# Implementing Regional Locale and Thinning Response in the Loblolly Pine Height-Diameter Relationship

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ABSTRACT

This study uses two regionwide data sets, one exemplified by intensive management and the other by nonintensive management, to investigate whether including regional locale and thinning response improves the loblolly pine height–diameter relationship. Results showed that including geographic coordinates as scaled variables, in addition to including a thinning response modifier, reduces the variability of an individual-tree height model compared with a baseline model without these covariates. Holding stand conditions constant, tree height for a given diameter will generally be greater at south and east locales within the natural range of loblolly pine, and thinning will lead to slightly greater tree heights. Equations that include geographic locale of the stand and a thinning modifier that incorporates amount of time since thinning are proposed. These equations can be used for thinned or nonthinned stands throughout the natural geographic range of the species.

**Keywords:** geographic locale, latitude, longitude, thinning, *Pinus taeda* L.

Understanding stand and tree responses from silvicultural treatments has long been desired by loblolly pine (*Pinus taeda* L.) plantation managers. Thinning has been extensively practiced in loblolly pine plantations, which are planted across a vast geographic area in the southeastern United States. It is generally thought that tree diameter growth is more influenced by thinning than is height growth. The dynamics of thinning and subsequent height growth, however, are multifaceted (Harrington and Reukema 1983). Zhang et al. (1997) found that thinning positively influenced both height and diameter in loblolly pine stands, and thinning showed a greater effect on height growth for high-quality sites compared with low-quality sites. Similarly, Sharma et al. (2006) concluded that thinning enhanced height growth of dominant and codominant trees, albeit a relatively small increase. Several thinning response modifiers have been proposed and evaluated for their applicability in stand and tree modeling to account for various thinning responses (Short and Burkhart 1992, Liu et al. 1995).

Across its natural range in the southeastern United States, loblolly pine is planted on a wide variety of sites, each with different soil properties, subject to varying climatic conditions. For example, loblolly pine in the Piedmont physiographic province are often planted on rolling topography typified with clayey soil types, whereas trees growing in the Coastal Plain are exposed to warmer air temperatures and more level terrain (Baker and Langdon 1990). Hasenauer et al. (1994) found that the maximum basal area that a stand can support varies across the natural range of loblolly pine. Similarly, wood properties in loblolly pine have been shown to vary across physiographic regions (Jordan et al. 2007). At a smaller geographic scale, precipitation was linked to loblolly pine site productivity in Alabama (Lockaby and Caulfield 1989). Incorporating regional variables directly into a prediction equation for stand dominant height offered improved model precision when evaluated against an equation without regional variables (Amateis et al. 2006). The objective of this study was to use two regionwide data sets to determine the effectiveness of using thinning response and regional locale in the loblolly pine height-diameter relationship.

## Data

Data from intensively managed plantations (IMPs) were acquired from 172 permanent plots planted across the natural range of loblolly pine (Amateis et al. 2006). These plots are representative of contemporary silviculture of loblolly pine plantations. Common management strategies of these plots include site preparation, planting genetically improved stock, and applying fertilizer and competition control as needed. Each installation consisted of one nonthinned control plot and two plots with thinning treatments. A heavily thinned plot was also pruned. Pruning protocols resulted in removing dead branches only. These plots were established in 1996–1999 in 3–8-year-old stands and continue to be measured every 2 or 3 years. To date, four or five remeasurements have occurred, depending on year of plot establishment.

Data from nonintensively managed plantations (NIMPs) were obtained from a regionwide thinning study established on 186 permanent plots planted on cutover, site-prepared lands (Burkhart et al. 1985). Routine silvicultural practices of these plots included less-intensive site preparation methods and planting of nongenetically improved (woods-run) stock. Midrotation fertilization and competition control treatments were not customary. Each plot consisted of a control, light thin (approximately 33% removal of basal

Manuscript received February 5, 2009; accepted September 3, 2009.

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**Table 1. Mean values by latitude of stand conditions for all measurements in nonthinned stands (NT) and stands that received some entry of thinning (ST) in intensively and nonintensively managed loblolly pine plantations (standard deviations in parentheses).**

