A Lodgepole Pine Density Management Diagram[1]

James B. McCarter *and* **James N. Long,** *Department of Forest Resources, Utah State University, Logan, UT 84322.*

*ABSTRACT. A diagram is presented that can greatly facilitate density management of lodgepole pine (*Pinus contorta*) stands. Together with site index tables or curves, the diagram can be used to estimate average tree sizes and total yields produced under various density management regimes. Its use is illustrated with three alternative regimes.*

West. J. Appl. For. 1:6–11, Jan. 1986

The control of growing stock to achieve specific management objectives is critical to effective forest management. The actual manipulation of stand density is relatively easy, but arriving at levels of growing stock consistent with particular management objectives and constraints is much more difficult (Davis 1966). In this paper we present a density management diagram for lodgepole pine, then we compare the diagram with a computer growth and yield model, and finally we illustrate use of the diagram with three alternative regimes.

Ultimately, the control of growing stock requires a biologically meaningful and easily applied index of stand density. The best measures of stand density are those that incorporate both the number and average size of individuals in a population (Curtis 1970, Curtis 1982, Daniel et al. 1979, West 1982). A familiar and easily applied example is Reineke's (1933) stand density index (*SDI*), which expresses the relation between the number of trees per acre (*TPA*) and their quadratic mean diameter (*Dq*):

$$SDI = TPA\,(Dq/10)^{1.6}$$

A major advantage of this and other size-density indexes is its independence of site quality and stand age (Curtis 1982, Daniel et al. 1979, Long 1985).

Various graphical aides have been developed for use in density management using indexes based on size–density relationships. Wilson's (1979) "Stand Density Sheets" allow stocking to be controlled, using an index of stand density based on *TPA* and average height. Stocking guides of the type first developed by Gingrich (1967) are commonly based on Crown Competition Factor (CCF), another size-density index; the relationships represented by their various stocking lines are easily understood and reproduced using *SDI* (Daniel et al. 1979).

The utility of these basic graphical aides can be greatly enhanced with inclusion of additional size parameters. Ando (1968) developed what he referred to as "stand density control diagrams" for most of the important commercial timber species in Japan. Similar diagrams have been produced for coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) (Drew and Flewelling 1979) and loblolly pine (*Pinus taeda* L.) (Flewelling 1981).

An obstacle in the construction of density management diagrams is the scarcity of appropriate data with which to build them. Previously, diagrams have been built using data from research growth plots, but for many species and locales in the Rocky Mountains such data are limited. We examined the feasibility of constructing a diagram with common timber inventory data for lodgepole pine.

CONSTRUCTION OF THE LODGEPOLE PINE DENSITY MANAGEMENT DIAGRAM

USDA Forest Service Stage II inventory data were compiled for 519 lodgepole pine stands from the Targhee, Salmon, and Medicine Bow National Forests, located in Idaho, Wyoming, and Colorado (Table 1). The only constraint in selecting stands for inclusion in the data set was that lodgepole pine represent at least 80% of the total basal area of each stand. The Targhee and Medicine Bow data were used to fit the regression equations used to construct the diagram; the Salmon data were then used to validate these equations.

Data from each of the stands included estimates of total stand volume (ft^3/ac to 4-in top), density (*TPA*), basal area (ft^2/ac) as well as average height (Ht_s), and age of site trees (open grown or dominant). Using these variables we calculated *Dq*, *SDI*, and mean tree volume (*MVOL*).

A nonlinear least-squares curve-fitting routine was used to develop regression models relating *TPA*, *Dq*, Ht_s, and *MVOL*. The first equation, relating *MVOL* and *TPA* to *Dq*, has a coefficient of determination (R^2) of 87% and a standard error of 0.7 in.

$$Dq = (54.4\ MVOL + 5.14)^{0.361}\,(1.0 - 0.00759\ TPA)^{0.446}$$

The second equation, relating Ht_s and *Dq* to *MVOL*, has a coefficient of determination (R^2) of 94% and a standard error of 0.8 ft^3.

$$MVOL = ((0.00396 + 0.000779\ Dq^{2.27})\,(1.27\ Ht_s^{1.09}))^{0.916}$$

Neither regression model was biased with respect to the independent variables, site index, or stand age.

