maintained throughout the study) the RGC steadily increases to a peak over one, two, or three months. How long it takes to reach the peak depends on the time that has elapsed after shoot elongation has ceased before cold temperatures are initiated. Once the peak is reached, the RGC generally decreases abruptly. Sometimes, depending on the species and seed source, it remains near the peak for a month or more and then decreases. Later, a second peak is reached, one that is generally lower than the first although in a few seed sources it is higher.

In our studies, when seedlings are subject to a warm interruption, the temperature is raised to 20°C for two weeks, six weeks after a 5°C temperature is initiated, and then the temperature is returned to 5°C. The result: the RGC decreases abruptly by 50 percent or more.

The RGC is always reduced when seedlings are placed in cold storage. When they have not been subject to a warm interruption the magnitude of the reduction is not uniform and depends on the length of the time the seedlings are exposed to a 5°C temperature before being placed in cold storage. Invariably the minimum reduction in the RGC occurs when the RGC reaches its first peak or shortly thereafter. Consequently, since the RGC is high to begin with during this period, a minimum reduction leaves these seedlings with the highest RGC. This means there is a better chance that seedlings placed in storage during this period will come out of storage with a RGC above the minimum acceptable level than if they were placed in storage either at an earlier or a later date.

On the other hand, when seedlings are subject to a warm interruption before being placed in cold storage, the RGC, already reduced by the warm night interruption, is further reduced by storage. In all cases the effect is sufficient to reduce the RGC of 70 to 80 percent of the seedlings coming out of storage to below the minimum acceptable level characterized by field survival.

Before we can characterize a climate as one with warm interruptions that can affect RGC, we must determine the minimum temperature and duration required for a warm interruption to be deleterious. Should warm interruptions prove to be anywhere near as effective in reducing RGC as our studies suggest, and should they prove to be as widespread as temperature records indicate, a strong case can be developed for moving nurseries subject to warm interruptions to locations where such interruptions rarely occur, or for identifying those species that can be grown without the danger that their RGC's will be reduced below a minimum acceptable level by warm interruptions.

In favorable years at some nurseries ponderosa pine seedlings, for example, are produced with an RGC considerably above the minimum acceptable level. At such nurseries, warm interruptions that reduce the RGC of these seedlings by 100 cm or more can be tolerated, because after such a reduction the RGC is still above the minimum acceptable level. But when true-fir seedlings are produced, we do not have this kind of latitude. The maximum RGC is much lower and any significant reduction because of warm interruptions in the nursery can be expected to be directly reflected in lower field survival.

Summary

It now appears that if bare-root, cold-stored, true-fir seedlings, with a consistent minimum acceptable RGC are to be available for planting in the Sierra, new nursery locations may be required. Additional studies will be needed to determine whether this is so, and if so, where new nurseries should be located.

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Restocking harvested forestland.

Optimum initial stocking density in ponderosa pine plantations

Dennis E. Teeguarden

Under California laws, private owners of forests are required to maintain certain minimum tree stocking levels. The Z'berg-Nejedly Forest Practices Act of 1973 requires that within 5 years after a timber harvest, tree stocking must average no less than 300 points per acre. A tree with a diameter no more than 4 inches counts as one point; one 4 inches to 12 inches counts as three points, and each tree over 12 inches at breast height counts as six. Expressed another way, if all trees are harvested by clearcutting, the owner must have established on the site within 5 years at least 300 trees per acre. The state forester may require interplanting to raise stocking to the minimum acceptable standard.

The state's objective is to maintain and improve the productivity of commercial forests, but in developing ponderosa pine plantations on clearcut land, how reasonable is the 300-tree requirement in terms of productivity and financial return to the owner? Should landowners try to develop plantations with greater initial stocking than are required by the minimum standards?

To answer these questions, a study was initiated in 1975 to determine the effect of initial stocking on physical and financial productivity of ponderosa pine plantations.

Procedures

Ideally, the effect of initial stocking on yield is best studied by planting trees in different densities and then measuring their growth for 100 years or more. The experiment should be designed to measure the effect on yields of site quality and such cultural practices as thinning. Numerous replications would be necessary to derive statistically acceptable data. Substantial capital and labor would be needed.