| Variable | | Latitude interval (°) | | | | |
|---|---|---|---|---|---|---|
| | | <31.5 | 31.5–33.9 | 33.9–35.5 | >35.5 | All plots |
| IMPs[a] | | | | | | |
| *n* | NT | 501 | 796 | 246 | 212 | 1755 |
| | ST | 85 | 123 | 27 | 58 | 293 |
| HD (ft) | NT | 27.6 (12.3) | 26.7 (11.4) | 30.8 (11.6) | 31.4 (10.5) | 29.4 (11.6) |
| | ST | 46.1 (6.6) | 47.8 (6.0) | 46.5 (4.9) | 46.1 (4.7) | 46.9 (5.9) |
| Quadratic dbh (in.) | NT | 4.3 (1.6) | 4.7 (1.6) | 5.3 (1.7) | 5.4 (1.4) | 4.8 (1.6) |
| | ST | 6.9 (1.2) | 7.2 (1.0) | 7.9 (1.0) | 7.7 (1.0) | 7.3 (1.1) |
| Trees/ac | NT | 636.6 (139.8) | 609.4 (94.6) | 573.9 (98.6) | 525.2 (92.4) | 602.0 (114.9) |
| | ST | 423.4 (232.8) | 422.6 (200.4) | 408.5 (207.2) | 335.9 (198.6) | 404.4 (212.3) |
| Basal area (ft$^2$/ac) | NT | 69.5 (41.6) | 83.5 (43.7) | 96.0 (49.8) | 88.2 (42.6) | 81.9 (44.8) |
| | ST | 68.1 (26.7) | 68.5 (26.1) | 78.0 (23.6) | 60.2 (21.3) | 67.6 (25.4) |
| NIMPs | | | | | | |
| *n* | NT | 204 | 222 | 330 | 312 | 1068 |
| | ST | 429 | 460 | 664 | 635 | 2188 |
| HD (ft) | NT | 56.4 (13.9) | 56.0 (15.0) | 52.9 (14.4) | 53.6 (13.0) | 54.4 (14.1) |
| | ST | 56.9 (14.2) | 57.4 (15.5) | 52.8 (14.6) | 53.6 (13.0) | 54.9 (14.4) |
| Quadratic dbh (in.) | NT | 7.2 (1.5) | 7.6 (1.6) | 7.4 (1.6) | 7.3 (1.4) | 7.4 (1.5) |
| | ST | 8.0 (1.7) | 8.6 (2.1) | 8.3 (2.0) | 8.3 (1.9) | 8.3 (2.0) |
| Trees/ac | NT | 481.9 (151.5) | 531.2 (160.0) | 527.0 (164.1) | 568.8 (156.0) | 531.5 (161.1) |
| | ST | 334.0 (150.5) | 352.1 (166.4) | 345.2 (156.5) | 346.6 (177.7) | 344.9 (163.9) |
| Basal area (ft$^2$/ac) | NT | 124.3 (29.2) | 150.7 (37.7) | 144.5 (38.1) | 147.8 (31.7) | 142.9 (35.8) |
| | ST | 102.4 (27.0) | 117.3 (30.8) | 111.4 (33.1) | 108.0 (29.9) | 109.9 (31.4) |

[a] IMPs, intensively managed plantation; NIMPs, nonintensively managed plantation; $n$ = number of plots; HD, average height of dominant and codominant trees.
[b] Measurements on IMP plots were initiated prior to thinning treatment.

**Table 2. Mean values by longitude of stand conditions for all measurements in nonthinned stands (NT) and stands that received some entry of thinning (ST) in intensively and nonintensively managed loblolly pine plantations (standard deviations in parentheses).**

| Variable | | Longitude interval (°) | | | | |
|---|---|---|---|---|---|---|
| | | >−79 | −79 to −84 | −84 to −90 | <−90 | All plots |
| IMPs[a] | | | | | | |
| *n* | NT | 229 | 403 | 388 | 735 | 1755 |
| | ST | 68 | 86 | 46 | 93 | 293 |
| HD (ft) | NT | 31.5 (10.6) | 33.3 (11.8) | 28.7 (10.9) | 27.1 (11.6) | 29.4 (11.6) |
| | ST | 46.2 (4.8) | 50.2 (6.5) | 47.4 (5.4) | 44.0 (4.5) | 46.9 (5.9) |
| Quadratic dbh (in) | NT | 5.4 (1.4) | 5.2 (1.4) | 4.7 (1.5) | 4.4 (1.7) | 4.8 (1.6) |
| | ST | 7.8 (1.1) | 7.4 (1.0) | 7.3 (1.2) | 6.8 (1.0) | 7.3 (1.1) |
| Trees/ac | NT | 518.6 (94.6) | 604.8 (67.3) | 646.3 (102.7) | 603.1 (132.3) | 602.0 (114.9) |
| | ST | 330.4 (192.8) | 407.3 (195.5) | 417.0 (214.3) | 449.5 (228.1) | 404.4 (212.3) |
| Basal area (ft$^2$/ac) | NT | 88.4 (43.3) | 94.9 (44.2) | 82.9 (43.9) | 72.2 (43.8) | 81.9 (44.8) |
| | ST | 62.0 (21.8) | 75.7 (24.0) | 68.0 (26.8) | 64.1 (27.1) | 67.6 (25.4) |
| NIMPs | | | | | | |
| *n* | NT | 417 | 195 | 257 | 199 | 1068 |
| | ST | 846 | 406 | 526 | 410 | 2188 |
| HD (ft) | NT | 54.1 (13.4) | 56.4 (13.5) | 53.4 (14.9) | 54.5 (15.2) | 54.4 (14.1) |
| | ST | 54.4 (13.7) | 56.9 (13.0) | 53.8 (15.5) | 55.1 (15.6) | 54.9 (14.4) |
| Quadratic dbh (in) | NT | 7.4 (1.6) | 7.5 (1.4) | 7.0 (1.5) | 7.6 (1.7) | 7.4 (1.5) |
| | ST | 8.4 (2.0) | 8.3 (1.7) | 7.9 (1.9) | 8.7 (2.2) | 8.3 (2.0) |
| Trees/ac | NT | 547.8 (158.8) | 511.7 (146.2) | 525.1 (183.4) | 524.7 (146.2) | 531.5 (161.1) |
| | ST | 341.0 (169.3) | 352.4 (157.2) | 348.6 (163.5) | 340.5 (159.5) | 344.9 (163.9) |
| Basal area (ft$^2$/ac) | NT | 146.3 (32.6) | 145.6 (31.0) | 128.3 (36.6) | 151.7 (40.2) | 142.9 (35.8) |
| | ST | 108.8 (30.3) | 115.8 (28.0) | 101.4 (30.9) | 117.1 (34.6) | 109.9 (31.4) |