The lodgepole pine density management diagram (Figure 1) has *Dq* and *TPA* on the two major axes. These were chosen because, of the variables included, they are the most commonly used and easiest to estimate in the field. The diameter axis ranges from 1–30 in, while the densities range from 50–5000 *TPA*. Both axes are plotted on a logarithmic scale. The parallel diagonal lines represent *SDI*. The uppermost line corresponds to an *SDI* of 700, approximating the maximum *SDI* represented in the data set

Table 1. Description of lodgepole pine data including maximum and minimum values.

	Number of stands	Volume (ft^3/ac)	TPA	Basal area (ft^2/ac)	Site height (ft)	Site tree age (yr)
Medicine Bow N.F.	294	196–8215	130–4541	4–318	23–78	24–225
Salmon N.F.	75	74–4950	22–1979	9–210	23–75	23–191
Targhee N F	150	294–5349	55–1481	14–186	21–93	12–195

[1] The help of Hank Cheatham, Bob Cottingham, and Reese Pope is gratefully acknowledged. This is Journal Paper No. 2959 of the Utah Agricultural Experiment Station

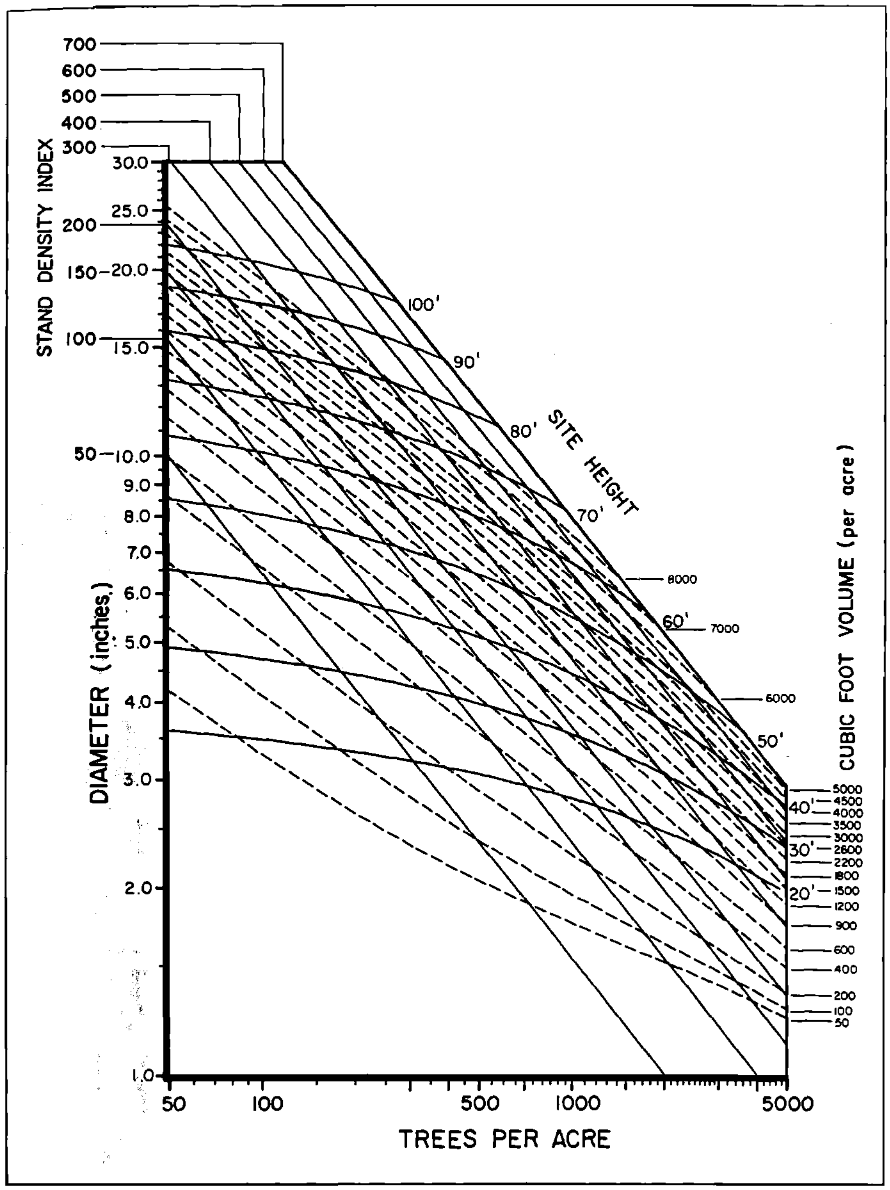

Fig. 1. Density management diagram for lodgepole pine. (An 8½ by 11 in copy of the diagram is available on request from the authors.)

