AN ABSTRACT OF THE THESIS OF

Samuel S. Chan for the degree of Master of Science

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Title: Competitive Effects of Overtopping Vegetation on Douglas-fir Morphology in the Oregon Coast Range

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The response of Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) saplings to various levels of brush overtopping when growing on three north-facing sites in the Oregon Coast Range was investigated for two consecutive years. A fisheye (hemispherical) photographic technique combined with a digitizing computer system was used to determine the percentage of visible skylight unimpeded by an overtopping brush canopy. Douglas-fir saplings were generally smaller in size under increasing levels of overtopping plant competition. The size of the basal stem diameter was most negatively affected and therefore the strongest indicator of possible competition from overtopping vegetation. A similar but weaker relationship was found for tree height. Subsequent-year (N+1) sapling height and basal stem diameter were strongly determined by the previous year's (N) sapling size and the degree of overtopping. Similar but more moderate relationships were found for predicting potential leader growth in Year N+1. Although strong empirical relationships were found, the exact mechanisms of competition were not identified. These results suggest that overtopping vegetation has both a negative impact on the current Douglas-fir size and a compounding negative effect on growth in the subsequent years. The results further demonstrate the importance of controlling competition from overtopping brush in the early years of reforestation. Management and research implications of this study are discussed.

Competitive Effects of Overtopping Vegetation on Douglas-fir Morphology in the Oregon Coast Range

by

Samuel S. Chan

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I dedicate this thesis in appreciation to my parents who immigrated to the United States and endured hardships in the hope of providing their children a better opportunity in life.

Thanks, Mom and Dad, for all the encouragement and hope that both of you have given me.

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INTRODUCTION

Overview

Few studies have been conducted to determine the influence of overtopping vegetation on the growth of young Douglas-fir trees. Sites located in the Western Hemlock/Sitka Spruce Zone of the Oregon Coast Range were selected because competition from overtopping brush is identified as the most severe obstacle to regeneration of Douglas-fir (Turpin & Knapp, 1980). Available radiant energy for photosynthesis expressed as the percent sky visible through an overtopping canopy is considered a critical factor for Douglas-fir survival and growth, provided temperature, moisture, nutrients and damage from pests and pathogens are not as critically limiting as the light resource.

Hemispherical photographs were taken to determine the degree of overtopping to which each individual tree was subjected. The amount of light unimpeded by overtopping vegetation and topographic obstacles was calculated and expressed as the percent sky visible (total area minus the area occupied by overtopping vegetation and slope equaled the percent sky visible). The size and subsequent growth of the trees were analyzed to form regression equations with respect to a percent sky visible gradient. Predictability of tree growth and size for the subsequent year's (N+1) growth, based upon the current year's (N) size and the percent sky visible, was determined.

Objectives

The objectives of this study were to: (1) describe the effects of overtopping vegetation on easily measured features of Douglas-fir sapling size and growth, (2) predict the potential tree size for the following year based upon the current year's tree size and overtopped status, and (3) test the usefulness of fisheye photography for describing overtopping brush canopies in quantitative terms.

Purpose and Justification

Practical improvements are needed in the process of prescribing forest vegetation treatments. Intensive forest management requires allocation of effort based on quantitative measures of problems to be solved and results to be expected from various levels of treatments. Current vegetation management prescriptions are mostly based upon the training, intuition, empirical observations, and the experience of the forest manager involved (Cafferata, Greenup and Turpin, personal communication). This is because vegetative competition is difficult to measure (Iverson, 1976). Yet managers need a system that will quantify the effects of vegetative competition in the Oregon Coast Range and thus provide a sound basis for vegetation management (Allen, 1969; Stewart, 1984; Turpin & Knapp, 1980).

This study provides managers of mesic coastal forests with a quantifiable way to partially assess the need for vegetation control. The study also adds to the data base documenting the competitive effects of overtopping vegetation in the Coast Range.

The use of the previous year's morphological features (e.g., diameter, heights, bud size) to estimate the following year's tree size can give managers a quantitative tool for predicting the effects of overtopping vegetation on future growth. The utility of morphological features has been demonstrated by Cannell et al. (1976), Kozlowski et al. (1973), and T. D. Petersen (unpublished data).* The inclusion of percent sky visible as index of the competitive status of a tree could add to the ability to predict tree growth.

Relatively few studies have been done on the effects of overtopping competing plants on crop trees growing in the Oregon Coast Range. Considering the economic importance of forests in the Oregon Coast Range, there is a sizable gap in knowledge about the competitive effects of overtopping plants on young Douglas-fir growth.

The Oregon Coast Range provides an ideal environment for the culture and production of forests and forest-related products. Temperatures are mild, soils are deep and rainfall is abundant (Franklin & Dyrness, 1973). This same environment is also ideal for the rapid growth of hardwood trees and shrubs. Major hardwood competitors in the Coast Range include: *Alnus rubra* Bong. (red alder); *Acer circinatum* Pursh. (vine maple); *A. macrophyllum* (big leaf maple); *Rubus parviflorus* Nutt. (thimbleberry); *Rubus spectabilis* Pursh. (salmonberry); *Sambucus racemosa* L. var. *arborescens* (red elderberry). The

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*T. D. Petersen; on file with Department of Forest Science, College of Forestry, Oregon State University, Corvallis, Oregon.

growth of these hardwood and shrub species often exceeds and overtops that of the desired conifers during the establishment phase of reforestation. The high dominance potential (Newton, 1973) of competing vegetation and its ability to monopolize available site resources has been demonstrated to reduce the survival and the growth of the desired crop (Ruth, 1956; Allen, 1969; Iverson, 1976).

Successional trends following disturbance (e.g., fire, logging) tend toward the development of dense shrub and hardwood communities dominated by red alder, salmonberry, red elderberry and thimbleberry in the Western Hemlock/Sitka Spruce Zone of the Oregon Coast Range (Ruth, 1979). In many cases, these species overtop conifer regeneration, resulting in nearly pure stands of hardwood trees and shrubs. Conifer establishment and development are slow because of the multilayered nature of these shrub/hardwood associations (Meurisse & Youngberg, 1971). Successional sequences of the hardwoods and shrubs have not been thoroughly studied, but it appears that the brushfields and hardwood stands remain semipermanent until senescence sets in or another disturbance occurs that favors conifer regeneration (Allen, 1969; Newton et al., 1968; Bailey, 1966).

The size of the Douglas-fir planting stock and the time elapsed following site preparation may also affect the survival and growth of the trees in areas in areas already invaded or prone to occupation by coastal brush and hardwoods. For example, planting large trees immediately after site preparation resulted in higher survival and more rapid growth rates than delaying reforestation or using smaller planting stock (M. Newton & D. E. White, n.d.).* However, even large Douglas-fir trees planted soon after site preparation tended to be adversely affected by overtopping.

Reduction of light availability by overtopping vegetation is very important ecologically to plant survival and growth (Daubenmire, 1974; Anderson, 1971; Donald, 1961; Emmingham, 1972; Franklin & Dyrness, 1973; Jackson & Palmer, 1977; Lakso, 1976; Kramer & Kozlowski, 1979). However, overtopping vegetation also affects other site factors such as temperature, wind, relative humidity, soil moisture, nutrients, and associated organisms. Therefore, it is extremely difficult to isolate the influence of the light factor alone. It must always be remembered that overtopping may affect a complex of interacting environmental and biological factors (Billings, 1952; Kramer & Kozlowski, 1979).

*Newton and White manuscript in preparation: "Effect of salmonberry on growth of planted conifers." Oregon State University, Corvallis, Oregon.

METHODS

Site Description

Three north-facing sites ranging from the northern to the southern portion of the Siuslaw National Forest in the Oregon Coast Range within 11 km of the coast were selected (Fig. 1). The sites were first established by the U.S.D.A. Forest Service in 1980 to provide long-term comparisons of manual and chemical methods of re-leasing Douglas-fir from competing brush (Dimock & Temple, 1980). Each of the sites met the criteria of (1) a north-facing aspect, (2) relatively close proximity to the coast, (3) location in the highly productive Oregon Coast Range, (4) relatively young plantings of Douglas-fir trees, (5) availability of the site for experimental purposes over an extended period of time, and (6) availability of a wide range of overtopping brush conditions. Since measurement of the influence of overtopping brush and light availability on crop tree growth was the main objective, the above criteria were used during site selection to minimize environmental restrictions caused by moisture, temperature and soil fertility.

The three study sites were located near Hebo (Farmer Roundtop), Waldport (Howell Ridge) and Florence (Bailey). Table 1 summarizes the characteristics of each site. Although the physical site characteristics of each site differed only slightly, the preparation of the site for planting and the age of the trees were different.

