Pine

USING LIVE-CROWN RATIO TO CONTROL WOOD QUALITY: AN EXAMPLE OF QUANTITATIVE SILVICULTURE[1]

Thomas J. Dean[2]

Abstract-Quantitative silviculture is the application of biological relationships in meeting specific, quantitative management objectives. It is a two-sided approach requiring the identification and application of biological relationships. An example of quantitative silviculture is presented that uses a relationship between average-live crown ratio and relative stand density to manage wood quality objectives in loblolly pine.

INTRODUCTION

In general, quantitative silviculture quantifies basic elements of stand structure and the biological relationships that strongly influence them (Jack and Long 1996). Quantitative silviculturists use this information to meet specific management goals and objectives by translating goals and objectives into a set of structural characteristics. Management issues that have been addressed with quantitative silviculture include calculating the number of trees to plant and thinning schedule necessary to produce a stand with a given average stand diameter, determining the stand conditions necessary for specified periodic annual increments, and creating specific wildlife habitats. To expand the range of potential management issues, research in quantitative silviculture draws from a variety of fields such as population biology, production ecology, and biometrics in addition to traditional silviculture.

There are two primary aspects of quantitative silviculture: (1) identifying a relationship and (2) applying the relationship. These two aspects can be clearly seen in the density management diagram: a widely used tool for quantitative silviculture. The density management diagram was first introduced in the United States by Drew and Flewelling (1977). The basic structure of the diagram depends on the relationship between average tree size and the stand density in self-thinning stands. Drew and Flewelling (1977) applied the relationship to the management of stand density. Another example of quantitative silviculture is the application of the relationship between sapwood cross-sectional area and leaf area to distributing growing stock among size classes in uneven-aged ponderosa pine stands (O'Hara 1996).

This paper presents an example of quantitative silviculture that shows how stand structure and associated biological relationships can be used to manage wood quality. Industries that have traditionally relied on wood from old-growth forests are having to switch their raw material source to intensively managed forests. The problem that these users face is finding material that meets their quality requirements because logs from these new sources generally have more juvenile wood, a greater number of knots, and larger diameter knots (among other characteristics). These characteristics affect the visual quality and the dimensional stability of the products, which clearwood users regard as important attributes of traditional old-growth sources (Eastin and others 1996). Theoretically, pruning can produce clear lumber regardless of the density or management intensity, and foresters have long known that the width of the juvenile core and average branch diameter can be minimized with high stand densities. However, pruning the live-crown and maintenance of high densities reduce diameter growth, conflicting with most current management objectives. An acceptable compromise between these conflicting objectives can be obtained, however, with quantitative silvicultural techniques using the relationship between average-live crown ratio and relative stand density.

THE RELATIONSHIP

As stand density increases, intertree shading causes death in the lower branches of the crown and a reduction in the live-crown ratio (the ratio between the length of the green crown and total height). This interaction results in a negative relationship between average live-crown ratio and its stand density (Long 1965). For loblolly pine plantations in the West Gulf between the ages of 1 I- and 16-years old, average live-crown ratio (C_r) decreases linearly with increases in relative stand density (R_d) according to the equation

$$C_r=82.74-0.67R_d \quad (n=32, R^2=0.75) \qquad (1)$$

(fig. 1). Relative stand density is the ratio between SDI and 450, the species specific SDI for loblolly pine. SDI is calculated as $TPA(Dq/10)^{1.6}$, where Dq is the diameter of the tree with average basal area.

THE APPLICATION

Management Objectives

An important step in quantitative silviculture is translating objectives into structural terms; for this example, objectives will be translated to target average live-crown ratios. While a wide variety of wood quality variables exist, important variables most readily influenced through density management are the width of the juvenile core and knot size. Juvenile wood is comprised of crown-formed wood and wood formed during the transition to mature wood after the crown moves up from a particular cross section (Clark and Saucier 1969). The length of time the live crown resides at a particular stem cross section also determines knot size. Since crown structure is related to stand density, trees grown in low-density stands will have larger knots sizes and wider juvenile cores than trees grown in high-density stands because of different crown structures. Once acceptable limits or goals for wood quality are stated, density management prescriptions can be prepared.

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-16, 1999.

[2] Associate Professor, School of Forestry, Wildlife, and Fisheries, Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, Baton Rouge, LA.

