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Volume and Value Growth of Hardwood Trees in Wisconsin

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ABSTRACT. *The volume of healthy trees of commercial size in the maple-birch forest type measured during the last two Forest Inventory Analysis surveys of Wisconsin grew at 2 to 3%/yr for sawtimber, and 3 to 4% for poletimber, with substantial differences among species. However, from 1967 to 1989, the real price of logs decreased or remained constant for most grades and species. The decrease was especially large for high grade logs. The only exceptions were red oak and elm, whose prices increased at 1 to 2%/yr, for all grades. As a result, the average value growth rate of the trees that did not improve in grade was a modest 2%/yr, and not different from zero at a 5% significance level. Holding high grade trees led to substantial losses. Red oak and elm provided good returns because of favorable price trends, and quaking aspen because of its fast volume growth. Among the worst financial performers were hard and soft maple and yellow birch, the most numerous trees in the sample. A simple equation was derived to predict volume growth rates as a function of tree diameter, site index, crown ratio, stand basal area, crown dominance, and tree species. Although these variables did influence volume growth, suggesting that silvicultural practices could be beneficial, they explained only a small part of volume growth, and less of value growth. The future of commercial forestry in Wisconsin depends at least as much on policies that will develop markets and obtain good prices as on improved silviculture. North. J. Appl. For. 10(2): 63–69.*

Within the forests of Wisconsin, the most important type is the maple-basswood-birch forest (also called the northern hardwoods, or maple-birch type), which covers 27% (4 million ac) of the total commercial forest area. Three fourths of this forest is privately owned (Railey 1985) by individuals who have varied reasons for managing (or not managing) their forests (Bliss and Martin 1988). This paper deals only with the economic motive: the financial returns from growing live and healthy trees over long periods of time. The purpose is to provide information on past rates of return and thus to allow better inference about what the returns might be in the future.

The paper is organized as follows. First, we summarize the rates of volume growth of hardwood trees, of various species and size, between the last two forest inventories of Wisconsin. Next, we present data on the rates of change in log prices that have occurred during the past 20 yr. Volume growth and price changes are then used to determine past value growth rates of single trees by species, size, and grade. To help in management decisions, an equation is then presented to predict the annual volume growth rate of a tree as a function of its characteristics and those of the stand in which it grows. This equation, together with price trends, can be used to decide whether a tree is earning a rate of return appropriate for the owner, and should be left to grow, or whether it should be replaced by a younger tree.

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Volume Growth Rates of Trees

The measurements used to determine the rate of growth in volume of individual hardwood trees in Wisconsin came from the database of the Forest Inventory and Analysis (FIA) research work unit at the USDA Forest Service North Central Forest Experiment Station (Hahn and Hansen 1985). The trees belonged to 613 random plots representative of the northern hardwood type in Wisconsin. The majority of the plots (440) were located in the northern part of the state. This study dealt with "growing-stock" trees only, i.e., live trees of commercial species and size, identified as desirable and acceptable, excluding rough, rotten, and dead trees.

Furthermore, only trees that had been measured twice were used. All measurements were done between 1966 and 1984. The interval between the two successive measurements on permanent plots ranged from 6 to 16 yr. Both poletimber and sawtimber sizes were considered. However the trees that grew from poletimber to sawtimber between the two measurements were not used. Their volume growth rate was not defined, due to the change of product from pulpwood to sawtimber.

The results are based on the measurements of 3801 trees: 2398 of pole size and 1403 of sawtimber size. The average annual rate of growth in volume of each tree was estimated from the volume in the first and second measurement. The volume of the sawtimber trees was measured in board feet (bf) (Scribner rule) and that of pole timber in cords (cd). Volumes were estimated from the diameter of the trees at breast height (dbh), using the equations of Hahn (1984), and conversion factors in Husch et al. (1982) and Grosenbaugh (1952).

