STAND DEVELOPMENT PATTERNS FOR YOUNG PLANTED OAK STANDS ON BOTTOMLAND HARDWOOD RESTORATION SITES

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Abstract—Over the last several decades, bottomland restoration efforts have established hundreds of thousands of acres of planted hardwood stands throughout the Southeastern U.S. Much of the initial research focused on planting approaches and early growth and survival, contributing to more effective establishment methods. However, less research attention has been focused on stand development and treatment options for these planted stands as they age. Given that many afforestation stands are approaching 20 years of age or greater and undergoing crown closure, an improved knowledge of stand conditions is needed to evaluate opportunities for silvicultural treatments aimed at enhancing growth, and/or structural or compositional diversity. An increasing demand for such knowledge by landowners is becoming evident particularly by those that have participated in hardwood planting initiatives including the Conservation Reserve Program and Wetlands Reserve Programs (CRP and WRP respectively). This study investigates tree and stand development within young (10 to 20 year old) planted oak stands across a range of stand ages and site conditions in the Lower Mississippi Alluvial Valley. Growth and yield and stand development were evaluated using field surveys of stand characteristics (species, diameter, density, height, and crown measurements) and destructive sampling of individual trees. Our results show that as stands reach 20 or more years of age individual trees begin to interact, crown closure occurs, and conditions approach full stocking (the "A-line") (Goelz 1995). At this point, stems have generally reached merchantable diameters for pulpwood, and self-pruning has, for a stand fully stocked, progressed to one log-length in height (17.3 feet). These results suggest that thinning treatments could be merchantable and desirable from a tree growth perspective, in addition to potentially enhancing desirable stand conditions for wildlife habitat. As such, this information can provide a basis for informing silvicultural treatments aimed at improving stand conditions. Improving our knowledge of stand development, and growth and yield, could prove critical for ensuring the continued commitment of landholders to the management of their hardwood plantings and ongoing participation in these restoration programs.

INTRODUCTION

The Lower Mississippi Alluvial Valley (LMAV), locally known as "The Delta," was once an almost continuous hardwood forest spanning 24 million acres from southern Illinois to Louisiana (Twedt 2004). In the last two centuries, the LMAV has been largely cleared for agriculture, with less than a quarter of the original forest cover remaining today (Twedt 2004). Recognizing the widespread loss and fragmentation of LMAV bottomland forests and the ecosystem services they provide, private and government interest in afforesting marginal agricultural land has risen sharply in the last several decades (Allen 1997, Twedt 2004). Since the 1980's, there have been hundreds of thousands of acres of marginal-agricultural land in the Southeastern United States planted back to hardwood forest for the purposes of soil conservation and enhancement, water quality, timber production, and wildlife habitat often through Conservation Reserve Program and Wetland Reserve Program contracts (CRP and WRP respectively) (Gardiner and others 2004, Twedt 2004). Early efforts at hardwood afforestation on marginal agricultural lands focused on heavy-seeded species such as oaks (*Quercus* spp.) and pecan (*Carya illinoinensis* (Wangenh.) K. Koch) to improve the speed at which succession can take place; the goal being to return land to diverse, structurally complex forests that can provide economic, wildlife, and ecosystem values to the region (Stanturf and others 2000). Decades later, few studies (noted above) have assessed whether the recent forest restoration is progressing toward these goals and a definition for success remains elusive (Stanturf and others 2001).

Many old field sites in the LMAV have limited natural seed sources due to decades of intensive agriculture that have left remnant trees and forest patches at the extreme edges of fields, leaving large agricultural fields well beyond the dispersal distances of most tree species (Battaglia and others 2008). Left alone, the

