Site Index and Height Growth Curves for *Pinus oocarpa* Schiede in Central Honduras[1]

C.T. Stiff, D.N. Perez**, F.D. Johnson**

ABSTRACT

Polymorphic site index and height growth equations are provided for *Pinus oocarpa* growing in pure and mixed upland pine forests of central Honduras. Stem-analysis data from 389 codominant/dominant site trees were used to estimate site index and average height growth for 195 sampled plots. Site index was defined as the average total height of site trees at an index age of 15 years located at breast height. Weighted regression, with 1 325 plot observations, was used to fit both models. A linear site index model explained 95% of the variability in plot site index and had an unweighted 1.26 m standard error. A logistic height growth model fit with nonlinear regression explained 95% of the variability in height with an unweighted standard error of 1.27 m. Precision curves are presented for determining sample size, and field procedures outlined for applying site index and height growth equations.

COMPENDIO

Ecuaciones de Indice de Sitio y crecimiento en altura polimórficas fueron desarrolladas para *Pinus oocarpa*, creciendo en rodales mixtos y puros en los pinares de tierras altas del centro de Honduras. Datos de análisis de tallo obtenidos en 389 árboles dominantes y codominantes, aptos para la determinación del Indice de Sitio (árboles sitio), se usaron para estimar Indice de Sitio y crecimiento promedio en altura en una muestra de 195 parcelas. El Indice de Sitio se definió como la altura total promedio de los árboles sitio (dominantes y codominantes) a la edad clave a la altura del pecho igual a 15 años. Un total de 1 325 observaciones se usaron para ajustar ambos modelos mediante regresión ponderada. Un modelo lineal fue usado para el Indice de Sitio, este modelo explicó el 95% de la variabilidad del Indice de Sitio en las parcelas muestra con un error estándar sin ponderar de 1.26 m. Un modelo logístico fue usado para ajustar la ecuación de crecimiento en altura, el ajuste fue realizado usando regresión no lineal y explicó un 95% de la variabilidad de la altura con un error estándar sin ponderar de 1.27 m. Curvas para determinar precisión y tamaño de la muestra requeridos para el uso correcto de las ecuaciones, junto a instrucciones de terreno para la aplicación de las curvas de Indice de Sitio y crecimiento en altura se presentan como parte integral de este trabajo.

INTRODUCTION

In Honduras most forest management activities are concentrated in the pine forests, which produce over 90% of wood exports. A serious impediment to forest management has been determining optimal land use. Honduran foresters are currently assessing site quality using a combination of slope, soil depth, and present use. While these factors are certainly important, a system which predicts site quality and potential productivity is essential for the rational allocation of money and personnel, and for prediction of future wood supplies.

The objective of this study was to develop a site classification system which could be readily applied by Honduran foresters to the multiple-use management of pine forests in central Honduras (1). A major feature of the system was that sites were evaluated on the basis of the growth and productivity of *Pinus oocarpa* Schiede.

This paper presents equations which provide estimates of *Pinus oocarpa* site index and height growth (2). Site index curves predict growth potential from height and age in existing stands, while height growth curves express average height development in stands of a given site index. Precision curves are also reported for determining sample size, along with field procedures for applying site index and height growth equations.

---

[1] Received for publication 16 March 1989.
Prepared as contribution No. 333 of the Idaho Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow, ID 83843. This study was supported by the United States Agency for International Development, Office of Science and Technology (AID/SCI 2E-05) and the Corporación Hondureña de Desarrollo Forestal (COHDEFOR). The authors thank forestry technicians from the Escuela Nacional de Ciencias Forestales (ESNACIFOR) and T.V. Dechert, University of Idaho, for field data collection.

* Assistant Professor and Professor, Department of Forest Resources, College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow, ID 83843, USA.

** Professor, Escuela Nacional de Ciencias Forestales, Corporación Hondureña de Desarrollo Forestal, Apartado Postal No. 2, Siguatepeque, Honduras.

