Density Trajectory For The Fastest Growth

Boris Zeide[1]

Abstract: Since forest yield declines at the extremes of stand density, traditional forest management maintains density at a medium level by regular thinning. In Europe these levels are known as medium thinning grades, B and C. In this country the levels are defined quantitatively, usually in terms of residual (after thinning) or average basal area per unit area. These recommendations would be sufficient to maximize wood production if we have to maintain the same stand density over rotation. But no one has proved that keeping density at 10 years the same as at 25 years is the best management practice. Although some forest scientists perceive the advantage of the density that increases with age ("staggered thinning"), the precise description of an optimal trajectory of density is yet to be developed. This report derives the optimal trajectory in two steps. First, the optimal initial and final points are established and, second, the rule for connecting the points is proposed. On a given site, stand volume in general and final harvest in particular increase with stand density and average tree size. This means that the densest stands with the largest trees will bring maximum yield and returns. The problem is that it is not possible to have both high density and large tree size. Maximum density maximizes volume growth at a given moment, but, in the long run, it decreases average tree size and, as a result, is not optimal for the most valuable, final harvest. On the other hand, the maximization of the second component of yield, average tree size, requires maintaining the lowest density. To minimize the negative side of density (small size) and maximize its positive side (maximum volume of trees with a given size), ideally, density should be minimal until harvest (to facilitate tree size) and then jump to the maximum. Since density does not increase instantly, we would have to find some equation describing a gradually increasing trajectory of basal area or stand density index. A simpler description of the optimal trajectory can be cast in terms of the number of trees per unit area: keep it constant. When the number is constant, stand density increases with age due to diameter growth. The number should be the minimum that assures the density sufficient to maximize financial returns by harvest time. Such a prescription is called the minimum number-maximum yield (minimax) strategy. Albeit unknown in forestry, it is not new: for millennia, farmers have grown only the plants (sometimes, after the initial thinning of seedlings) they intend to harvest. In addition to the chief advantage–maximum income from final harvest–this strategy has several other advantages such as saving on planting and precommercial thinning.

Keywords: financial returns, forest yield, forest management, staggered thinning, stand density, thinning.

---

1 School of Forest Resources, University of Arkansas, Monticello, AR 71656-3468

PROBLEM: OPTIMAL TRAJECTORY OF CURRENT DENSITY

For centuries, foresters were searching for a single level of optimal density, to be maintained throughout stand life. Studies conducted on permanent sample plots showed that an indistinct peak of total volume production occurs at a moderate levels of density. That is why forest management maintains density at a medium level by regular thinning. In Europe these levels are known as medium thinning grades, B and C. In the United States the levels are defined quantitatively, usually in terms of residual (after thinning) or average basal area per unit area. To maximize stand volume, many authors (Chapman 1953, Wahlenberg 1960, Schultz 1997) recommend reducing basal area in even-aged loblolly pine stands to the residual level of 18 m^2/ha when they reach 27-28 m^2/ha (thinning density). Lately, stand density index has become popular for specifying these midrange levels. Thus, Dean and Chang (2002) recommend growing loblolly pine between indices of 610 (thinning density) and 390 (residual density).

These results would be sufficient for maximizing wood production if we have to maintain the same level over the rotation. But nobody proved that keeping density at 15 years the same as at 35 years would maximize harvest. It may be possible to increase forest production by varying current density during the lifetime of a stand. Whereas in the past foresters were concerned mostly with finding one optimal fixed level of average density, now the challenge is to find an optimal trajectory of current density.

ADVANTAGES OF INCREASING DENSITY

A combination of theoretical reasons, practical expediency, and economic factors contribute to the trend of increasing current density with age.

Variable density: from a fixed level to increasing trajectory

Although maintaining a fixed level of average (and residual) density is still a common practice, at least in the United States, some forest scientists perceive the advantage of density that increases with age. Already Wiedemann (1937) and later Assmann and Franz (1965) advocated the so called “staggered thinning” characterized by decreasing intensity. Its advantages are twofold: fast growth at the beginning when density is low and high final yield and income secured by full stocking at the end. In the United States, Burton (1980, p.22) arrived at a similar conclusion. He found that the best sawtimber yield is produced by "initial heavy thinning from below, on good sides, to a basal area of 70 ft^2/acre [16 m^2/ha] at age 20 and then increasing the residual stand density by 5-ft^2 [1.15 m2/ha] steps."

