APPLYING SILVICS TO STAND MANAGEMENT[1/]

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Abstract.--Three guiding concepts are proposed: (1) Any silvicultural decision affects all future silvicultural decisions. Failure to appreciate that management actions influence basic physical and biological processes of the site and thereby tree and stand growth in complex and longlasting ways can result in costly errors that may be difficult or impossible to correct. (2) Bringing a growth-limiting factor closer to its optimum level will increase production. Applying a knowledge of silvics to the concept of limiting factors can enable the silviculturist to diagnose and often correct site and stand conditions that prevent attainment of potential growth. (3) Silvicultural requirements change with stand development. Five distinct stages of development can be recognized in even-aged stands: regeneration/establishment, precompetition, competition/premortality, competition/self-thinning, and post competition. At each stage there are needs and opportunities for silvicultural intervention to maintain or improve growth. Taken together, these concepts provide a basis for developing biologically and economically sound silvicultural prescriptions.

INTRODUCTION

Silvics is the study of the biology of forest stands and forest trees, how they grow, reproduce, and respond to changes in their environment. Silviculturists apply knowledge of silvics to control establishment, growth, species composition, and quality of forest vegetation. Forming a useful picture of the silvics of a species is difficult, however, because of the complexity of the many processes and conditions involved in plant-environment interactions.

In practice, complexity is reduced because a silviculturist deals with only one area at a time, and on each area species combinations and management objectives are restricted. But even where loblolly pine (*Pinus taeda* L.) is grown in even-aged stands on specific sites, the situation is complex enough that successful management requires a firm grasp of the interplay among stand growth and development, the environment, and silvicultural manipulations.

There are two major sources of published information about these factors as they relate to loblolly pine. Wahlenberg's (1960) monograph is most comprehensive; it treats all aspects of biology, ecology, and silviculture in considerable detail. A short, but also very useful, summary of facts is given in the "Silvics of Forest Trees of the United States" (USDA Forest Service 1965).

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In this paper, I briefly develop some concepts about the use of silvical knowledge in the management of loblolly pine stands for wood and fiber. There is little that is new in these ideas, but taken together they provide a basis for integrating management and silvics to optimize stand growth and yield. An earlier version of these concepts is published elsewhere (Harms 1982). For valuable insights into some of the ideas discussed here, see also the paper by Stone (1983).

THREE CONCEPTS

1. <u>In General, any Silvicultural Decision Affects all Future Silvicultural Decisions</u>.

The basic silvicultural measures for achieving the aims of management can be grouped as (a) procedures for regeneration and establishment of the stand, (b) treatments for tending the stand during the rotation or management period, mostly involving control of competition and density, and (c) site amelioration measures, that is, creating an optimum environment for growth, usually by the addition of chemical fertilizer.

The central problem for the silviculturist is to prescribe the treatments that will maximize useful yield while maintaining or, if possible, improving site quality. All silvicultural treatments affect tree growth, but the situation is complicated because treatments interact (Harms 1982). For example, the density at which a stand is established, whether by planting or from natural reproduction, will affect final yield and also determine the need for thinning. Failure to recognize and account for these interacting effects can result in costly errors that may be difficult or impossible to correct, such as when a mechanical site preparation treatment removes so much surface soil or organic matter that site productivity is reduced.

2. <u>Bringing a Growth-Limiting Factor Closer to its Optimum Level will Increase Production</u>.

In prescribing for a particular stand, the silviculturist first examines and describes the stand and site in terms of such things as stand structure, species composition, soils, site quality, microclimate and other site factors that influence the kind of silvicultural treatments that can be applied. He then must examine the information for the presence of existing or potential problems that may affect management objectives. In particular he must identify physical and biological factors that will limit growth. For loblolly pine such factors as excessively wet or dry sites, eroded soils, soils low in nutrients, or a heavy understory or overstory of hardwood competitors would signal problems.

In simplest terms, the basic requirements for tree growth are light and carbon dioxide from the air, and water and chemical nutrients from the soil. Deficiencies in one or more of these factors will limit growth. Site producitivity is determined primarily by soil moisture and nutrient availability and their interactions. On very dry sites, nutrients are less critical than moisture because lack of water adversely affects all physiological processes and conditions--chemical as well as physical. As moisture becomes more plentiful, nutrition's role in determining productivity increases.

