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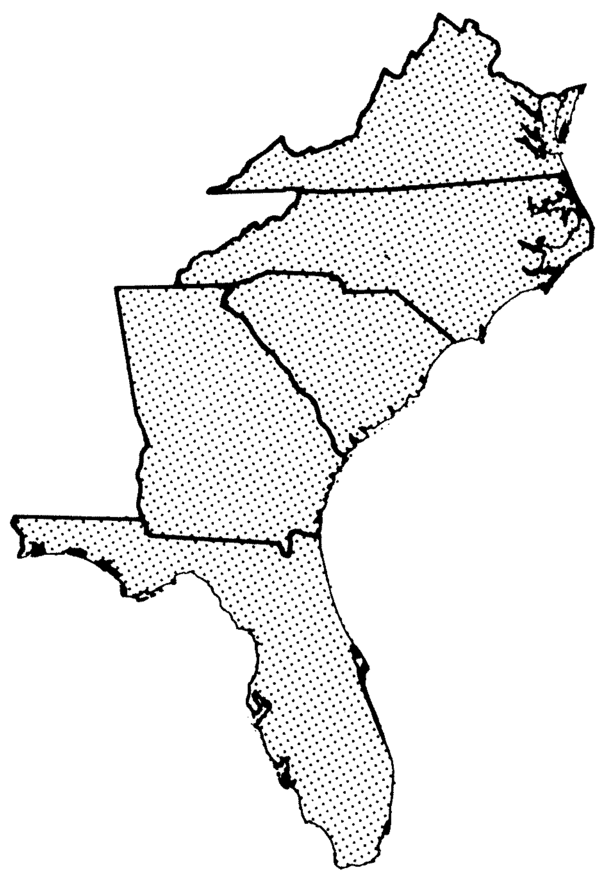

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Growth and Yield in Natural Stands of Slash Pine and Suggested Management Alternatives

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ABSTRACT.—Yields are presented by stand age, site index, and stand basal area at the beginning of a growth period. Differences between these yields and those projected 20 and 50 years ago are explained partly by changing definitions of normal or full stocking and partly by changes in forest management. If only pulpwood harvesting is envisioned, fairly high stocking is needed to get full production from the site. To produce sawtimber and veneer in a 35-year rotation, however, stocking must be considerably lower. For longer sawtimber-veneer rotations, heavier stocking is required to maximize yield.

Keywords: *Pinus elliottii*, stand density, stocking, growth projections, yield tables.

In 1929 the U.S. Department of Agriculture issued Miscellaneous Publication 50 (MP-50), which contained yields for unthinned natural stands of slash pine (*Pinus elliottii* Engelm. var. *elliottii*), and other southern pines, with "normal" or full stocking. In 1960, Schumacher and Coile published yields for unthinned, "well-stocked" stands of slash and other southern pines. In 1970, I published variable-density yield tables and projected yields for thinned stands of natural slash pine (Bennett 1970). I also published yields for unthinned old-field slash pine plantations (Bennett and Clutter 1968).

This array of information might seem to preclude any need for additional reports on yields for this species, especially for natural stands. However, there are no published estimates of the effects of density on yields in unthinned natural stands, or of the effects of thinning on growth in natural stands. And the published effect of density on board-foot yield is contradictory—positive in natural stands and negative in plantations. Furthermore, the yield estimates in MP-50 and in Schumacher and Coile differ greatly. In this Paper, I—

- Describe and attempt to reconcile some of the differences between the earlier natural-stand data sets.
- Present yield tables by density classes for unthinned natural slash pine stands.
- Present data on periodic annual growth in thinned natural slash stands.
- Present modern slash pine yields for maximum stocking levels (normal yields).
- Explain the apparent contradictory effects of density on board-foot yields.
- Suggest some management alternatives based on growth and yield patterns observed in both natural stands and plantations.

CONFLICTING ESTIMATES

Differences between yields reported in MP-50 for "normal" stands and those in Schumacher and Coile for unthinned, well-stocked stands are quite large (table 1). MP-50 shows 13 to 133 percent more surviving trees per acre, 1 to 49 percent greater basal-area stocking, and 1 to 46 percent greater cubic-volume yield. Differences of this magnitude are of considerable practical significance.