Turrialba Vol. 39, No. 2, 1989, pp. 247-253

Study area

About 17% of the interior highlands of Honduras are covered with pinelands which are dominated by *Pinus oocarpa*, but include *Pinus maximinoi* and *Pinus tecunumanii* at higher elevations, and *Pinus caribaea* in the dry valleys. *Pinus oocarpa*, the primary commercial species, covers about 1.8 million ha at elevations ranging from 600 to 1 900 masl where it often forms pure stands. The study area, centered within 100 km of Siguatepeque, included nearly 500 000 ha of upland pine forests in central Honduras (Fig. 1).

Interior pine forests vary from open and savanna-like to dense with closed canopy, depending on site and precipitation. The terrain is mountainous, with steep slopes being more common than gentle ones. Undergrowth varies from low-density grasses to dense mid-shrubs with scattered young broadleaf trees. The presence of broadleaf species within the pine forests leads many observers to believe the pine is seral to a subtropical deciduous or semievergreen forest. Geological materials and soils affect forest composition and productivity in the upland pine forests, but relationships are poorly understood. The soils are generally nutrient-deficient. Fire may well be the most important functional element of the pine ecosystem, and is undoubtedly necessary to retain the high level of pine composition.

The climate of central Honduras is subtropical, with moist summers and dry winters. The upland pine forests have a wet season with two periods of maximum precipitation (June-July and September-November), and a long dry season from December to May. The average annual precipitation is 1 190 mm with only 60 mm falling from January through April (3). Precipitation generally increases with elevation but is rather localized, and adjacent areas may receive very divergent amounts of rain in a given period. The highest average monthly temperature is 24°C in May and June. The lowest average monthly temperature of 17°C occurs in December.

Table 1. Number of sampled plots by site index class for levels of slope, aspect, and elevation.

Levels of slope, aspect and elevation	Site index class (m) at age 15					
	5	10	15	20	25	Total
Slope (%)						
1-10	1	11	13	6	1	32
11-20	0	13	19	8	0	40
21-30	1	13	16	7	0	37
31-40	3	10	17	4	0	34
41-50	2	5	8	2	1	18
51-60	2	7	6	0	0	15
> 60	2	12	5	0	0	19
Aspect						
N	2	11	10	4	0	27
NE	4	9	15	3	0	31
E	3	15	8	2	0	28
SE	1	7	9	4	1	22
S	1	8	15	4	0	28
SW	0	8	11	3	1	23
W	0	5	8	2	0	15
NW	0	8	8	5	0	21
Elevation (m)						
< 1051	6	27	23	9	1	66
1051-1250	2	22	27	6	1	58
1251-1450	1	5	16	4	0	26
1451-1650	0	9	5	6	0	20
> 1650	2	8	13	2	0	25
Totals	11	71	84	27	2	195

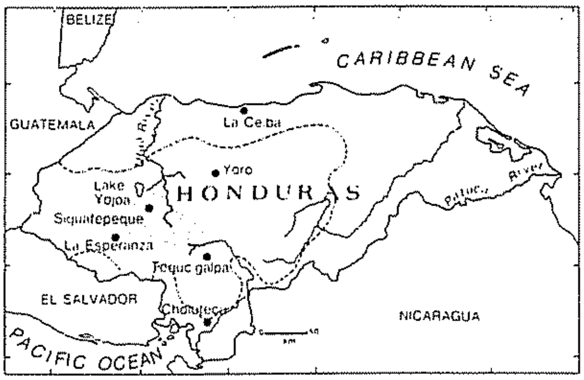

Fig. 1 Study area in Honduras (shaded), centering near Siguatepeque. Interior pine forests delimited by broken line.