The last row of Table 1 shows that the average growth rate of all trees in the sample was 3%/yr , with a standard deviation of 1.6%. Pole timber grew faster (3.3%/yr) than sawtimber (2.3%/yr). This was true for every species, in agreement with the well-known inverse relationship between the growth rate and the size of trees. However, a proper determination of the influence of size or species on growth rate requires that everything else be kept constant (see the last part of this article).

Table 2 summarizes the distribution of trees according to their growth rate, by species and size. The data confirm the faster growth rate of small trees. For example, they show that 63% of the basswood trees of poletimber size grew at 3%/yr or more, while only 26% of those of sawtimber size did so. The data also confirm the substantial differences between species. For quaking aspen, 63% of the sawtimber trees grew at least 3%/yr, compared to 9% for the soft maple trees.

Statistical analysis showed that there was little difference in volume growth rate by grade, but, as will be seen, there were substantial differences in the value growth rates, due to differences in the trends of log prices by grade.

Rates of Change in Wood Prices

Wood prices vary considerably by location, species, size, and grade, and they also change over time. The source of price data for this study was the Wisconsin Forest Products Price Review (Peterson 1967–1989), which gave data on prices of logs and pulpwood, delivered to the mill, for most of the species and grades considered here. Delivered prices were preferred because they were available by grade, and they were probably more accurate than stumpage prices. We assumed that stumpage prices, for a given grade, were proportional to delivered prices, so that the rates of price change would be the same for delivered logs and stumpage. Delivered pulpwood prices were not available for elm, hard and soft maple, and yellow birch, for which the price was assumed to change at the same rate as that of "other hardwoods." These prices were deflated by the producer price index of the U.S. Bureau of Labor Statistics to get real prices

Table 1. Annual volume growth rates of single trees.

Size/ Species	Mean (%)	Standard deviation	Number of trees
Sawtimber			
Basswood	2.5	1.1	234
Elm	2.3	1.2	76
Hard maple	2.3	1.0	556
Paper birch	2.2	1.2	39
Quaking aspen	3.5	1.3	72
Red oak	2.6	1.0	157
Soft maple	1.8	0.9	130
Yellow birch	1.9	1.1	139
All species	2.3	1.1	1403
Poletimber			
Basswood	3.6	1.8	465
Elm	4.1	2.3	88
Hard maple	3.3	1.7	875
Paper birch	2.3	1.1	241
Quaking aspen	3.9	1.8	115
Red oak	3.4	1.4	105
Soft maple	3.3	1.7	386
Yellow birch	3.6	2.2	123
All species	3.3	1.7	2398
All trees	3.0	1.6	3801

Table 2. Distribution of trees according to volume growth rate

Size/ Species	Percent of trees with volume growth rate		
	≥ 5%	≥ 3%	≥ 1%
Sawtimber			
Basswood	2	26	92
Elm	4	29	87
Hard maple	1	22	90
Paper birch	0	23	80
Quaking aspen	15	63	97
Red oak	2	34	98
Soft maple	1	9	85
Yellow birch	1	14	76
Poletimber			
Basswood	21	63	92
Elm	30	61	96
Hard maple	16	55	93
Paper birch	2	25	88
Quaking aspen	23	67	98
Red oak	12	52	97
Soft maple	17	52	92
Yellow birch	27	55	89

Figure 1 shows the annual series of average real log prices in Wisconsin from 1967 to 1989, expressed in 1982 dollars Throughout that period, there was a large difference between the price of different grades. For example, the unit price of hard maple grade 1 logs was double that of grade 3 in the late 1980's However, the graphs also show that the price difference between grades decreased between 1967 and 1989. The only exception was red oak, for which the difference between the price of the lowest and highest grades remained constant, or increased slightly between 1967 and 1989.

