PROJECTION OF STEM QUALITY DISTRIBUTION IN SUGAR MAPLE STANDS[1]

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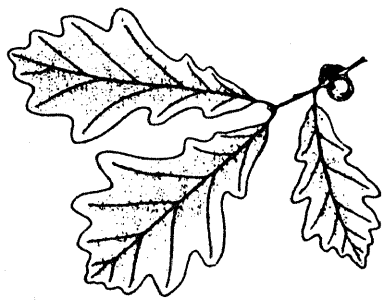

ABSTRACT.--Observations from individual tree records in a continuous forest inventory remeasurement data base are used to develop methodology for projecting changes in butt log tree grade on individual trees over time. These observations were taken on a five-year remeasurement period from mesic hardwood stands in Upper Michigan, the majority of which were at least 50 percent sugar maple in basal area. Methods are presented to predict future butt log tree grade given initial butt log tree grade, individual tree and stand characteristics for sugar maple, red maple, yellow birch, and basswood. This quality projection methodology is incorporated into an existing stand table projection system allowing the projection of value increase due to quality change as well as biological growth through time.

There has been considerable effort devoted to the development of management and silvicultural systems for even and uneven-aged hardwoods. In the past few years, there have been a number of studies describing the effects of management and silvicultural activities on stem quality distribution within the stand. Examples include recent studies of the effects of thinning on quality and growth of white oak (Quercus alba) by Sonderman (1984) and Dale and Sonderman (1984). Guidelines for individual tree selection during thinning which consider growth and grade have been proposed for sugar maple (Acer saccharum) by Godman and Mendel (1978). For the most part, incorporation of the effects of stand conditions and management activities on stem quality distribution into growth and yield projection systems has not been accomplished, even though it is widely accepted that stem quality development is as important a consideration as biological growth in management planning in hardwoods (Tubbs 1977).

This paper reports the development of methodology for projecting stem quality changes in four commercial species (sugar maple, red maple (Acer rubrum), yellow birch (Betula alleghaniensis), and basswood (Tilia americana)) occurring in predominantly sugar maple stands in Upper Michigan. The stands of interest are managed under the individual tree selection system as described by Arbogast (1957) and Tubbs (1977). Butt log tree grade is used as the measure of stem quality in this study. The stem quality projection methodology is incorporated into an existing stand table projection system (Adams and Ek 1974) using a conceptual framework similar to that proposed by Ffolliott and Rasmussen (1983) for projecting stem quality in ponderosa pine (Pinus ponderosa). The combined system allows the projection of value growth due to quality change as well as biological growth through time.

METHODS

Data

The data used in this study consisted of individual tree measurements from one-fifth acre permanent plots located on the Ford Forestry Center, Michigan Technological University in Baraga County, Michigan. Measurements were initiated in the 1950's; plots were remeasured every five years thereafter. Stands in which plots were located had greater than 50 percent of their basal area in sugar maple with red maple, yellow birch, basswood, elm (Ulmus americana), and hemlock (Tsuga canadensis) also present, but tended to become more predominantly sugar maple stands through time. Most of the hardwood stands in the area had a significant conifer (white pine (Pinus strobus)) component removed around the turn of the century. The stands were also subject to a

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heavy commercial harvest in the 1920's to 1930's in which as much as 70 percent of the volume and 90 percent of the value was removed.[3]

At each measurement, the individual trees on a plot were examined with at least the following information recorded: species, d.b.h., merchantable height (to a 10-inch top), butt log tree grade (Stott 1961), and soundness percent. This gave detailed information on each tree as well as a stand table giving number of trees per acre by diameter class. Measurement periods in which the stands were cut were excluded from the data. As a result, records from individual trees for as many as three measurement periods could be included in the data. In the analysis, these were assumed to be independent with any dependence of tree grade change from measurement to measurement describable by the observed variables.