MATERIALS AND METHODS

Plot selection

An ecological site classification was developed which stratified the study area into small homogeneous site units with closely defined landscape characteristics. Two hundred 0.4 ha sample plots were subjectively distributed over the study area in site units occurring on ignimbritic parent material. Plot size was chosen to more accurately describe the divergent site and stand conditions observed within the study area. Within each sample site, overstory and understory vegetation, soil type, slope position, and slope shape were nearly uniform. Furthermore, selected sites were fully utilized by the trees and relatively free of recent disturbance such as logging, fire, or insect infestation. Plots were located to cover a wide range of aspects, slopes, and elevations; however, plot selection was not constrained by species composition, stand density, or age structure. At each plot, data were collected regarding the physical environment, understory vegetation, and stand characteristics.

Sample plots were located only in stands possessing suitable site trees of *Pinus oocarpa*. Suitable site trees were either codominant or dominant, and at least 15 years old at breast height. The trees had healthy-appearing crowns with no observable top damage, and no past history of suppression or damage as evidenced by increment cores taken at 1.3 m. Since *Pinus oocarpa* is shade intolerant, dominant and codominant trees should retain the same crown position throughout their lifetime, thus minimizing the chance of sampling trees with past suppression.

Stem analysis

Two site trees representative of the local growing conditions within the stand were felled on each plot. Site trees were cut with a 0.3 m stump, and sectioned at 0.8 and 1.3 m above the ground. Above 1.3 m, trees were cut into ten equal-length segments. Diameters (inside and outside bark) and height growth were measured, and rings were counted for all 12 sections.

Pine species which dominate the Honduran forests pose a special problem when evaluating site productivity because they do not always produce distinct annual growth rings (4). Often, two or more rings are produced in a given year due to two or more wet seasons separated by dry periods. Fires also influence ring production, for crown scorching may affect growth ring production for up to three years after fire. Thus upland pines in central Honduras may produce one or more or even no rings in a particular year. For this study, it was assumed that ring-counts recorded per section were equivalent to age.

Plot site index and height growth

Total height was plotted against breast height age for 402 stem-analysis trees. Tree records were deleted from subsequent analyses if plotted data indicated evidence of past suppression. This procedure reduced the total number of trees and plots to 389 and 195, respectively. The remaining stem-analysis trees averaged 20.7 m total height, 31.8 cm dbh, and 37 years of age at breast height. The range of measurements were 11.0 to 34.4 m, 16.1 to 78.1 cm, and 15 to 129 years. Of the 389 trees, 232 were classified as dominants and 157 codominants.

An average height growth curve was determined for each sample plot using the individual tree stem-analysis data and a Richards' function (5, 6):

$$HT = b_0 * [1 - \exp(b_1 * A)]^{b_2} \qquad (1)$$

where HT is total tree height minus 1.3 m, A is breast height age, exp is the base of natural logarithms, and b's are estimated by plot using derivative-free nonlinear regression (7). Equation 1 was then evaluated at index age 15 years to estimate plot site index. The number of sampled plots by 5 m site index class and levels of slope, aspect, and elevation are provided in Table 1. Index age was set to include trees from highly productive 15-year-old stands and to avoid extrapolation of equation 1 when determining plot site index. Age was referenced at breast height rather than the base of the tree to eliminate variability in early height growth due to the intensity and timing of such factors as climate, competition, fire, and grazing. The median number of years for *Pinus oocarpa* to reach breast height was 2, 3, 4, 5, and 6 years for site index class 25, 20, 15, 10, and 5 m, respectively. Equation 1 was also evaluated by five-year periods from age five to the five-year age class less than or equal to the youngest stem analysis tree on the plot. This procedure produced 1470 observations of total height, age, and site index by five-year age class for 195 plots.

A summary of stand and site variables for all 195 plots is given in Table 2. Data indicated a decline in observed plot site index with increasing average plot age. This apparent decline is due to better sites being harvested at younger ages; consequently, older stands are found only on the poorer sites. Therefore, observations with age equal to or greater than 50 years were omitted to eliminate the skewing effect of old stands found on poorer sites.