(Figure 2). It is assumed that this *SDI* is a reasonable approximation of the maximum size–density relation for lodgepole pine and thus represents the maximum combination of *Dq* and *TPA* possible in stands of this species (Drew and Flewelling 1977, West 1982). Additional *SDI* lines range down to 50.

The two regression equations were used to produce site height and total volume (ft³/ac) lines. Site height lines range from 20–100 ft; the volume lines from 50–8000 ft³/ac. The range of values represented by the various axes and lines approximate the range of values included in the data used to construct the diagram (Table 1).

USE OF THE DIAGRAM

A key assumption in the use of this diagram is that a particular level of growing stock, or stage of stand development, is represented by *SDI*. For example, initial crown closure corresponds to a *SDI* of about 125. This is based on the relationship between *DBH* and crown width for open-grown lodgepole pine (Alexander et al. 1967). Similarly, a range of *SDI*s from approximately 250 to 700 corresponds to levels of growing stock representing full site occupancy (Bradley et al., Long 1985), and thus levels of current annual increment approaching the potential for a particular site quality and stand age.

For every species there is a zone of self-thinning or "imminent competition mortality" (Drew and Flewelling 1977, Long and Smith 1984). The *SDI* lines on the diagram corresponding to 400 and 700 form the approximate lower and upper limits of the self-thinning zone for lodgepole pine (Flewelling and Drew 1985). A stand with a *SDI* less than 400 would not be expected to experience competition-induced or density-related mortality. These zones can aid both in estimating the condition of a particular stand and in arriving at a density management regime to accomplish particular management objectives.

The development of a stand under a particular thinning regime is illustrated in Figure 3. This simulation is based on results from RMYLD, a computer growth and yield model widely used in the Rocky Mountain region (Edminster 1978). Initial conditions for the computer run included *Dq* = 4.5 in and 1000 *TPA*. The step-like pattern moving from the lower right side of the diagram to the upper left reflects increasing *Dq* with time, and decreased density following each thinning. Details of the pattern produced result from the way in which this computer model simulates thinning. That *Dq* increases during thinning reflects the fact that RMYLD assumes that thinnings are made from below. The decreasing size of each subsequent step is a function of RMYLD's fixed-interval thinning cycle, which,