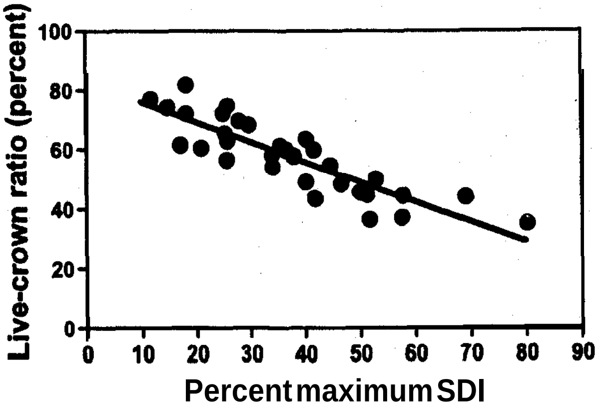

Figure I-Relationship between average live-crown ratio and relative stand density expressed as percent maximum **SDI** for midrotation (1 **1** to **16-years** old) loblolly pine plantations growing in the West Gulf region of the United States. Line fitted with simple linear regression: Y-82.74-0.67X **(n=32,** R^2**=0.75).**

The principal approach to managing juvenile wood is to minimize its development. A seemingly semantic approach is to maximize the proportion of mature wood. This approach, however, suggests prescriptions that concentrate on diameter growth and actually results in a greater proportion of juvenile wood within the stem than the minimization approach. Simulations conducted by Maguire and others (1991) show that the amount of crown wood within the stems of Douglas-fir stems is less for trees grown under high densities than for trees grown under lower densities. Consequently, the higher the stand density, the smaller the juvenile core.

Knot size is also related to stand density. Ballard and Long (1988) showed a strong, negative exponential relationship between the mean of the five largest branches on the butt log and the number of lodgepole pine trees per acre. Simulations conducted by Maguire and others (1991) also indicated that branch size on the first log of Douglas-fir decreases with stand density. According to the grading rules published by the Southern Pine Inspection Bureau for P-inch dimension lumber, for all other factors being equal, decreasing average branch diameter will improve lumber grade. Indeed, Clark and others (1994) found that the percentage of loblolly pine lumber graded No. 2 and better increased with decreased spacing and increased basal area after thinning.

Management Constraints
The actual minimum proportion of juvenile wood that can be achieved at a particular age is limited by practical management constraints. In this case, efforts to minimize the proportion of juvenile wood within the stem may produce trees too weak to respond to thinning quickly. As with management objectives, management constraints must also be expressed in terms of stand structure. Maintaining a tree's ability to quickly respond to thinning is usually accomplished by preventing average live-crown ratio from falling below 40 percent (Smith 1988). if the stand is to be pruned, an additional constraint may be to eliminate green pruning within the first log. This constraint may be met by setting the lower stand density such that when the stand is thinned and pruned, the base of the live crown is above some specified standard such as 18 ft. If it is not pruned, this constraint would ensure no grade reduction of the butt log after thinning due to branch persistence and growth.

Expressing these constraints in structural terms is accomplished with the relationship between average **live-**crown ratio and relative stand density. The relative stand density corresponding to 40 percent average live-crown ratio for West Gulf iobloliy pine is 63 percent. The minimum height **required** for a minimum of 18 **ft** to the base of the live crown is calculated with equation [I] at regular intervals of stand density. The two lines representing these constraints form a wedge on the West Gulf density management diagram for lobioily pine (fig. 2). Marketing constraints are commonly set by a minimum average stand diameter, and lower growing stock limits are usually set no lower than canopy closure (Dean and Baldwin 1993).