Polymorphic site index and height growth curves were fit with the remaining 1325 plot observations. Both models were constrained such that height equalled site index at index age. Heteroscedasticity was handled by using the inverse of the empirical residual variance for each five-year period as weights in iteratively re-weighted regressions (8). Final parameter estimates were obtained in three to four iterations when successive parameter estimates changed by less than one percent.

RESULTS AND DISCUSSION

Site index model

Several nonlinear model formulations were examined, but all performed poorly. Subsequently, a procedure first described by Dahms (9) and later modified by Monserud (10) was used to derive a linear site index model. First, plot site index was fit as a linear function of total height by five-year age class (11):

$$SI = b_0 + b_1 * HT \qquad (2)$$

where HT and SI are defined as HT − 1.3 and SI − 1.3 m, respectively, and b_0 and b_1 are age-dependent parameters. Regressions by age class accounted for between 67% and 95% of the variability in observed site index. The standard error was 2.0 m at age five, declining to 0 m at 15 years (index age), and then gradually increasing to 1.5 m at age 50.

Mean height, mean site index, and b_1 from equation 2 were then expressed as functions of breast height age. Stepwise linear regressions, with observations weighted by the number of plots per five-year age class, were used to screen functions of age. The model formulation for predicting site index at any age was obtained by correcting equation 2 for the mean site index, and substituting age-specific equations for mean height and b_1. Subsequently, the transformed equation 2 was fit as a function of total height and age.

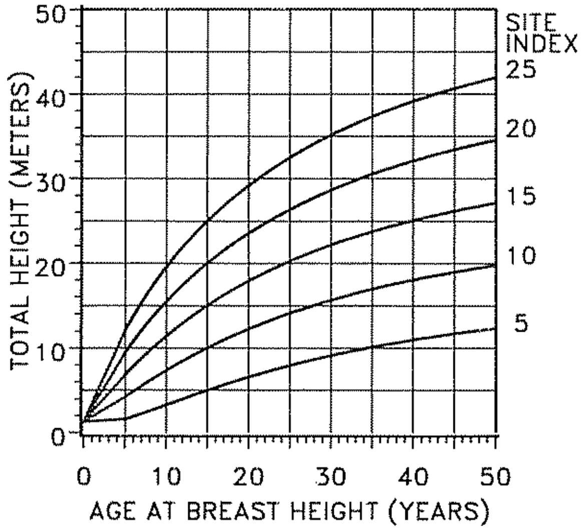

Fig 2. Site index curves for *Pinus oocarpa* in the upland pine forests of central Honduras.

Table 2. Means and ranges for stand and site level variables.

Variable	Mean	Minimum	Maximum
Plot site index (m)	14	5	26
Plot age (yrs)	36	12	120
Basal area (m^2/ha)	22	6	40
Trees per hectare	536	71	1 374
Slope (%)	31	0	90
Elevation (m)	1 212	600	1 900
Soil depth (dm)[a]	9	1	15
Precipitation (mm)[b]	1 360	900	2 000
Temperature (°C)	20	17	24

[a] Soil pits were dug to a 15 dm maximum depth

[b] Mean annual precipitation and temperature

The modified Dahms' procedure produced the following site index model:

$$\begin{aligned} SI = 1.3 + HT &+ b_1 * [\ln(A)^2 - \ln(15)^2] \\ &+ b_2 * [A * \ln(A) - 15 * \ln(15)] \\ &+ b_3 * [(HT/A) - (HT/15)] \end{aligned} \qquad (3)$$

where SI is predicted site index in m, HT is total height minus 1.3 m, ln is the natural logarithm, $b_1 = -0.76119$, $b_2 = 0.01473$, and $b_3 = 6.96787$. The model explained 95% of the variability in site index, and had an unweighted 1.26 m standard error. Equation 3 is plotted as total height versus age at breast height for five site index classes in Fig 2.