Some of the differences can be explained by utilization standards. Schumacher and Coile include inside-bark volumes from stump to tip, but the appropriate MP-50 table for this comparison also includes stump volumes. Most of the differences in yield, however, arise from variations in the observed number of surviving trees per acre. The "normal" stands in MP-50 clearly are more heavily stocked than the "well-stocked" stands in Schumacher and Coile. For example, MP-50 shows 380 trees per acre as normal stock-

[1]Retired.

Table 1.—Slash pine stocking and cubic-yield inside bark from Miscellaneous Publication 50 (USDA 1929) and Schumacher and Coile (1960)

Age (years)	Data source[1]	Site index 60	70	80	90	100
		Number of trees/acre				
20	MP-50	2,035	1,445	1,090	835	625
	S&C	875	628	474	373	303
30	MP-50	1,140	820	610	470	365
	S&C	499	377	298	244	206
40	MP-50	710	500	380	295	225
	S&C	379	294	238	199	172
50	MP-50	550	390	295	220	175
	S&C	318	254	209	177	155
		Basal area in square feet/acre				
20	MP-50	143	146	148	149	150
	S&C	96	102	108	116	126
30	MP-50	152	156	158	159	160
	S&C	104	111	120	130	143
40	MP-50	155	159	161	163	164
	S&C	109	117	128	140	155
50	MP-50	157	161	163	165	166
	S&C	113	122	134	147	164
		Peeled cubic feet/acre				
20	MP-50	1,800	2,250	2,700	3,100	3,500
	S&C	1,360	1,770	2,240	2,810	3,480
30	MP-50	2,500	3,150	3,750	4,300	4,800
	S&C	1,870	2,390	3,000	3,720	4,580
40	MP-50	3,050	3,850	4,600	5,300	5,950
	S&C	2,200	2,800	3,500	4,320	5,350
50	MP-50	3,500	4,400	5,300	6,050	6,750
	S&C	2,390	3,100	3,880	4,780	5,920

[1]Data from Miscellaneous Publication 50 (MP-50) include trees 2 inches d.b.h. and above; total volumes inside bark are measured from groundline to treetop. Data from Schumacher and Coile (S&C) include all trees; total volumes inside bark are measured from stump height to tree top.

ing for site 80 at age 40. Schumacher and Coile show 238 trees per acre under comparable conditions. But I have measured stands at this age and site quality containing more than 700 stems per acre. In fact, in my study on natural stands of slash pine (Bennett 1970), the three stands I measured in the 60-year-age class contained an average of 445 stems per acre. These data illustrate that "normal stocking" and "well-stocked" are subjective terms impossible to calibrate in the forest. Today's intensive management practices require more precise information. Therefore, in this and other papers, I have reported yields for a wide range of ages, sites, and densities identified and accurately measured in the field.

SAMPLE DATA

The data used here came from 176 permanent, ¼-acre plots established in pure, natural slash pine stands in 1955–56. The sample area extended from Dooly County, Georgia, in the north to Hernando County, Florida, in the south and from the east coast of Florida and Georgia to

Santa Rosa County, Florida, in the west. Stands selected for sampling showed no evidence of thinning, severe burning, insect or disease damage, or collection of naval stores. Stocking ranged from 88 to 1,800 trees per acre, site index from 40 to 100, and age from 17 to 68 years. Average age was 31.4 years.

CUBIC YIELDS IN UNTHINNED STANDS

The diameters of all trees on each plot were measured to the nearest 0.1 inch. From a height-diameter curve constructed for each plot, a mean volume for each diameter class 5 inches and above was calculated from an equation from Cooper and Olson (1958):

$$\text{cubic-foot volume (outside bark)} = 0.002853D^2H - 0.976 \qquad (1)$$

where:

D = diameter at breast height in inches
H = total height in feet.

Plot volumes were established by applying diameter-class volumes to the observed diameter distributions and summing the results.

After expanding plot volumes to an acre basis, multivariate regression analysis was used to develop the following predictor:

$$\text{Log CFY} = 2.7058 - \frac{10.204}{\text{age}} + 0.87266\,(\text{log basal area}) - \frac{51.051}{\text{site index}} \qquad (2)$$

where log = common logarithm and CFY = cubic-foot yield (outside bark) per acre.

This simple model removed 94 percent of the variation in the logarithm of yield. The density variable accounted for 53 percent of the variation removed. The strong influence of density is reflected in yields as predicted by Equation (2) (table 2). For example, 100 square feet of basal-area stocking produce 83 percent more cubic yield than 50 square feet, and 125 square feet produce 56 percent more yield than 75 square feet. Since the average basal-area stocking in the slash-longleaf pine type is about 50 square feet, these figures demonstrate the urgent need to increase stocking on much of the acreage occupied by these species.