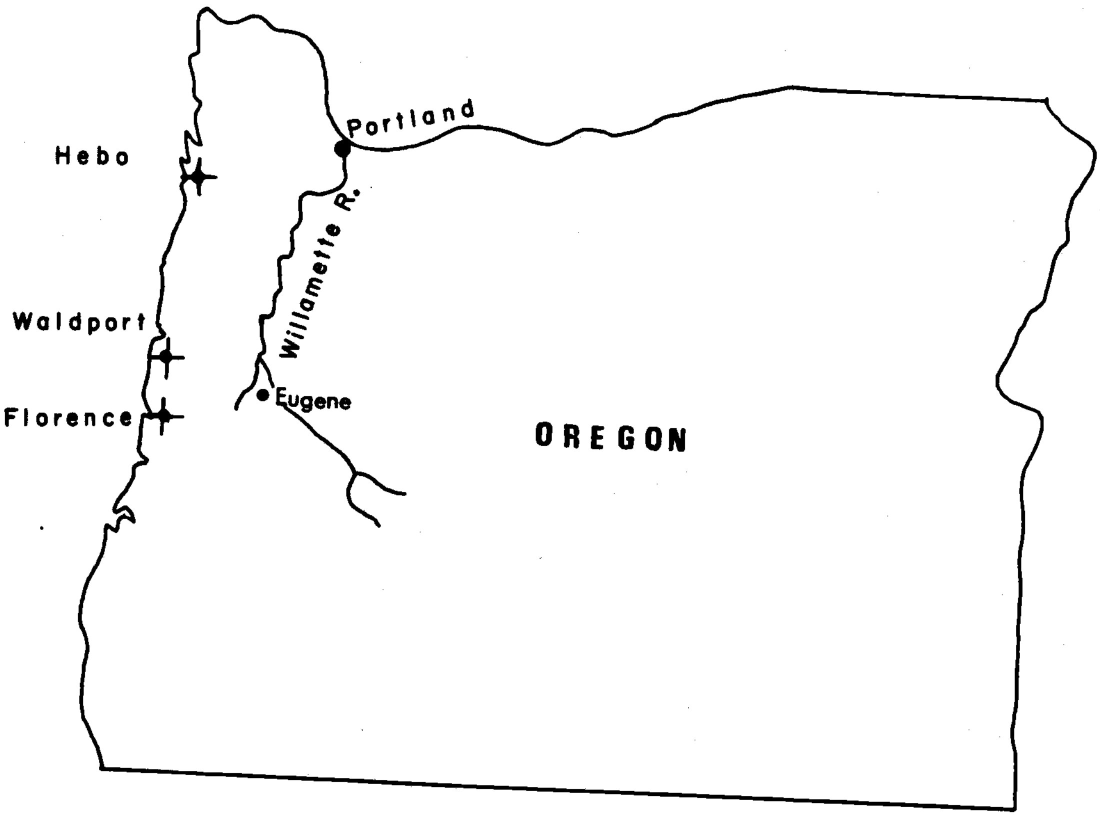

FIGURE 1. Approximate location of the three study sites in the Oregon Coast Range near Hebo, Waldport and Florence (sites denoted as +).

TABLE 1. Site characteristics associated with the three study sites.

Site Description	Site: Florence	Hebo	Waldport
Unit name	Bailey	Farmer Roundtop	Howell Ridge
Location	T17S, R11W, Sec. 18	T4S, R10W, Sec. 34	T14S, R10W, Sec. 29
Distance to coastline	6 km	6 km	11 km
Aspect	N.E.	N.E.	N.E.
Slope	80%	40%	60%
Annual precipitation	230 cm	250 cm	250 cm
Elevation	120 M	150 M	150 M
Soil (SRI) mapping unit**	443, 421	221 F	414
Soil series	Preacher - Bohannon Slickrock complex	*	Bohannon
Texture	gravelly loam, loam	loam	gravelly loam
Average soil depth	120 cm	91 cm	76 cm
Douglas-fir site class	II	II	II
Stand site index	180	170	160
Method of site preparation	burn	none	chemical/burn
Planting stock type	2+0 Douglas-fir	2+1 Douglas-fir	2+0 Douglas-fir
Tree age (years) at first sampling	6	7	5
Major overtopping brush species	red alder, salmonberry	salmonberry, vine maple	salmonberry, red elderberry, red alder

*Information not available.

**Badura et al., 1974.

The Hebo site was planted with 2+1* Douglas-fir seedlings in the spring of 1978 on land that received no planting site preparation. The lack of previous site preparation has left the site occupied by salmonberry and vine maple. The sprouts from established vine maple and salmonberry provided a difficult environment for crop tree growth.

The Waldport site was planted with 2+0** Douglas-fir seedlings during the spring of 1979 on land that received extensive site preparation. The site preparation included a chemical spray of 2,4-D and picloram followed by a successful prescribed burn. Brush species on this site consist of salmonberry, red elderberry and red alder. Brush cover on this site was moderate.

The southernmost site located near Florence was planted with 2+0 Douglas-fir seedlings on land prepared for planting by burning. Red alder and salmonberry were very dense on the site.

Plot Layout and Overtopped Tree Selection

Field crews from the U.S.D.A. Forest Service marked an arbitrary 50-sample point grid (10 m x 10 m spacing) on each of the treatment plots within the sites. The grid was arranged as a matrix consisting of five rows containing 10 points each (Dimock & Temple, 1980). Only the control (no release treatment) and the two-year

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*Seedlings grown for two years then transplanted to another nursery bed and grown for one additional year.

**Seedlings grown in nursery for two years.

manual release plot (trees kept free of surrounding brush by manual cutting for two years) were utilized for this study. The control plots provided a wide range of overtopping brush conditions, and the manual plots provided situations where trees were free from overtopping brush for a minimum of two years. The first manual release treatment was completed during the spring of 1981 at the early foliar stage.

A stratified random frame sampling method (Susan Stafford, consulting statistician, Department of Forest Science, College of Forestry, Oregon State University; personal communication) was employed to select the study trees and assure an adequate range of overtopping conditions. A stratified random frame sampling method requires that individuals (e.g., trees) in a population (e.g., stand) be initially sampled and assigned to pre-determined classes. Sample trees are then randomly selected from each class in the population to ensure an adequate range of cases.

The stratified random frame method was used at each site during July, 1981 by first locating all Douglas-fir trees of the same age within three meters of the 50 staked grid points for both plots (manual release plot and control plot). The overtopped situations for each of the trees were ocularly estimated by a technique similar to that described by Iverson (1976), where an imaginary 90° cone is projected from the base of the apical shoot. The percent of this area occupied by foliage and branches of competing vegetation within the imaginary cone projection is the percent of overtopping. The trees were classified into four classes of overtopping: Group 1 =

0-24 percent; Group 2 = 25-49 percent; Group 3 = 50-74 percent; Group 4 = 75-100 percent. Sampled trees were then pooled from both treatment plots. Approximately 10 trees were randomly selected for study from each of the overtopping classes within the pooled sample at each site. The 40 selected trees at each site thus provided a representative sample that was fairly evenly distributed throughout the range of overtopping conditions.

Hemispherical Photography - Determining the Degree of Overtopping

The use of ocular estimates for determining the degree of overtopping is highly subjective. Therefore, fisheye photographs of the overtopping canopy were taken to obtain a more precise and quantitative measurement of the overtopping canopy. Fisheye photographs of each of the trees selected in the stratified frame sampling were taken during early August, 1981.

Comparisons between the ocular estimates of overtopping with values obtained from computer analysis of fisheye photographs indicated that ocular estimates became less accurate and more subjective as overtopping increased. The ocular classification of both open grown (0-24% overtopping; Group 1) and severely overtopped (75-100% overtopping; Group 4) trees correlated well with values obtained from the fisheye photo analysis. Trees in Groups 2 and 3 sometimes varied from the values obtained from the photos. That is, some of the trees classified in Group 2 (25-49% overtopped) were actually overtopped more than 49 percent, whereas some of the trees classified in Group 3

(50-74% overtopped) were overtopped less than 50 percent. In general, however, the ocular classification procedure provided a suitable range of overtopping conditions for purposes of this study.

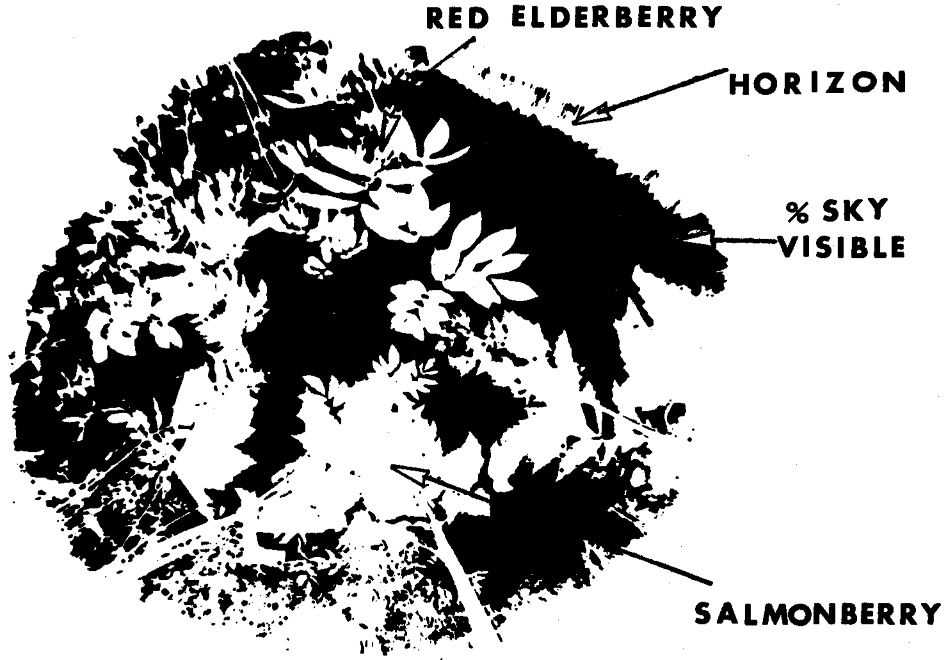
Overtopping canopy cover, or inversely the probability of direct and diffuse light (expressed as percent sky visible) penetrating the canopy, was determined from hemispherical (fisheye) photographs pointing skyward (i.e., the tree's point of view). A fisheye photo is a projection of a hemisphere onto a plane such that the size of the image on the film plane is proportional to the actual size of the objects. Fisheye photography in ecological studies has been used for analyzing plant canopy density, canopy closure, leaf area index, cloud cover, time of day or year when direct solar radiation reaches a certain point, and the probability of direct and diffuse radiation penetrating a plant canopy (Anderson, 1971, 1976; Lakso, 1976, 1980; Miller, 1981).

Fisheye photographs of the overtopping situation for each of the Douglas-fir saplings were taken with a 7.5 mm Canon equidistance fisheye lens mounted on a Canon AE-1 body using Kodak 5362 high contrast film (ASA 15) during August, 1981. The exposed film was developed in D-19 developer.