Addition of fertilizers to nutrient-deficient soils may produce increases in loblolly growth if moisture conditions are adequate. Where a site is too wet, however, chemical reactions caused by lack of oxygen in the soil change the availability of nutrients, in some cases causing deficiencies and/or toxic reactions. The usual correction for this condition is to remove excess water by drainage or bedding. Some limiting factors cannot be reasonably eliminated: irrigation of droughty sites to relieve moisture deficits, for example, is not normally cost effective although in some situations eliminating competing vegetation from loblolly pine sites may give short-term relief (Zahner 1968).

A working knowledge of loblolly pine silvics and its growth requirements, and the application of the concept of limiting factors can enable the silviculturist to diagnose, and often correct by cultural measures, stand and site conditions that prevent attainment of potential growth. For example, loblolly is intolerant of shade and release from competing and overtopping hardwoods has been shown to pay large dividends (Langdon and Trousdell 1974). Furthermore, silvical knowledge will help in recognizing management-caused site degradation such as soil compaction or puddling caused by wet weather logging, or soil loss by erosion or scraping during site preparation for pine regeneration.

3. Silvicultural Requirements Change with Stand Development.

Silvicultural treatments are prescribed on a stand basis, and applied over the lifetime of a stand. It is important therefore that the silviculturist understand the dynamics of stand development--how stands change over time.

Five distinct stages can be recognized in the development of even-age stands: (1) regeneration/establishment, (2) precompetition, (3) competition/premortality, (4) competition/self-thinning, and (5) post competition. Once a stand is established, competition is the major driving force in the developmental process. The natural path or trajectory of a stand is the result of progressive changes in size and number of trees.

Stand dynamics are most easily understood by examining the development trajectory of a single stand that is traced out over time by the relationship between mean stand d.b.h. and surviving number of trees, and the density-effect trajectory that is described by the relationship between mean stand d.b.h. and surviving number of trees of a series of stands of the same age but of differing initial densities. The development of hypothetical stands through the five stages is characterized below and illustrated in Figure 1.

Stage 1--Regeneration and establishment.--The stand is created during this stage either naturally from seed or by planting (point A, fig. 1). Silvicultural treatments are primarily preparatory. Potential seed crop is evaluated, seed trees are released, sites are prepared for regeneration, and regeneration takes place through natural or artificial mechanisims. Development of the new stand is characterized by rapid seedling root growth and growth of the photosynthetic system. The end of the establishment stage is arbitrarily defined to be when mean stand height reaches 4-½ feet, i.e., when the stand has measurable d.b.h.

Stage 2. Precompetition.--This stage extends from establishment to the time when competition between trees begins. It is represented in Figure 1 for stands 1 and 2 by the region between points A and B. Precompetition is characterized by unrestricted growth. Mean stand diameter is increasing equally at all densities; the density-effect trajectory is flat. Any recognizable size differences among trees of the same age are the result of genetic variation, microsite differences, and small differences in time of germination, or size of seedling at planting. This is a period of rapid root and shoot growth; the developing crowns require large amounts of nutrients, which are not yet being returned to the soil in large amounts through litterfall (Jorgensen and Wells 1980). The site is not being fully utilized by the pines, and much of the soil volume and above ground growing space may be taken up by undesirable woody and herbaceous vegetation. During this stage, concentration of available nutrients can be the limiting factor controlling tree growth. A significant amount of nutrients is tied up in the forest floor, and fertilizer may be needed. Release from competing and overtopping vegetation may also be needed.

During this stage mean diameter increases but number of trees remains constant (A→B, stands 1 and 2, fig. 1). The duration of the precompetition stage depends on the density at establishment. The lower the density, the older the stand will be before competition begins.

Stage 3. Competition/premortality.--The more trees per unit of area, the sooner the precompetition stage will give way to the competition/premortality stage. Theoretically, this stage can begin at stand establishment if the seedlings are so close together that competition begins at once (stand 3, fig. 1). Stage 3 covers the period from the beginning of competition between trees to the completion of crown closure. During this period the crowns continue to enlarge, differentiation into crown classes begins, and the root systems presumably extend to fully occupy the soil. As the crowns and root systems enlarge, competition for space, moisture, and nutrients begins to reduce the growth rate of individual trees. The density-effect trajectories become concave downward (region B-C, fig. 1).

The silvicultural considerations during this stage are to reduce competition: by precommercial thinning if the stand is young, by a commercial cut if the stand is old enough and trees are large enough to provide one. Thinning, by opening up the stand, may temporarily shift the stand back to the precompetition stage, and fertilizer may be helpful to rebuild crowns and promote growth.

The stand trajectory continues to follow a path of increasing diameter and constant number of trees (B→C, fig. 1). Because of intensifying competition, however, mean diameter growth is less than in stands of the same age that are less dense and therefore still in the precompetitive stage as is illustrated by the flat and curved parts of the density-effect trajectory (age t_{10}, fig. 1).