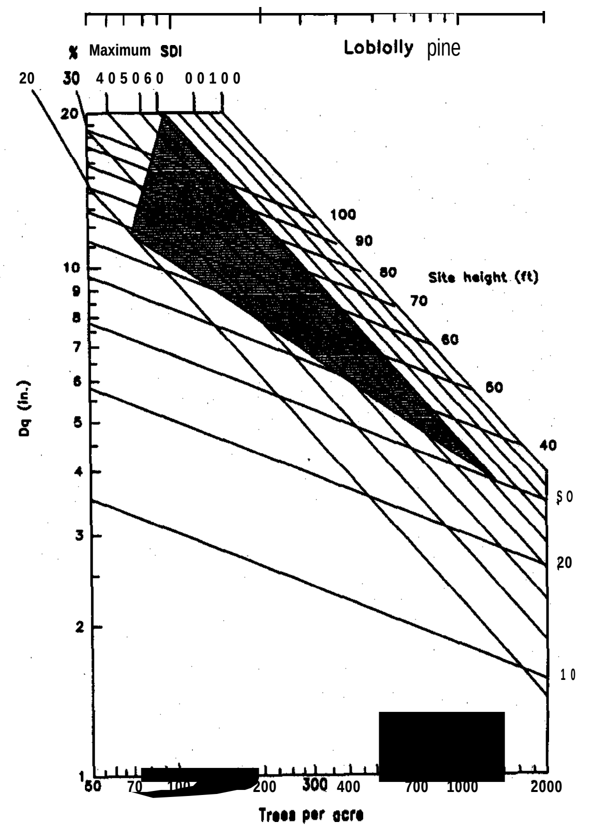

Figure 2-Density management diagram showing the region where average live-crown ratio is greater that 40 percent (upper boundary of shaded area) and the height to the base of the live crown is at least 18 ft (lower boundary of shaded area). The left boundary of the shaded area is arbitrarily set..

Prescriptions
To minimize the proportion of juvenile wood and to satisfy a **5-inch** diameter thinning requirement, 890 trees per acre must survive to the first thinning at age twelve, assuming a site index of 60 (base age 25 years) (fig. 3, option A). At 100 percent survival, this translates into a 7 x **7-ft** spacing. Such close spacing is vulnerable to wind and ice damage after

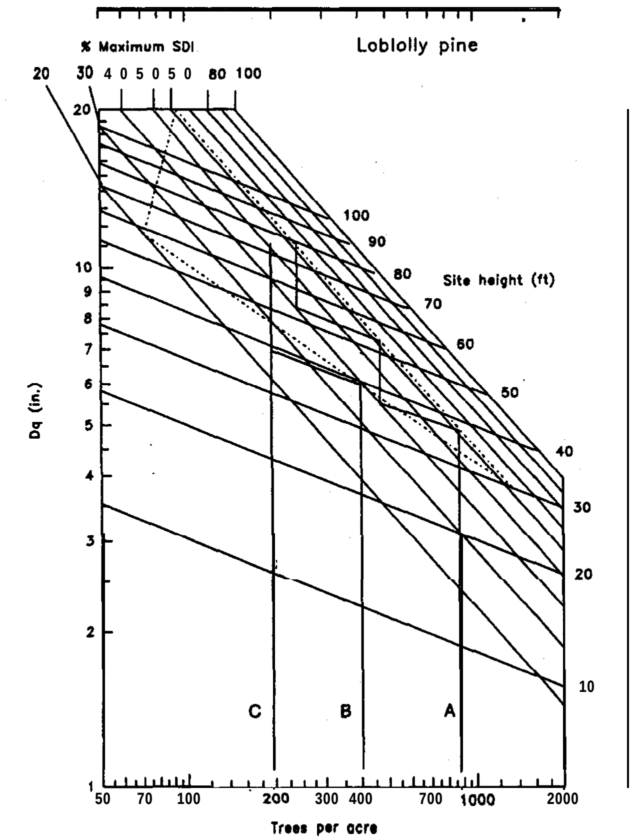

Figure 3-Density management diagram showing three alternative prescriptions for managing the quality of the butt log at rotation age. Option A results in the smallest proportion of juvenile wood. Yields for each option shown in Table **1.** The wedge outlined with the dash-dot line is the shaded area shown in Figure 2.

thinning; consequently, this plan prescribes two thinnings to avoid inherent dangers with one radical thinning before harvest. At a rotation age of 47 years, the average stand diameter is projected to be 11.6 inches. For this option, the projected proportion of juvenile wood in the butt log of the average tree at rotation age is 19 percent. This prescription would yield 61 **cunits/acre** over a **47-year** rotation (table 1).