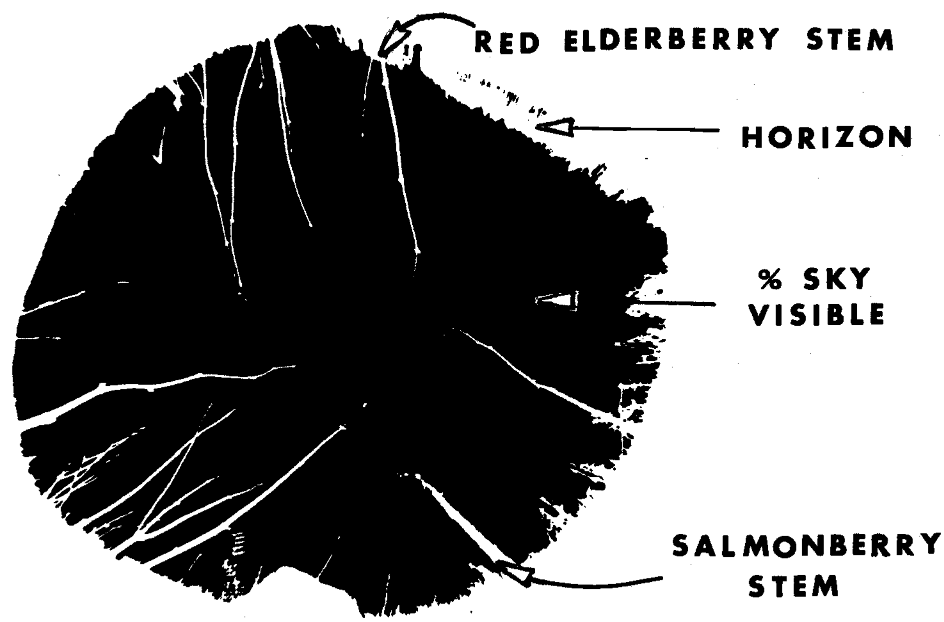
High contrast exposure was achieved by adjusting the shutter speed and f-stop to give proper exposure of the sky and slight under-exposure of the vegetation. Pictures were taken under overcast skies or during the early morning before the sun reached a high elevation, or in the late afternoon, or after sunset when the canopy received only diffuse radiation. Cloudy and foggy conditions during the morning were prevalent on the selected sites during the summer due to the close proximity of the ocean. These conditions provided fairly uniform illumination of the canopy and avoided the presence of sun flares (over-exposed areas on the negative) or shadows (false indications of cover due to shading) from direct sunlight that would have made analysis of the photos extremely difficult. Figure 2 is an example of a typical fisheye photo with 38 percent sky visible during the summer and 86 percent sky visible during the winter through the overtopping plant canopy.

Fisheye photos were taken under rugged field conditions of steep terrain, heavy logging slash and thick brush. Proper positioning of the cmaera and taking the picture required only a few minutes. A sturdy, lightweight and easily adjustable tripod was crucial to avoid exposure blurs caused by camera movement. The camera was positioned vertically facing the sky and adjacent to the north-facing base of the Douglas-fir sapling's apical (leader) shoot. The leader shoot was bent out of the way during film exposure to prevent it from appearing in the photo. The base of the leader shoot was selected as the photographic point. This point represented the lowest possible point where the tree could be bent out of the way without damage. The camera was then carefully leveled with a bubble level to ensure that the film plane axis was horizontal. True north was always oriented on the center top edge of the photograph.

Interpreting fisheye photos by the ocular grid method was tedious, subjective and time-consuming. Therefore, overtopping (expressed as percent sky visible) was accomplished by a computerized



Summer: 38% sky visible



Winter: 86% sky visible

FIGURE 2. Fisheye photographs depicting the % sky visible during the full canopy summer season and after leaf abscission in winter of overtopping salmonberry and red elderberry by a Douglas-fir sapling in the Oregon Coast Range.

method (Miller, 1981). Determination of the percent of sky visible through an encroaching canopy was rapid and accurate through use of computerized analysis. The computerized method was accomplished by projecting a fisheye image onto a flat surface and sensing the light level which was transmitted through the negative onto the flat surface. Equipment needed for this analysis included a film projector, light sensor, voltmeter, and graphics plotter which were interfaced to a microcomputer. The film projector was placed so the projected image was perpendicular to the plotter. The silicone cell light sensor was positioned inside a small tube to reduce the amount of peripheral light hitting the sensor and then placed in the pen holder on the plotter arm. Light hitting the sensor generated signals that were sent to the digital voltmeter. The voltage reading was then sent to the computer and stored for analysis.

A circular grid system of movement consisting of concentric circles at every 5° elevation zone increment (see Fig. 3) was programmed into the computer, which, in turn, controlled the plotter arm containing the light sensor. Following the circular grid path over each elevation zone (from the image's horizon to the zenith), the sensor sensed the light intensity from the image and stored the reading in a separate file. The process was repeated for 18 elevation angle zones spaced 5° apart, thus completing a total 90° elevation angle (i.e., a hemisphere) analysis. The sensor was set to sample the zone between two consecutive 5° elevation increments. The number of points analyzed within each zone equaled the degree of the elevation zone (e.g., 62 were analyzed for the elevation zone

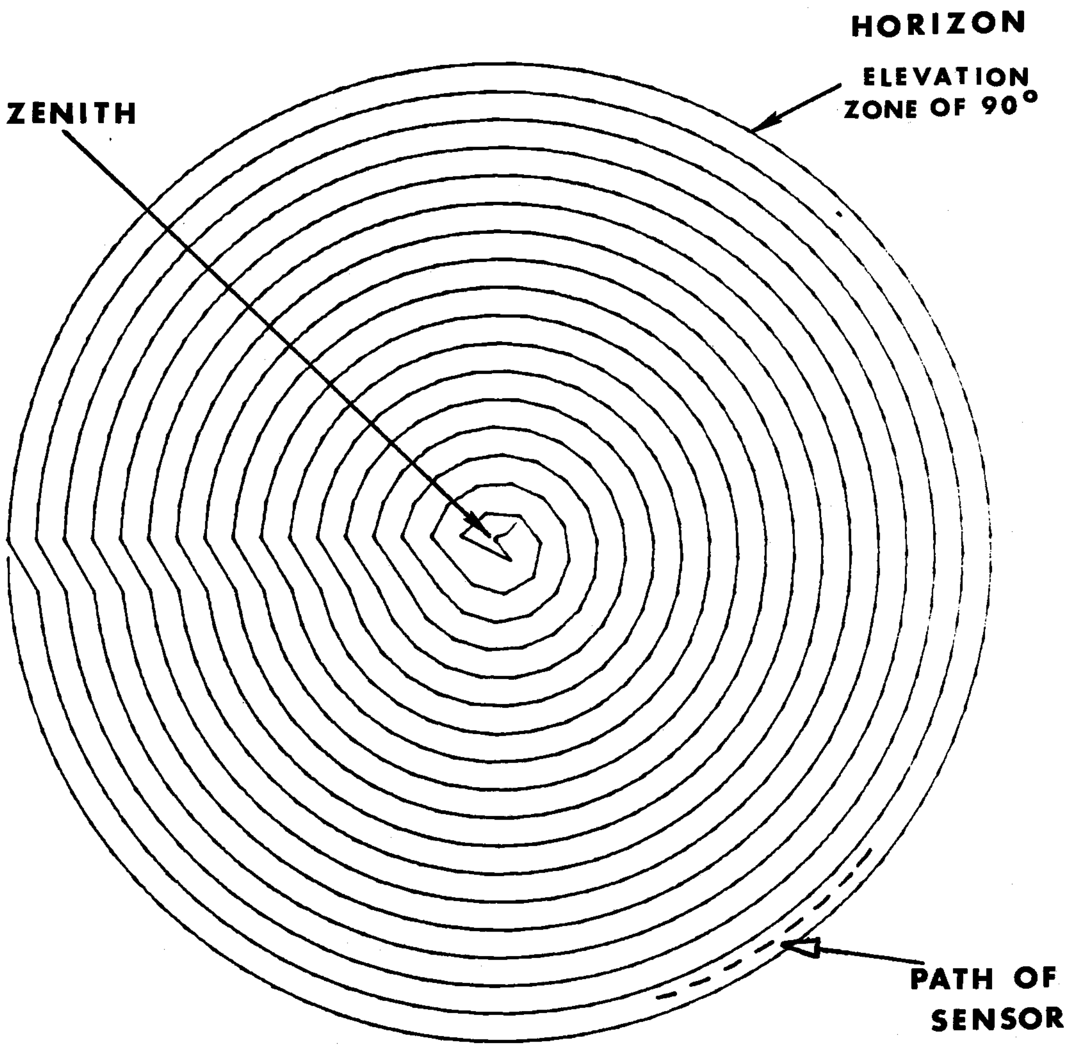


FIGURE 3. Circular grid system depicts the plotting path by a microcomputer-controlled silicone light sensor for fisheye photo analysis.

between 60° and 65°), thereby providing a total of 801 points for each fisheye photo.

Initial analysis of a clear negative, using the method described previously, was stored in the computer for comparison with readings from fisheye images. The clear negative simulated a completely overtopped plant canopy with all the sectors filled with vegetation. Analysis of the clear negative was also necessary because the projected light distribution was not uniform (the center of the projected image was brighter than the edge). The average probability of radiation penetrating at each elevation zone (P_Φ) was determined by adding the scores for each elevation zone, dividing by the total score possible and subtracting from one.