Note that, for a given basal-area density, 73 percent of the 50-year yield is produced by age 30 (table 2). The corresponding percentages for the data in MP-50 and Schumacher and Coile are 72 and 74, respectively. Yields estimated by Equation (2) for the basal-area stockings in MP-50 at age 30 range from 78 to 98 percent of the yields (outside bark) listed for normal stands. Estimates for Schumacher and Coile's densities at the same age range from 93 to 109 percent of the yields they list for well-stocked stands:

Site index	Estimated yield at age 30 as a percent of yield in—	
	(MP-50)	(Schumacher and Coile)[1]
60	78	93
70	86	106
80	88	107
90	94	109
100	98	103

[1]Outside-bark yields were estimated by applying ratios of inside-bark yields in MP-50 and Schumacher and Coile to the outside-bark yields in MP-50.

The differences between my estimates and those in MP-50 can be explained largely by differences in merchantability limits. MP-50 includes volumes in the entire stem from groundline to tip as well as those in trees 2 to 5 inches d.b.h. I report volumes from stump to a 4-inch top diameter outside bark, and I exclude yields in trees smaller than 5 inches d.b.h.

There is no easy explanation for my yields being larger than those of Schumacher and Coile. The difference would be even greater if they had not included upper-stem volumes and those in trees 1 to 5 inches d.b.h. No doubt, differences in the methods of construction of volume tables contribute to the discrepancies in yield. Schumacher and Coile's yields for slash pine are based on an adaptation of a loblolly pine volume table by MacKinney and Chaiken (1949).

The yields in table 2 cannot be directly compared on a maximum stocking basis with the yields in MP-50 or Schumacher and Coile. In order to produce such a comparison, the observed maximum numbers of surviving trees per acre in the study plots were smoothed by regression. The following equation was then entered with the predicted maximum number of trees, by age-site categories, to produce estimates of basal-area stocking:

Table 2.—Estimated per acre yields outside bark for unthinned, natural stands of slash pine[1]

Age (years)	50-year site index	Basal area (square feet)				
		50	75	100	125	150
		Cubic feet				
20	60	672	957	1,230	1,495	1,753
	70	889	1,267	1,628	1,978	2,319
	80	1,097	1,562	2,008	2,440	2,861
	90	1,291	1,840	2,364	2,873	3,368
	100	1,477	2,087	2,694	3,274	3,838
30	60	994	1,416	1,820	2,212	2,593
	70	1,315	1,874	2,408	2,926	3,431
	80	1,623	2,311	2,971	3,610	4,232
	90	1,910	2,721	3,498	4,250	4,983
	100	2,177	3,101	3,986	4,842	5,677
40	60	1,209	1,723	2,214	2,690	3,154
	70	1,600	2,279	2,929	3,559	4,173
	80	1,974	2,811	3,614	4,390	5,148
	90	2,323	3,310	4,254	5,169	6,061
	100	2,647	3,771	4,847	5,890	6,905
50	60	1,360	1,937	2,490	3,026	3,548
	70	1,799	2,563	3,295	4,003	4,693
	80	2,220	3,162	4,064	4,938	5,789
	90	2,613	3,722	4,785	5,813	6,816
	100	2,977	4,241	5,451	6,624	7,766

[1]Includes all trees 4.6 inches d.b.h. and larger to a 4-inch top d.o.b.

$$\text{Log basal area} = 1.52417 - \frac{6.74476}{\text{age}} - \frac{32.227}{\text{site}} + 0.45395\ \text{LogN} \quad (3)$$

$$R^2 = 0.70$$

where log = common logarithm and N = number of trees per acre. Basal-area estimates from Equation (3) were then used in Equation (2) to estimate maximum cubic yields (table 3).

Except for site 60, the predicted maximum numbers of surviving trees per acre through age 40 are somewhat greater than the corresponding numbers in MP-50 and are, of course, well above those in Schumacher and Coile. For example, through age 40 the data on surviving trees in table 3 for sites 80 and above are from 25 to 100 percent greater than the corresponding data in MP-50. If volumes were computed with the same threshold diameter and utilization standards, it is evident that the yields in table 3 would be well above the MP-50 estimates, at least through age 40. This difference indicates that so-called normal stocking of one era will not necessarily apply in another.