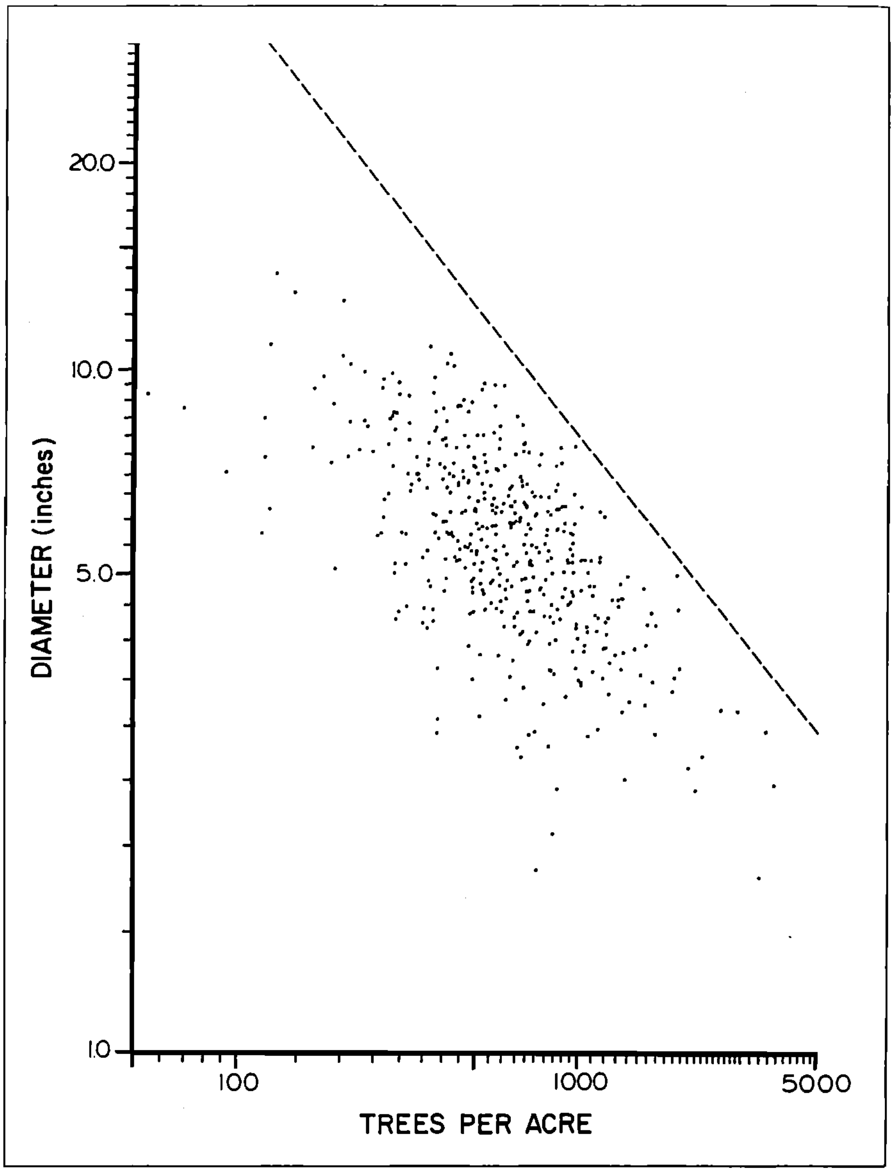

Fig. 2. The maximum size-density relationship for lodgepole pine. Dashed line represents a SDI of 700.

in the case of this run, is 20 years. The decline in growing stock, as reflected by *SDI*, following each subsequent thinning results from the use in RMYLD of a user-specified, constant, residual level of basal area. We do not, of course, advocate thinning to a constant residual basal area.

The sum of volumes removed during each thinning (the difference between volume before and after a thinning) and volume at the end of the rotation represent an estimate of the total volume produced by this density management regime. The estimate of 8500 ft^3/ac generated by the diagram is within 1% of that generated by RMYLD.

DESIGN OF ALTERNATIVE DENSITY MANAGEMENT REGIMES

Use of the diagram will be illustrated by three alternative density management regimes (Figure 4) for a hypothetical stand with 3050 *TPA* and *Dq* equal to 1.5 in. Site index (base age 100) is assumed to be 90 ft. For each of the alternatives, the end-of-rotation *Dq* will be 12 in. In addition, it is assumed that commercial thinning requires a volume removal of at least 1000 ft^3/ac/entry and a *Dq* of at least 6 in.

In the "unthinned" alternative, *Dq* and Ht_s increase with little, if any, reduction in *TPA* until the stand enters the self-thinning zone ($SDI > 400$). Subsequent increases in average size and total volume are accompanied by declining *TPA* such that *SDI* remains more or less constant at a level somewhat below the species maximum (Long and Smith 1984). Mortality that may occur after a stand's establishment and prior to its entry into the self-thinning zone is for the most part independent of density and thus exceedingly difficult to predict (Drew and Flewelling 1977). We therefore make the simplifying assumption that no natural mortality will occur in a stand with a *SDI* less than 400.

Estimates of time and growth can be included in this analysis using Ht_s from the diagram and appropriate site index curves or tables. For the unthinned alternative, when *Dq* equals 12 in, the estimate of Ht_s is 78 ft. Lodgepole pine variable density site index tables for SI_{100} = 90 ft (Alexander et al 1967) indicate a rotation age of about 102 years (Table 2). Note that the reduced Ht_s (78 ft) relative to that suggested by the site index (>90 ft) reflects the negative interaction between height growth and density incorporated into these site index tables (Alexander et al. 1967).