The price trends are summarized in Table 3, which shows the average rate of change in real price for each species and grade from 1967 to 1989. The last row of Table 3 shows that for all species taken together, the price of grades 1 and 2, and the price of pulpwood declined significantly, while the price of grade 3 remained constant. The largest decline in price occurred for grade 1 yellow birch logs: an average decrease of almost 3%/yr The largest increase was for grade 3 red oak logs, whose price rose at an average rate of about 2%/yr. The real price of grade 1 and grade 2 logs decreased, except for elm (soft) and red oak The price of all grades increased significantly for elm, at about 1%/yr and for red oak, at 1.2 to 2%/yr. The price of grade 3 has remained about constant for all the other species.

For pulpwood, the price decreased at an average rate of 1.1%/yr, the largest price drop was for quaking aspen: 2%/yr over the 23 yr considered.

Value Growth Rate of Trees

Since the commercial value of a tree is the product of its volume by its unit price, the annual percent growth rate in value is, to a close approximation, the sum of the annual percentage

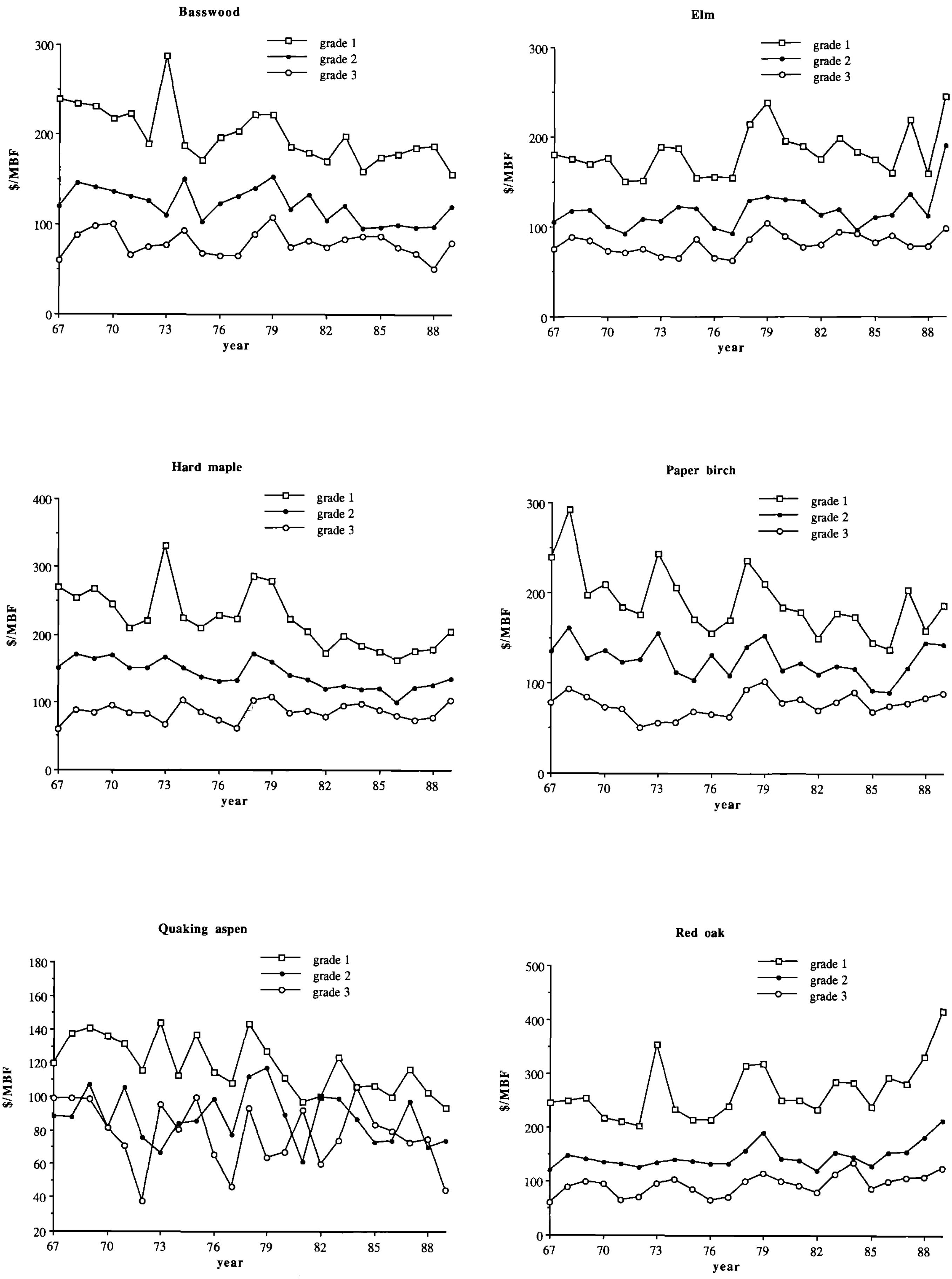

Figure 1. Delivered log prices in constant 1982 dollars.

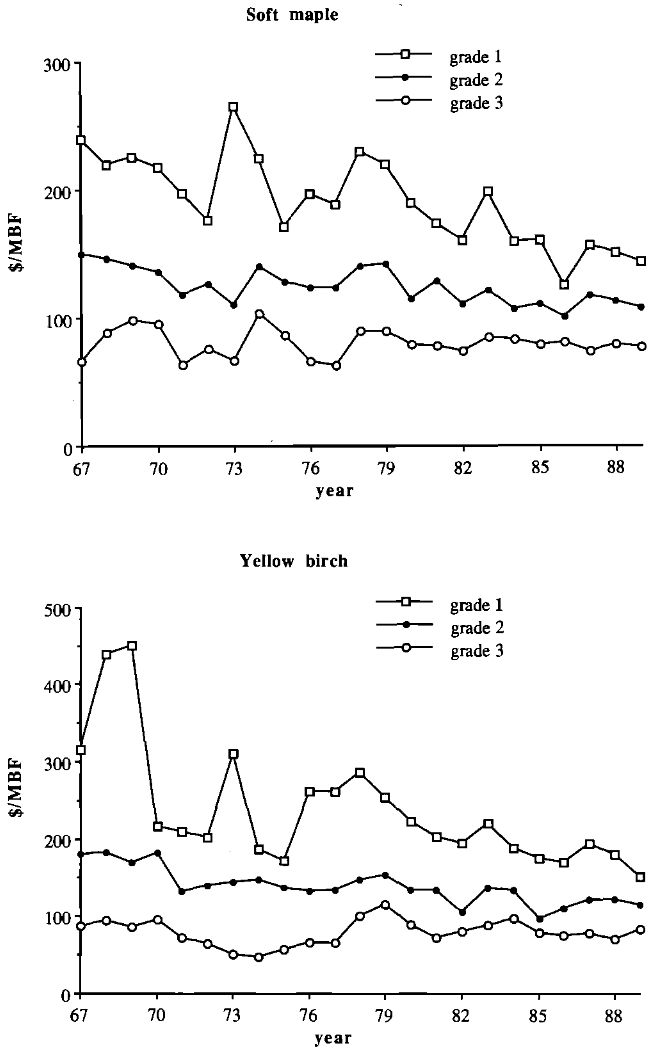

Figure 1. (continued) Delivered log prices in constant 1982 dollars.

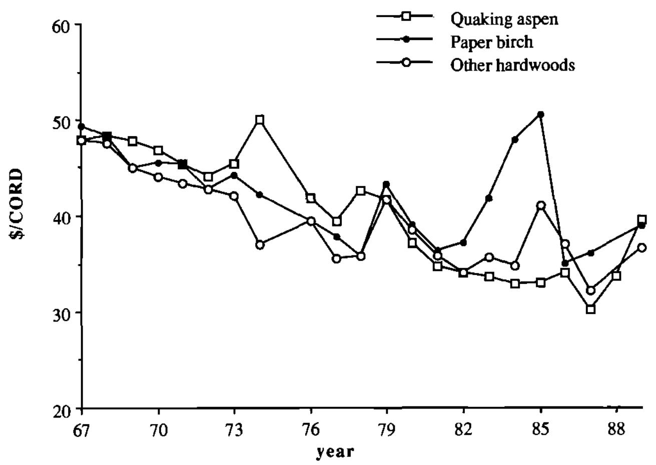

Figure 2. Pulpwood delivered price in constant 1982 dollars.

rates of volume growth and price change (Buongiorno and Gilless 1987). The average value growth rates for the trees in the sample appear in Table 4.