If traced further, the idea that optimal trajectory of density increases towards harvest should lead not to “staggered thinning” but to abolishing thinning altogether. However reasonable, this inference was made (Zeide 2006) almost 70 years after Wiedemann's (1937) insight.

Wide space planting

In the past, foresters tried to copy nature and planted as many seedlings as found in natural regeneration. As reported in Savill et al. (1997, p. 160-161), in some parts of Germany, even the relatively intolerant Scotch pine is still planted at 10,000 to 18,000 trees per hectare, which is "a considerable reduction from earlier practice." This tradition overlooks the critical difference between natural and planted regeneration–us, foresters. Only few trees survive until maturity under natural conditions and almost all when we control intra-and interspecific competition. As a result, we witness a considerable reduction in the number of planted trees (to 250 per hectare) with correspondingly greater distances between them. This number does not leave many trees for thinning.

Vanishing demand for small timber

The demand for small timber, produced by what used to be called commercial thinning, is decreasing, making it all but impossible to find contractors willing to thin plantations. At the same time the demand and prices for sawlogs are up.

Going ahead of trial and error

Slowly, we learn to complement empirical thinning and spacing studies by reasoning. The utility of this development is demonstrated in the next section.

These trends point to the same outcome: in the future, we may give up thinning and control density by initial spacing alone.

MINIMUM NUMBER-MAXIMUM YIELD STRATEGY

Although some forest scientists perceive the advantage of density that increases with age, the precise description of an optimal trajectory of density is yet to be developed. This can be done by reasoning alone, without new experiments. First, the optimal initial and final points of the trajectory are established and, then, the rule for connecting the points is proposed. On a given site, stand volume in general and final harvest in particular increase with density and average tree size. This means that the densest stands with the largest trees will bring maximum yield and returns.

The problem is that it is not possible to have both high density and large tree size. They are mutually exclusive opposites. Maximum density maximizes volume growth at a given moment, but, in the long run, it decreases average tree size and, as a result, is not optimal for the most valuable, final harvest. On the other hand, maximization of the second component of yield, average tree size, requires maintaining the lowest density. To minimize the negative side of density (small size) and maximize its positive side (maximum volume of trees with a given size), ideally, density should be minimal until harvest (to facilitate tree size) and then jump to the maximum. These arguments define the initial and final points of the optimal density trajectory.

Since density cannot be increased instantly, we would have to find some equation describing a gradually increasing trajectory of some measure of stand density. A simpler description of the optimal trajectory can be cast in terms of the number of trees per unit area: keep it constant. This rule is the best solution of the conflict imposed by the boundary conditions of the trajectory. When the number is constant, stand density increases with age due to diameter growth. The number should be the minimum that assures the density sufficient to maximize financial returns by harvest time.

Such a prescription can be called the minimum number-maximum yield (minimax) strategy (unrelated to the minimax in mathematics). This is the terminus to which the discussed forestry trends lead us. Albeit unknown in forestry, it is not new: for millennia, farmers have grown only the plants (sometimes, after the initial thinning of seedlings) they intend to harvest.

Advantages of minimax

In addition to the chief advantage–maximum returns from final harvest–this strategy provides several other benefits:
- saving on planting and precommercial thinning;
- minimization of root rot, insect infestation, and other risks associated with high density, which would be maintained only during a relatively short period before harvest;
- sturdy well-spaced trees with symmetrical crowns which reduces ice damage and other hazards.
- before the trees close their canopies, up to 90% of the land can be used for other purposes.

Disadvantages of minimax

The minimax strategy may maximize final yield and profit in theory but in practice it poses several formidable problems.

Establishment mortality. Even well-spaced trees suffer mortality, especially during the establishment period. Losing 20-30 percent of trees does not have much effect on regular plantations but would hurt those started with a minimum number of trees.

The lack of selection. In regular plantations the excessive number of trees allows the forester to select the better ones. Planting the minimal number removes this important method of stand improvement.