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typically large agricultural fields in the Delta would take decades or even centuries for heavy seeded species to naturally invade large portions of the field. Because of this, reforestation sites have typically been planted with one to three heavy seeded species, with the expectation of natural recruitment by better dispersed species. Oaks (Quercus spp.) are some of the most valuable species both economically and functionally to the ecosystem and have been, by far, the most heavily planted group of species in hardwood afforestation efforts in the LMAV (Schoenholtz and others 2001). Early afforestation efforts also included direct seeding (at around 4000 acorns per acre), but direct seeding often had poor success and lacked predictability relative to planting (Allen 1990, Lockhart and others 2003, Twedt and Wilson 2002). Due to the poor survival of many direct seeded sites, planting with 1-0 bare root seedlings has been the preferred approach. However, due to the costs of hardwood afforestation, and the expectation of natural recruitment from other species, most stands, at least those established through CRP or WRP contracts, were planted at a relatively low spacing of 12 x 12 or 10 x 15 feet (Allen 1997, Meadows and Goelz 2001, Twedt and Wilson 2002). Unfortunately, in many cases, this afforestation approach has produced many nearly pure oak stands, particularly where survival is high and natural recruitment of other species is limited (Allen 1997).

Many stands are now well beyond the establishment phase and undergoing crown closure, and concerns have been raised about development of these well-stocked, mono-dominant oak stands, including concerns about a lack of species diversity, poor vertical structure, and poor self-pruning. Unlike natural stands which establish at much higher densities, trees in lower density, planted stands do not appear to be naturally pruning at a young age and thus have yet to produce much clear wood, which may reduce timber quality at maturity. This study aims to describe structural conditions within young (10-20 year old) planted stands with a focus on crown development. Oaks, like many hardwoods, are generally decurrent in form and respond to light by expanding their crowns into open growing space (Oliver and Larson 1996); this complicates plantation management. How individual oak trees and their crowns develop in relatively low-density, mono-dominant conditions has not been well described and represents a particular knowledge gap for management of afforestation stands. By taking inventory of stands across an age range within which canopy closure occurs, we hope to describe crown development in individual trees as it relates to stands conditions. With such information, better guidelines for silvicultural treatments such as thinning can be developed.

METHODS

The study used two approaches: a field survey of stand conditions, and an analysis of individual trees using destructive sampling. Sampling sites included state Wildlife Management Areas (WMA), mitigation areas, and private lands enrolled in WRP. The LMAV sites are typically characterized by heavy soils, often Sharkey clay, that would otherwise be difficult to farm. Other than one site in Louisiana, all of these forests are outside the Mississippi River levee system and are rarely inundated by more than one foot of flood water for extended periods. Of the range of possible stands to inventory, the focus for this study was on oak dominated stands, 10-20 years of age that had good survival to date. Plots were established randomly within the selected stands, at least 50 feet from the stand edge. Species composition in the sampled stands was most commonly a single oak species or a mix of Nuttall (*Quercus texana* Buckley) water (*Quercus nigra* L.), willow (*Quercus phellos* L.) or cherrybark (*Quercus pagoda* Raf.) oak.

Within each stand, 20th acre plots were used to inventory planted oak trees and 100th acre sub-plots were used for natural regeneration. All oaks within the plot were measured for diameter at breast height (DBH) and identified to species. On each plot, the two closest dominant or co-dominant trees to plot center were measured for height, height to live crown, and crown diameter in two directions. Where age data were not reliably available for a given stand, it was determined by extracting an increment core from the base of a dominant tree within the stand.

A subset of individual trees were destructively sampled for stem growth analysis and to develop allometric models of bole, branch, and leaf biomass. Trees were felled and total height, crown height, and crown diameter were measured. Trees were then sampled at ground level, 1.1 feet, 4.5 feet, and then in 3.3 foot sections thereafter. Within each section, all branches were removed and basal diameters were recorded. The branches (with leaves attached) were then bagged and weighed by section. The remaining 3.3 foot section of bole was then weighed and an approximately one inch cross section was cut off the butt of each section, placed in an air tight bag in a cooler, and then returned to the lab for processing. Discs were weighed green and then placed in a drying oven at 60°C to constant weight. Resulting moisture ratios from the wet and dry weights were applied to the green weights of stems measured in the field.