An observation was taken to be the initial and final tree grades over a five-year measurement period and all of the associated variables at the tree and stand level at the beginning of the measurement interval. Four species were represented by enough observations to be included in the analysis; there were 3426 sugar maple observations, 249 observations in red maple, 776 in yellow birch, and 183 basswood observations.

Table 1 presents the initial/final tree grade transition matrix for sugar maple. As was the case for the other species, most observations fell on the main diagonal because most trees did not change tree grade over a measurement interval. A general trend toward improvement in tree grade in the data is indicated by the greater number of grade 1 and 2 trees in the final tree grades.

TABLE 1.--Number of observations by initial and final tree grade over a five-year measurement period for sugar maple.

Initial Tree Grade	Final Tree Grade[a] 1	2	3	nm	Total
1	680	8	1	1	690
2	138	994	21	0	1153
3	0	312	1225	7	1544
nm [a]	0	1	6	32	39
Total	818	1315	1253	40	3426

[a] The nonmerchantable (nm) grade class includes cull trees as well as trees in the 12-inch d.b.h. class that do not have any merchantable sawlog volume.

[3] Bourdo, E.A. 1957. Plan for the establishment of 1956 stocking level management studies in 'selectively cut' northern hardwoods and a brief outline of associated terminal studies. Study plan on file at the Ford Forestry Center, Michigan Technological University.

Predicting Future Tree Grade

The methodology for predicting the future grade of a tree is conceptually similar to that described by Ffolliott and Rasmussen (1983). The change in tree grade during a measurement period is expressed as a function of initial tree and stand characteristics. The relationships between future tree quality distribution and initial tree and stand characteristics are expressed as probability statements. The probabilities of a tree falling into each of the four grade classes (grade 1, 2, 3, or nonmerchantable) are expressed in terms of the initial tree and stand characteristics; these probabilities must be constrained so that their sum is unity.

A tree's future grade must fall into one of the four possible grade classes. Using discriminant analysis (Anderson 1973), a method of assigning a tree to a future grade class was developed. In discriminant analysis, a set of linear discriminant functions of the independent variables (in this case the initial tree and stand characteristics) is developed with the number of functions being equal to the number of classes to which the observation could be assigned. If the objective is to assign the observation to a class, the discriminant functions are evaluated and the observation is assigned to the class associated with the function taking on the largest value. These functions may also be utilized to express the probability of an observation falling into each class. In particular,

$$P_i = \frac{EXP(f_i)}{\sum_j EXP(f_j)}$$

where P_i is the probability of the observation falling into the ith class and f_i is the linear discriminant function associated with the ith class. In this case, a discriminant function is developed corresponding to each of the four tree grade classes. These functions are of the form:

$$f_i = b_{0i} + b_{1i} X_1 + b_{2i} X_2 + \ldots + b_{ki} X_k$$

where f_i is the function associated with the ith grade class, $b_{0i}, b_{1i}, \ldots b_{Ki}$ are coefficients to be estimated, and $X_1, X_2, \ldots X_K$ are variables taken from the list of initial tree and stand characteristics and are common for a species. In this fashion, the required statements expressing the probability of a tree taking on each possible future tree grade are developed.

Stand Table Projection Methods

Adams and Ek (1974) developed a stand table projection system for hardwood stands in Wisconsin. Their data came from stands very similar in structure and composition to those represented in this study; their system was used without modification to project the stand table through time. The projection equations are based on a five-year growth period and the stand table is expressed as number of trees per acre per two-

inch diameter class, beginning with the six-inch class. The number of trees expected to grow into the six-inch class in a five year period is given by:

$$I_6 = 7.07933 \left(\frac{B}{N}\right)^{-1.40072}$$

where B is basal area per acre and N is the number of trees per acre. The number of trees per acre growing from diameter class i to diameter class i+1 are given by:

$$U_i = 0.0033 \; N_i^{0.88218} \; S \; D_i^{0.48383} \; EXP(-0.00286B)$$

where U_i is the number of trees growing from class i to class i+1, N_i is the initial number of trees in class i , S is a variable representing site quality (40 for poor sites, increasing to 50, 60, and 70 for good sites), and D_i is the midpoint of diameter class i . The number of mortality trees per acre in class i (M_i) is given by:

$$M_i = 0.01409 \; N_i$$

The number of trees per acre at the end of a growth period (t) are given by:

$$N_6(t) = N_6(t-1) + I_6(t) - M_6(t) - U_6(t)$$

and

$$N_i(t) = N_i(t-1) + U_{i-1}(t) - M_i(t) - U_i(t)$$

for diameter classes 6, 8, 10, ..., n (the number of two-inch diameter classes at the beginning of the growth period and

$$N_{n+1} = U_n(t)$$

In the projection of stem quality, the future grade distribution of the trees in a diameter class is predicted from the grade distribution in that class at the beginning of the projection period, as well as the other initial tree and stand characteristics. The upgrowth and mortality from a given diameter class is also assumed to occur proportionally to the tree grade distribution in that class. The upgrowth into a diameter class is, therefore, proportional to the future tree grade distribution of the next smallest diameter class. After the change in tree grade distribution of the survivor trees within a diameter class, the upgrowth and mortality from that diameter class, and the upgrowth into the diameter class have been combined, the stand table at the end of the projection period may be summarized and, if desired, projected to a future date.

RESULTS

Predicting Future Tree Grade

The sets of linear discriminant functions used to estimate future tree grade distribution for each of the four species are given in Table 2.

TABLE 2.--Linear discriminant functions used to predict future tree grade distribution for each of the four species.

Species Tree Grade	Equation[a]
Sugar Maple	
Grade 1	2.83482 D + 0.27235 H + 0.11994 B + 20.02377 Q1 - 50.60788
Grade 2	2.82284 D + 0.27972 H + 0.12747 B + 28.76861 Q1 - 65.86915
Grade 3	2.96217 D + 0.22466 H + 0.13210 B + 35.09009 Q1 - 83.45056
Non-merchantable	3.87285 D + 0.16780 H + 0.15222 B + 43.83247 Q1 - 131.49264
Red Maple	
Grade 1	5.07973 D + 0.17642 N + 35.44741 Q1 - 85.92308
Grade 2	5.23850 D + 0.15744 N + 57.28349 Q1 - 119.88573
Grade 3	5.21592 D + 0.15576 N + 72.28424 Q1 - 157.71202
Non-merchantable	6.69626 D + 0.17713 N + 95.81834 Q1 - 267.74310
Yellow Birch	
Grade 1	2.74359 D + 19.25625 Q1 - 36.42369
Grade 2	2.71074 D + 31.16073 Q1 - 54.67333
Grade 3	2.68454 D + 41.70047 Q1 - 81.29487
Non-merchantable	3.72306 D + 56.30064 Q1 - 151.00362
Basswood	
Grade 1	1.40133 D + 0.67861 H + 14.47794 Q1 + 0.60460 DP - 63.00177
Grade 2	1.03584 D + 0.62429 H + 22.04653 Q1 + 0.54062 DP - 62.57648
Grade 3	1.31015 D + 0.53681 H + 27.36351 Q1 + 0.40901 DP - 69.02361
Non-merchantable	2.33171 D + 0.92095 H + 39.20051 Q1 + 0.47094 DP - 144.90158

[a] Notation:

D=d.b.h. (inches)
H=merchantable height (feet to a 10-inch top)
Q1=initial tree quality (1-Grade 1, 2-Grade 2, 3-Grade 3, 4-Nonmerchantable)
N=number of trees per acre
B=basal area per acre ($ft.^2$)
DP=diameter percentile

To test the ability to project tree grade for individual trees, the probability of each future tree grade was predicted for each observation in the data. A tree was assigned the grade corresponding to the greatest probability. Thus, some trees were not assigned a grade change and some were assigned changes of one or two grade classes. The equations for sugar maple classify future (five year) tree grade correctly for 85.7 percent of the data, the red maple system is correct in 93.7 percent of the observations, the yellow birch system correctly classifies 91.1 percent, and the basswood system is correct for 85.2 percent of the data. Approximately twenty percent of the observations for each species were reserved for validation; the percentage of correct classifications for the validation data were 85.7, 93.7, 91.1, and 84.5 for sugar maple, red maple, yellow birch, and basswood, respectively.