In using the diagram to plan a density management regime it is necessary to first translate the management objectives into appropriate levels of growing stock, i.e., upper and lower limits to *SDI*. For example, the "commercial thinning" alternative is designed to maintain levels of growing

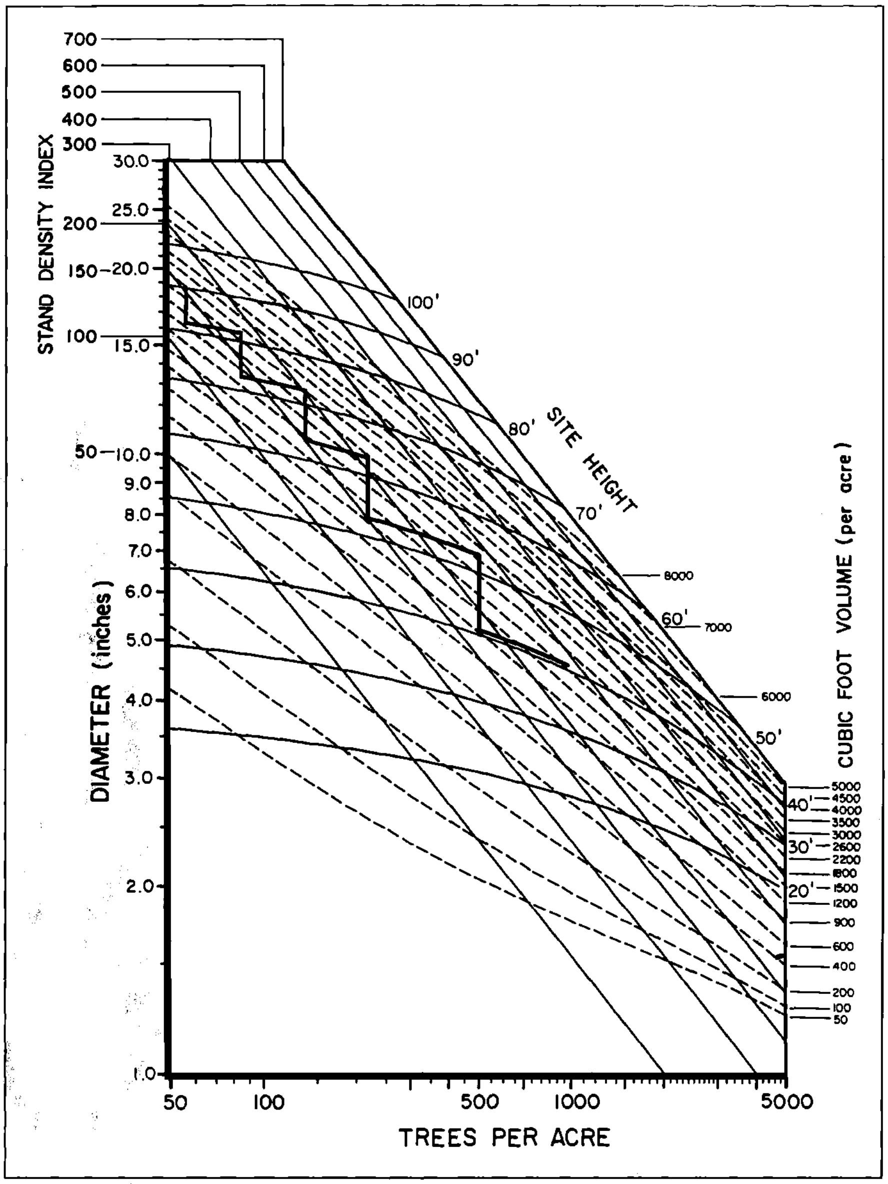

Fig. 3. Computer model simulation of a density management regime.

stock sufficient to ensure full site occupancy (*SDI* > 250) but to avoid self-thinning (*SDI* < 400). In this example we actually use *SDI* = 350 as the upper limit to growing stock. This somewhat conservative value illustrates that minimum levels of tree vigor may be a factor in density management planning. For example, Berryman (1982) suggests that increasing tree vigor by reducing competition may prevent catastrophic losses to the mountain pine beetle. Similarly, Long (1985) suggests that for lodgepole pine an *SDI* of 350 should result in crown-to-stem ratios sufficient to ensure prompt response to thinning.