Weight

A weight equation for green tons/acre was calculated using stem weights of the felled trees that were sampled. A total of nine trees were used: one cherrybark oak, one water oak, and seven Nuttall oaks. The equation used was as follows:

$$W = b_0 + b_1(D^2H) \quad \text{Equation 1}$$

where W is weight in tons, D is diameter at breast height in inches, and H is total height in feet.

Statistical analyses were performed using analysis of variance (ANOVA) and simple linear regression. Regressions were used to find trends between different factors in multiple stands of different ages. Weight equations from green weights of the stem were regressed against height and diameter.

RESULTS

Stand Dynamics

For the range of stands sampled, average diameters ranged from slightly below three inches, to almost nine inches. This diameter range was within a density range, at the plot level, from approximately 150 to 500 trees per acre (TPA) (fig. 1). There was no evident relationship (R^2 = 0.03, P = 0.29) between diameter and stand density for the range of stand conditions sampled.

To investigate stocking levels for these stands, plot averages were plotted on a bottomland stocking guide (Goelz 1995). Stocking ranged from less than 50 percent to over 100 percent of "full" stocking, with only a few stands falling below the "B-line" ("understocked") or exceeding the "A-line" ("overstocked"). The variation in stocking was attributable to the wide range in basal area (BA) (from 15 ft^2/acre to over 100 ft^2/acre) which was largely a function of the relatively wide range in stand developmental conditions across the age range (fig. 2). It is notable that even the younger stands (>10 years) are mostly above the "B-line" for minimal stocking reflecting the selection of better stocked stands.

Total heights for these plots ranged from 25 to 60 feet, and were positively correlated with diameter (fig. 3). Based on the regression, a tree at either end of this height spectrum would be 2.5 and 10.2 inches DBH respectively. The corresponding live crown height for this same range would be approximately 6 to 16 feet. As expected, the live crown height increased with height-dbh growth, although the average live crown ratio remained at approximately 70 percent across the sampled size range. Both total height (TH) and height to live crown (HLC) showed substantial variance across the size range, likely reflecting differences in site condition and stand establishment history. The regression data

