Comparison of FVS Projection of Oak Decline on the Mark Twain National Forest to Actual Growth and Mortality as Measured Over Three FIA Inventory Cycles

Don Vandendriesche[1]
Linda Haugen[2]

Abstract—Oak decline has been recorded on oak forests throughout the Ozark Plateau of Missouri since the 1970s, but severe drought in the late 1990s, combined with the advancing age of the Ozark forests, has intensified the levels of crown dieback and mortality beyond historical levels. The purpose of this project was to determine whether the Forest Vegetation Simulator (FVS) model could accurately predict the effect of oak decline on the Mark Twain National Forest (MTNF). Forest Inventory and Analysis (FIA) data were used to benchmark mortality magnitude and to adjust FVS growth projections. Data from inventory cycles 3 (1976–1977), 4 (1986–1987), and 5 (1999–2003) were available for approximately 150 oak stands on the MTNF. These data were translated into FVS-ready format and projected with and without the Oak Decline Event Monitor (ODEM) addfile. Actual growth and mortality versus projected values were compared. In the absence of harvesting or other major disturbance, baseline mortality per size class in a healthy forest is generally constant and departure from this constant may indicate unsustainable forest conditions. We compared current mortality rates to calculated mortality rates between inventory cycles 3 and 4 (i.e. prior to the latest decline events) to indicate whether mortality rates increased between inventory periods. This paper describes the FVS adjustments and methodology used; assesses the usefulness of FIA data and application of the ODEM addfile for this project; and discusses how FVS tools and comparison of baseline mortality rates could be used to predict future trends in Missouri oak forests.

The characteristics of the oak forests that dominate southern Missouri have been largely determined by human activities on the landscape. From 1870 to 1930, most of the natural shortleaf pine (*Pinus echinata* Mill.) and oak-pine woodlands were eliminated by extensive logging followed by annual burning and overgrazing. Around 1930, fire suppression and conservation efforts allowed trees, particularly oaks, to begin to reclaim the land. The resultant forested landscape is much different in composition and structure than the presettlement forest. Many of these stands have a similar time of origin and grow on degraded soils. By the end of the 1900s, a large proportion of the landscape was characterized by aging oak forests, which were predisposed to decline (Law and others 2004; Lawrence and others 2002).

Widespread crown dieback, growth reduction, and mortality in oak forests on the Ozark Plateau of Missouri were documented in the 1970s and 80s, particularly following periods of drought that incited decline (Law and Gott 1987). A severe drought from 1999–2001, combined with the advancing age of the Ozark forests, has intensified the spread and severity of oak decline and mortality (Starkey and others 2004). Although components of the oak decline complex have been present in the Ozark Region for decades, recent mortality has exceeded historic trends. With the unprecedented levels of mortality being observed, land managers in southern Missouri have many questions about the current and future conditions of oak stands affected by decline. The purpose of this project was to use Forest Inventory and Analysis (FIA) data and Forest Vegetation Simulator (FVS) projections to address some of those questions, particularly related to past and current mortality rates and anticipated future conditions.

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[1] Forester, USDA Forest Service, Forest Management Service Center, Fort Collins, CO; e-mail: dvandendriesche@fs.fed.us.

[2] Plant Pathologist, USDA Forest Service, Northeastern Area State and Private Forestry, St. Paul, MN.

Data and Methods

Source of Data

In Missouri, the 3rd FIA periodic inventory was collected from 1969–1972. Subsequently, data for the Mark Twain National Forest (MTNF) was also gathered in 1976–1977. The 4th FIA periodic inventory cycle for Missouri was completed in 1989 with most of the data on the MTNF collected from 1986–1987. Both the 3rd and 4th inventory data were gathered in accordance with a 10-point sample design distributed over approximately an acre of ground around plot center (NCRS 1969, 1986). All trees 5.0 inches dbh and larger were tallied on a variable radius plot (37.5 basal area factor prism). Trees less than 5.0 inches dbh were tallied on a fixed radius plot (1/300 acre). In 1999, FIA began the 5th inventory cycle for Missouri with a new annualized survey design (NCRS 1999). Under this sampling scheme, four subplots 1/24 acre in size are used to measure trees 5 inches dbh and larger. A microplot 1/300 acre in size was co-located within the major plot, offset from plot center, to gather information on trees less than 5 inches dbh. For the annualized system, 1/5 of all FIA plots are visited each year so that a complete cycle is measured every 5 years.

We acquired FIA data for cycles 4 and 5 in FVS-ready format through the Internet using the Forest Inventory Mapmaker program (Miles 1992). Cycle 3 data was not readily available. It was obtained directly from the North Central Research Station FIA Unit and required subsequent effort to convert to FVS-ready format.