The target end-of-rotation *Dq* (i.e., 12 in) and growing stock upper limit (i.e., *SDI* = 350) define a stand with approximately 260 *TPA* and 6000 ft^3/ac. It is then easy to work backwards through the rotation as indicated on the diagram (Figure 4). A single precommercial thinning is required to set up the first commercial thinning. With two commercial thinnings and the final harvest, this regime results in an estimated total yield of 8100 ft^3/ac and *MAI* of about 107 ft^3/ac/yr.

The "precommercial thinning only" alternative uses a growing stock upper limit of *SDI* = 200 and eliminates the commercial thinnings. A heavy precommercial thinning is used to set up the final harvest. This regime results in the production of final crop trees in a shortened rotation (i.e., 72 years) but does so at the expense of considerable potential yield. Compared with the commercial thinning alternative, this regime results in a 58% reduction in total yield and a 56% reduction in *MAI*.

SUMMARY

The diagram is a tool that can facilitate the design of density management regimes for lodgepole pine. The use of *SDI*, a size-density based index of growing stock, provides the user with a mechanism with which to quantify those aspects of stand and individual tree performance important to specific management objectives. For example, the trade-off between rapid individual tree growth and short rotations, or greater yields associated with higher levels of growing stock, is easily demonstrated with the diagram. The consequences of various management objectives or constraints can also be examined using the diagram. For example, if we reduce the minimum volume and *Dq* assumed to be necessary for a commercial thinning entry, the total yield and *MAI* of the commercial thinning alternative can be substantially increased. Together with appropriate site index curves or tables, the diagram can be used to generate reasonable first approximations of growth and yield for density management regimes.