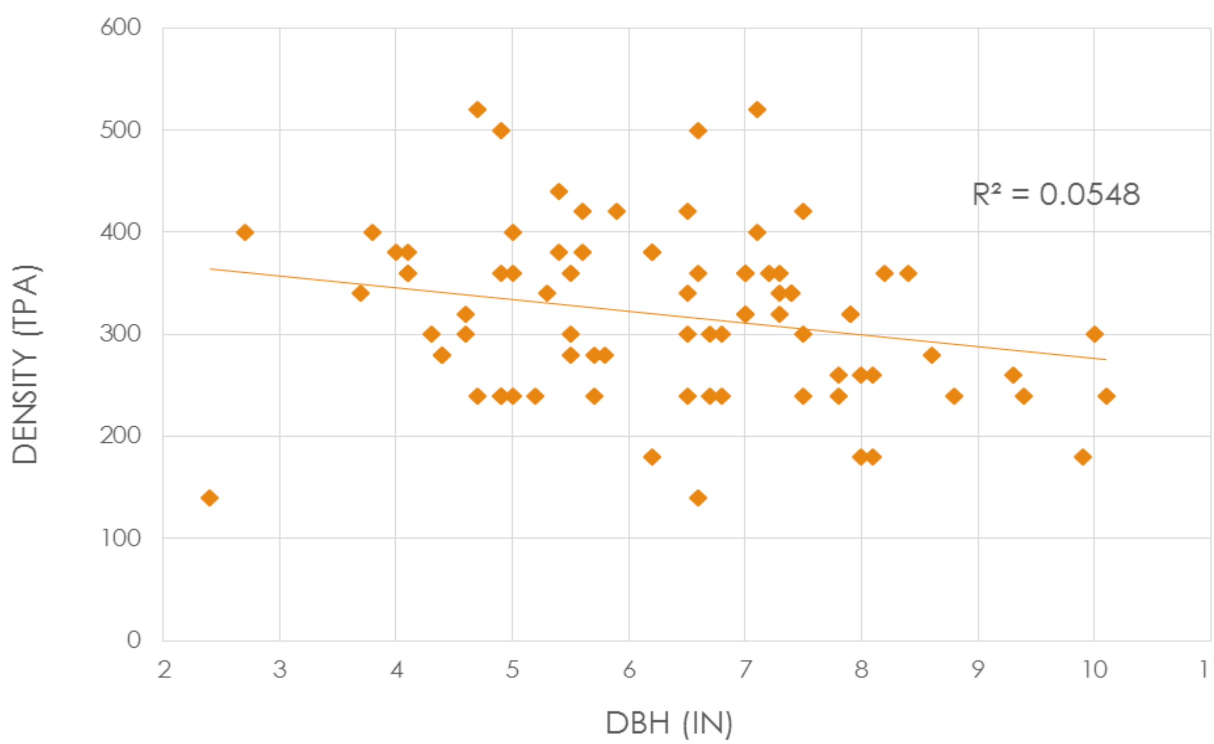

Figure 1—Density/diameter relationship for oak stands in the LMAV.

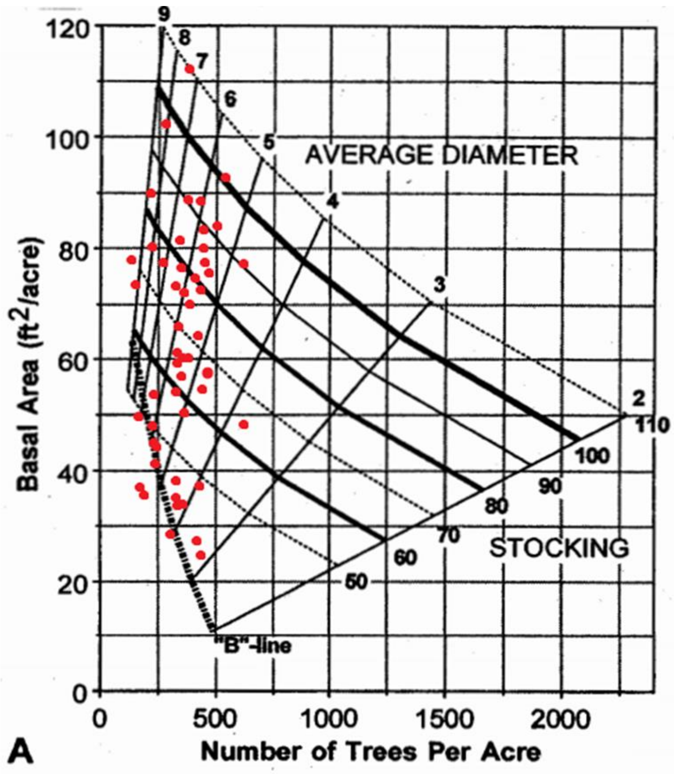

Figure 2—Bottomland stocking diagram (Goelz 1995) with plot-level averages indicated in red.

