slightly higher site quality was thought to have caused a more rapid stand differentiation and thus to have somewhat compensated for this age discrepancy.

In sampling, 1/100th acre plots (11.78 feet radius) were laid out at 2 chain intervals along compass lines of cardinal direction. This distance was judged great enough to remove any chance of trees from one plot affecting those on any other plot. At the Adair Tract where trees were smaller, this distance between plots was reduced to 1.5 chains. The five most vigorous trees with living tops were selected on each plot and designated "subject" trees between which comparisons would be made. All trees in the study were judged to be in the strong intermediate crown class or better.

A plot was rejected on the basis of either of two criteria specified prior to making the study.[1/] These plot rejection criteria were (1) if fewer than five trees of intermediate crown class or better were represented, or (2) if trees of species other than Douglas-fir were present. At the Adair Tract, plots were also rejected if any of the subject trees lay immediately adjacent to small scattered natural openings that occurred in the stand.

For each subject tree, measurement was made of d.b.h., height, age, and competition. D.b.h. measurements were made in inches and

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1/ Krueger, Kenneth W. The relation of age and competition to dominance in Douglas-fir. 5 p. Typed study plan dated Sept. 11, 1958. On file at U. S. Forest Service Puget Sound Research Center, Olympia, Washington.

tenths with a standard diameter tape. Heights were determined with a percent Abney level and chain. Age determinations and competition measurements are described below.

Age Determinations

Most age determinations in forestry work are made by boring a tree at some convenient point and adding a constant determined by the average number of years that a seedling on that site quality grows to reach that point. To determine total age accurately, however, a ring count must be made at ground level.

Age borings require a penetration of the stem to include the center. The words of Bauer emphasize that this is more easily said than done: "It becomes quite an art to find the center of a tree accurately when a complex of factors act all at once to shift it from its logical position" (9, p. 299). The following technique was devised as being most satisfactory to solve this problem.

At the base of the tree where the age was to be determined, a hole was dug sufficiently wide and deep to allow turning an increment borer when placed perpendicular to the trunk at ground level. Since a one-year-old Douglas-fir seedling including stem and root totals about eight inches in length (32, p. 130) (33, p. 52), a target height of four to five inches was assumed. A single boring destroys about one square inch of area from the standpoint of other borings, so a good indication of the exact center location is necessary to avoid ruining the age determination location by mere exploration in the target area. By boring with a standard 3/16-inch inside-diameter increment borer, the center of the tree was located about 12 inches above the ground line and followed by repeated borings down to the target area (Figure 2). Then, using an oversize 5/16-inch inside-diameter increment borer, parallel borings were made until the tree center was included in an extracted core.

The rapid growth of Douglas-fir in the region west of the Cascade Mountains leads to wide and distinct growth rings. However, it was found that rings near the center of the tree were difficult to distinguish even when viewed under 20 power magnification. This was apparently the difficulty experienced with ponderosa pine noted above (6, p. 293). To obtain accurate age counts, it was found necessary to take thin sections of the tree centers from cores previously softened by soaking in water. These sections were then moistened and stained lightly using a differential stain for spring wood suggested by Smith (59, p. 5). Viewed by reflected light at magnifications of 20X or 48X, the boundaries between rings were quite distinct. Once beyond the central five to eight rings, counting with low magnification on a smoothed surface was an easy matter.

Competition

Examples of several measures of competition have been cited in the literature. The density in number of trees per acre was used to measure the effect of stocking on the expression of dominance within white pine stands (21, p. 12). In another study, a competition