Stage 4. Competition/self-thinning.--The self-thinning stage begins when the stand completely occupies its growing space, i.e., when crown closure is complete and branches at the base of the canopy are dying from lack of light. The photosynthetic surface approaches a maximum at this stage. Competition for light, moisture, and nutrients has reached the point where the smallest, weakest, trees are no longer able to obtain sufficient amounts for growth, and they begin to die. The root and crown space they release is soon occupied by the remaining trees. Growth, competition, and mortality become continuing and controlling factors in development of the stand. The development trajectory continues to follow a path of increasing mean diameter, but because of the thinning process, number of trees is no longer constant; rather, it is decreasing and the trajectory becomes curved (C→D, fig. 1). The density-effect trajectory becomes steeper in the self-thinning region (C→D, fig. 1).

After a stand has been self-thinning for a time, a pattern emerges in which the relationship of mean stand diameter to surviving number of trees becomes linear on a log-log scale and asymptotic to a limiting density trajectory (D→E, stands 2 and 3, fig. 1). Many species of plants grown in pure even-aged stands have been found to follow this pattern (Yoda et al. 1963). It has also been found, with all species so far studied, that the slope of the linear portion of the self-thinning curve varies but little from the value of 3/2, where mean plant dry weight rather than d.b.h. is used. This relationship, known as the 3/2-power rule of self-thinning, was first described by Japanese researchers (Yoda et al. 1963). When plotted as numbers of trees over diameter, the relationship is equivalent to Reineke's (1933) stand density measure. The only difference between species appears to be in the height of the limiting density trajectory above the horizontal axis; and for any given species the height appears to be constant and independent of site quality (White and Harper 1970). This implies that a stand on a low quality site will take longer, because of slower growth, to reach the self-thinning stage than a stand of the same species and density on a better site, but that both stands will reach it with the same mean d.b.h. and number of stems.

Taking into consideration the self-thinning rule, even-age stand development can be generalized to cover all stand densities at which competition will sooner or later be a factor. Stands of a particular species established at different densities will tend to follow trajectories that eventually bring them to the same limiting density trajectory defined for that species by the self-thinning rule. Once on the trajectory, all stands will follow it for the duration of the self-thinning stage.

The self-thinning process maintains full biological occupancy of the site and the 3/2-power rule defines the limiting density. Thus, for a given number of surviving trees, there is a maximum mean stand diameter that cannot be exceeded except by a reduction in number of stems to allow for continued growth. It follows that stands following the limiting density trajectory will tend to be producing maximum biomass for a particular combination of mean diameter and number of trees.

The implications of the self-thinning stage are obvious. Such stands are overstocked, potential yield is being lost to mortality, trees established at some cost will not be harvested, and competition is having its maximum impact on the growth of individual trees. The silvicultural strategy is to avoid this stage either by periodically reducing density to a premortality state by planned thinning, or by prescribing an establishment density so as to attain rotation age short of serious self-thinning losses.

To properly plan establishment density and intermediate cuts, a knowledge of stand dynamics and of growth rate in relation to site quality must be applied. As pointed out above, the height of the limiting density trajectory appears to be a species constant; the critical idea for the silviculturist is thus the rate at which a stand approaches the line. In general, the better the growth the faster the approach. Inherent site productivity and treatments such as drainage, fertilization, and thinning are all factors that will influence rate of development and hence should influence decisions regarding establishment density and the need for thinning.

Stage 6. Postcompetition.--The self-thinning stage ends at some ill-defined time when stand growth slows because of aging. The need for an increasing growing space decreases, overall mortality declines, and mortality attributable to disease and declining vigor becomes more important than mortality due to competition. During this stage, yield reaches the maximum or ceiling value for the species and site.

CONCLUSIONS

The job of the forester is to produce a crop of loblolly pine that requires 30 or more years to mature. To bring the crop to harvest he must cope with drought, fire, insects, and diseases, and the number of silvicultural tools is limited. The three concepts introduced here provide a helpful framework. By considering the long-term and interacting effects of cultural treatments and limiting environmental factors, and taking into account that each stage of stand development is unique and has opportunities for silvicultural intervention, the silviculturist can produce sound management prescriptions that are compatible with the physiological requirements, environmental constraints, and economic necessities of the loblolly pine ecosystem.