Residuals plotted by predicted 5 m site index class indicated significant but small (< 0.5 m) under- and overpredictions for the 5 and 20 m classes, respectively. The 25 m site class had a significant 2 m overprediction, which is most likely due to the lack of observations in the older age classes (12). A similar bias was observed for residuals by 5 m total height class. In this case, however, all mean absolute residuals were less than 0.5 m. Numerous functions of age and total height were attempted, but there was no significant improvement in observed bias for the site index model. Residuals plotted against other site and stand variables indicated that important predictor variables were not excluded from the model.

Groothousen (13) used a guide-curve technique and temporary sample plot (TSP) data to construct anamorphic height growth curves for *Pinus oocarpa* in Honduras. Comparisons with equation 3 produced expected results, in that Groothousen's curves were steeper at younger ages and flattened out more rapidly. Stem analysis data, along with polymorphic curve-fitting, reduce or eliminate these biases associated with anamorphic curves.

Height growth model

A logistic height growth model was fit after considering a modified Dahms' model and several alternative nonlinear model formulations. The resultant height growth model was:

$$HT = 1.3 + SI^{*}\ 1 + \exp[b_0 + b_1{}^{*} \ln(15) + b_2{}^{*} \ln(SI)] \ / \ 1 + \exp[b_0 + b_1{}^{*} \ln(A) + b_2{}^{*} \ln(SI)] \quad (4)$$

where HT is the average height of codominant/dominants, SI is the observed plot site index minus 1.3 m, A is age at breast height. $b_0 = 6.75433$, $b_1 = -1.23093$, and $b_2 = -1.18605$. The fitted model explained 95% of the variability in height with an unweighted standard error of 1.27 m. Height growth curves are plotted against breast height age for five site index classes in Fig. 3. Residuals for the height growth model plotted against predicted height, age at breast height, and site index, revealed no problems with bias. Residuals plotted against other site and stand variables did not indicate that additional variables would improve model performance.

Further data analyses indicated that *Pinus oocarpa* height growth was not suppressed by increased stand density. To the contrary, significant positive correlations showed that higher site index values were associated with higher densities. This results suggests that factors such as precipitation and soil depth, which determine the site's innate productive capacity, were also influencing observed density.

Application

Differences between Figs. 2 and 3 illustrate the behavior that Curtis *et al.* (2) and Monserud (10) described for a system of site index and height growth curves. As stated earlier, the models answer two different questions. For instance, the site curve labelled 25 (Fig. 2) passes through 40 m height at age 43 years. If a tree were sampled with that particular height and age, the best estimate of site index would be 25 m. However, 40 m trees were not observed during this study and are probably not in the population. An alternative objective would be to estimate the average height growth for codominant/dominant trees within a stand of known site index. In that case, Fig. 3 would provide an estimated 35 m height for a 43-year-old tree in a stand with a 25 m site index.

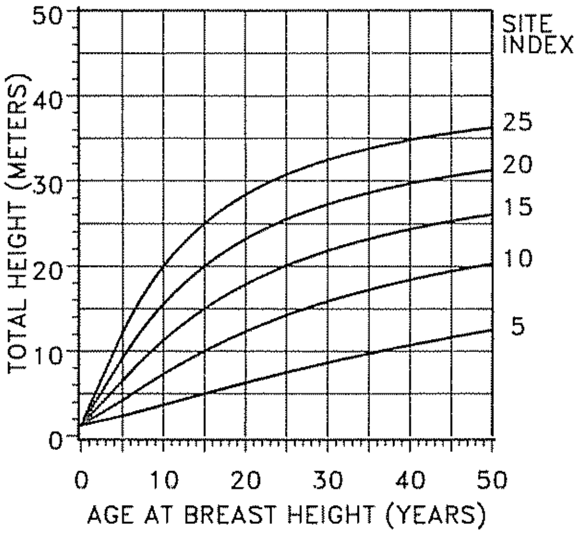

Fig. 3. Height growth curves for *Pinus oocarpa* in the upland pine forests of central Honduras.