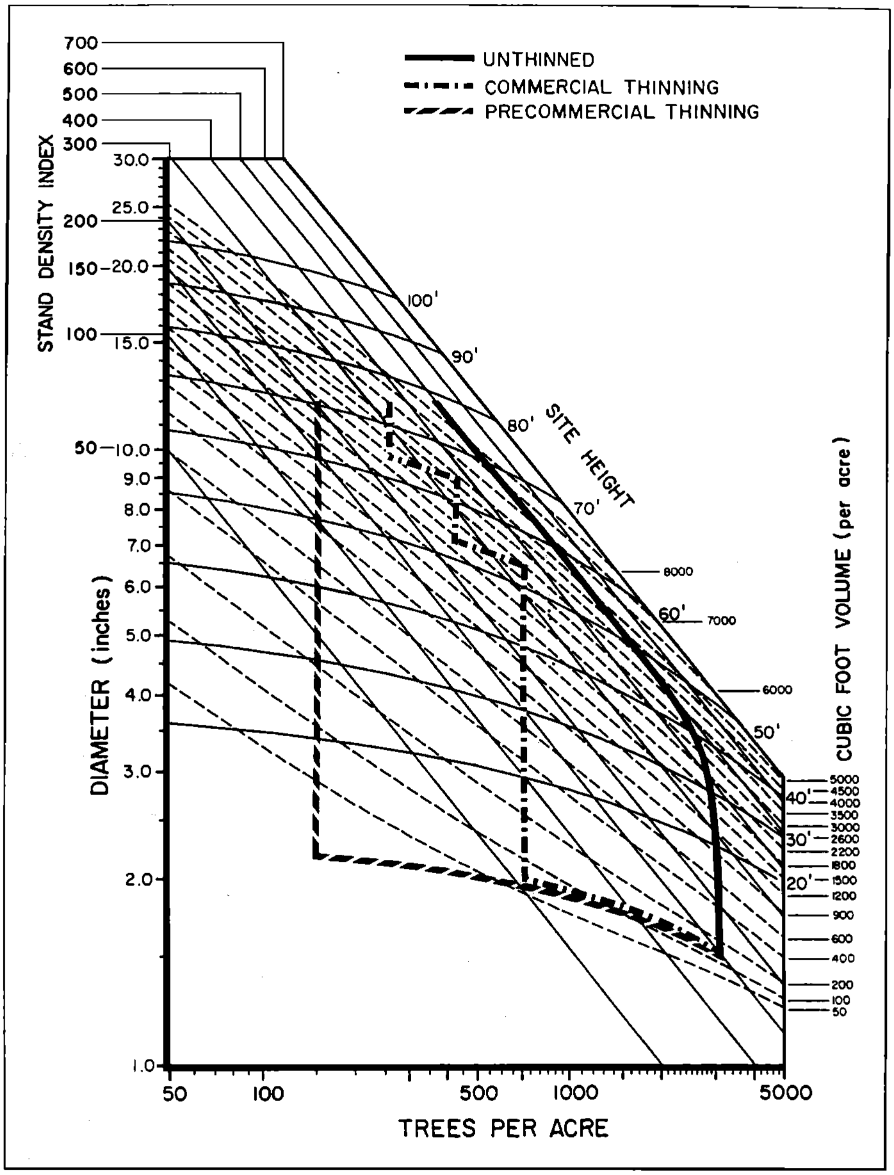

Fig. 4. Alternative density management regimes.

Table 2. Comparison of three density management alternatives. Mean annual increment is based on age at final harvest and includes yield from commercial thinnings and final harvest only.

	Age	Hts (ft)	*TPA* before	*TPA* after	*Dq (in)* before	*Dq (in)* after	Volume removed (ft³/ac)
			Unthinned				
Final harvest	102	78	375		12.0		9000
Total yield							9000
MAI							88 ft³/ac/yr
			Commercial thinning				
PCT	5	8	3050	725	1.5	2.0	
CT1	45	53	725	420	6.3	7.0	1000
CT2	59	64	420	260	8.8	9.6	1100
Final harvest	76	75	260		12.0		6000
Total yield							8100
MAI							107 ft³/ac/yr
			Precommercial thinning only				
PCT	5	8	3050	150	1.5	2.1	
Final harvest	72	70	150		12.0		3400
Total yield							3400
MAI							47 ft³/ac/yr

LITERATURE CITED

ALEXANDER R. R., D. TACKLE, and W. G. DAHMS 1967. Site indexes for lodgepole pine, with corrections for stand density: methodology USDA For. Serv. Res. Pap. RM-29. 18 p.

ANDO, T. 1968. Ecological studies on the stand density control in even-aged pure stand. Bull Gov. For. Exp. Stn. Tokyo. 210:1–153.

BERRYMAN, A. A. 1982. Mountain pine beetle outbreaks in Rocky Mountain lodgepole pine forests. J. For. 80:410–413.

BRADLEY, R. T., J. M. CHRISTIE, and D. R. JOHNSTON. 1966. Forest management tables. Forestry Commission Booklet No. 16. Her Majesty's Stationery Office, London. 218 p.

CURTIS, R. O. 1970. Stand density measures an interpretation. For Sci. 16:403–414.

CURTIS, R. O. 1982. A simple index of stand density for Douglas-fir. For. Sci. 28:92–94.

DANIEL, T. W., J. A. HELMS, and F. S. BAKER 1979. Principles of silviculture. 2nd edition McGraw-Hill Book Co., N.Y. 500 p.

DAVIS, K. P. 1966. Forest management: regulation and valuation. 2nd edition. McGraw-Hill Book Co., N.Y. 519 p.

DREW, T J and J W FLEWELLING 1977 Some recent Japanese theories of yield-density relationships and their application to Monterey pine plantations. For. Sci. 23:517–534.
DREW, T. J. and J. W. FLEWELLING, 1979. Stand density management: an alternative approach and its application to Douglas-fir plantations. For. Sci. 25:518–532.
EDMINSTER, C. B. 1978. RMYLD: computation of yield tables for even-aged and two-storied stands. USDA For. Serv. Res. Pap. RM-199. 16 p.
FLEWELLING, J. W. 1981. A comparison of three stand density indices for predicting gross volume growth in plantations of loblolly pine Diss., Univ. of Georgia, Athens. 83 p.
FLEWELLING, J. W. and T. J. DREW. 1985. A stand density management diagram for lodgepole pine. *In* D. M. Baumgarter, R. G. Krebill, J. T. Arnott, and G. F. Weetman. Lodgepole pine: the species and its management. Coop. Ext., Washington State Univ., Pullman. P. 239–244.
GINGRICH, S. F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the central states. For. Sci. 13:38–53.
LONG, J. N. 1985. A practical approach to density management. For. Chron. 61:23–27.
LONG, J N and F W SMITH 1984 Relation between size and density in developing stands: a description and possible mechanisms. For Ecol. and Manage. 7:191–206.
REINEKE, L. H. 1933. Perfecting a stand-density index for even-aged forests. J. Agric. Res 46:627–638.
WEST, P. W. 1982. Comparison of stand density measures in even-aged regrowth eucalypt forest of southern Tasmania. Can. J. For. Res. 13:22–31.
WILSON, F. G. 1979. Thinning as an orderly discipline: a graphic spacing schedule for red pine. J. For. 77:483–486.