The spread in basal-area yield within each site index class is much greater in table 3 than in MP-50 because of a much smaller spread in number of trees per acre in MP-50. Consequently, the effect of site on cubic yield as shown in table 3 is much greater than that shown in MP-50. For example, yields in MP-50 for site 70 are about 70 percent of the yields for site 100, whereas yields in table 3 for site 70 range from 49 to 56 percent of the yields for site 100. The effect of site on yield in table 3 would be reduced, of course, if volume for all trees 2 inches and above were included.

PERIODIC ANNUAL GROWTH IN THINNED STANDS

The 176 quarter-acre plots were established to evaluate growth and total yield for given residual densities in thinned stands. Accordingly, each plot was assigned a stocking density and, if

Table 3.—Per acre cubic-volume and basal-area yields outside bark for maximum stocking levels in unthinned, natural stands of slash pine

Age (years)	Site index 60			70			80			90			100		
	Trees	Yield[1]	Basal area	Trees	Yield[1]	Basal area	Trees	Yield[1]	Basal area	Trees	Yield[1]	Basal area	Trees	Yield[1]	Basal area
	No.	*Cubic feet*	*Square feet*	*No.*	*Cubic feet*	*Square feet*	*No.*	*Cubic feet*	*Square feet*	*No.*	*Cubic feet*	*Square feet*	*No.*	*Cubic feet*	*Square feet*
20	1,652	1,537	129	1,520	2,292	148	1,421	2,507	164	1,344	3,305	177	1,282	4,695	189
30	1,020	2,608	134	888	3,450	151	789	4,550	163	712	5,614	172	651	6,656	180
40	704	2,765	129	572	3,929	140	474	5,057	147	394	6,060	150	335	6,945	151
50	515	2,941	121	383	4,030	126	284	4,792	126						

[1]Includes all trees 4.6 inches d.b.h. and larger to a 4-inch top d.o.b.

required, was thinned to that level initially, and at 5-year intervals thereafter. Unfortunately, 94 plots were destroyed or inadvertently thinned during the first 5-year growth period. Our study design held basal area constant within site and forced a negative correlation between site index and number of trees per acre. Also, mortality in number of trees per acre was essentially the same on all sites. These results masked the effect of site on basal area and cubic-volume growth since tree sizes increased as site increased. However, remeasurement of 121 plots at the end of the second 5-year growth period permitted development of the following equations for predicted and projected yield and growth:

$$\text{Ln}Y = 5.98812 - \frac{121.713}{S} - \frac{19.758}{A} + 0.89683\,\text{Ln}B \quad (4)$$

$$\text{Ln}Y_2 = 5.98812 - \frac{121.713}{S} - \frac{19.758}{A_2} + 4.632\left(1 - \frac{A_1}{A_2}\right) + 0.89683(\text{Ln}B_1)\left(\frac{A_1}{A_2}\right) \quad (5)$$

$$\text{Ln}B_2 = \text{Ln}B_1\left(\frac{A_1}{A_2}\right) + 5.1649\left(1 - \frac{A_1}{A_2}\right) \quad (6)$$

$$CFG = Y\left[\frac{19.758}{A^2} - 0.89683\,\frac{\text{Ln}B}{A} + \frac{4.632}{A}\right] \quad (7)^2$$

[2]Equation (7) was not published at the time the others in this group were, but it was developed at the time the others were.

$$BFY = 1236.12 - 186.16011(B) + 7.31406\,(\text{cubic-foot stocking}) \quad (8)^3$$

where:

Ln = natural logarithm
Y = cubic-foot yield
Y_2 = projected cubic-foot yield
S = 50-year site index
A = any given age
A_1 and A_2 = initial and terminal age
B = any given basal area
B_1 and B_2 = initial and terminal basal-area stocking
CFG = periodic annual cubic-foot growth rate
BFY = board-foot yield

Theoretically, Equation (7) does not estimate the volume that accrues over a year; rather, it gives an instantaneous growth rate applicable only at a specific age (table 4). Practically, however, estimates derived from this equation are good indicators of current annual increment, because the amount of change in cubic volume and basal-area stocking (independent variables in this equation) over the span of a year does not greatly alter the growth rate.

Slightly more accurate estimates of current annual growth can be obtained by using Equations (5) and (6) to project cubic volume and basal-area stockings at yearly intervals. From these stocking data, growth rate can be estimated at

[3]All equations were developed by Dr. J. L. Clutter, University of Georgia.