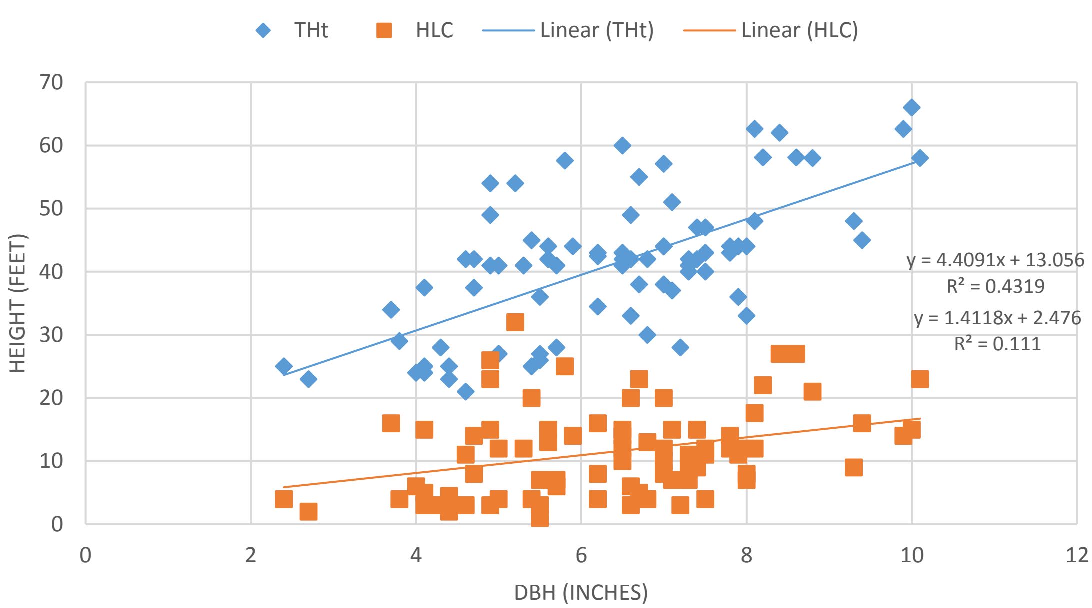

Figure 3—Total height (TH) and representative height to live crown (HLC) for oak plantations in the LMAV.

suggests that a well-pruned butt-log (16 feet) may be expected from an average density stand approaching 10 inches in diameter.

Weight

The linear regression of the nine destructively sampled trees, using equation 1 yielded the following weight equation:

$$W = - 34.671 + 1.859(D^2H) \qquad \text{Equation 1.1}$$

This simple linear regression model yielded an R^2 of 0.90 (fig. 4). The sample trees ranged in weight from 0.015 to 0.17 tons. Analysis of variance for this regression model shows the relationship to be very significance ($P < 0.001$). The single tree model was then applied to plot average diameter and height and multiplied by the density of that plot and converted to estimate per acre values for volume. The plot level values fitted against height show that a stand with good survival at 25 feet would be between 8 and 12 tons per acre of green stem weight. Well stocked stands approaching 60 feet should carry up to 70 tons of green stem weight per acre (fig. 5). We emphasize again that these are values for well stocked stands between 200 and 500 trees per acre (TPA).

DISCUSSION

While the main priority of most bottomland afforestation efforts is for enhancing wildlife habitat or other ecosystem services, timber quality is an important element that will provide revenue and management options to meet these goals. As such, improving our knowledge of stand development is critical for supporting the goals of afforestation efforts.

In this study we examined conditions in young, well-stocked, oak-dominated stands representing an age range from 10-20 years old. The primary species measured were water, willow and Nuttall oak. These species represent the most frequently planted bottomland species of the 1985-1998 period by the Natural Resource Conservation Service (NRCS), WMA's, and U.S. Fish and Wildlife Service (USFWS) in the LMAV (Schoenholtz and others 2001). While some studies such as Schweitzer (1998) have indicated very poor establishment, we specifically evaluated a range of stands with high-stocking. These oak dominated stands are of particular interest to managers because of their lack of diversity (Allen 1997). Furthermore, where oak survival has been high, the relatively wide initial spacing (302 trees per acre) has likely delayed crown closure and competition among individual trees. This poses concerns for stem quality because of potentially delayed self-pruning that reduces merchantable bole length (Clatterbuck and Hodges 1988).

Most sampled stands fell in the range of 20 to 90 square feet of basal area per acre. Based on the bottomland stocking guide it is apparent that most older stands measured fell above the minimum level for "full stocking" (i.e. "B-line") (Goelz 1995). This suggests stands are generally approaching or have reached crown closure, although a wide range of stand conditions were apparent given the range of stand ages evaluated in this study. Few sampled stands approached the 100 percent line that would presumably qualify them as "overstocked" (Goelz 1995). This same stocking guide predicted that hardwood stands established at around 300 TPA would approach 100 percent stocking just before 8 inches average DBH which corresponds to the 20 plus year old stands in this study (Goelz and Meadows 1997). Stands approaching 100 percent stocking are likely experiencing reduced diameter increment and thus thinning would be desirable to maintain growth and vigor of individual trees (Goelz 1995; Goelz and Meadows 1997).