[a] IMPs, intensively managed plantation; NIMPs, nonintensively managed plantation; $n$ = number of plots; HD, average height of dominant and codominant trees.
[b] Measurements on IMP plots were initiated prior to thinning treatment.

area), and heavy thin (around 50% removal of basal area) treatment. These plots were established in 1980–1982 in 8–25-year-old stands. The plots were measured every 3 years for 21 years, totaling seven remeasurements.

For the IMP data, average age of thinning was 12.1 (standard deviation [SD] = 1.7) years, and average basal area removed was 56%. For the NIMP data, average age of thinning was 15.2 (SD = 4.2) years, and average basal area removed was 36%. Approximately 45% of NIMP plots were thinned twice. Average age of second thinning was 26.7 (SD = 4.2) years, and average basal area removed was 13%. IMP plots were only thinned once, and those plots that received thinning were generally older than other plots within the data set. Measurements on IMP plots were initiated prior to thinning treatment. Stand conditions were similar for IMPs and NIMPs across the geographic range of the plots (Tables 1 and 2). IMPs spanned approximately 7° of latitude and 18° of longitude, whereas NIMPs spanned approximately 8° of latitude and 20° of longitude (Figure 1).

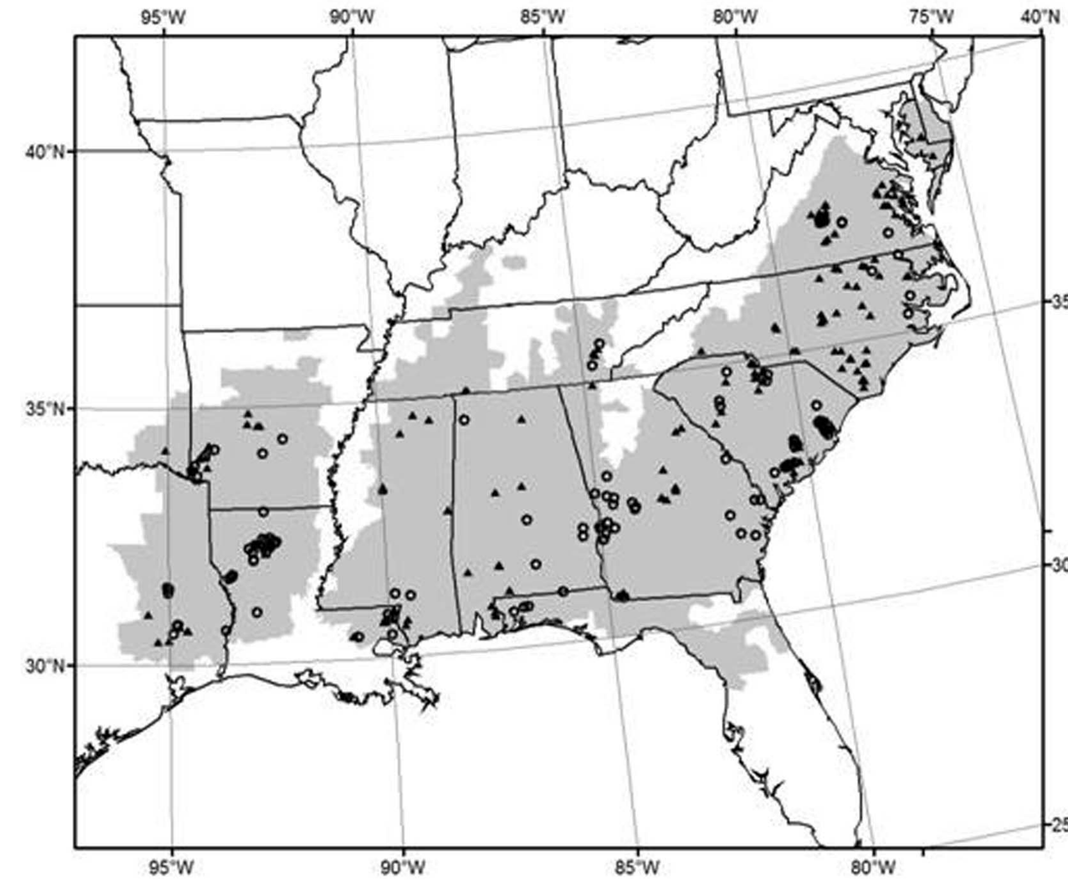


**Figure 1. Location of the original 170 intensively managed (triangles) and 186 nonintensively managed (circles) permanent remeasurement plots over the natural loblolly pine range (gray) (Miles et al. 2001) in the southeastern United States. NOTE: Longitude values are expressed as negative values west of the prime meridian.**

Trees with broken tops or forked stems were excluded in this analysis. To validate the models, the second and sixth remeasurements from the NIMP data set were withheld from model fitting and used for evaluation. Similarly, the second and fourth remeasurements from the

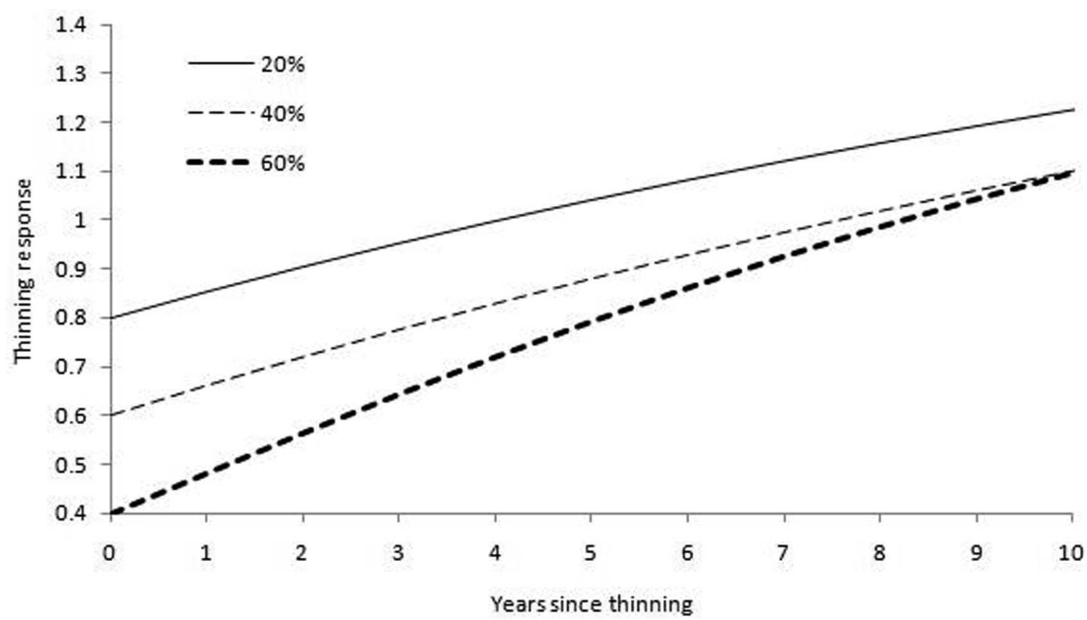


**Figure 2. General performance of thinning response (TR) modifier found in Equation 3 after removing 20, 40, and 60% of stand basal area at age of thinning ($A_T$) = 14 years with initial basal area ($BA_B$) of 130 ft$^2$/ac (assumes subsequent 7% stand basal area growth per year following thinning). Formulation is TR = $(BA_A/BA_B)^{A_T/A_P}$, where $BA_A$ is basal area (ft$^2$/ac) after thinning and $A_P$ is stand age (years) at prediction.**