A summation equation (Jones & Campbell, 1979) was programmed into the computer to calculate the probability of diffuse light penetration (percent sky visible) through the overtopping plant canopy from the entire fisheye image:

$$X = \Delta\Phi \sum_{\Phi=1}^{\Phi_n} (P_\Phi \operatorname{Sin}\Phi \operatorname{Cos}\Phi)$$

where, X = probability of light penetration through the canopy (percent sky visible)

$\Delta\Phi$ = elevation zone increment in radians (e.g., for 5° increments in this study)

n = number of elevation zones (e.g., 18 total in this study)

Φ = elevation zone

P_Φ = the average probability of radiation penetrating at each elevation zone

$\mathrm{Sin}\Phi$ = corrects the cosine response for incoming radiation, i.e., perpendicular radiation has higher intensity than oblique radiation

$\mathrm{Cos}\Phi$ = corrects for the solid angle subtended by vegetation (correction due to the fact that objects toward center appear larger than they actually are)

Tree Measurements

The size and growth of all the sampled Douglas-fir trees were measured during February beginning in 1982 and ending in 1983. Measurements were taken during February when plant tissues were fully hydrated but height and diameter growth were at a minimum. All measurements were made with micrometer calipers or meter sticks. The morphological variables measured included:

- Total tree height (to the nearest cm)
- Leader shoot length (to the nearest cm)
- Basal diameter measured at the base of the first year's lateral branch whorl (to the nearest 0.1 cm)
- Leader shoot diameter measured at the base (to the nearest 0.1 cm)
- Leader shoot bud length (to the nearest 0.1 mm)
- Leader shoot bud diameter measured at the widest portion of the bud (to the nearest 0.1 mm)

RESULTS

Correlations between Percent Sky Visible and Douglas-fir Size

Table 2 displays the simple correlation coefficients (r) for all the morphological variables measured. Basal diameter and tree volume consistently showed the highest correlation with percent sky visible at all three sites. Correlations were less evident for the other morphological features, but the relationships varied by site. For example, the Florence site which was heavily occupied by overtopping red alder showed consistently higher correlations for all of the features than did the other two sites.

Although tree volumes were highly correlated with the percent skylight coming through the overtopping canopy, volumes are of low practical utility since the trees measured were only young saplings. Furthermore, the correlation with volume was primarily attributed to the diameter component, since tree heights were less well correlated with overtopping conditions.

In general, the results of the simple correlation analysis indicated a positive relationship between Douglas-fir sapling size (especially diameter and volume) and the percent sky visible. Therefore, a tree growing in the open was likely to be larger than one that was severely overtopped.

TABLE 2. Simple correlations of Year N (1981) % sky visible with the Douglas-fir morphological features measured at each of the three sites at the end of that growing season.

Morphological features	Simple Correlations (r) with % sky visible		
	Florence	Hebo	Waldport
Tree height	.63	.46	.47
Basal diameter	.80	.75	.66
Leader length	.54	.20	.40
Leader diameter	.77	.38	.42
Leader bud length	.67	.50	.29
Leader bud diameter	.74	.52	.42
Leader bud volume	.74	.59	.42
Leader volume $(\text{Diameter})^2$ (Height)	.74	.45	.42
Tree volume $(\text{Diameter})^2$ (Height)	.77	.64	.61

Variations in Tree Size Due to the Percent Sky Visible

Simple correlation analysis indicated that a significant relationship existed between tree size and the percent sky visible (Table 2); therefore, the next step in the analysis was to determine the pattern of the relationship and how much of the variation in the size of the trees could be explained by the percent sky visible. These features were determined by linear regression. Only linear regressions of percent sky visible with tree height and basal diameter are discussed because these were the only two morphological features (besides tree volume and terminal bud volume) that displayed consistently high correlations with percent sky visible at all three sites. Tree volume relationships were not analyzed further because they would be expected to follow the same pattern as that for diameter. Bud volume relationships were not analyzed further because of the impracticality of using this attribute as an indicator of competitive status.

The percent sky visible used in the height and diameter regressions was derived from fisheye photos taken during the first year of the study. The reason for using the percent sky visible values from only the first year (N) with tree size data for two years (N and N+1) was to test whether overtopping conditions (percent sky visible) during the initial year of the study could be correlated with the size of the tree during the initial and following years. The results (Figs. 4-9) suggest that both the initial year's (N)

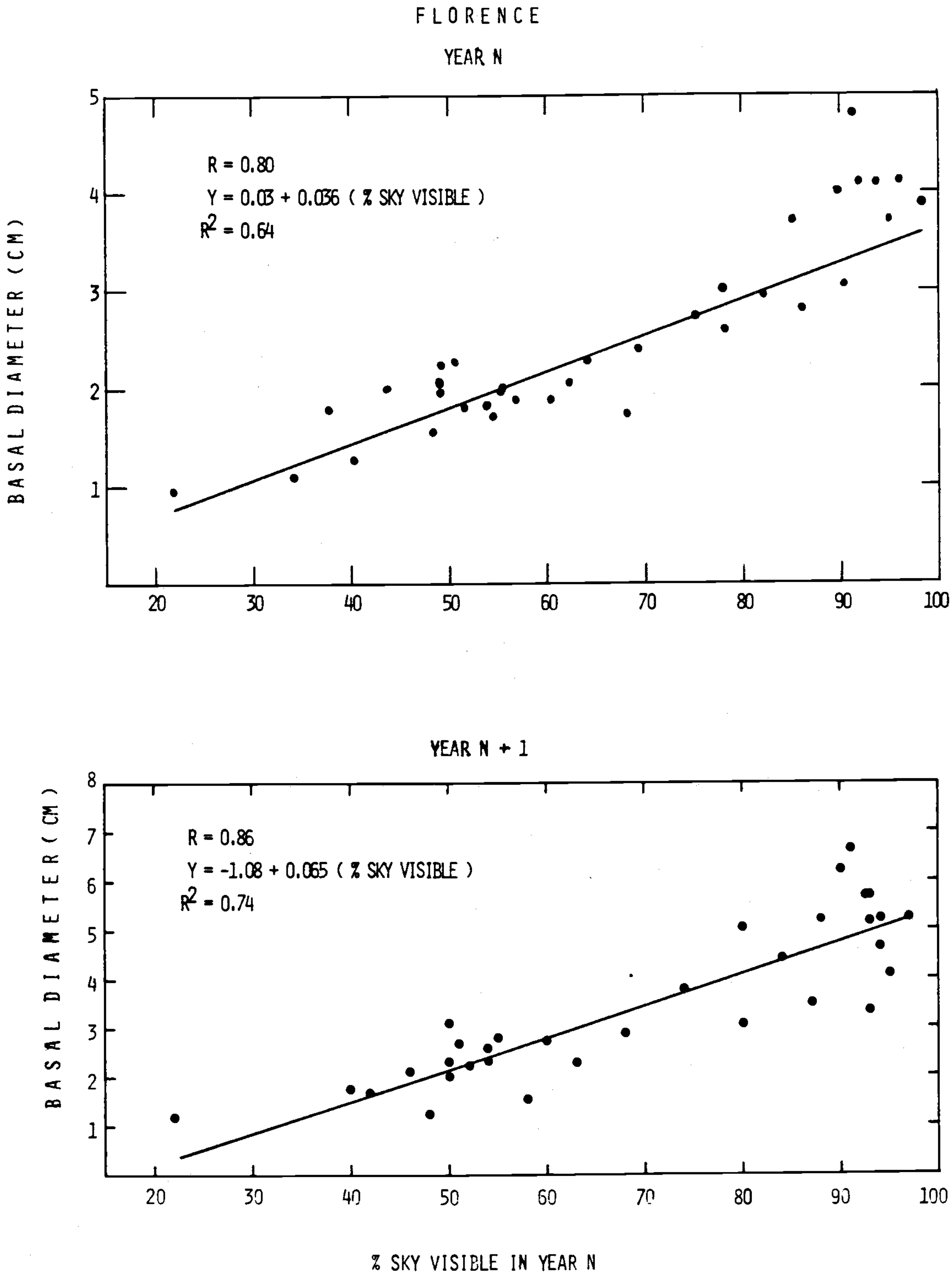


FIGURE 4. Basal diameters of overtopped Douglas-fir saplings at the Florence site measured over two complete growing seasons (Year N, Year N+1) expressed as a function of % sky visible measured during August of Year N.

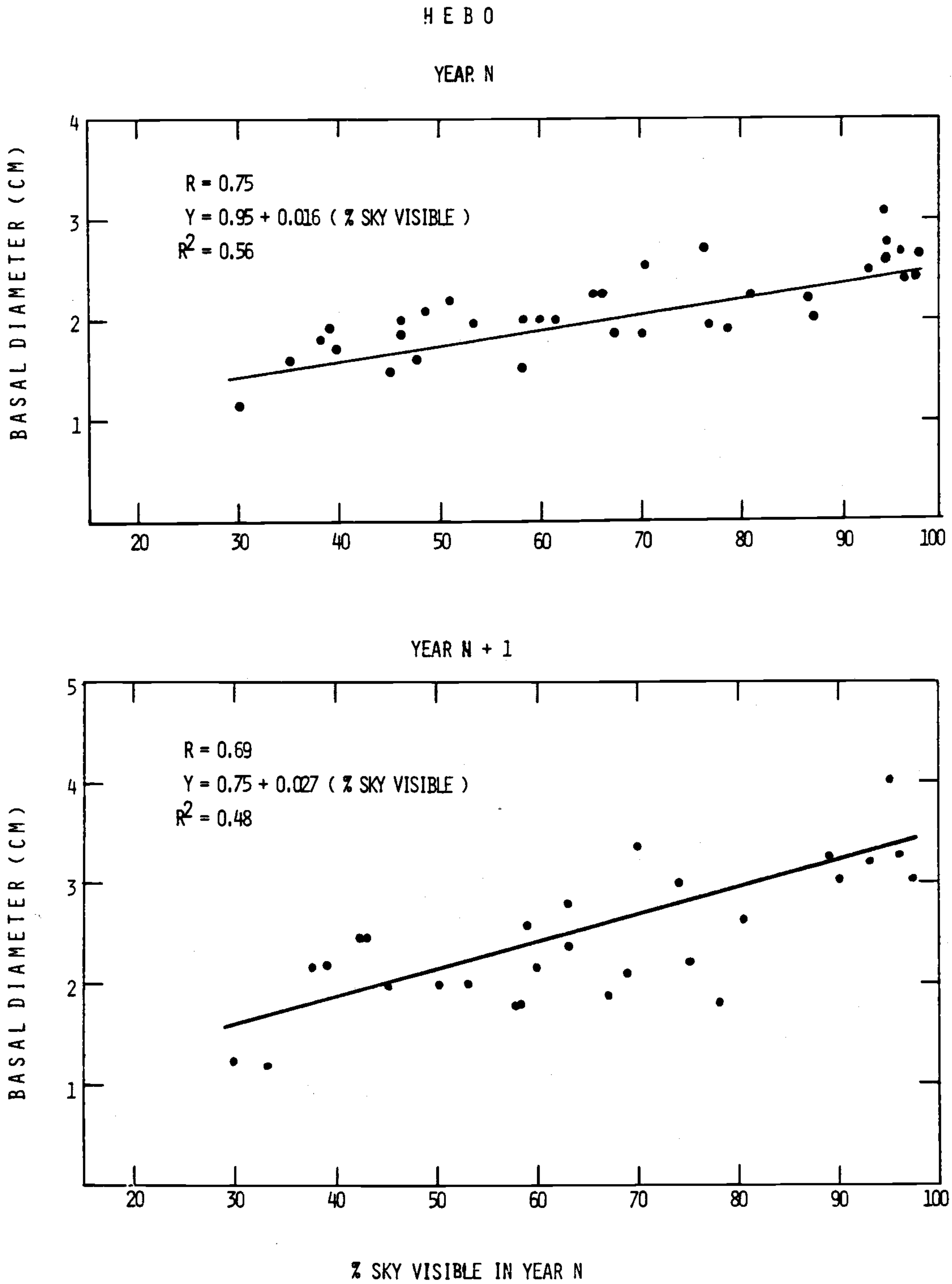


FIGURE 5. Basal diameters of overtopped Douglas-fir saplings at the Hebo site measured over two complete growing seasons (Year N, Year N+1) expressed as a function of the % sky visible measured during August of Year N.