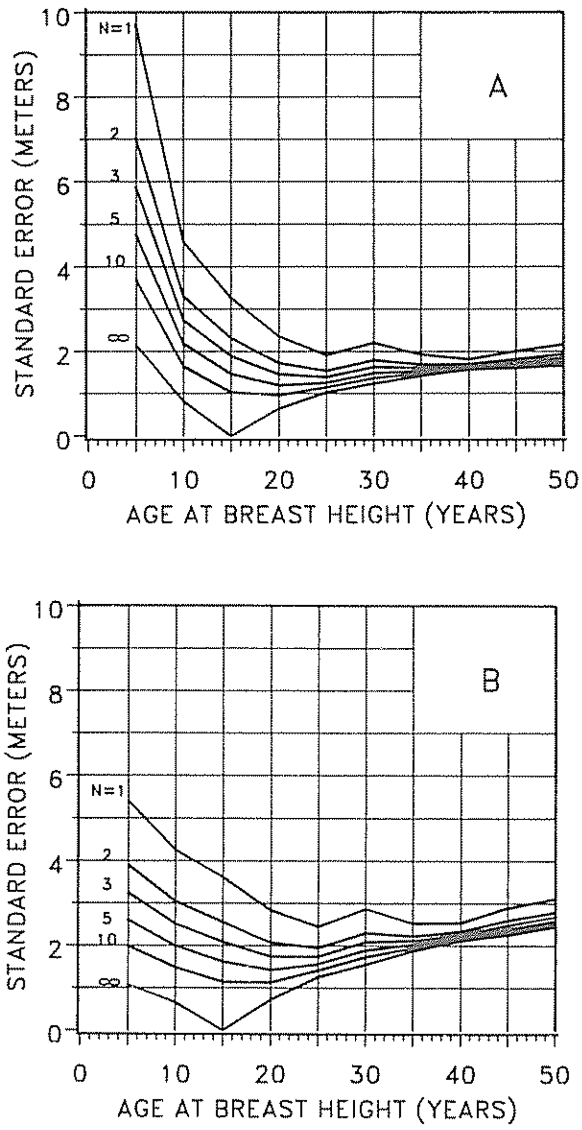

Fig. 4. Precision curves of the (A) site index, and (B) height growth equations for *Pinus oocarpa* in the upland pine forests of central Honduras.

This estimate, which answers a different question, falls within the observed range of total height.

There will be error associated with applying the height growth and site index models, even if measurement error is ignored. This overall variance, or error resulting from variability unaccounted for by the models, arises from two sources: the error which was minimized for each of the 195 plots summarized with the Richards function; and the error which was minimized while fitting the height growth and site index models. Precision curves for calculating sample size for a desired standard error and known stand age were developed for the height growth and site index models (14).

The relationship between the overall error and sample size (n) as age varies from five to 50 years is illustrated in Figs. 4-A and 4-B. The precision curves are based on the sampling variability in the data per five year period. Values on the curves labeled $n = \infty$ are the overall errors associated with fitting the height growth and site index models. Site index or height estimates can be no more precise than these values, no matter how many trees are sampled on a plot. For example, it would be impossible to obtain a standard error of less than two meters when estimating site index with five-year-old trees. As expected, site index is more difficult to predict at ages less than 15 years. In comparison, height growth is more predictable at younger ages and less predictable as age increases.

The correct procedure for estimating site index or height growth depends on the methods used for constructing the curves (15). The following field procedures should be used for determining *Pinus oocarpa* site index in central Honduras:

1. First, determine the sample size (n) needed to attain a desired standard error using Fig. 4-A. For example, if a 1.5 m standard error is desired and the average stand age at breast height was 20 years, then $n = 3$ site trees should be chosen. In all cases, account for site variability.