Montana's Mission-Oriented Research Program

Robert D. Pfister *and* **Carl E. Fiedler,** *School of Forestry, University of Montana, Missoula, MT 59812.*

ABSTRACT. The Mission-Oriented Research Program (MORP) was established at the University of Montana in 1981 to work on current second-growth management problems in northern Rocky Mountain forests. Research is focused on the five traditional resources—timber, range, water, wildlife, and recreation—in relation to major program goals of inventory, productivity, and management. The program emphasizes studies of the multiple effects of alternative silvicultural treatments; close liaison with researchers, forest industry, and private landowners; and prompt distribution of information to users.

West. J. Appl. For. 1:11–12, Jan. 1986

In 1981 the Montana Legislature appropriated funds to establish the Mission-Oriented Research Program (MORP) within the Montana Forest and Conservation Experiment Station. The Experiment Station is the research branch of the School of Forestry at the University of Montana. This funding provided support for an applied research program aimed at problems facing owners and managers of second-growth forests in Montana. The need for such an interdisciplinary and sustained state forestry research program was first documented in a 1970 School of Forestry report. This goal became a reality with the establishment of MORP.

GOALS OF THE PROGRAM

The three major goals of MORP deal with (1) inventory, (2) productivity, and (3) management.

Inventory efforts focus on collecting existing data on all forest resources in the state. These data are being assembled to provide general information for broad levels of planning.

Productivity efforts are aimed at defining potential resource production on all forest types in the state. Potential productivity is being compared to current productivity as measured by inventories. The difference represents the opportunity for improving production through good management.

Management activities are centered on testing the most promising known treatments and developing new ones to improve productivity. Where practical, MORP studies are designed to determine the levels of production of several resources over a range of management treatments.

Program Philosophy

The first priority of our research program is to meet users' needs. We are looking at fundamental resource management questions from the users' standpoint as they relate to MORP goals:

What is the resource base? (inventory)

Where is it? (inventory and geographic information system)

How much is it producing? (inventory and existing productivity)

How much could it produce? (potential productivity)

How can productivity be increased? (management treatments)

What happens to other resources if production of one resource is increased? (multiresource productivity, integration, and evaluation)

How can multiresource production be balanced? (integration, evaluation and planning)

Because Montana is not unique in terms of land management problems, we are also relying on the research and experience of others. For example, Davis and Henderson (1976) worked on a computerized multiresource information system coupled with a management decision-making philosophy that views management problems in terms of *actions, outcomes,* and *place.* Actions are specified in terms of the kinds of management treatments and the stands or sites being treated. Outcomes are predicted on the basis of knowledge of typical stand and site responses to specified management treatments. Place requires both a geographic information system and an inventory of the data pertinent to each geographic unit. These concepts are applicable at both the stand- and area-planning levels.

We are also looking at breakthroughs in other fields of science that have potential application to forestry. One such example is the "expert system," a computer-based information storage and analysis system. This concept was originally developed to improve medical diagnoses. MORP is cooperating in a project that applies this technology to forestry. Parts of the system can be adopted immediately, especially the concept of "programming the logic of experts" (Webster and Miner 1982). This conceptual approach can be used for: (1) developing a knowledge storage and retrieval system; (2) applying stored knowledge to diagnose the condition of existing stands; (3) selecting alternative silvicultural prescriptions; and (4) predicting multiresource outcomes of different prescriptions.