WALDPORT

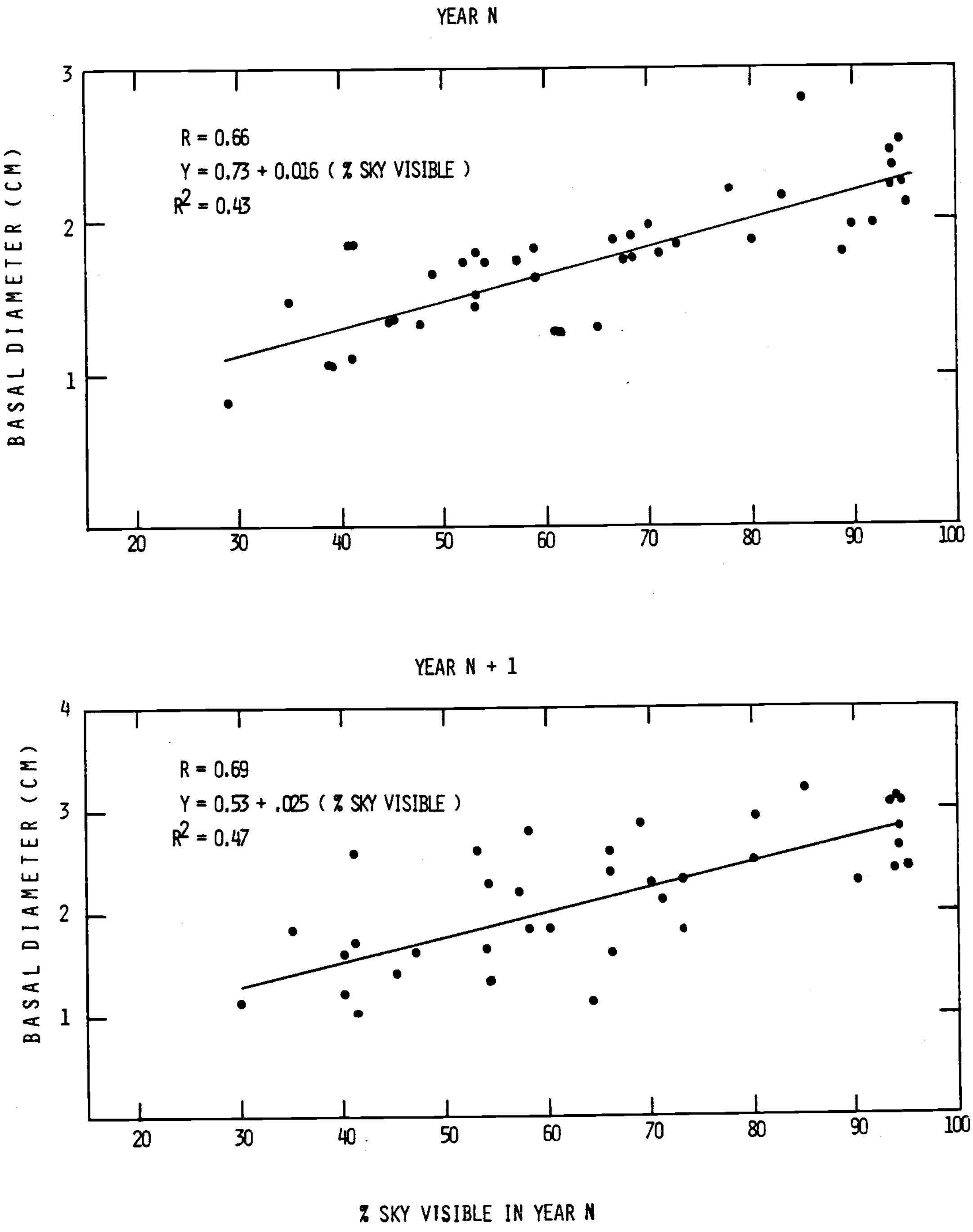


FIGURE 6. Basal diameters of overtopped Douglas-fir saplings at the Waldport site measured over two complete growing seasons (Year N, Year N+1) expressed as a function of the % sky visible measured during August of Year N.

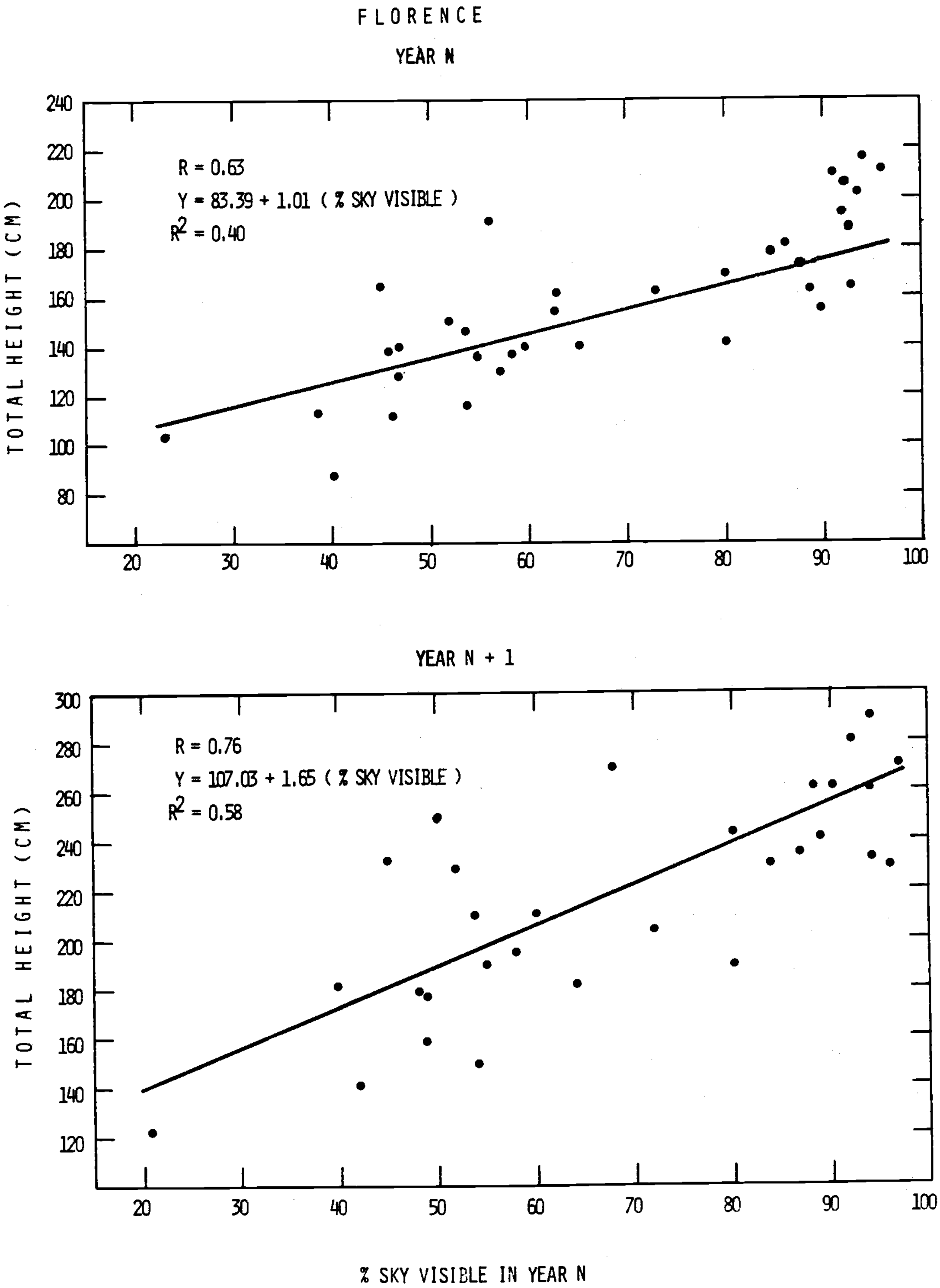


FIGURE 7. Total heights of overtopped Douglas-fir saplings at the Florence site measured over two complete growing seasons (Year N, Year N+1) expressed as a function of the % sky visible measured during August of Year N.