Table 4.—Instantaneous rates of cubic-foot growth per acre at specific ages in thinned, natural stands of slash pine, by site index and basal-area stocking

Age (years)	50-year site index	Basal area (square feet)				
		50	75	100	125	150
		Cubic feet				
	60	69	82	90	96	98
	70	92	109	121	128	131
20	80	114	136	150	159	163
	90	135	161	178	188	193
	100	155	184	204	215	221
	60	54	62	65	66	64
	70	72	82	87	88	86
30	80	89	102	108	110	107
	90	106	121	128	130	127
	100	121	139	147	149	145
	60	43	48	49	48	45
	70	58	64	66	65	60
40	80	72	80	82	80	75
	90	85	95	97	95	89
	100	97	108	111	109	102
	60	36	39	39	37	34
	70	48	52	53	50	45
50	80	59	65	65	62	56
	90	70	77	77	73	66
	100	81	88	89	84	76

yearly intervals and average growth rates can be computed. For example, the average of the growth rates at ages 20 and 21 would represent current annual growth for the 20th year.

Current annual increment of merchantable volume is greatest at age 20 and declines thereafter. As in unthinned stands, this increment is maximum in thinned stands at an early age (sometime prior to age 20) because it is a function of number of trees per acre. Consequently, ingrowth, diameter growth, and good height growth at young ages, produce early culmination of current and periodic annual increment of merchantable volume.

As with all growth patterns, added units of stocking contribute successively lower volumes of increment. Otherwise, culmination would never occur. The point of primary interest on managed stands is the amount of volume increase per increased unit of stocking. At the point of culmination of periodic annual growth, a large portion of the stocking contributes only a minor amount to the total production (table 5). On the basis of the data in table 5, attainment of the biological growth potential is financially unattractive, to say the least.

Although no equation for board-foot growth was developed in the analysis of the study data, an estimate of sawtimber growth can be derived from

Table 5.—Contributions of various stocking levels to total growth at the point of culmination in thinned, natural stands of slash pine

Age (years)	Basal-area stocking (square feet)						
	25	50	75	100	125	150	175
	Percent of total growth[1]						
20	48	70	83	91	97	99	100
30	59	81	93	98	100		
40	65	88	98	100			
50	69	91	100				

[1]These data hold, with very minor variations, for all sites.

Table 6.—Periodic annual board-foot growth as developed from projected board-foot yields for thinned, natural stands of slash pine

Age (years)	50-year site index	Basal area (square feet)			
		50	75	100	125
		Board feet			
20	70	0	0	0	0
	80	0	0	0	0
	90	434	609	726	275
	100	576	783	912	1,138
30	70	43	208	0	0
	80	67	348	445	577
	90	290	489	585	680
	100	400	612	719	818
40	70	130	178	224	274
	80	236	284	339	388
	90	332	393	446	488
	100	418	489	551	591
50	70	113	146	173	209
	80	204	239	265	295
	90	279	326	355	380
	100	353	406	433	461

projected board-foot yields (table 6). Projected board-foot yields were obtained by applying Equation (8) to projected cubic volume and basal-area yields (Bennett 1970). Like cubic-volume growth, periodic annual board-foot growth is greatest at age 20. The very high growth rate on the best site at age 20 no doubt reflects heavy ingrowth. Site 60 is excluded from table 6 because it shows no sawtimber potential. Sites 70 and 80 show no board-foot production at age 20, even for low densities. Stands on these sites averaged 714 and 466 trees per acre at age 20, and thinnings did not occur until this age or later. Board-foot growth shows no culmination in relation to density except on site 90 at age 20 and on site 70 at age 30. The projected board-foot yields show essentially the same pattern. In contrast, board-foot yields in plantations culminate in relation to stocking on all sites at 200 to 300 trees per acre, but they do not culminate on any site in relation to age up to age 30. Light stockings in both plantations and natural stands permit rapid diameter growth and, of course, produce early and large board-foot yields. However, as age increases in both types of stands, more and more trees become sawtimber size, and board-foot yield then tends to increase as density increases. Once all trees reach sawtimber size, to use the perfect example, every time we add a cubic foot of growth we increase board-foot yield, and we know that cubic-foot growth and yield increase as density increases.

CHANGING CONDITIONS

Comparison of the new cubic yields for maximum stocking in table 3 with those from MP-50 and Schumacher and Coile in table 1 illustrates that "normal stocking" and "well stocked" are concepts that are strongly influenced by personal judgment. Although based on a sound biological principle, the concept of normal stocking is not useful in applied management because it is not definable in measureable parameters. Furthermore, it is not economically viable in a freely competitive market of diversified primary products, nor will it be as long as the free market dictates management. Even if defined in terms of products, the concept is not economically viable because there is a point beyond which the cost of carrying additional stocking exceeds the return from the added stocking.