In this study, we did not analyze the returns due to changes in quality class. Clearly, very high returns occur when a tree

Table 3. Average annual percentage rates of change of log prices in Wisconsin from 1967 to 1989.

	Log			
Species	Grade 1	Grade 2	Grade 3	Pulpwood
Basswood	-1.5*	-1.3*	-0.4	-0.3
Elm	0.8*	1.0*	0.8*	
Hard maple	-1.9*	-1.6*	0.5	
Paper birch	-1.5*	-0.8	0.7	-0.9*
Quaking aspen	-1.4*	-0.6	-0.4	-2.0*
Red oak	1.5*	1.2*	1.9*	-0.1
Soft maple	-2.2*	-1.2*	-0.2	
Yellow birch	-2.9*	-1.9*	0.4	
Other hardwoods				-1.4*
All species	-1.2*	-0.9*	0.3	-1.1*

Each rate is the coefficient of the year variable in a regression of the logarithm of price on the year of observation. An "*" indicates that the rate was significantly different from zero, at the 5% level. Rates for "all species" are averages of rates for individual species, weighted by the number of trees in each species. Standard errors of rates were computed similarly, ignoring correlations between prices of different species.

moves from the pole size to the sawtimber size. Therefore, a tree which is likely to become of sawtimber size by the time of the next harvest should not be cut. Similarly, as stressed by Davies(1991) and confirmed by the data in Figure 1, high rates of return are earned on trees that move to a higher log grade due to the price difference between log grades. This change could not be measured because data on tree grade were available for the second inventory only, and tree grade is not necessarily coupled with size. The average relationship between log grade, g (equal to 1, 2, 3, or 4), and diameter at breast height, d (in in., obtained from 1103 trees of sawtimber size for which data on log grade were recorded was:

$$g = \underset{(0.10)}{3.9} - \underset{(0.06)}{0.10}\,d \qquad R^2 = 0.19$$

where the numbers in parentheses are standard errors. Thus, the relationship between diameter and grade is rather flat: it takes a difference of 10 in. in diameter to yield a difference of 1 point in grade. Furthermore, the low R^2 shows that only a small part of the log grade is determined by size. Thus, value growth rates were computed for (1) pole trees that stayed in the pole class, and (2) sawtimber trees, as if their log grade had not changed (it is certainly true that the trees of highest grade cannot improve) It was assumed that total tree value was directly proportional to the value of the butt log, which defined the tree grade, so that the value growth rate of the tree was the same as the value growth rate of the butt log.

The results in Table 4 show that the average value growth rate of all the trees was about 2%/yr, but not statistically different from zero at the 5% significance level. However, there were some good performers. The average value growth rates for elm trees of sawtimber size exceeded 3%/yr in real terms, for sawtimber oak it was more than 4%/yr, both statistically significant. It is striking that for elm and oak trees, the value growth rates were not significantly different by grade.

In general, over the period considered, there was no economic advantage in holding high grade trees. Rather, the average value growth rate of most species was substantially higher for trees of lower grade. For hard maple, the most common

Table 4. Average annual percentage rates of value growth of trees in Wisconsin from 1967 to 1989.