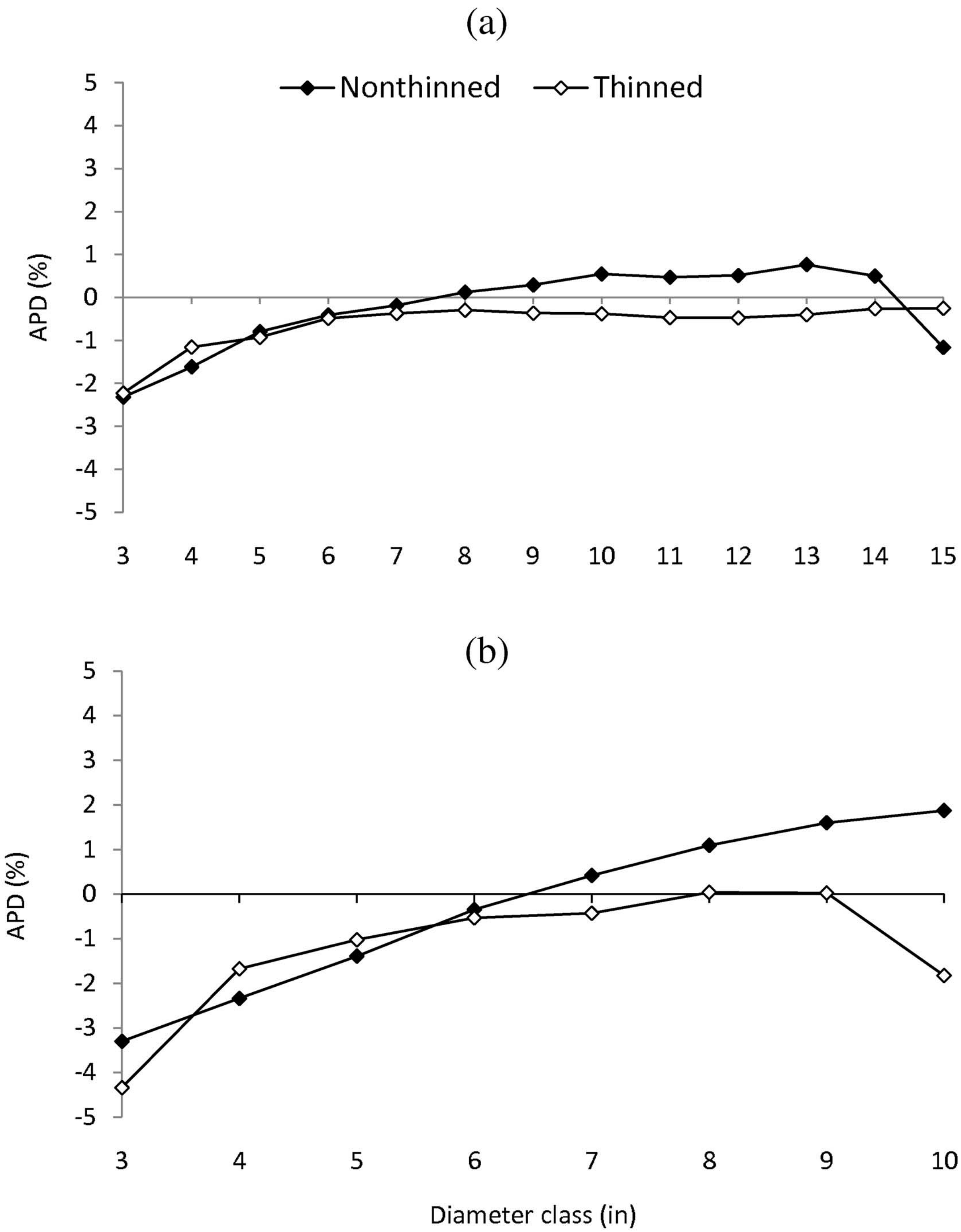


**Figure 3. Average percentage deviation (APD) of individual-tree height by diameter class for a test data set from nonintensively managed (a) and intensively managed (b) loblolly pine plantations.**

IMP data set were used in evaluation, with all other observations used in model fitting.

## Model Development and Evaluation

To determine individual-tree height, stand conditions and tree diameter are often used as independent variables. Bennett and Clutter (1968) used site index (SI), number of stems per acre ($N$), the inverse of stand age ($A^{-1}$; years), and the inverse of tree dbh ($D^{-1}$; in.) to characterize the height-diameter relationship in even-aged loblolly pine plantations. Alternatively, as a measure of site productivity, average height of dominant and codominant trees (HD) can be used in place of SI. To build upon the former relationship, Lenhart and Clutter (1971) included the term $D^{-1} - D_{\max}^{-1}$, where $D_{\max}$ is commonly specified as the midpoint value of the largest dbh class (Clutter et al. 1983). This modifier captures the fact that trees with dbh near the maximum stand dbh will generally display a height that is close to the average height of dominant and codominant trees. After examining these variables, Zhang et al. (1997) concluded that the loblolly pine height-diameter relationship was represented adequately by an equation that took the form

$$H = b_0 \mathrm{HD}^{b_1} \exp\left(\frac{b_2}{A} + (D^{-1} - D_{\max}^{-1})\left(b_3 + b_4\left(\frac{\ln N}{A}\right)\right)\right), \quad (1)$$

Table 3. Parameter estimates for an individual-tree height equation (Equation 5) for loblolly pine trees grown in intensively managed plantations.