If we grant that the yields published in 1929 for normal stocking represented the maximum for that era, then the data in table 3, especially for ages 20 and 30, demonstrate that optimum stocking of one period may not apply to subsequent stands produced under different conditions. A stand or forest type is a product of its history. The lack of management—indeed, the mismanagement and destructive practices of the late 1800's and early 1900's—must have been reflected, to some extent, in the normal yields of the 1920's. It is not surprising, therefore, that optimum stocking and yield patterns developed under a better level of management and fire protection are different from those presented in MP-50.

MANAGEMENT ALTERNATIVES

From the growth and yield patterns reported here for natural stands and those previously observed in slash pine plantations, we can determine stocking levels and rotation lengths that appear best for growing various products. Yield tables for both plantations and natural stands demonstrate that cubic yield is a function of number of trees per acre—as trees per acre increase, cubic yield increases. Tables of board-foot yields for natural stands also show that both these yields and periodic growth increase as density increases. Tables of board-foot yields for plantations, on the other hand, show that board-foot yields at age 35 and under are greatest in stands of 200 to 300 trees per acre. These growth and yield patterns suggest the following alternative management regimes for the two types of stands:

1. For pulpwood production on a 25- or 30-year rotation, a fairly heavily stocked stand is needed. Since the yield increase per unit of stocking will decline as stocking increases, the optimum stocking level will depend on overall management costs, including harvesting costs as influenced by tree size. For this reason, specific stand stockings are not suggested. The owner or manager can be guided by the fact that cubic production and harvesting costs increase with density and that densities beyond 600 trees per acre significantly reduce height growth.

2. For sawtimber and veneer production in a relatively short rotation (35 years), no more than 200 to 300 surviving trees per acre are needed to maximize yields. In plantations, the equivalent of a 10- by 10-foot or greater spacing should be used if total product yield is the primary concern. This assumes a survival percentage of 75 to 80. In natural stands, a precommercial thinning to this level of stocking at an early age (before age 5) would be required. Lightly stocked stands on good sites can be commercially thinned around age 20 to stimulate diameter growth without reducing sawtimber ingrowth in a short rotation.

3. For sawtimber and veneer production in rotations over 40 years, especially those 45 years and above, the stand should be started with several hundred surviving trees per acre, if near maximum volume production is desired. Such a level will permit two or more thinnings, with an accompanying increase in average tree quality and the heavier basal-area stocking necessary for optimum, or near optimum, board-foot and veneer yields in these long rotations.

As we have seen, board-foot yields in natural stands increase as basal-area density increases. This pattern develops when a majority of the trees reach sawtimber-size and it will continue until density causes mortality among sawtimber-size trees. It is easy to rationalize a positive correlation between board-food growth and density. As noted earlier, once all trees are of sawtimber size and quality, every cubic foot of growth, at least in the saw-log portion of the tree, is board-foot growth. Hence, heavier stocking is needed to maximize board-foot growth and yield in long rotations.

We should note again, however, that the density which maximizes product yield is not likely to optimize net return. The stocking level that will produce the greatest net return is influenced greatly by management costs, interest rates, taxes, etc., and these are not stable variables. When we consider further that the law of diminishing returns applies to stocking, it becomes difficult to specify an optimum density that will hold for a majority of owners. As with cubic production, the owner or manager must be guided by the fact that board-foot and veneer-stock production is positively correlated with density in long rotations, and that harvesting and manufacturing costs are markedly influenced by tree size.

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KEYWORDS: *Pinus elliottii*, stand density, stocking, growth projections, yield tables.

Bennett, Frank A.
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Yields are presented by stand age, site index, and stand basal area at the beginning of a growth period. Differences between these yields and those projected 20 and 50 years ago are explained partly by changing definitions of normal or full stocking and partly by changes in forest management. If only pulpwood harvesting is envisioned, fairly high stocking is needed to get full production from the site. To produce sawtimber and veneer in a 35-year rotation, however, stocking must be considerably lower. For longer sawtimber-veneer rotations, heavier stocking is required to maximize yield.

KEYWORDS: *Pinus elliottii*, stand density, stocking, growth projections, yield tables.

The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.