An alternative prescription designed to produce the same average stand diameter 7 years earlier, increases the projected proportion of juvenile wood in the butt log to 25 percent. The accelerated diameter growth is accomplished by maintaining larger values of average live-crown ratio throughout the rotation but with the constraint that the height to the base of the live crown is 18 ft when the stand is thinned at age 13 years. This plan requires that 400 TPA survive to the first thinning and includes only one thinning since the relative density when the stand is thinned should only be 39 percent (fig. 3, option B). An additional consequence of this option is lower yields from thinning and final harvest (table 1).

The effect of planting sufficient number of trees to allow for a thinning on the projected proportion of juvenile wood is illustrated by eliminating the thinning in option B (fig. 3, option C). By having 190 TPA survive to the end of the rotation, 1 **1 .6-inch** trees are produced within the same 40

Table I-Yields of various options for managing the quality of the butt log in loblolly pine plantations

Option	Operation	Age	Yield[a]
			cunits/acre
A	Thinning	12	6.7
	Thinning	23	13.4
	Harvest	47	61.2
Total			81.3
B	Thinning	13	6.5
	Harvest	40	49.0
Total			55.5
C	Harvest	40	49.0

[a] Yields calculated as described by Dean and Baldwin (1993) using a growth-and-yield simulation program (COMPUTE P-LOB) to calculate volume to a **3-inch** top.

years, but the proportion of juvenile wood within the butt log of the average tree increases to 37 percent. Eliminating the thinning increases the overall live-crown ratio of the trees averaged over the length of the rotation, increasing the width of the juvenile core within the first log.

Option A is the superior of the three options based on the projected proportion of juvenile wood in the butt log at the end of the rotation. A quantitative relationship between average branch size on the butt log and relative stand density does 'not yet exist for loblolly pine; however, based on reports for other species, option A would probably have smallest, average knot size between the three alternatives. Economics, obviously, exert a strong influence on the **choice** of the three alternatives. Without **a** premium on the value of the logs produced by option A, the spacing prescribed by this option would likely make it economically inferior to the other options, unless interest rates were extremely low. However, if a premium on logs with small knots and a preponderance of mature xylem were available, economic analyses may favor, at the very least, increased planting densities over those prescribed in options B and C.

ACKNOWLEDGMENTS

This work was supported by McIntire-Stennis fund **(LAB03250).** I wish to thank Dr. V. Clark Baldwin, Jr. and the USDA Forest Service for making their long-term, growth and yield data available and Dr. James N. Long, Dr. Scott D. Roberts, and Dr. W. Ramsey Smith for reviewing this paper.

REFERENCES

Baldwin, V.C., Jr.; Feduccia, D.P. 1987. Lobioiiy pine growth and yield prediction for managed west gulf plantations. Res. Pap. **SO-**238. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 27 p.

Ballard, L.A.; Long, J.N. 1988. influence of stand density on log quality of lodgepole pine. Canadian Journal of Forest Research. 18: **911-916.**

Clark, A., III; Saucier, J.R. 1989. Influence of initial planting density, geographic location, and species on juvenile wood formation in southern pine. Forest Products Journal. 39: 42-48.

Clark, A., III; Saucier, J.R.; Baldwin, V.C.; Bower, D.R. 1994. Effect of initial spacing and thinning on lumber grade, yield, and strength of loblolly pine. Forest Products Journal. 44: 14-20.

Drew, T.J.; Flewelling, J.W. 1977. Some recent Japanese theories of yield-density relationships and their application to Monterey pine plantations. Forest Science. 23: 517-534.

Eastln, I.L.; Lane, C.L.; Flght, R.D.; Barbour, J. 1998. An assessment of the industrial markets for softwood clearwood lumber. Forest Products Journal. 48: 48-54.

Jack, S.B.; Long, J.N. 1996. Linkages between silviculture and ecology: an analysis of density management diagrams. Forest Ecology and Management. 88: 205-220.

Long, J.N. 1985. A practical approach to density management. Forestry Chronicle. 81: 23-27.

Magulre, D.A.; Kershaw, J.A.; Hann, D.W. 1991. Predicting the effects of silvlcultural regime on branch size and crown wood core in Douglas-fir. Forest Science. 37: 14041428.

O'Hara, K.L. 1998. Dynamics and stocking-level relationships of multi-aged **ponderosa** pine stands. Monogr. 33. Forest Science. 34 **p.**

Smith, **D.M.** 1988. The practice of silviwlture. New York: John Wiley. 527 p.