Species	Sawtimber Grade 1	Sawtimber Grade 2	Sawtimber Grade 3	Sawtimber All grades	Poletimber
Basswood	1.0	1.2	2.1	1.3	3.3
Elm	3.1*	3.3*	3.1*	3.2*	2.7
Hard maple	0.4	0.7	2.8*	1.5	1.9
Paper birch	0.7	1.4	2.9*	2.3*	1.4
Quaking aspen	2.1	2.9*	3.1*	2.9*	1.9
Red oak	4.1*	3.8*	4.5*	4.1*	3.3*
Soft maple	-0.4	0.6	1.6	0.9	1.9
Yellow birch	-1.0	0.0	2.3*	0.8	2.2
All species	1.1	1.4	2.6*	1.8	2.2
All trees		2.1			

* Growth rate significantly different from zero at the 5% level, based on variance equal to the sum of the variance of volume growth rate and price change.

species, the value growth rate was nearly 3%/yr for trees of log grade 3, while it was not significantly different from zero for grades 1 and 2. As pointed out earlier, this was not because of differences in volume growth rates, which were nearly the same across grade, but to the fast decline in the real price of grade 1 logs, which occurred for several species. Conversely, although the price of quaking aspen logs declined during the period considered (Table 3), the value growth rate increased at nearly 3%/yr on average, because of the fast volume growth rate of that species (Table 1).

The distribution of sawtimber trees by rate of value growth is shown in Table 5. It confirms the good economic performance of red oak, elm, and quaking aspen. Among the worst performers were hard and soft maples (the dominant species, see Table 1), yellow birch, and basswood. Table 6 shows that trees of poletimber size gave often higher rates of return than sawtimber, due in part to higher volume growth rates (Table 1).

Table 5. Distribution of sawtimber trees according to value growth.

Species	Grade	Proportions of trees with value growth rate ≥ 5%	≥ 3%	≥ 1%
Basswood	1	0	4	47
	2	0	6	57
	3	5	27	91
Elm	1	0	13	100
	2	4	71	100
	3	0	48	96
Hard maple	1	0	1	22
	2	0	1	40
	3	2	18	86
Paper birch	1	0	0	100
	2	0	17	67
	3	0	26	83
Quaking aspen	1	0	67	83
	2	26	68	100
	3	13	53	95
Red oak	1	10	94	100
	2	0	68	100
	3	32	93	100
Soft maple	1	0	0	10
	2	0	0	21
	3	0	7	80
Yellow birch	1	0	0	0
	2	0	0	18
	3	2	17	83

Management Implications

For the purpose of forest management, especially under a selective cutting system, it would be useful to be able to predict tree growth. The following model was developed with the data of the northern hardwoods trees studied above. The model is a linear equation that gives the growth rate of a tree as a function of tree, site, and stand characteristics. Specifically:

$$r_q = a + bSize + cSite + dCrown + eBasal + fDom + gBass + hElm + iPBirch + jQAsp + lSmap$$

where $a, b, c, d, e, f, g, h, i, j$ and l are parameters, and

r_q = predicted annual volume growth rate

Size = 1 if the diameter of the tree was at least 11 in., 0 otherwise

Site = 1 if the tree site index was at least 70 ft, 0 otherwise

Crown = 1 if the tree crown ratio was at least 30%, 0 otherwise

Basal = 1 if the basal area of the plot to which the tree belonged was at least 110 ft^2/ac, 0 otherwise

Dom = 1 if the tree was dominant or codominant, 0 otherwise

Elm = 1 if the tree was an elm, 0 otherwise

Bass = 1 if the tree was a basswood, 0 otherwise;

Pbirch = 1 if the tree was a paper birch, 0 otherwise;

Qasp = 1 if the tree was a quaking aspen, 0 otherwise;

Smap = 1 if the tree was a soft maple, 0 otherwise;

Table 6. Distribution of poletimber trees according to value growth.