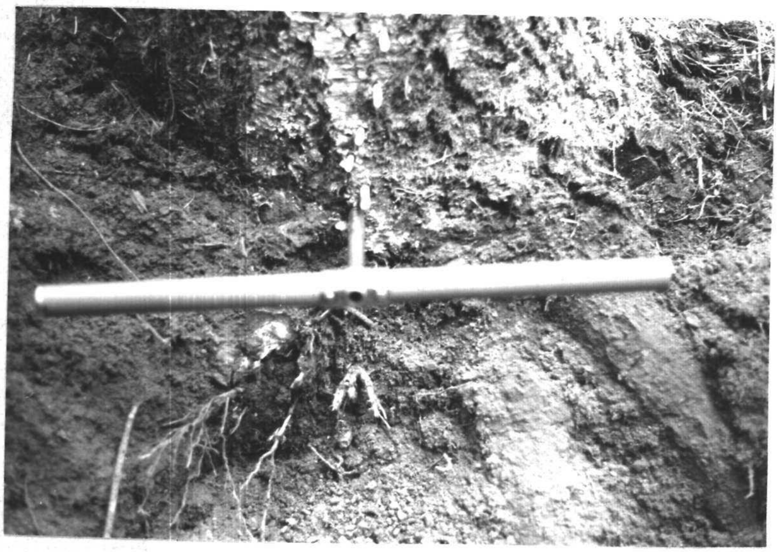

Figure 2. The increment cores show the repeated borings made in following the tree's center to ground level.

index was devised to measure the stand density and competition offered by trees of the same species on the height of balsam fir trees (26, p. 3). Directed somewhat more specifically toward a single tree was a study of the height of the tallest tree on a 20 x 20 foot square and the number of trees on the same square (58, p. 370). To measure the effect of spacing on vigor of individual white and Engelmann spruce trees, an encircling 12-foot radius circle was measured and the average number of trees within each of four diameter classes weighted on a volume basis was used as a competition factor. When related to 10-year height increment, a significant correlation coefficient of 0.69 was obtained (20, p. 30-31). To measure the theoretical growing space of "subdominant" *Pinus strobus* L. trees, the radius of a circle was calculated as the arithmetic mean of the distance from the center of the investigated tree to points on the lines between the trees and its neighbors, the positions of the points being determined by the proportion of subject tree diameter to diameter of the neighbor. A correlation coefficient of 0.82 was obtained for the relation of this growing space to basal area growth percent (74).

These measures of competition on individual trees all have one of two weaknesses. Those workers who have obtained the highest correlations between growth or size and competition have used the diameter of the subject tree to determine their measure of competition. If the size of the dependent variable, the subject tree, is allowed to influence the independent variable, for example a measure of growing space, then the independent variable is no longer independent and a rule of logic has been violated. The results are clearly not valid.

The second approach has been to use an area of constant size representing free-growing-space around the subject tree. Within this area centered around the subject tree, the number of trees, basal area or some other measure has been made. Because size of the area designated is inherently constant, however, no increase can be made even though the subject trees may vary in size due to other factors. Certainly a large tree requires a larger free-growing-space than a small one, at least until the root extension period has been completed.

Just as a tree can receive competition over a given area, it also must exert competition over that same area. With this approach as the key, the competition around a given tree can be measured using as a basis the assumed horizontal extent of the neighboring trees' root systems. While still subjective, the measure of competition derived remains an independent variable and the question of a constant free-growing-space regardless of tree size is avoided.

But at what distance does a neighboring tree cease to become a competitor? While the length of the horizontal root system would seem to be a satisfactory criterion, only inconclusive evidence is available on which to base a figure. As noted above, the extent of root development in jack pine has been found to be in proportion to the size of the tree when available soil moisture became limiting (3, p. 30). In Scotch pine, d.b.h. has been found to develop in the same manner as the length of the horizontal root system (45, p. 351). Consequently this easily obtained measure was assumed as proportionally indicating the extent of a tree's root system or its competition. It should be noted that d.b.h. is also closely related to crown width in Douglas-fir (11, p. 530). To represent the maximum distance at which a tree was considered a competitor, a "constant times d.b.h." type of spacing rule was selected. This type of spacing rule gives heavier weight to the larger competing trees (7, p. 650). Such a measure assumes a circular root habit, and although root systems are not strictly symmetrical, a circular form is approached more closely than any other shape (45, p. 341).