Instead, this study used a computer-operated mathematical model to simulate the growth and development of ponderosa pine plantations. The model, *PIPOND,* relies on mathematical equations that describe the diameter, height, and volume growth of individual trees as a function of initial stocking density, site quality, percentage of survival of trees planted, and other factors. In effect, trees are grown in a computer by mathematical rules intended to mimic development of real plantations. *PIPOND* permits the investigator to forecast the probable response of wood yield to initial stocking and management decisions quickly and at modest expense. (A technical description of an earlier version of the simulation model is given by Joseph Buongiorno and Dennis E. Teeguarden in "An Economic Model for Selecting Douglas-Fir Reforestation Projects," *Hilgardia* 42(3):35-120, July, 1973.)

Data from the U.S. Forest Service's Pacific Southwest Forest and Range Experiment Station, Berkeley, had been obtained from ponderosa pine plantations set out on different site qualities at various densities in various northern California locations. The oldest plantations were about 60 years old. They were not set out according to an experimental plan, but they provide the best available source of data.

Simulations were made for 5 year intervals up to either a predetermined, or computer-calculated rotation period, not exceeding 70 years. A simulation run begins by specifying the inital stocking densities to be analyzed, say, 200, 400, and 600 trees per acre. Trees are planted at equal distances apart on a grid. In the first 5 years some trees die; mortality expressed as a percentage of trees planted is specified by the analyst. (Trees that die are selected randomly.) At the end of the period, stand characteristics are calculated, including number, diameter, and height of trees. The simulation is then repeated. After the first 5 years, mortality is determined as a function of stand characteristics. (The specific form of the equations is not reported here, but it is available on request from the author.)

PIPOND's ability to forecast stand growth and development was tested by comparing its results with those of plantations used as a data base, and it appears that the model produces reasonably accurate forecasts of stand development. However, we cannot verify that the model will produce accurate forecasts for non-data base plantations. Further testing, using data from different plantations, will be necessary. Nonetheless, the simulation results provided the best available evidence for establishing guides to initial stocking decisions.

Results

Simulation experiments were made on six different initial stocking levels, four site classes of different productive capacities, and four levels of tree survival. The effects on yields of replanting and of commercial thinnings were also tested. Partial results are reported here.

Physical yields. If the forest owner wants to maximize plantation yields when periodic commercial thinning is not feasible or likely and the survival rate is 80 percent, the simulations suggest an initial density of 300 trees per acre on site class 40, 400 on site class 60 and 80, and 500 on site class 100, the most productive site (Table 1). In general, as site quality increases, optimum initial stocking density increases. For this reason, forest owners should carefully assess site quality before establishing new pine plantations. On site class 100, yields for the 500-tree stocking level are 3,300 board feet, or 6.3 percent, greater than for a 300-tree level.

TABLE 1. Ponderosa Pine Yields in Board Feet, by Site Class and Initial Stocking Density[1]

Initial stocking density	Site Class 40	60	80	100
(80 Percent Survival Rate)				
	(thousand board feet)			
200	8.2	15.6	29.6	48.5
300	9.5*	17.5	32.1	51.9
400	9.1	18.3*	33.4*	53.5
500	7.9	18.2	34.1	55.2*
600	6.5	16.1	32.2	53.5
700	5.0	13.6	30.1	51.2
(60 Percent Survival Rate)				
200	7.1	13.6	26.0	43.0
300	8.3	15.5	29.0	47.3
400	9.4	17.5	32.0	51.6
500	8.7*	17.1	31.4	50.6
600	8.7	17.6*	33.2*	53.8*
700	7.7	16.4	31.9	53.6

[1] Yields for site class 60, 80, and 100 are for trees with 10-inch diameter breast height and larger at age 60 years; for site class 40 trees are 70 years old.
* Indicates maximum values.

TABLE 2. Present Net Worth of Ponderosa Pine Yields, by Site Class and Initial Stocking Density[1]

Initial stocking density	Site Class 40	60	80	100
(5 Percent Rate of Interest)				
	(dollars per acre)			
200	- 77*	- 2*	120	320
300	- 88	- 5	121*	327*
400	-139	- 29	112	320
500	-127	- 42	91	305
600	-147	- 85	45	250
700	-167	-105	1	204
(7 Percent Rate of Interest)				
200	- 98*	- 65*	- 6*	102*
300	-113	- 74	- 9	102
400	-131	- 93	- 24	93
500	-148	-112	- 45	76
600	-166	-136	- 78	37
700	-182	-157	-108	- 3

[1] Yields for site class 60, 80, and 100 are for trees with 10-inch diameter breast height and larger at age 60 years; for site class 40 trees are 70 years old.
* Indicates maximum values.