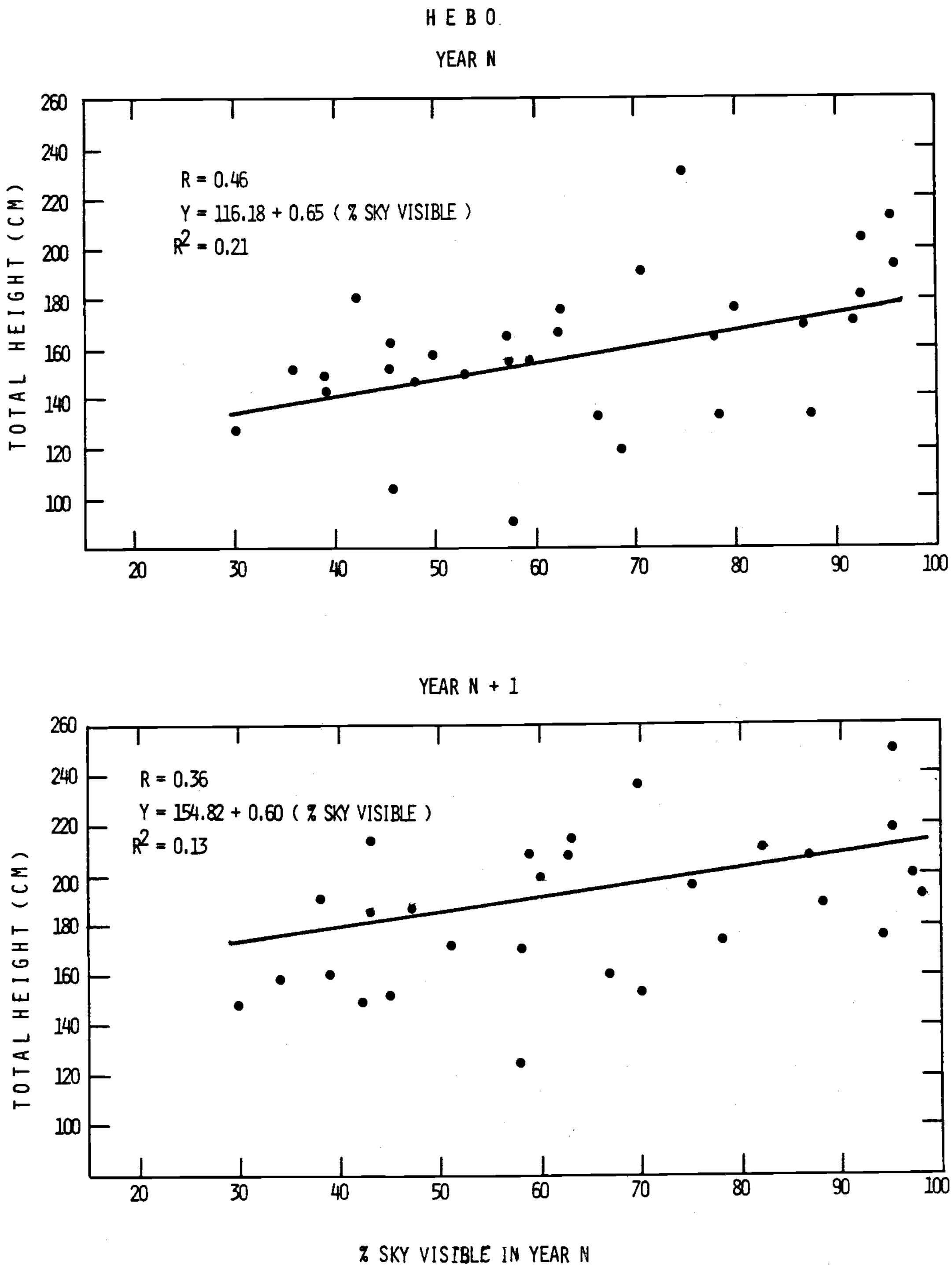


FIGURE 8. Total heights of overtopped Douglas-fir saplings at the Hebo site measured over two complete growing seasons (Year N, Year N+1) expressed as a function of the % sky visible measured during August of Year N.

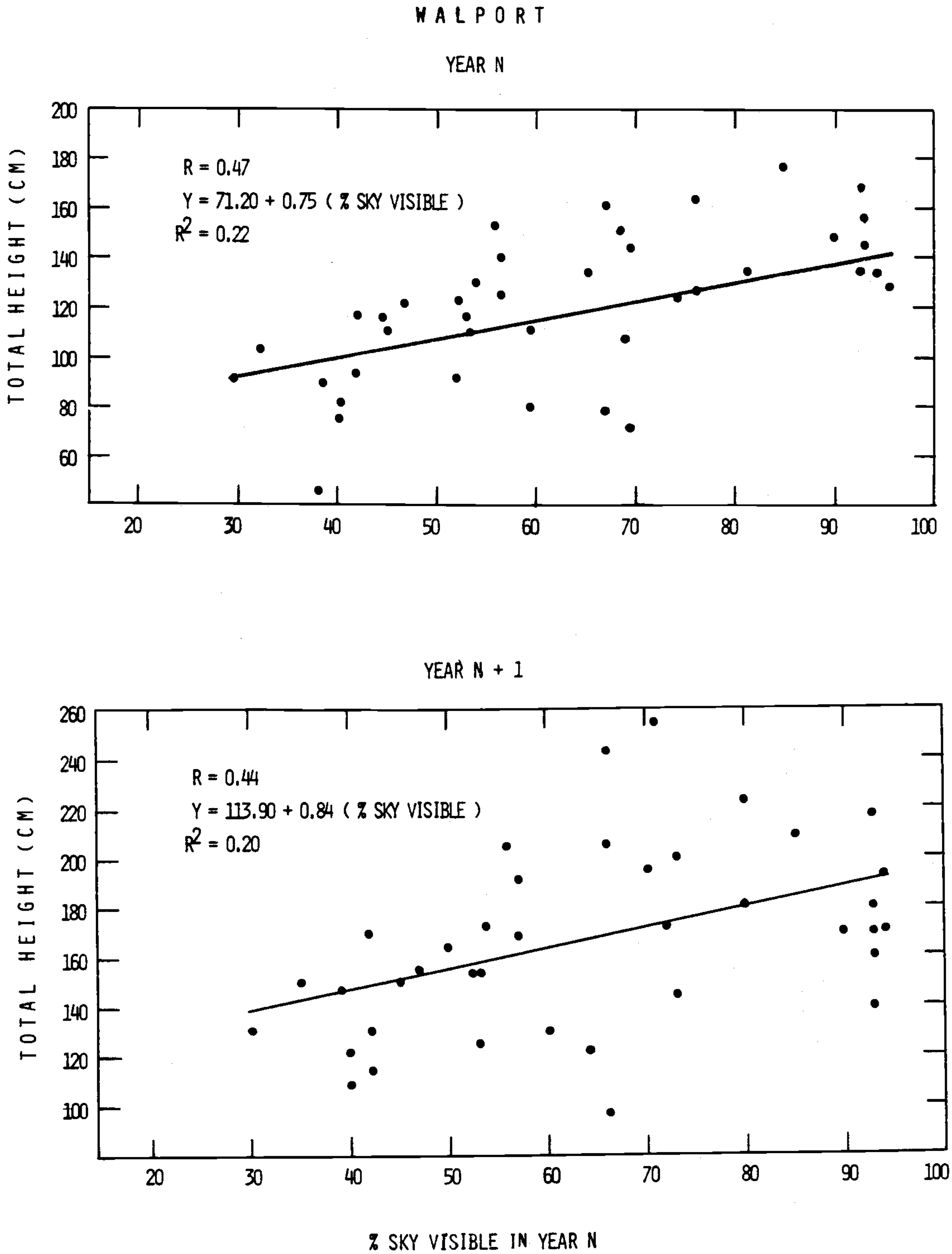


FIGURE 9. Total heights of overtopped Douglas-fir saplings at the Waldport site measured over two complete growing seasons (Year N, Year N+1) expressed as a function of the % sky visible measured during August of year N.

and the following year's (N+1) tree size were related to the initial overtopping condition.

Results from Figures 4-9 indicate that Douglas-fir saplings growing on the north-facing Coast Range sites used in this study were smaller when subjected to increasing levels of overtopping plant competition (expressed as decreasing amount of percent sky visible). Basal diameters were better indicators of competition from overtopping vegetation than were tree heights, which exhibited much weaker correlations. Figures 4-6 show that 43-74 percent of the variation in basal diameter size could be attributed to the percent of skylight occluded by overtopping plant canopies, whereas only 13-58 percent of the variation in tree height could be accounted for (Figs. 7-9). All the regressions were significant at the one percent level.

Differences in the degree to which tree size variation could be explained depended upon the study site. Relationships were strongest for the Florence site (Fig. 4) where 64 percent of the variation for year (N) basal diameter size could be explained by the percent sky from the same year. Variation in basal diameter size for the following year was even better correlated (R^2 = 0.74) when the previous year's percent sky was used in the regression equation. This suggests that the overtopping conditions in the current year may affect the size of the tree the following year. Similar trends were also observed for basal diameters at the other two sites: Hebo (Fig. 5) and Waldport (Fig. 6).

Prediction of the Subsequent Year's Tree Growth and Size

Stepwise multiple linear regression analysis was used to determine the variation in tree size (height, basal diameter, terminal leader length and terminal leader diameter) in the subsequent growth year (N+1) explained by the morphological features and percent sky visible values measured during the previous growth year (N). Figure 10 shows the analysis scheme and the variables employed in the stepwise multiple regression. The F tolerance level was set at 0.01, and the maximum number of variables entered in the regression equation was set at 4.

The group of features from the previous year (N) that best explained variations in tree size and growth the following year (N+1) are shown in Tables 3, 4 and 5, respectively, for each of the sites. The first independent variable listed explained the greatest amount of variation in size predictions for the subsequent year. The adjusted R^2 values* indicate the relative strength of the independent variables in explaining the variation in tree size or growth in the subsequent year.

The ability to predict the subsequent year's tree size or growth based upon the current year's tree size and percent sky visible is shown in Tables 3-5. Values of the ability to account for variation in tree height and tree basal diameter ranged

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*Adjusted R^2 is a more conservative estimate of the percent of variance explained (Neter & Wasserman, 1974; Kim, 1975).