Diagrams of Douglas-fir root systems available are as yet too few to be of help in selecting maximum root extension (48, p. 31). Another possible approach is through the results of spacing studies, but lack of replication of spacings makes results questionable. It is of interest to note that the greatest difference in height growth in the Wind River spacing has occurred between the 8 x 8 and 10 x 10 foot spacings. If the average tree d.b.h. which was found at ages 22 and 27 is divided into the square spacing (10 feet/4.7 inches and 10 feet/6.4 inches), "constant times d.b.h." spacings of 2.1D and 1.6D are derived (24, p. 17) (50, p. 3). To obtain maximum growth of young Douglas-firs, spacing distances of 1.5 times d.b.h. on site quality 150 and 2 times d.b.h. on site quality 100 have been suggested (60, p. 496). Because the site quality in this study lies between these latter recommendations and is higher than that of the spacing study at Wind River, it was decided to collect data to allow analyses using 1.5, 1.75 and 2 times d.b.h. to define the maximum distance at which neighboring trees were considered competitors.

Accordingly, from each subject tree the distance to each surrounding tree and the surrounding tree's diameter were recorded provided that they were within 2 times their d.b.h. expressed in feet from the subject tree. Use of these measurements is explained in the section on analysis.

ANALYSIS

A total of 24 trees on 6 plots were examined at Voight Creek, 25 trees on 5 plots at Black Rock, and 50 trees on 10 plots at the Adair Tract. Although 5 trees per plot were originally measured at Voight Creek, poor condition of some increment cores necessitated that they be discarded. So that comparisons could be made on the basis of the same number of trees for each plot, the poorest core from the standpoint of making an age determination was removed from each of the other plots in this one area.

Analyses of the data were made to find the correlation of total age and height, competition and height, and the combination of these factors and height in each of the separate study areas. Before a linear regression analysis of the individual tree data within an area could be made, it was first necessary to adjust the tree heights on the individual plots to a common base.

Many factors including location with regard to slope (66, p. 724) affect tree height at a given age. Accordingly, the height of each tree on a given plot was expressed as a percentage of the average height of the trees on that plot. Comparison using percentages has been recommended in selecting genetically plus trees as it largely eliminates soil and site differences as variables (57, p. 6). Soil and site on the 1/100th acre plots were necessarily considered homogeneous. Since the range of ages tended to vary slightly between plots, the individual tree ages were also expressed as a percentage of the average plot age. Observations for the individual trees on plots within a given study area were then combined, and with x representing percent of average plot age and y representing percent of average plot height, linear regressions of the form $\bar{y}_x = a + b(x-\bar{x})$ were calculated (46). A previously plotted scatter diagram indicated a curvilinear relationship was not involved.

Using the Voight Creek data, several methods of expressing competition were explored, the sum of the figures derived from the neighboring trees being the competition upon the subject tree. Around each individual subject tree, the diameter and the distance to its neighboring trees were known provided they were within two times their diameter expressed in feet. These competition expressions were:

(1) summing the d.b.h.'s of the competing trees.

(2) summing the basal areas of the competing trees. This gave more weight to the larger competitors since their radius was squared.

(3) expressing each competitor as the tangent of the angle it subtended, that is, as its diameter in feet divided by its distance in feet from the subject tree. This measure gave greater weight to large competitors and to competitors nearby.

(4) converting the tangent in (3) to degrees and squaring it. This increased the weight given to larger or closer competitors.

The sum of individual competitors expressed the total competition exerted upon a subject tree. These competition measures were then converted to a percent of the average competition for trees on the individual plot. This was done since any site changes occurring between plots undoubtedly changed the influence of the same number of competitors. Combining the data for individual trees, linear regressions of the form $\bar{y}_x = a + b(x-\bar{x})$ were calculated where x represented percent of average plot competition and y represented percent of average plot height.

The sum of the tangents of the competitors and the sum of the basal area of the competitors were found to give the highest correlations. In calculations for the other two areas, only these two methods of handling the data were used.