2. The sample plot should be selected to be representative of the growing conditions in the stand. Since site trees used for model development were selected at a rate of two per 0.4 ha or 5 per ha, then sample plot size should be n/5 ha. For example, if $n = 3$, then sample trees should be chosen on a plot of approximately 0.6 ha.

3. Codominant or dominant *Pinus oocarpa* site trees should be selected, which have healthy-appearing crowns and no visible top damage. Complete increment cores should be obtained at breast height (1.3 m) for each of the "n" site trees. Trees which show evidence of past suppression should be replaced in the sample.

4. Measure total height (to the nearest 0.1 m) and count the number of rings at breast height for the "n" sampled trees. Trees with breast height age greater than 50 years should be replaced in the sample. Site index should not be estimated for stands greater than 50 years old.

5. Site index is estimated for each site tree using either the site curves (Fig. 2) or equation 3, and plot site index is calculated as the average site index for the "n" sampled trees.

Height growth for codominant/dominant stands less than 50 years old is calculated using the above procedure, a known site index, Fig. 4-B, and either the height growth curves (Fig. 3) or equation 4. Any deviations from the prescribed application procedures listed above could result in significant errors (14, 15). Field testing indicates possible bias when applying the site index and height growth curves on soils other than ignimbrites.

LITERATURE CITED

1. STIFF, C.T.; PEREZ, D.N.; JOHNSON, F.D. 1987. Classification of the upland pine forests of central Honduras for site quality and productivity. In Land and resource evaluation for national planning in the tropics: Proceedings of the international conference and workshop. Ed. by H.G. Lund, M. Caballero-Deloya. Chetumal, Mexico, United States Department of Agriculture. Forest Service General Technical Report WO-39. p. 128-133.

2. CURTIS, R.O.; DeMARS, D.J.; HERMAN, F.R. 1974. Which dependent variable in site index-height-age regression? Forest Science 20:74-87.

3. CLEWELL, A.F. 1973. Floristic composition of a stand of *Pinus oocarpa* in Honduras. Biotrópica 5:175-182.

4. HUGHES, J.F. 1970. A preliminary investigation of some structural features and properties of the wood of *Pinus caribaea* from British Honduras. Commonwealth Forestry Review 49:336-355.

5 CURTIS, R.O. 1964 A stem-analysis approach to site-index curves. Forest Science 10:241-256.

6 RICHARDS, F.J. 1959. A flexible growth function for empirical use. Journal of Experimental Botany 10:290-300

7 SAS INSTITUTE INC. 1982. SAS user's guide: statistics, 1982 edition. Cary, NC: SAS Institute Inc 584 p.

8 DRAPER, N.R.; SMITH, H. 1981. Applied regression analysis 2 ed New York. John Wiley 709 p

9 DAHMS, W.G 1975 Gross yield of central Oregon lodgepole pine In Management of lodgepole pine ecosystems Proceeding of a Symposium. Ed. by D.M Baumgartner. Washington State University Co-operative Extension Service, Pullman, WA p. 208-232

10.MONSERUD, R.A 1984. Height growth and site index curves for inland Douglas fir based on stem analysis data and forest habitat type. Forest Science 30:943-965.

11 HEGER, L. 1968 A method for constructing site index curves from stem analyses. Forestry Chronicle 44:11-15

12 SMITH. V.G. 1984. Asymptotic site-index curves, fact or artifact? Forestry Chronicle 60:150-156.

13 GROOTHOUSEN, C. 1980. Site index curves for *Pinus oocarpa* Schiede in Honduras. COHDEFOR Sección Manejo Forestal. Boletín Silvicola no. 3 5 p

14 MONSERUD, R.A. 1985. Applying height growth and site index curves for inland Douglas-fir. United States Department of Agriculture. Forest Service Research Paper INT-347. 22 p.

15 CLUTTER, J.L.; FORTSON, J.C ; PIENAAR, L.V.; BRISTER, G.H.; BAILEY, R.L. 1983. Timber management: A quantitative approach New York, John Wiley 333 p.