| Parameter | Estimate | Standard error | 95% Confidence limits Lower | Upper | P values |
|---|---|---|---|---|---|
| $b_1$ | 1.8531 | 0.0085 | 1.8365 | 1.8697 | <0.0001 |
| $b_2$ | 0.8710 | 0.0010 | 0.8690 | 0.8731 | <0.0001 |
| $b_3$ | −0.0099 | 0.0005 | −0.0108 | −0.0090 | <0.0001 |
| $b_4$ | −0.6711 | 0.0093 | −0.6892 | −0.6529 | <0.0001 |
| $b_5$ | −2.5269 | 0.0060 | −2.5386 | −2.5151 | <0.0001 |
| $b_6$ | 1.0647 | 0.0042 | 1.0564 | 1.0730 | <0.0001 |
| $b_7$ | −0.0720 | 0.0015 | −0.0749 | −0.0691 | <0.0001 |
| $b_8$ | 0.0023 | 0.0004 | 0.0015 | 0.0032 | <0.0001 |

$$H = b_1 \mathrm{HD}^{b_2}\mathrm{TR}^{b_3}\exp\left(\frac{b_4}{A} + \left(\frac{1}{D} - \frac{1}{D_{\max}}\right)\left(b_5 + b_6\left(\frac{\ln N}{A}\right) + b_7\mathrm{LAT} + b_8\mathrm{LONG}\right)\right)$$

Table 4. Parameter estimates for an individual-tree height equation (Equation 5) for loblolly pine trees grown in nonintensively managed plantations.

| Parameter | Estimate | Standard error | 95% Confidence limits Lower | Upper | P values |
|---|---|---|---|---|---|
| $b_1$ | 1.5738 | 0.0087 | 1.5568 | 1.5907 | <0.0001 |
| $b_2$ | 0.9176 | 0.0012 | 0.9153 | 0.9198 | <0.0001 |
| $b_3$ | −0.0081 | 0.0006 | −0.0092 | −0.0070 | <0.0001 |
| $b_4$ | −0.9740 | 0.0219 | −1.0169 | −0.9311 | <0.0001 |
| $b_5$ | −3.0605 | 0.0113 | −3.0827 | −3.0382 | <0.0001 |
| $b_6$ | 2.6145 | 0.0305 | 2.5547 | 2.6743 | <0.0001 |
| $b_7$ | −0.0105 | 0.0017 | −0.0138 | −0.0071 | <0.0001 |
| $b_8$ | 0.0053 | 0.0007 | 0.0039 | 0.0067 | <0.0001 |

$$H = b_1 \mathrm{HD}^{b_2}\mathrm{TR}^{b_3}\exp\left(\frac{b_4}{A} + \left(\frac{1}{D} - \frac{1}{D_{\max}}\right)\left(b_5 + b_6\left(\frac{\ln N}{A}\right) + b_7\mathrm{LAT} + b_8\mathrm{LONG}\right)\right)$$

where $H$ is predicted individual-tree height (ft) and ln is the natural logarithm. In their analysis, the occurrence and extent of thinning and its subsequent effect on tree height growth were related to intensity of thinning, site quality, and tree vigor. Hence, Equation 1 was used as a baseline model in this investigation.

Variables can be calculated that describe the intensity and time effects that arise following silvicultural thinning. Termed thinning response (TR) modifiers, these variables can be evaluated for their effectiveness in describing height-diameter dynamics. One modifier used is directly proportional to thinning intensity:

$$\mathrm{TR}_1 = \frac{\mathrm{BA}_\mathrm{A}}{\mathrm{BA}_\mathrm{B}}, \tag{2}$$

where $\mathrm{BA}_\mathrm{A}$ and $\mathrm{BA}_\mathrm{B}$ are stand basal area (ft$^2$/ac) after and before thinning, respectively. Another incorporates the amount of time since thinning (Short and Burkhart 1992):

$$\mathrm{TR}_2 = \left(\frac{\mathrm{BA}_\mathrm{A}}{\mathrm{BA}_\mathrm{B}}\right)^{A_\mathrm{T}/A_\mathrm{P}}, \tag{3}$$

where $A_\mathrm{T}$ and $A_\mathrm{P}$ are stand age at thinning and prediction (years), respectively. $\mathrm{TR}_1$ is strictly proportional to thinning intensity, whereas $\mathrm{TR}_2$ incorporates age since thinning. In years directly following thinning, $\mathrm{TR}_2$ has a more immediate effect than $\mathrm{TR}_1$, whereas the effect of $\mathrm{TR}_2$ several years post-thinning (e.g., >10 years) results in a lesser effect. For nonthinned stands, both modifiers collapse to equal 1. For NIMP plots that were thinned twice, $\mathrm{TR}_1$ and $\mathrm{TR}_2$ were computed for the first and second thinning entries, separately. To describe the effects that thinning has on the dynamics of height and diameter, the thinning response variable in Equation 3 proved effective when used in the height-diameter relationship. This equation took the form

$$H = b_1 \mathrm{HD}^{b_2}\mathrm{TR}^{b_3}\exp\left(\frac{b_4}{A} + \left(\frac{1}{D} - \frac{1}{D_{\max}}\right)\left(b_5 + b_6\left(\frac{\ln N}{A}\right)\right)\right), \tag{4}$$

where $\mathrm{TR} = \mathrm{TR}_2$. Figure 2 demonstrates the general performance of the TR modifier (Equation 3).