We considered the data from each inventory cycle as unique condition class samples. There were 911 'total' plots assembled and utilized for various aspects of the study. The data were used to: calibrate the FVS model; determine the biological maximums expected for stand density and tree size attainment; and construct regeneration input response files.

North Central FIA also provided a plot number "crosswalk" that enabled us to match center points of sample plots among the 3rd, 4th, and 5th FIA inventory cycles. We restricted our data scope to oak forests of the Mark Twain National Forest residing within the Ozark Plateau in south-central Missouri. This corresponds to forestlands in the Northwest Ozark, Southwest Ozark, and Eastern Ozark FIA Survey Units. Through this screening, we were able to identify 154 'common' plots on the MTNF that were remeasured in FIA cycles 3 (1976–1977), 4 (1986–1987), and 5 (1999–2003). After filtering to exclude disturbed plots, non-oak forest types, small diameter stands, and other anomalous plots (such as cycle 3 plots that were measured during 1969–1971), there were 100 'base' plots available for analysis. For each of these plots, we had field measurements from the same plot center for each of the three inventory cycles spanning a 25-year period.

Adjustments to FVS Base Model

A subset of FIA plots were used for FVS self-calibration procedures. Plots containing trees with repeat measurements of diameter provide an empirical basis to rescale the large-tree diameter increment models within FVS. These data were available from the cycle 3 and 4 periodic inventories. There were 557 'calibration' plots utilized for this purpose. The scaling values derived from these plots are listed in table 1. Given that repeat diameter measurements were not available for some species (e.g. eastern redcedar (*Juniperus virginiana* Lam.)), calibration scale factors were not computed.

Multipliers (i.e. ReadCorD keyword values) less than one indicate that the observed tree growth was less than that predicted by the Central States variant of FVS. Internal algorithms use the multipliers to adjust the predicted large-tree diameter growth to match the rates observed from the calibration data set.

Initially, we pursued comparative analysis based on merchantable tree volume. Soundness factors were needed to compute net volume from gross. This required an estimate of tree defect to be applied to gross tree dimensions. We consulted with the MTNF and other sources to develop an FVS "addfile" (i.e. an auxiliary keyword file) that applied defect deductions to enable determination of net cubic and board foot volume per acre. Upon further evaluation, we chose to display resultant basal area per acre estimates in this paper. We deduced that stand basal area better described overall stand structure.

It was important to set stand density bounds to limit FVS modeled projections to reflect actual growth capacity as exhibited by oak stands on the MTNF. Stocking charts

Table 1— Large-tree diameter growth. Calibration scale factors computed from cycle 3 and cycle 4 FIA data.

Tree species	Total tree records	Mean ReadCorD multiplier
Shortleaf Pine	417	0.511
Pignut Hickory	18	0.851
Black Hickory	10	0.669
Slippery Elm	10	0.566
White Oak	803	0.512
Red Oak	42	0.365
Black Oak	674	0.503
Scarlet Oak	316	0.445
Blackjack Oak	39	0.585
Post Oak	222	0.620
Misc. Hardwood	62	0.499

can be utilized in consort with a growth and yield model such as FVS to display management regimes (Puuri and others 1986). The biological relationship to the average maximum density (AMD) or the effects of density on growth is evident. The upland central hardwoods stocking chart, introduced by Gingrich (1967), has become one the forest manager's most useful tools. The "A" line on the chart was developed from stands of average maximum density, and the "B" line was developed from open-grown trees. The upper extent of the Gingrich chart defines overly dense conditions at 110 stocking percent. Stocking relates the area occupied by an individual tree to the area occupied by a tree of the same size growing in a fully stocked stand of like trees. Visual inspection of the Gingrich chart indicates an approximate basal area maximum of 140 ft^2/acre for larger average diameter stands. An examination of the FIA plots from MTNF reinforced using this value to set the basal area maximum for the projection runs.

The "TreeSzCp" keyword addfile sets the biological limits for maximum diameter and height for a given tree species. The specified diameter acts as a surrogate for age to invoke senescence mortality. Tree size limits were derived using FIA tree measurement data from the total plot set on the MTNF. Adjustments were made based on input from the Forest.

Estimating Natural Regeneration

In order to obtain an accurate FVS prediction of future stand composition, it is necessary to provide FVS with information about the expected regeneration that will occur after long periods of time in the absence of disturbance. An estimation procedure was used that compared measured observations of regeneration as related to stand parameters (i.e. ecological strata, stand size, canopy density) to predict the expected regeneration. For this study, potential tree species for regeneration were divided into nine possible shade tolerance and maximum height attainment groups (e.g. high shade tolerance/mid-story height attainment group, low shade tolerance/overstory height attainment group). The total plot set was used to determine the typical distribution of advance regeneration in each of the nine potential shade tolerance/height attainment groups for four different ecological strata/stand size/canopy density classes. An FVS addfile was created to determine the ecological strata and size/density class of each plot; then, input the target amount of advance regeneration as small saplings from the appropriate shade tolerance/height attainment group.