GROWTH AND SIZE PREDICTIONS FROM THE PREVIOUS YEAR'S GROWTH

FEATURE SIZE AND % SKY VISIBLE

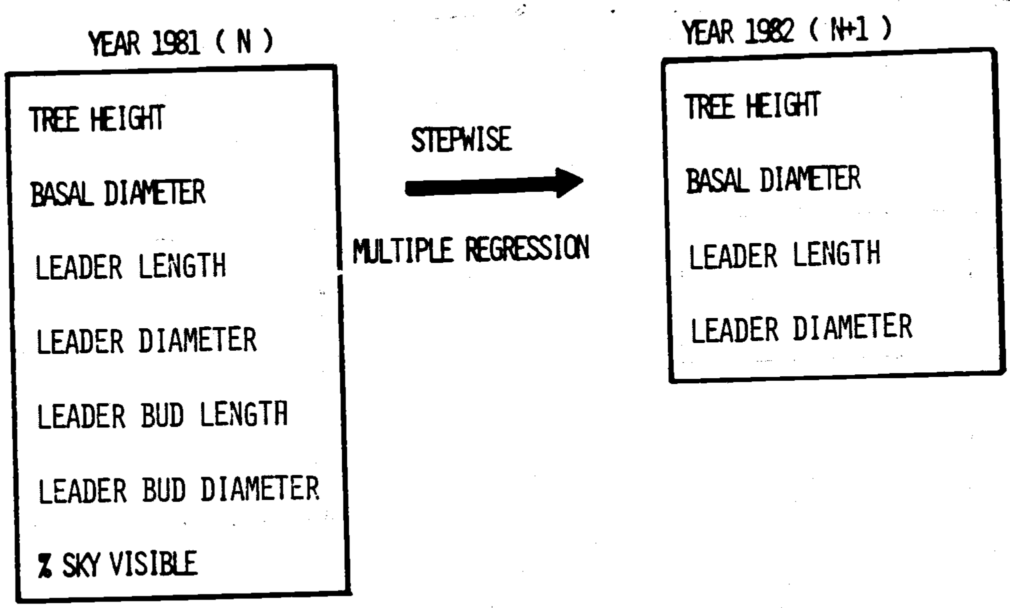

FIGURE 10. Flow chart of the stepwise multiple regression process used in making growth and size predictions of the subsequent year's growth and size from the previous year's % sky visible value and growth features.

TABLE 3. Summary table predicting 1982 (Year N+1) Douglas-fir tree size from 1981 (Year N) morphological growth features and % sky visible variables entered into a stepwise multiple regression procedure. Numbers in parentheses are expressed as adjusted R^2 values which indicate the additive effects of the independent variables to the total predictive equations for tree size. Regression equations are provided in Appendix I.

FLORENCE SITE

(Y) Dependent Variable	Independent Variables (X) X_1	X_2	X_3	X_4	Adjusted R^2
1982 Tree Height	1981 Basal Diam. (0.67)	1981 Leader Length (0.78)	1981 % Sky Visible (0.82)	*	0.82
1982 Basal Diameter	1981 Basal Diam. (0.89)	1981 % Sky Visible (0.92)	*	*	0.92
1982 Leader Length	1981 Leader Diam. (0.46)	1981 Leader Length (0.48)	1981 Basal Diam. (0.52)	1981 Tree Hgt. (0.60)	0.60
1982 Leader Diameter	1981 Basal Diam. (0.68)	1981 Leader Bud Diam. (0.73)	1981 Tree Hgt. (0.75)	1981 % Sky Visible (0.80)	0.80

*Adding another variable did not improve prediction.

TABLE 4. Summary table predicting 1982 (Year N+1) Douglas-fir tree size from 1981 (Year N) morphological growth features and % sky visible variables entered into a stepwise multiple regression procedure. Numbers in parentheses are expressed as adjusted R^2 values which indicate the additive effects of the independent variables to the total predictive equations for tree size. Regression equations are provided in Appendix II.

HEBO SITE

(Y) Dependent Variable	Independent Variables (X) X_1	X_2	X_3	X_4	Adjusted R^2
1982 Tree Height	1981 Tree Height (0.86)	1981 Leader Length (0.88)	1981 % Sky Visible (0.90)	1981 Leader Diam. (0.92)	0.92
1982 Basal Diameter	1981 Basal Diam. (0.80)	1981 % Sky Visible (0.84)	*	*	0.84
1982 Leader Length	1981 Leader Length (0.35)	1981 Leader Diam. (0.36)	1981 % Sky Visible (0.40)	*	0.40
1982 Leader Diameter	1981 Leader Diam. (0.60)	1981 Leader Length (0.62)	1981 Leader Bud Diameter (0.65)	1981 % Sky Visible (0.67)	0.67

*Adding another variable did not improve prediction.

TABLE 5. Summary table predicting 1982 (Year N+1) Douglas-fir tree size from 1981 (Year N) morphological growth features and % sky visible variables entered into a stepwise multiple regression procedure. Numbers in parentheses are expressed as adjusted R^2 values which indicate the additive effects of the independent variables to the total predictive equations for tree size. Regression equations are provided in Appendix III.

WALDPORT SITE

(Y) Dependent Variable	Independent Variables (X) X_1	X_2	X_3	X_4	Adjusted R^2
1982 Tree Height	1981 Tree Height (0.86)	1981 Leader Length (0.89)	1981 % Sky (0.90)	1981 Lateral Bud Diameter (0.92)	0.92
1982 Basal Diameter	1981 Basal Diam. (0.66)	1981 % Sky (0.69)	*	*	0.69
1982 Leader Length	1981 Leader Length (0.18)	1981 % Sky (0.24)	1981 Tree Height (0.35)	*	0.35
1982 Leader Diameter	1981 Leader Bud Diameter (0.20)	1981 Leader Diam. (0.22)	1981 % Sky (0.25)	*	0.25

*Adding another variable did not improve prediction.

from 69-92 percent. This means that large trees will continue to be large trees. Usually the most influential variable in the regression equation was the previous year's value for the parameter being estimated except for tree height at the Florence site. Of significance is that leader bud diameter and leader diameter from the previous year were good predictors of the following year's leader diameter at both Florence (Table 3) and Hebo (Table 4). However, the values of the bud and leader diameters as a predictor were not as evident for Waldport (Table 5). Percent sky visible, a measure of the previous year's overtopping condition, was significant ($P > .01$) to be entered into almost every regression equation. However, percent sky visible was usually one of the least influential variables and, therefore, did not contribute greatly to the predictive model.

DISCUSSION

Influence of Overtopping on Tree Growth and Size

Correlations were high between the basal diameter and percent sky visible, but weak for heights. The concept of internal resource allocation offers a hypothesis to explain why tree diameter is the best indicator amongst all the variables on the effects of overtopping competition from brush. Under conditions of low or negligible competition, Douglas-fir sapling foliage will photosynthesize and permit progressive increases in the size of nonphotosynthetic storage organs such as stems, roots and petioles (Donald, 1961). Under competitive stress, however, allocation patterns are likely to be different. Kramer & Kozlowski (1979) hypothesized the following resource priority sink when plants are under stress: fruits and seeds > young leaves and stem tips > mature leaves > cambium > roots. The cambium (diameter) was thus the above-ground morphological feature measured in the study that had one of the lowest priorities for resource allocation when the tree is under stress from overtopping competition. Therefore, it is not surprising that diameter tended to be most greatly influenced by overtopping competition. Furthermore, trees growing in the open are more vigorous and, therefore, need more stem tissue to support the rapidly developing canopy. Future studies on the root structure and biomass responses to varying degrees of percent sky visible through an overtopping plant canopy may result in even stronger relationships.

The strong relationship between basal diameter and percent sky visible can also be interpreted as a vigor index. Waring et al. (1980) have shown that increasing sapwood area (which is related to basal stem diameter) is linearly correlated with increasing leaf area. Therefore, Douglas-fir trees with larger basal diameters should have higher gross photosynthesis.

Tree height and terminal leader length may initially seem to be only slightly affected by overtopping competition because of stem elongation via the resource allocation priorities discussed previously. Elongation of the tree's leader, thus bringing more foliage up into more brightly illuminated regions, may be of value to the overtopped fir trees. Elongation may occur at the expense of diameter growth. Elongation's value as a survival strategy is successful only if the tree can expose enough foliage to intercept sufficient light to maintain a net positive carbon balance (i.e., photosynthesis greater than respiration). Zedaker (1982), E. C. Cole et al. (unpublished data)[*] and M. Newton et al. (unpublished data)[**] demonstrated that Douglas-fir sapling height growth under overtopping vegetation is initially comparable to trees grown in the open for a few years, but eventually succumbs to the competition. Seidel (1980) also mentioned a lack of immediate growth response of grand-fir following overstory removal.

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[*] Cole et al.: on file with Department of Forest Science, College of Forestry, Oregon State University, Corvallis, Oregon.

[**] Newton et al.: on file with Department of Forest Science, College of Forestry, Oregon State University, Corvallis, Oregon.

The mixed results obtained for height growth and total height with respect to the degree of overtopping may be due to the intermediate lag phase of response to competitive stress mentioned earlier. Dimock (1983) worked on the same sites where this study was conducted. After two years, he found that there was little difference in height growth of trees growing in the control (unreleased from brush), manually released and chemically released plots. Data from the study reported here involving the same Dimock (1983) plots also indicate weak relationships between height growth and overtopping brush expressed as percent of sky visible. However, the data indicate that though height was not yet affected by overtopping, the stem (diameter) already has. Prolonged overtopping plant competition could eventually lead to significant effects on height (or shoot elongation), because the reserve resource sinks (roots, stem and mature foliage) would ultimately be exhausted. Such responses have been reported for other conifers (Logan, 1966).

Relationship of Tree Size to Growth Trajectory

Field studies by Seidel (1980) also established that large saplings tended to grow faster and respond more rapidly to favorable environmental changes that did smaller saplings. Physiological studies suggest that growth responses of trees often lag behind environmental changes. Cambial growth and, to a lesser degree, shoot growth are influenced by the environmental conditions of the previous year(s) as well as by the current year's environmental condition

(Kramer & Kozlowski, 1979). Cannell et al. (1976) and Lavender (1981) also wrote that tree growth in many species is correlated with tree size, the number of shoot primordia present in a dormant bud and the environment.