To incorporate regional locale in the individual-tree height model, the influence of the geographic position of each plot installation was evaluated. The mean geographic coordinates within the natural range of loblolly pine are approximately 34°N and −84°W. Amateis et al. (2006) used latitude and longitude (as scaled independent variables around the mean geographic coordinates) to estimate the dominant height of loblolly pine stands, where LAT = latitude (decimal degrees) − 34 and LONG = longitude (decimal degrees expressed as a negative value west of the prime meridian) + 84. LAT and LONG were incorporated into Equation 4 to determine their usefulness in describing the loblolly pine height–diameter relationship.

LAT and LONG proved significant when incorporated into the height prediction equation. A final model chosen to explain the individual-tree height for loblolly pine took the form

$$H = b_1 \mathrm{HD}^{b_2}\mathrm{TR}^{b_3}\exp\left(\frac{b_4}{A} + \left(\frac{1}{D} - \frac{1}{D_{\max}}\right) \cdot \left(b_5 + b_6\left(\frac{\ln N}{A}\right) + b_7\mathrm{LAT} + b_8\mathrm{LONG}\right)\right) \tag{5}$$

where $D_{\max}$ is the tree of maximum observed dbh (in.) in the stand. A long-term average of precipitation at each installation did not offer any improvement when considering the IMP data. Furthermore, a bioclimatic index (Hopkins 1938) computed for IMP and NIMP data did not prove significant to the height–diameter model.

For the data set used in model fitting, mean squared errors (MSEs; ft$^2$) were 4.88 and 10.35 for the IMP and NIMP data, respectively, using the baseline model (Equation 1). On incorporating TR into the model (Equation 4), MSEs were 4.87 and 10.34 for the IMP and NIMP data, respectively. In addition, including geographic coordinates to the individual-tree height model further reduced overall model variability. MSEs for Equation 5 were 4.77 and 10.33 for the IMP and NIMP data, respectively. $F$-tests were conducted comparing residual sums of squares between the baseline model (Equation 1) and model including TR (Equation 4), LAT, and LONG (Equation 5), and it was concluded that the more complex model is appropriate compared with the baseline model.

The average percentage deviations $[(H - \hat{H})/H \times 100]$ for the subset of observations from the IMP evaluation data set were −0.79 and −0.54 for nonthinned and thinned plots, respectively. For NIMPs, the same values were −0.34 and −0.55. Generally, tree heights tended to be underestimated for thinned plots, albeit by a small value (Figure 3).

To make full use of the data collected during the study years, all remeasurements were used in the estimation of the parameters for the final equations (Tables 3 and 4). Trees of a given diameter