To determine the distance within which a neighboring tree furnished significant competition, a series of linear regressions were calculated using the above measures of competition. Neighboring trees were included if they were nearer than (1) 1.5 times their diameter, (2) 1.75 times their diameter, and (3) 2 times their diameter expressed in feet. These regressions were of the form $\bar{y}_x = a + b(x-\bar{x})$ where x represented percent of average competition and y represented percent of average height. Since soils were slightly different between the three study areas and may have affected horizontal root spread, this series of regressions was calculated for all three areas.

RESULTS

Results of the regressions of percent of average age on percent of average height are shown in Table 2. At the Adair Tract stand, the average age difference which existed between the oldest and youngest tree on the plots was insufficient to compute a regression. At Voight Creek the b value of +1.00 indicates a one percent increase in age was on the average accompanied by a one percent increase in height. At Black Rock the influence of age was slightly greater, the b value being +1.47. The squared positive correlation coefficient, r^2, indicates 17.8 percent of the variation in height at Voight Creek is associated with differences in age. At Black Rock, 22.1 percent of the variation in height is associated with differences in age. In both areas, greater age and greater height are significantly related at the five percent confidence level.

Correlation coefficients of the two competition measures and the three competition distance criteria are shown in Table 3. For all areas tested the percent of average basal area at a maximum distance of 1.75 times the competitor's diameter correlated most closely with the percent of average height of the subject trees. At the Black Rock Forest this correlation was statistically non-significant however. The squared correlation coefficients indicate 33.7 percent of the variation in height is associated with differences in competition at Voight Creek, and 12.7 percent of the variation in height is associated with differences in competition at Adair Tract.

Table 2. Relation of percent of average age and percent of average height

Area	Basis (number of trees)	Regression analyses values: Regression coefficient, b	F	Squared correlation coefficient, r^2
Voight Creek	24	+1.00	4.96*	0.178
Black Rock	25	+1.47	6.52*	0.221

* Significant at the 5 percent confidence level

Table 3. Squared correlation coefficients (r^2) of the relation between percent of average height and the empirical competition measures

Competition Measure	Maximum Distance Criterion	- Area -		
		Voight Creek	Black Rock	Adair Tract
Basal Area of Competitors	1.5 D	.130	.020	.042
	1.75 D	.337**	.035	.127*
	2 D	.196*	.016	.048
Tangent of Competitors	1.5 D	.128	.001	.006
	1.75 D	.327**	.008	.011
	2 D	.175*	.006	.012

* Significant at the 5 percent confidence level
** Significant at the 1 percent confidence level

Since the competition measure at Black Rock Forest and the age of the Adair Tract stand contributed so little to the height variation, a multiple correlation analysis was calculated only for the Voight Creek data. In order to associate larger values for the measure of competition with shorter trees, the inverse of the original competition measure was calculated prior to expressing the measure in percent. The multiple regression equation was of the form $\bar{y}_x = a + bx_1 + cx_2$ where x_1 represented percent of average age, x_2 represented the percent of average plot competition, and y represented percent of average plot height. The squared correlation coefficient was 0.527 indicating 52.7 percent of the variation in height was associated with differences of age and competition at Voight Creek. The relationship was significant at the one percent confidence level.

DISCUSSION

In the case of natural regeneration, those individuals established first would seem to have a better opportunity to extend their roots into the largest territory. Root system superiority seems to be mandatory if a tree is to achieve and maintain dominance (64, p. 54). On the two areas in this study where small age differences between trees occurred, greater age and greater height were significantly related. It would seem logical that greater age differences might lead to a larger interval between comparative heights. However, at Voight Creek where the average age difference between the oldest and youngest trees on the plots was 4.2 years, a less significant relation between age and height was found than at Black Rock where using the same measure the average age difference was 3.2 years (Table 1). Graphic examination of the data indicated no curvilinear relationship was involved.