Finally, this study demonstrates that larger trees, because of their faster growth rates, have a better chance of achieving dominance over competing brush in the Coast Range environments studied. Smaller trees, whether the result of competition from brush, inherent genetic traits, or microsite deficiencies, will be under increasing competitive stress because: (1) their growth trajectory is inherently lower and (2) rapidly growing competing vegetation may continue to dominate them.

Possible Confounding Factors Concerning Overtopping Effects

Trees growing in the open in this study tended to be larger than those currently overtopped. Overtopping competition could (and probably does) account for most of the difference. However, overtopping effects cannot be specifically isolated due to possible confounding factors. For example, it is possible that trees sampled in the more open conditions were larger to begin with. This point cannot be thoroughly examined in this study since the first diameter measurements were not taken until the third year after planting. To determine diameters at the time of planting would have required destructive sampling of the seedlings--a technique precluded by the long-term nature of the study plots used. Height internodes were measured back to the first year after planting and differences in height growth that year were not significant ($p < .05$). This suggests that all of the trees were about equivalent in size to begin with.

Other possible confounding influences include: (1) more or less favorable soil conditions associated with trees growing in the open; (2) more or less animal damage to trees growing in the open; (3) positive or detrimental effects of manual release; and (4) more or less efficient genotypes among the open grown trees.

Similarly, trees subjected to manual release could have suffered from "thinning shock" and had poor growth for several seasons following treatment. However, Dimock's (1983) data on manually released trees growing on the same sites did not indicate any "shock" due to manual release.

In any event, the sampling scheme used in this study should have reduced the chances of confounding interactions. The possibility of confounding interactions cannot be totally eliminated, however, due to the inherent plot design on which this study was superimposed. For example, poor soil conditions could account for some of the trees being relatively open grown. The growth of these trees would probably be less than expected for trees growing in the open as a result of release treatment. Thus, the results of this study could be a conservative estimate of the competitive effects on overtopping shrubs on Douglas-fir growth.

Site Influences

The strength of the findings and predictions also varied amonst the three sites. A majority of trees growing on the Waldport site are now (Year N+2) either equal in height or slightly above the brush canopy. The vigor of these trees is partially due to the excellent site preparation the area received prior to planting. Initial growth during the first two years after planting was sufficient to allow the trees to contend with and eventually emerge from the surrounding brush competition.

The Florence site on which the plantation is a year older than on the Waldport site is rapidly being overtaken by red alder and salmonberry. This may account for the strong diameter relationships and the moderate height relationships with the percent sky visible. The onset of carbohydrate depletion as a result of shoot elongation may explain why the height relationships with the percent visible sky were best for this site.

The Hebo site was most difficult to assess. Many of the trees growing at Hebo were not as severely overtopped as those at the Florence site, because Hebo presented a situation in which microsite differences may account for the substantial variations in growth. Trees planted in areas where residual brush was not present or did not encroach upon them were probably able to grow rapidly and set a steep initial growth trajectory above the brush.

rapidly and set a steep initial growth trajectory above the brush. Trees planted in the middle or along the margins of pre-existing brush either died due to competition or were predisposed to animal damage. Surviving trees may have been planted along the margins of brush clumps and thus were able to maintain moderate to mediocre growth. However, many of these partially overtopped trees are now being rapidly encroached upon by spreading salmonberry and vine maple.

Management Implications

Results from this study suggest that the size and subsequent growth of Douglas-fir saplings growing in the Oregon Coast Range are reduced by the effects of overtopping brush competition. However, the effects of overtopping cannot be attributed to light availability alone, although light is probably the major resource being affected. The manager must assess the effects of overtopping plant competition on the complete resource environment (e.g., light, water, nutrients, temperature, space) and prescribe treatments that will enhance the availability of these resources for crop tree growth. Plantations should begin with good site preparation and the planting of vigorous trees. Forest managers should reduce competition from overtopping brush early since trees relatively free from overtopping brush tend to be larger and capable of more growth in subsequent years. The current year's overtopping condition may not only affect the current season's growth and size but also the subsequent season's. Therefore, delays in controlling overtopping vegetation can compound loss of crop growth during subsequent years, leading to longer rotations and even crop mortality.

The fisheye photo method for assessing overtopping plant canopies provides managers with a quantitative tool for surveying reforestation units and the potential to stratify them according to the degree of overtopping. Managers can then prioritize the need for vegetation management on specific Coast Range sites based upon the degree of overtopping and the relative growth rates of the conifers, shrubs and hardwoods involved.

Research Implications

This study was designed to assess empirically the effects of overtopping brush competition on Douglas-fir saplings growing on north-facing slopes in the Oregon Coast Range. Although strong empirical relationships were found, causation was not proved nor were the exact mechanisms of competition identified. Light alone may not be the only factor limiting the size and growth of the saplings since the maximum variation explained by percent sky visible was only 74 percent. Therefore, other site conditions and influences could also be responsible for limiting tree growth. These factors should be identified and quantified according to importance in well-designed future studies.

The mechanisms of internal resource allocation in overtopped Douglas-fir saplings also need to be carefully studied. Some of the morphological growth features (e.g., leader growth) did not exhibit a very strong relationship with percent sky visible (overtopping). The mechanisms of internal resource allocation in overtopped trees should be studied to determine: (1) the morphological and physiological effect of overtopping on leader growth; (2) the priority of resource allocation; (3) the primary carbohydrate sinks and sources when a plant is under competitive stress; (4) the effect of competition on hormone production and transport which ultimately affects growth, given availability of resources as in (1)-(3) above; (5) the duration that an overtopped tree can continue to elongate at the expense of other morphological organs; (6) the importance of microsite differences; and (7) the importance of winter photosynthesis in a conifer overtopped by deciduous brush. The fifth point is of most immediate concern because managers need to know the range in the quantity and duration of overtopping competition that a Douglas-fir sapling can withstand in the Oregon Coast Range. However, isolating the effects of overtopping competition on growth and internal resource allocation is difficult and best studied on individual trees or a group of clones under controlled conditions. The competitive situation can then be controlled and modified and the resulting growth responses observed both empirically and physiologically.

Finally, the value of fisheye photography will continue to be refined and adapted for more applications in forest vegetation management. Practical improvements are needed in the field apparatus so that pictures can be taken rapidly and under a wider range of weather conditions.

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APPENDICES

APPENDIX I. Summary table of multiple regression equations used to predict 1982 (Year N+1) Douglas-fir tree size and growth from 1981 (Year N) morphological growth features and % sky visible.

FLORENCE SITE

Year N Independent Variables (X)

(Y) (Year N+1) Dependent Variable	= Constant	+ X_1	+ X_2	+ X_3	+ X_4	Std. Dev.	Adj R^2
THT	= 68.62	+ 17.25(BDIA)	+ 0.96(LLG)	+ 0.70(% sky)	*	20.16	0.82
BDIA	= -1.22	+ 1.24(BDIA)	+ 0.02(% sky)	+ *	*	0.47	0.92
LLG	= 30.65	- 0.09(LDIA)	+ 0.73(LLG)	+ 14.87(BDIA)	- 0.31(THT)	13.43	0.60
LDIA	= 0.0016	+ 0.26(BDIA)	+ 0.094 (LBDIA)	- 0.004(THT)	+ 0.003(% sky)	0.16	0.80

THT = Tree Height (cm)
BDIA = Basal Diameter (cm)
LLG = Leader Length (cm)
LDIA = Leader Diameter (cm)
LBDIA = Leader Bud Diameter (cm)
% sky = Percent sky visible

*Adding another variable did not improve prediction.

APPENDIX II. Summary table of multiple regression equations used to predict 1982 (Year N+1) Douglas-fir tree size and growth from 1981 (Year N) morphological growth features and % sky visible.

(Y) (Year N+1) Dependent Variable	=	Constant	+	X_1	+	X_2	+	X_3	+	X_4	Std. Dev.	Adj R^2
				HEBO SITE — Year N Independent Variables (X)								
THT	=	7.57	+	0.92(THT)	+	0.67(LLG)	-	0.15(% sky)	+	21.90(LDIA)	12.1	0.92
BDIA	=	-0.67	+	1.64(BDIA)	+	0.008(% sky)		*		*	0.36	0.84
LLG	=	4.09	+	0.56(LLG)	+	27.30(LDIA)	-	0.17(% sky)		*	11.39	0.40
LDIA	=	-0.34	+	0.68(LDIA)	+	.005(LLG)	+	0.09(LBDIA)	-	0.19(% sky)	0.13	0.67

THT = Tree Height (cm)
BDIA = Basal Diameter (cm)
LLG = Leader Length (cm)
LDIA = Leader Diameter (cm)
LBDIA = Leader Bud Diameter (cm)
% sky = Percent Sky Visible

*Adding another variable did not improve prediction.

APPENDIX III. Summary table of multiple regression equations used to predict 1982 (Year N+1) Douglas-fir tree size and growth from 1981 (Year N) morphological growth features and % sky visible.

WALDPORT SITE

(Y) (Year N+1) Dependent Variable	=	Constant	+	Year N Independent Variables (X) X_1	+	X_2	+	X_3	+	X_4	Std. Dev.	Adj R^2
THT	=	28.80	+	0.81(THT)	=	0.89(LLG)	-	0.24 (% sky)	+	1.40(LBDIA)	10.86	0.92
BDIA	=	-0.002	+	1.00(BDIA)	+	0.005(% sky)		*		*	0.38	0.69
LLG	=	39.44	+	0.94(LLG)	-	0.20(% sky)	+	0.20(THT)		*	10.87	0.35
LDIA	=	0.40	+	0.56(LBDIA)	+	0.20(LDIA)	-	0.003(% sky)		*	0.14	0.25

THT = Tree Height (cm)
BDIA = Basal Diameter (cm)
LLG = Leader Length (cm)
LDIA = Leader Diameter (cm)
LBDIA = Leader Bud Diameter (cm)
% sky = Percent Sky Visible

*Adding another variable did not improve predictions.