As survival rate decreases, optimum initial stocking also increases. For example, for site index 80, if tree mortality of 60 rather than 80 percent is expected, best stocking is 600 trees rather than 400. In effect, 200 more trees should be planted to ensure full use of the site. There is another reason: should the number of surviving trees fail to meet forest practice standards, it would be costly to replant.

Judged by physical yields, the state minimum stocking standard of 300 trees appears reasonable. Moreover, if costs are disregarded, the simulations indicate that landowners will maximize yields with higher densities than the rules require.

Financial returns. Most owners will want to choose initial stocking levels using financial rather than physical yield criteria. *PIPOND* is designed to convert estimates of physical yields to estimates of present net worth, given data on stumpage values, site preparation and planting costs, and the discount rate of interest. **Present net worth**—a measure of investment efficiency—is the difference between future net receipts from the sale of timber and the cost of site preparation, planting, and such cultural treatments as thinning, all discounted to the present at a specified rate of interest.

Table 2 shows the effect of initial stocking on present net worth in dollars per acre for the simple situation where the only expenditures are for site preparation and planting. Stumpage is valued at $100 per thousand board feet. The two rates of interest—5 and 7 percent—span the *real* rate of return (net of inflation) that many private owners might reasonably expect on long-term investments. The cost of site preparation is set at $80 per acre and planting (trees and labor) at $0.15 per tree. Taxes have not been deducted because owner situations are so variable. Nonetheless, the financial simulations are useful for making *relative* comparisons of the financial efficiency of alternative stocking levels.

If stocking decisions are based on financial criteria, optimum stocking is less than if judged by physical yields. The reason is simple: as density is increased, diminishing yields "at the margin" are encountered. Economic efficiency requires that density be increased to the point where the incremental cost of planting one more tree just equals the incremental return. This point will always be reached short of the density that maximizes physical yields.

As seen in table 2, optimum density at the 5 percent rate of interest on sites 80 and 100 is 300 trees per acre, 100 and 200 trees less, respectively, than suggested by table 1. At 5 percent, investments on sites classes 40 and 60 will not pay their way, even before taxes are considered. This does not mean such land is unsuitable for tree growing and harvesting operations, but rather that clearcutting, followed by out-of-pocket investments for site preparation and planting, may not be economically feasible for growing trees. In such situations, other silvicultural systems should be considered. On the other hand, if a stand *is* harvested and then planted, the owner should select the initial stocking density that minimizes losses, subject to the constraint that at least 300 trees are required.

For sites where plantations pay their way, the state minimum stocking standards appear reasonable. In the case of poor quality sites, they may require unjustifiable investments. Moreover, there appears to be no financial incentive to exceed these standards, under the assumptions in table 2. The exception is the situation where fairly frequent commercial thinnings can be made. Our simulation studies then suggest higher initial stocking than required by the minimum standard.

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Economic importance of forest industries in northern California

William McKillop ☐ Kent Connaughton

California ranks second only to Oregon in the production of lumber and is a major producer of softwood plywood. Some 5.5 billion board feet of lumber and more than 0.5 billion square feet of softwood plywood were produced by California mills in 1977. Most of the plywood and more than 60 percent of the lumber go to rapidly growing markets within the state. The remainder is distributed nationally and internationally.

Lumber and wood products, together with the pulp and paper industries, are important to the California economy. They account for, respectively, 3.5 and 2.3 percent of employment and 2.9 and 2.8 percent of value added by manufacturing. Value added is the value of the output of an industry minus purchases of raw materials and other inputs. Each industry accounts for 3 percent of the value of shipments of manufactured goods from California businesses. In 1975, lumber and wood products employed some 54,000 persons; paper and allied products employed 35,000 persons. Value of shipments from each sector was approximately $2.7 billion.

The economic significance of the lumber and wood products industry is particularly evident in many northern California counties. The key to the economic strength of a county or region is the size of the "export base" (or economic base) which is that