When applying these equations, total height is calculated using estimation equations given by Ek and others (1984) and then merchantable height to a 10-inch diameter limit is estimated using the predicted total height and the stem taper curve for the species given by Richards (1984). The diameter percentile for each diameter class is calculated by dividing the number of trees per acre greater than 5.1 inches in diameter but smaller than the tree's d.b.h. by the total number of trees per acre greater than 5.1 inches d.b.h. Number of trees per acre and basal area per acre are taken from the stand table. These calculations are performed using the number of trees per acre and basal area per acre for all species combined.

Initial Tree Grade

The ability of the linear discriminant functions to accurately classify future tree grade is dependent on the availability of initial tree grade as an independent variable. Unfortunately, the initial tree grade distribution is not always known. Instead of sacrificing the use of initial tree grade in the discriminent analysis, procedures for generating an initial tree grade distribution were developed. Use of the generated initial tree grade distribution is, of course, not recommended when the actual initial tree grade distribution is available for a given stand.

Generation of an initial tree grade distribution is accomplished using procedures similar to those used to project the tree grade distribution through time. Linear discriminant functions were developed for each species (Table 3) and used to determine the probability of a tree of given characteristics taking on each of the four possible tree grades. These probabilities are multiplied by the initial number of trees per acre in the appropriate diameter class to obtain the number of trees per acre expected in each grade class within each diameter class.

TABLE 3.--Linear discriminant functions used to predict initial tree grade distribution for each of the four species.

Species Tree Grade	Equation[a]
Sugar Maple	
Grade 1	0.71781 D + 0.17038 H + 0.21367 B - 0.03755 N + 0.58992 DP - 46.22631
Grade 2	0.37544 D + 0.12978 H + 0.21388 B - 0.03415 N + 0.59429 DP - 39.25904
Grade 3	0.29791 D + 0.01426 H + 0.20090 B - 0.07533 N + 0.55311 DP - 31.47001
Nonmerchantable	1.13173 D - o.12035 H + 0.20015 B - 0.01389 N + 0.48020 DP - 41.01268
Red Maple	
Grade 1	4.61047 D - 0.08594 H + 0.16944 N - 59.81389
Grade 2	4.41336 D - 0.16648 H + 0.15172 N - 49.34744
Grade 3	3.80912 D - 0.23000 H + 0.14345 N - 36.32275
Nonmerchantable	5.01169 D - 0.39405 H + 0.16371 N - 56.05691
Yellow Birch	
Grade 1	2.09673 D + 0.37670 H - 25.87860
Grade 2	1.81147 D + 0.32757 H - 19.48805
Grade 3	1.56718 D + 0.23194 H - 13.92268
Nonmerchantable	2.21918 D + 0.26432 H - 27.17149
Basswood	
Grade 1	2.06211 D + 0.44728 H - 29.93459
Grade 2	1.46557 D + 0.36634 H - 17.11802
Grade 3	1.41478 D + 0.16080 H - 11.38761
Nonmerchantable	2.30109 D + 0.39691 H - 35.08628

[a] Notation:
D=d.b.h. (inches)
H=merchantable height (feet to a 10-inch top)
N=number of trees per acre
B=basal area per acre (ft^2)
DP=diameter percentile

The discriminating power of the functions classifying initial tree grade is not as great as that of the functions classifying future tree

grade. The initial tree grade was correctly classified for 61.1 percent of the sugar maple observations, 73.0 percent of the red maple observations, 58.9 percent for yellow birch, and 71.8 percent for basswood. Again, approximately twenty percent of the data for each species were reserved for validation; the percentage of correct classifications for the validation data were 60.8, 70.9, 58.1, and 69.7 for sugar maple, red maple, yellow birch, and basswood, respectively. These functions are used to assign an initial tree grade distribution when the actual distribution cannot be specified.