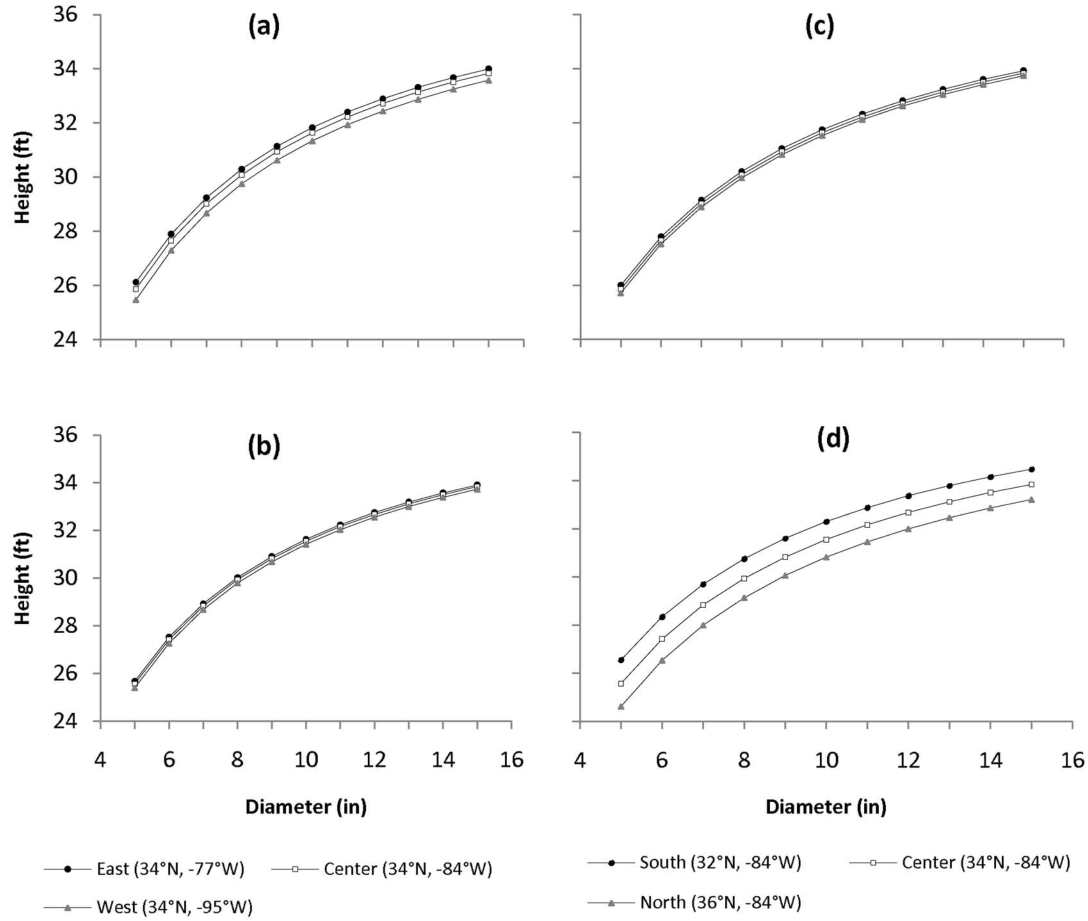


**Figure 4. Height-diameter relationships using a representative stand for loblolly pine trees growing at east, center, and west locales for nonintensively (a) and intensively (b) managed plantations, and at south, center, and north locales for nonintensively (c) and intensively (d) managed plantations. Stand conditions were as follows: average height of dominant and codominant trees = 40 ft, stand age = 16 years, density = 600 trees/ac, maximum observed diameter = 16 in, and a thinning prescription of 50% basal area removed at age 12.**

located south and east in the natural range were shown to be taller than trees north and west (Figure 4).

## Discussion

This analysis shows that using geographic coordinates and a thinning response modifier can aid in predicting loblolly pine individual-tree heights. Including these variables was significant to the model and resulted in a lower model bias. In addition to thinning intensity, including the amount of time since thinning proved significant in explaining tree height in relation to diameter. Zhang et al. (1997) concluded that adding a TR modifier did not greatly improve the predictive ability of a model when MSE was used as a criterion, and the results presented herein with the NIMP data show somewhat similar trends, as MSE was reduced only by 0.02. Alternatively, MSE for the IMP data set was reduced by over 2% when TR and geographic locale were included. Although these differences are small, the impact of including additional variables may be amplified when the height-diameter model is incorporated into a stand simulator. Westfall and Burkhart (2001) found that adding TR variables to component equations can result in unanticipated overall model behavior; thus, evaluation of stand-level as well as component-level prediction is advised. Holding stand conditions and tree diameter constant, parameter estimates show that slightly greater tree heights are predicted in post-thinning years. When $BA_A < BA_B$ (i.e., immediately after thinning), Equation 5 predicts loblolly pine trees growing in thinned stands to be slightly taller than trees grown in stands that have not received thinning or stands where the basal area after thinning has grown to exceed the basal area prior to thinning.

In combination with previous research, this analysis shows that geographic coordinates can be used directly in growth and yield models to help predict loblolly pine attributes. The signs of the parameter estimates in Tables 3 and 4 indicate that trees of a given diameter located south and east in the range will be taller than trees north and west (Figure 4). Using a mixed-effects modeling approach, Trincado et al. (2007) showed that separate height-diameter equations were needed for loblolly pine trees growing in the Coastal Plain and Piedmont regions. These results were consistent with the predictions of mean dominant height at the stand level (Amateis et al. 2006). Precipitation has been linked with loblolly pine site productivity (Lockaby and Caulfield 1989); however, in this analysis, precipitation did not offer any improvement when considering the IMP data, and a bioclimatic index (Hopkins 1938) computed for IMP and NIMP data did not improve the model. For the loblolly pine height-diameter relationship, geographic coordinates appear to be sufficient in explaining the growing differences across the range of the species, which can no doubt be attributed to the variety of abiotic and climatic factors found in the disparate areas of the region. Climate factors, however, were found to be more effective than geographic coordinates in describing shoot growth of black spruce (Wei et al. 2004). There is much to be learned regarding the effectiveness of using geographic coordinates as surrogates for more complex climatic processes in predicting loblolly pine attributes.

The ability to use models that reflect present-day silvicultural operations is central to estimating loblolly pine productivity. It is important to recognize the underlying differences between intensively and nonintensively managed stands. When using the equations presented herein, note the relatively younger stands exemplified in the IMP data set. Given the wide use of geographic technologies among foresters today and the relative ease of computing the thinning modifier, the equations presented can aid in predicting the growth response of loblolly pine trees for thinned and nonthinned stands under a variety of management schemes.

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