Species	Percent of trees with value growth rate ≥ 5%	≥ 3%	≥ 1%
Basswood	21	63	92
Elm	22	36	73
Hard maple	4	25	69
Paper birch	0	7	67
Quaking aspen	6	23	67
Red oak	12	52	97
Soft maple	6	25	67
Yellow birch	11	32	66

The other species in the data set were yellow birch, hard maple, and red oak. This linear model with (0,1) variables was adopted because it gave predictions that were nearly as accurate as those obtained with more complex models and continuous variables. We feel that the gain in simplicity is well worth the small loss of accuracy. With (0,1) variables, predictions can be obtained by a quick judgment of the tree characteristics, and then by simply adding the corresponding parameters. The threshold for each (0,1) variable was set at a round number near the mean (see Table 7). Thus one can think of "0" as meaning below the average and "1" above the average for all Wisconsin northern hardwood stands. Correspondingly, each parameter has a simple interpretation. For example d is the effect of above average site on growth, other things equal.

The estimated values of the parameters are shown in Table 8. They were all statistically significant at the 1% level. As expected, other things being equal, the growth rate was lower for large trees and for trees growing in a stand of large basal area. The growth rate was higher for trees growing on good sites, with high crown ratios, and a dominant or codominant position in the canopy. Other things being equal, yellow birch, hard maple, and red oak grew at about the same rate, measured by the constant a. Basswood, elm, and quaking aspen grew significantly faster, while paper birch and soft maple had slower growth.

Equation (1) explained only 25% of the between-tree variation in growth rate. This is low, but it is an honest statement of the accuracy to be expected with measurements that can be done in the field at a reasonable cost, and it is comparable to the results from the more complex diameter growth equations of Hahn and Leary (1979). Stratification of the data by species, grades of trees, or changes in the form of the equation improved the accuracy only marginally, and would make the estimation of growth more complicated. Still, the standard errors of the coefficients were very small, so that the equation should predict accurately the expected value of the effect of differences in tree or stand characteristics. For example, one can expect a 0.25 (±0.05)% smaller growth rate for trees in stands of above-average basal area than in those below average.

The application of the growth equation in Table 8 is straightforward. For example, the predicted growth rate of a soft maple of sawtimber size, on an above-average site, with a crown ratio of more than 30%, in a stand of above-average basal area, and a dominant or codominant position in the canopy is predicted to be:

Table 8. Effects of tree and stand characteristics on individual tree growth.

Variable	Effect (%/yr)	Standard error
Constant	2.10*	0.08
Tree diameter ≥ 11 in.	-1.43*	0.05
Tree site index ≥ 70 ft	0.26*	0.05
Tree crown ratio≥ 30 %	0.57*	0.05
Stand basal area≥ 110 ft^2/ac	-0.25*	0.05
Tree dominant or codominant	1.23*	0.07
Basswood	0.26*	0.06
Elm	0.61*	0.12
Paper birch	-0.92*	0.09
Quaking aspen	0.73*	0.11
Soft maple	-0.23*	0.07
Coefficient of determination	0.24	
Standard error of estimates	1.42	

* Coefficient significantly different from zero at the 1% level. Growth rates of yellow birch, hard maple, and red oak are equal to the constant, plus or minus the effect of the other variables.

$$2.10 - 1.43 + 0.26 + 0.57 - 0.25 + 1.23 - 0.23 = 2.3\%/\text{yr}$$

where the numbers on the left side of the equation are the constant (2.10), the size effect (-1.43), the site effect (0.26), the crown-ratio effect (0.57), the basal area effect (-0.25), the dominance effect (1.23), and the species effect (-0.23). Other things being equal, size and dominance have the largest effects on growth. Site, crown ratio, and basal area have relatively smaller effects.

Let us assume that we expect future real prices of soft maple to change as they have in the past. If the butt log of the tree is of grade 2, then the expected price change would be -1.2%/yr (Table 3), so that the expected value growth rate would be, to a close approximation:

$$2.3 - 1.2 = 1.1\%/\text{yr}$$

Assuming that there is a 5% risk that the tree will be lost to various causes before it is reconsidered for harvest, and assuming that the lost tree will have zero value, leads to a final expected rate of return of:

$$0.95 \times 1.1 = 1.0\%/\text{yr}$$

Table 7. Summary statistics of tree and stand characteristics.