Stand Table Projection

The application of the equations of Adams and Ek (1974) to the stand table projection is straightforward. They are not species specific and depend only on knowledge of the number of trees per acre in each diameter class. The stem quality projection methodology is species specific and a seperate count of the stand table for each species is required. Since the stem quality projection is dependent in part on individual tree merchantable height and diameter, which can change dramatically over a diameter class, the stem quality projection probabilities were evaluated at the lower limit (D-0.9 inches), midpoint (D), and upper limit (D+1.0 inches) of each two-inch diameter class. Heights were calculated for each diameter using the equations of Ek and others (1984); diameter percentile was calculated assuming a uniform distribution of diameters within a diameter class. A weighted average of the probabilities was calculated using the arbitrarily assigned weights of 1, 2, and 1 for the lower limit, the midpoint, and the upper limit of the diameter class, respectively.

The stem quality and stand table projection methodology is illustrated using a pure sugar maple stand as an example. The initial stand table is the target stand table recommended by Arbogast (1957) and Tubbs (1977) for these stands (Table 4). The initial tree grade distribution is generated using the linear discriminant functions and the probability procedures described above. The future stand table and stem quality distribution following a five-year growth period are projected using the equations of Adams and Ek (1974) and the procedures for projecting future tree grade, respectively. Table 4 contains the initial and future stand tables and stem quality distributions.

CONCLUSION

Methodology is presented for projecting the stem quality distribution in sugar maple stands in Upper Michigan through time. Butt log tree grade (Stott 1961) is used as the indicator of stem quality; the methods of Adams and Ek (1974) are used to project the stand table. Future tree grade is a function of individual tree and stand characteristics. The stand table and stem quality projection procedures are illustrated using a five-year growth period and the recommended stand table of Arbogast (1957) and Tubbs (1977) as the initial stand. Procedures are also given for generating an initial tree grade distribution if one is not available for the stand of interest.

TABLE 4.--Stand table and stem quality distribution (in terms of number of trees per acre) following a five-year growth period given a recommended stand structure (Arbogast 1957; Tubbs 1977) and generated initial stem quality distribution.

	Time 0					Time 5				
Diameter	Tree Grade					Tree Grade				
Class (in.)	1	2	3	nm[a]	Total[b]	1	2	3	nm[a]	Total[b]
6	0	0	0	32	32	0	0	0	36	36
8	0	0	0	19	19	0	0	0	20	20
10	0	0	0	14	14	0	0	0	14	14
12	0	0	10	0	10	0	0	6	3	10
14	0	2	8	0	10	0	2	8	0	9
16	1	3	3	0	8	1	3	4	0	8
18	2	3	2	0	6	2	3	2	0	6
20	2	1	0	0	4	2	2	1	0	4
22	3	1	0	0	4	3	1	0	0	4
24	1	0	0	0	1	2	0	0	0	2
Total[b/]	9	11	23	65	108	9	11	21	73	113

a/ Nonmerchantable, includes culls.
b/ Number of trees per acre are rounded to the nearest whole tree, the values may not sum to the total due to this rounding.

The stand table and stem quality projection system is currently being refined and tested. The ability to estimate log grade and board foot volumes given butt log tree grade, as well as tree and stand characteristics, has been refined, quantified, and incorporated into the described projection system. The capacity for making economic analyses for given stand conditions and management scenarios is also being incorporated into the system[4]. At some later date, it might be possible to include methods for predicting lumber grade recovery (Wilson and others 1982) and accompanying economic information. The described projection system is an evolving entity subject to refinement and enhancement.

[4]Reed, D.D., G.W. Lyon, E.A. Jones, and R.A. Leary. Methods for projecting log grade yield and economic return through time for sugar maple stands. Manuscript in preparation.

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