Interspecific competition. At the beginning, minimax requires less than 10 percent of land for trees, which provides large savings on tree planting and tending. Yet, this feature is a mixed blessing if the remaining land is left unattended. Competing vegetation would kill most of the planted trees and reduce the growth of the remaining survivors.

Poor quality of wood. The initial low stand density would diminish wood quality so that trees could be sold only for pulpwood.

Forfeiting intermediate harvest. When there is demand for small-size timber, frequent thinnings provide substantial returns, which is not available under the minimax strategy.

Rectangularity. To facilitate utilization of alleys between tree rows, they are often wider than distances between trees within a row. Rectangularity is the ratio of the distance between trees within tree rows to that between rows. Many researchers studied the effect of rectangularity on tree growth. West (2006, p.116), analyzing the data published by Sequeira and Gholz (1991) came to an alarming conclusion: "tree development seemed to be constrained by the distance to the nearest neighboring tree, no matter what the rectangularity of the spacing." This means that for rectangularity of 1:6 trees would utilize only about 3% of the land ($1/6^2$).

Imprinting. So far, a rapid learning process, called imprinting, that takes place early in the life and establishes a behavior pattern has been documented mainly in animals. Imprinting involves an interplay between developmental plasticity and rigidity. The ability of a duckling to follow the first object it sees demonstrates plasticity, while continuing attachment to the object, even when it is an inanimate substitute, points to rigidity.

Only recently imprinting was found in flowering plants where it works differently than in animals (Scott and Spielman 2006). Imprinted gene expression in plants occurs in the endosperm, and does not contribute a genome to the next generation. It is still unknown whether some kind of imprinting exists in coniferous trees. Imprinting could be documented by showing that the initial density and other growth conditions influence characteristics of older trees such as their growth, shape, light utilization, parameters of the growth-density model, and the levels of normal and maximum density. The growth-density model says that tree and stand growth is a function of three current variables (age, average size, density). The question is whether stand history affects growth in addition to these variables. It would be interesting to learn if low initial density impairs the form or diminishes the growth of mature trees.

To realize the potential of the minimax strategy these shortcomings have to be corrected. This can be done using known techniques, developing new ones, and combining them into a practical management system.

LITERATURE CITED

Assmann, E. und F. Franz. 1965. Vorläufige Fichten-Ertragstafel für Bayern. Forstwissenschaftliches Centralblatt 84: 13-43.

Burton, J.D. 1980. Growth and yield in managed natural stands of loblolly and shortleaf pine in the West Gulf Coastal Plain. USDA Forest Service Res. Paper SO-159. 23 p.

Chapman, H.H. 1953. Effects of thinning on yields of forest-grown longleaf and loblolly pines at Urania, LA. Journal of Forestry 51(1):16-26.

Dean T.J., and S.J. Chang. 2002. Using simple marginal analysis and density management diagrams for prescribing density management. Southern Journal of Applied Forestry 26(2):85-92.

Savill, P., J. Evans, D. Auclair, and J. Falck. 1997. Plantation silviculture in Europe. Oxford University Press, Oxford. 297 p.

Schultz, R.P. 1997. Loblolly pine. USDA Forest Service. Agricultural Handbook 713.

Scott, R.J., and M. Spielman. 2006. Genomic imprinting in plants and mammals: how life history constrains convergence. Cytogenetic and Genome Research113:53-67.

Sequeira, W., and H.L. Gholz. 1991. Canopy structure, light penetration and tree growth in a slash pine (*Pinus elliottii*) silvo-pastoral system at different stand configurations in Florida. Forestry Chronicle 67(3): 263-267.

Wahlenberg, W.G. 1960. Loblolly pine. The School of Forestry, Duke University. 603 p.

West, P.W. 2006. Growing plantation forests. Springer-Verlag, Berlin. 304 p.

Wiedemann, E. 1937. Die Fichte 1936, Verlag M. & H. Schaper, Hannover, 248 p.

Zeide, B. 2006. Evolution of silvicultural thinning: from rejection to transcendence. Pages 322-327 in Connor, K.F., editor. Proceedings of the 13th Biennial Southern Silvicultural Research Conference. USDA Forest Service Gen.Tech.Rep. SRS-92. 640 p.