	Diameter (in.)		Site index (ft)		Crown ratio (%)		Basal area (ft^2/ac)	
Species	Mean	Standard dev.	Mean	Standard dev.	Mean	Standard dev.	Mean	Standard dev.
Basswood	10.4	4.1	73.3	9.6	28.3	9.3	116.2	28.6
Elm	11.1	4.4	71.1	10.0	26.5	10.9	112.9	30.2
Hard maple	11.0	4.9	67.6	8.7	34.0	10.5	111.2	25.3
Paper birch	8.6	2.3	69.4	9.0	27.2	9.0	113.8	31.9
Quaking aspen	10.2	3.3	71.5	9.2	27.1	9.6	97.2	29.0
Red oak	13.7	5.7	73.8	10.5	34.6	10.8	103.7	26.0
Soft maple	9.5	3.8	66.9	8.7	32.9	10.0	108.5	25.5
Yellow birch	12.3	5.1	69.9	9.4	32.4	10.6	121.2	26.3
All species	10.7	5.0	69.6	9.5	31.6	10.5	111.5	27.5

So that, according to the financial maturity principle (Duerr 1960), an owner with a real guiding rate of interest larger than 1 0%/yr would cut the tree, while someone requiring a lower interest rate would let it grow. A real interest rate of 2.5 to 3% seems like a reasonable guide in private forestry (Buongiorno and Gilless 1987). Of course, the decision would also hinge in part on how important this living tree is to the owner, apart from being a source of income.

Although silvicultural practices that keep smaller trees with a high crown ratio in stands with relatively low basal area are beneficial because they lead to faster growing trees, it should be kept in mind that what is wanted is not the highest possible return to a single tree, but the highest possible return per acre of land. From an economic viewpoint, the ideal to strive for is the stand with the highest value of growing stock, where no tree is growing at a lower rate than the guiding rate of interest of the owner. Equation (1), together with price trends, can help identify the trees that do not yield this return.

Conclusions

Silviculture is only one aspect of commercial forestry. Selecting trees of fast growing species and helping them to grow faster is of no financial advantage if the price trends are unfavorable. The data of this paper show clearly that, except for elms and red oaks, the owners of high quality (grade 1) sawtimber stands in Wisconsin who have held them during the past 20 yr have been losing money. They would have gotten a better return on their investment by liquidating the grade 1 trees as soon as they had reached that grade.

The data also show that the volume growth rate of pole-size trees was generally superior to that of sawtimber trees (about one percentage point difference in average growth rate), so that, despite declining pulpwood prices, the real rate of return on pole size timber was often better than 3%. That in itself speaks in favor of cutting lightly the poletimber. Another argument for holding on to those small trees is the large gain that can be made when a tree moves from the poletimber size to the sawtimber size. The same is true, to a lesser extent, when trees move from grade 3 to grade 2, and from grade 2 to grade 1, a process which was not addressed in this paper, and which is only partially related to tree size.

The general principle for the owner of hardwood trees in Wisconsin should be to manage stands for a large number of intermediate grade sawtimber, liquidating most grade 1 trees as soon as they enter that grade, and cutting lightly the poletimber. Meanwhile, a careful owner should watch prices constantly, for a price increase of 10% can achieve in one month the same value growth that would take 4 of 5 yr of biological growth to accomplish at constant prices. Cutting guides for northern hardwoods that imbed these principles (conserving the poletimber trees, keeping a low stock of the largest trees, and cutting when markets are good) are available, and should be considered as part of the manager's tool kit (Kaya and Buongiorno 1989).

In terms of forest policy, it seems clear that the main forestry problem in Wisconsin is not on the supply side. The resource is abundant and growing at a reasonable rate. The problem is demand. Substantial investments in oak management, including the culture of large high-quality trees, are now possible because of the favorable price trends due in a large part to the international demand for oak. This is not the case for other species. To make big-tree silviculture economical for other hardwoods in Wisconsin, it is imperative to develop new markets and/or products to reverse the declining or stagnating trends in real prices that have occurred during the past 20 yr.

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