Another apparent inconsistency is that seven of the trees sampled at Black Rock were observed to have been broken at some time. Ice accumulation was probably the cause as damage seemed to have occurred about 15 years previously on all trees. Although this could possibly obliterate any age-height relationship, a significant correlation was found. Deen reports an experiment with 17-year-old Norway (red) pine where two years height growth was pruned from the top of selected trees and after only two years the loss in height growth was of no significance as far as releasing other trees. This was due to straightening up of lateral branches (21, p. 16).

At Adair Tract where the average age difference between the oldest and youngest trees on the plot was only 2.3 years, no relation between height and age was found. At the age of this stand, 26 years, small differences in time of establishment have already been obscured by other factors. Evidence of breakage could be seen in 3 of the 50 trees studied, one of these being the oldest tree sampled.

These correlations of age and height are somewhat lower than anticipated. Formation of a false annual ring during lammas growth seemed a possible source of error and warranted a supplementary investigation. To determine the effect of lammas growth on annual ring formation, an examination was made of 30 seedlings showing lammas growth and 20 seedlings with no lammas growth all collected from the Wind River nursery. Seedlings were collected in late August four weeks after watering had ceased. Microscopic examination of stained basal stem sections showed that while on a few of the seedlings the final 2-4 tracheids of the current year's growth appeared to be of slightly larger diameter than the preceding summerwood cells, no sharp boundary was formed and no confusion with an annual ring could result. This would seem to eliminate lammas growth as a source of error.

The empirical competition measure used in this investigation indicated its possible validity on two areas but failed almost completely on the third. Greater competition and decreased height were related in a highly significant manner at Voigt Creek and significantly at Adair Tract. At Black Rock almost no relationship was found.

Expressing competition, a highly complex relationship, as a single number can be but a crude approximation; how closely it approaches actuality is problematical. With no knowledge of many factors, e.g. the quantitative mineral and moisture requirements for growth of 40-year-old trees, and only limited knowledge of others, e.g. root spread, several assumptions in the competition measure may be weak. While as a general rule symmetry of roots may be assumed, several factors may have exerted a modifying influence. The effect of slope on symmetry may be the principal reason for the poor performance of the competition measure at Black Rock. Although no effect of a slope of 65 percent on the root morphology of Scotch pine has been reported (45, p. 344), an uphill/downhill asymmetry of both structural and absorbing roots has been found for Douglas-fir on a slope of 50 percent (48, p. 30). The majority of the plots at Black Rock were on steep slopes, but at Voight Creek the slopes were moderate and at Adair Tract very gentle.

The presence of other roots may also influence the symmetry of some tree root systems. Scotch pine roots develop best in the direction in which the smallest number of strange roots are encountered (45, p. 343). Douglas-fir roots, however, may grow almost under the stumps of neighboring trees (48, p. 25). Although plots at the Adair Tract were rejected if they fell immediately adjacent to small stand openings, openings nearby may have influenced asymmetry of root systems and lowered the efficiency of the competition measure, though not below a significant level.

That consideration of the distance of the competitors from the subject tree did not result in a stronger correlation may also indicate weakness of the competition measure. In all three areas a maximum and minimum distance in the definition of a competitor is shown by the variation in the squared correlation coefficients at the three distance criteria (Table 3). More exact distance considerations seemed to have little or negative effect as indicated by preliminary analysis and the lower correlation of the tangent compared to the basal area competition measure. Since at least some conifers seem capable of absorbing appreciable quantities of water through suberized roots (42, p. 40), it would seem that distance would be a strong factor since roots located anywhere within the horizontal root extent would be competitors for moisture. Absorption of lithium by Scotch pine, however, was found to be greater in a tree planted 2 meters from the absorption site than in a tree 0.5 meter away (1). The existence of root grafts which are commonly reported for Douglas-fir, undoubtedly further confuses this relationship. Failure of size or position of competing Monterey pine trees to exert an influence on release effects in thinning experiments has been attributed to root grafts (43, p. 21).