Height growth trends were similar to those reported in other studies in the southeastern U.S. evaluating oak performance during the first 20-30 years (Carlson and Goelz 1998, Krinard and Johnson 1988, Krinard and Kennedy 1987, Roth and others 1993, Stine and others 1995). Our results are comparable to those of Carlson and Goelz (1998) where both water and Nuttall oak approached 45 to 50 feet and 6 to 8 inches in diameter at age 20 for 12 x 12 foot spacing in a minor bottom in Arkansas. Our study incorporated a larger range of site indices and so had more variation in both height and diameter. It is also apparent that despite Nuttall oak's reputation for fast growth, on average, water oak out performed both Nuttall and willow oak in height and diameter. Similarly, Rousseau (2008) found that 20 year-old willow, water, and Nuttall oak approached 60, 63, and 55 feet tall, respectively, in a selection trial situated on a moderately productive site in western Kentucky. Average diameters for these same three species were 7.3, 7.9, and 6.3 inches respectively. These growth rates and height diameter relationships correspond with the upper range of performance values in our data, which is to be expected given the more controlled environments of species trials.

Average live crown ratios remained similar throughout the range of diameters sampled. A crown ratio of 70 percent or greater may be favorable to diameter growth but is less desirable for clear wood production. Stand density, particularly crown competition from adjacent trees, is one of the primary factors determining self-pruning and thus frequency of defects in trees in young hardwood stands (Sonderman 1985, Ward 1964). Density, along with age and species were the greatest

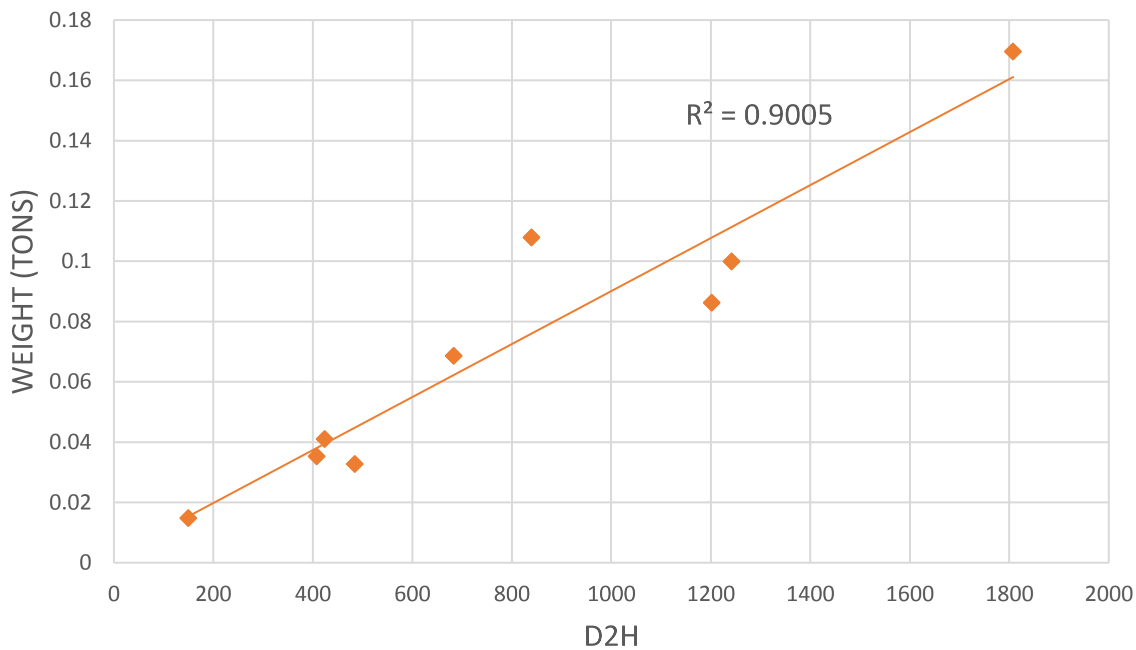

Figure 4—Weight regression model using nine felled trees.