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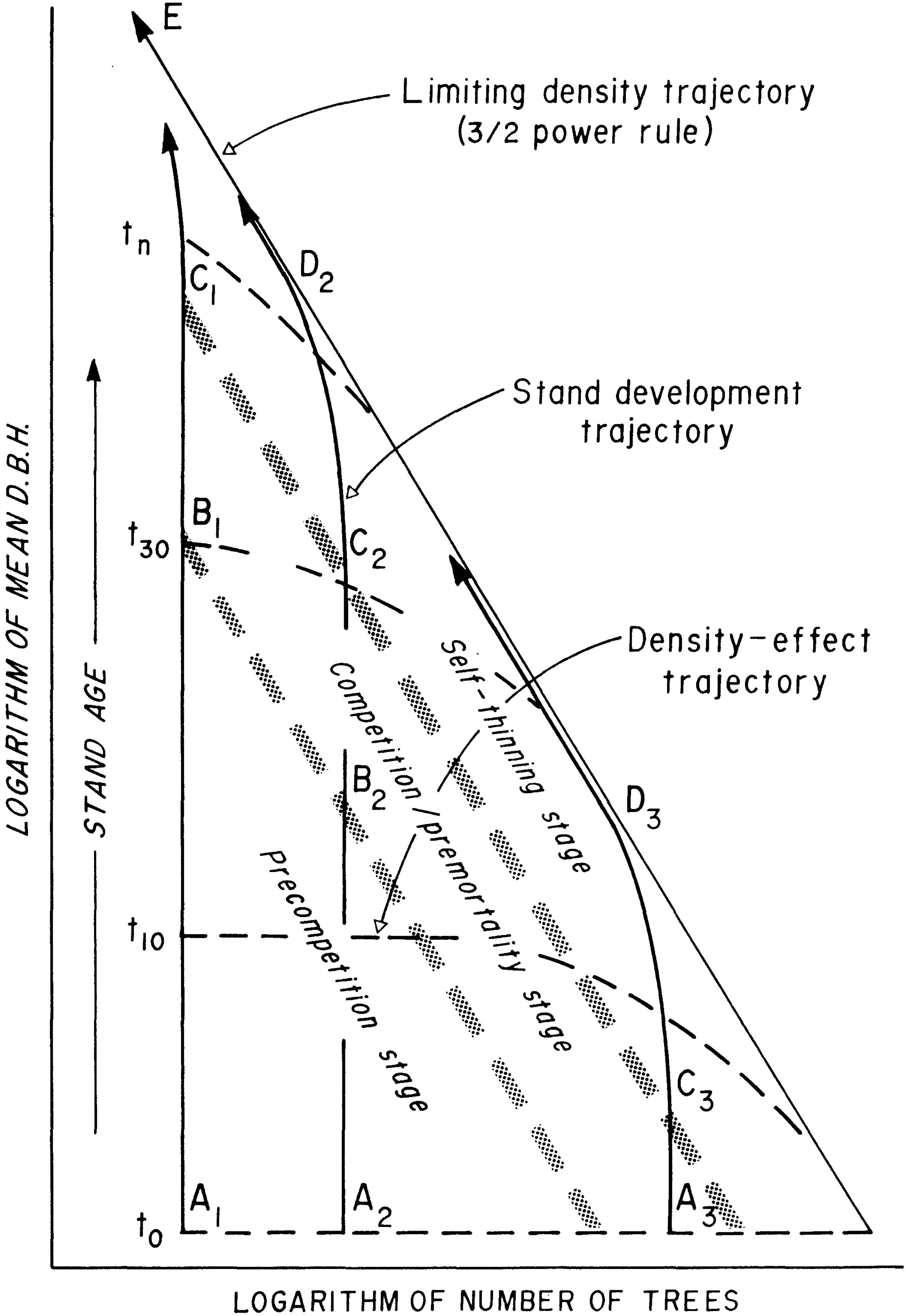
E
Limiting density trajectory
(3/2 power rule)
t_n
C_1
D_2
Stand development
trajectory
B_1
t_{30}
C_2
Density-effect
trajectory
Self-thinning stage
Competition/premortality stage
B_2
D_3
Precompetition stage
t_{10}
C_3
A_1
A_2
A_3
t_0
STAND AGE
LOGARITHM OF MEAN D.B.H.
LOGARITHM OF NUMBER OF TREES

Figure 1.--Development trajectories of 3 hypothetical stands of differing initial densities (A_1, A_2, A_3). Shown is the relationship between log of mean tree size and log of number of trees per unit area (——) from time of establishment at t_o, point A, through self-thinning (B→C→D) to attainment of the limiting density trajectory, E. Density-effect trajectories (---) relating mean tree size and density of same age stands of differing densities are plotted for 4 ages (t_o-t_n). Three stages of stand development are shown. See text for explanation.