The squared multiple regression correlation coefficient for Voight Creek indicates 52.7 percent of the variation in comparative heights of individuals is associated with factors of age and competition. The question arises then—how is the remaining variation divided between genetic and environmental factors?

For slash pine on a 5-acre plantation of uniform site, after eight growing seasons the tallest trees were 30 percent taller than average. This variability was attributed to genetic factors (22, p. 38). Whether Douglas-fir is characterized by such variation in growth rate can only be speculated. It would seem more likely that at least an equal portion of the remaining variability is due to environmental factors. These may include competing vegetation which during the seedling stages may drastically reduce height growth. For 4-year-old Douglas-firs, trees in low brush were only 94 percent and in braken only 41 percent of the height of trees established on grass cover (63, p. 733). In another study braken was found to have suppressed young trees to 43 percent of normal height growth at six years of age (12, p. 21).

Browsing by various animals may seriously impede normal height growth. Douglas-fir trees were reduced to 29 percent of normal height at 10 years by severe browsing of grouse and deer (12, p. 21).

Height of moderately browsed individuals was 89 percent of unbrowsed Douglas-firs at 15 years of age (41, p. 4).

In addition to ice damage which has been previously mentioned, late or early frosts may cause extensive injury to new growth. Height growth may be checked or completely stopped for one or more years. If terminal buds are killed by frost, it may be three or more years before a leading shoot is formed (34, p. 5). Breakage by falling snags and bark has been cited as frequently occurring in Douglas-fir plantations (51, p. 55).

It may be concluded from this study that while differences in age and/or competition contributed significantly to height differentiation within the Douglas-fir stands sampled, factors of genetic constitution and of environment including unmeasured competition apparently contribute an equal or greater amount. While the competition effect remains a variable perhaps best evaluated by observation, in selecting "plus" trees from second growth stands of the site and age class studied consideration should be given the fact that approximately 20 percent of the observed variation in height may be due to small differences in time of establishment. If the positive b values of 1.00 and 1.47 can be considered typical for site III Douglas-fir of this approximate age range in the Pacific Northwest, their significance in choosing "plus" trees on the basis of superior height (or indirectly, volume) is considerable. For example, in a small group of trees whose average age is 40 years and average height is 80 feet, a 42-year-old tree (105 percent of average age) could be expected to show a height superiority of from 4 to 6 feet over the average as a result of greater age alone.

SUMMARY AND CONCLUSIONS

Presented are the results of a study made with the objective of measuring the variation in heights of individuals within small groups of second growth Douglas-fir attributable to differences in age and the modifying effects of competition from neighboring trees. Heights were measured with Abney level and chain, and total age was determined by ground level borings through the tree's center followed by microscopic examination of stained sections from the increment cores. Several methods of expressing competition were explored with relative success gauged by their correlation with present height. All data were converted to a percentage basis within plots and compared within areas using regression analyses.

Although limited by areas, age distributions and number of trees sampled, the following tentative conclusions seem indicated from the results obtained:

(1) When the establishment of a stand of site III Douglas-fir has occurred over a period of several years, those individuals established first may maintain their initial lead to a significant degree. This was found true to 45 years, the maximum age investigated. When the period of establishment is short, however, this relationship may not be evident at 25 years.

(2) If considered in a group of four to five individuals on a small uniform area and at an average age of 45 years, age

superiority is on the average related to height superiority with a regression coefficient of 1.0 to 1.5 when both age and height are expressed as percentages of the group averages. This indicates a one percent superiority in age is on the average accompanied by a 1.0 to 1.5 percent superiority in height.

(3) The empirical competition measures developed in this study could in several cases significantly relate lack of competition with greater height. While no consistently successful measure was devised, basal area of the competitors resulted in the highest correlations. It was found that a spacing factor of 1.75 D, where D equaled the competitor's diameter, seemed to best define the extent of competition.

The areal extent of conifer root systems and examples of empirical competition measures cited in the literature are reviewed. Effects of other environmental factors on height are discussed and the consideration of small age differences in choosing "plus" trees for genetics work is pointed out.

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