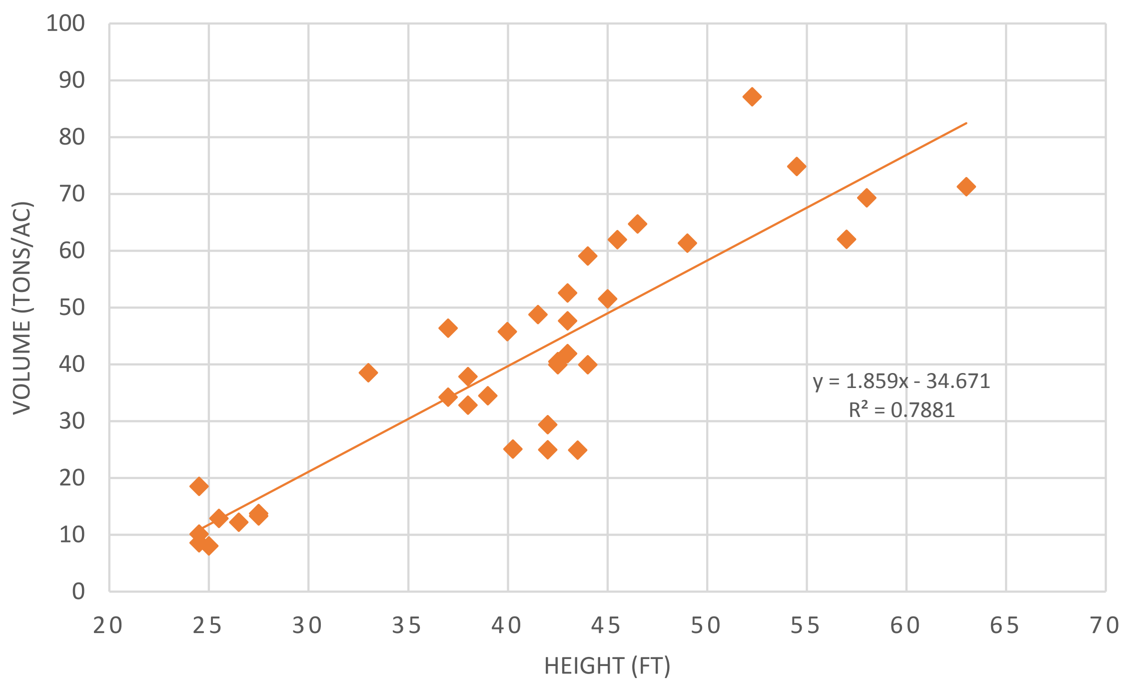

Figure 5—Weight model applied to plot-level averages(diameter and height) and plotted against height.

factors in determining natural pruning and defect, especially in the second 8 feet of the butt log. Live crown height does not exceed one log (17.3 feet) until a stand has grown to around 55 to 60 feet tall which would correspond to around 70 square feet of basal area at 300 TPA (fig. 2, 3). Given the low establishment density and lack of natural recruitment, it is not surprising that self-pruning has not progressed rapidly. However, it appears that as stands approach the upper limits of full-stocking, this process is well underway.

As stand weight approaches 70 tons per acre in the 20 year old stands, thinning is becoming economically feasible. It has been suggested that up to one third of the volume can be removed while still leaving desirable stocking for both tree and stand growth (Meadows and Goelz 2001). The critical tradeoff is providing sufficient time for stems to undergo self-pruning while limiting declines in tree vigor and diameter increment. If diameter growth slows, it will take much longer for wounds to close over prolonging the development of clear wood (Della-Bianca 1983). However, if thinning is applied too early (e.g. precommercial thinning) it may limit self-pruning and future stem quality (Heitzman and Nyland 1991). Based on our study, this tradeoff will vary between stands depending on stocking conditions and, most likely, species composition. Further study is needed to evaluate species-specific differences in these processes, particularly in older planted stands. Improving our knowledge of tree growth and crown development will be important for refining thinning approaches and their timing, particularly as we aim to provide environmental benefits (i.e. wildlife habitat and other ecosystem services) while maintaining future stand management options.

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