Assigning Plots to Ecological Strata

Early on, it became readily apparent that in order to make meaningful comparisons, the plots needed to be assigned to distinct strata. Although we had remeasurement data for specific stands, the variable plot design of the periodic inventories prevented valid tree-by-tree or plot-by-plot comparisons over time. Per acre tree expansion factors vary based on changes in tree diameter. Inferences of tree and plot dynamics become obscure as a result. However, given a large enough plot sample size, strata-based conclusions could be drawn.

In brief, the 100 base plots were assigned to strata based on slope exposure (aspect) and productive capacity (site index). Aspect was defined as southerly (113–292 degrees) or northerly (0–112 or 293–360 degrees). High site quality was classified as site index values greater than 70; low was 70 or below. Since black oak was not always the tree species measured for site index, each plot was adjusted to a relative black oak site index as averaged over the three inventory cycles. To simplify tracking the results, sites with northerly aspect and high site quality were designated as "good sites" and sites with southerly aspect with low site quality were designated as "poor sites." Sites with northerly aspect and low site quality responded similarly to sites with southerly aspect and high site quality so they were combined into one stratum designated as "moderate sites".

Additional details regarding model adjustments, regeneration estimates, and ecological stratifications used for this study can be found in an interoffice publication (Vandendriesche 2006).

Assigning Plots to Mortality Groups

Although FIA field crews had gathered information on tree damaging agents and the associated severity, quantifiable measures to identify oak decline events were limited. Another method was needed to determine the threshold between *endemic* levels of tree mortality versus *epidemic*. Endemic implies being constantly present in a particular region and generally considered under control. In contrast, epidemic refers to out of control situations where the vector is spreading rapidly among many individuals. To that end, a process of evaluation presented by Manion and Griffin (2001) that distinguishes between endemic and epidemic conditions was pursued. Their basic tenet for assessing the likelihood of a self-sustaining forest is as follows:

> We propose that healthy forests depend on quantitatively predictable tree death as a continuous process linked to forest structure and growth. Quantifying a baseline mortality value by forest structure analysis using the Law of de Liocourt allows estimation of forest health by comparing the observed mortality to a baseline value.

In quantitative terms, the baseline mortality per dbh class can be used with estimates of dbh growth rates to determine an annual mortality rate needed for stand equilibrium. A given number of trees must die within a dbh class to allow space for the survivors to progress to the next larger dbh class. This number can be transformed into a rate or percentage for all dbh classes.

In application of the Manion and Griffin method, 125 FIA 'mortality' plots were used that were resident from cycle 3 through cycle 5 (i.e. 154 common plots, minus 29 that had experienced disturbance, mainly cutting treatments). Note that for this part of the analysis we were able to use an additional 25 common plots that were of smaller size class or were slightly "off-cycle" from the cycle 3 measurement period. Mortality inferences were based upon the cycle 3 measurements. This period pre-dates the drought years that triggered intensification of oak decline. "Past diameter" and "mortality tree" data is included in each FIA remeasurement dataset; as such, we were able to extrapolate cycle 2 trees per acre values from the cycle 3 data set. The resulting stand table is presented as table 2.

Notice the general trend of approximately twice as many trees per acre from the largest to the next smallest diameter class for cycle 2 data. The computed q-slope across all diameter classes equals a 2.038 factor. Think of this as a survivability factor. Conversely, a mortality factor would equal one minus the inverse of the q-slope. Expressing the baseline relative mortality as a percent equals 50.932 (that is: (1-1/2.038)*100). Thus, approximately one-half of the trees need to die for the survivors to progress to the next larger diameter size class. Knowing the average annual diameter growth rate of the trees allows calculation of the baseline relative mortality. For oak forests on the MTNF, a baseline relative mortality rate of 2.183 percent was computed. The observed mortality rate derived from the data set was 1.582 percent. According to Manion and Griffin, this indicates an evolving forest structure that will trend toward the baseline relative mortality rate.

Applying these same methods to cycles 4 and 5 data rendered the results shown in table 3. The reconstruction of cycle 2 from cycle 3 data represents the 1966 to 1976

Table 2—Stand table displaying trees per acre in each 2-inch dbh size class from FIA cycle 2 to cycle 3 with associated diameter growth, baseline mortality estimates, and observed mortality percent.

DBH Size class (inches)	Trees/Ac Cycle 2	DBH Growth/Yr (inches)	Annual Baseline Mort %[a]	Annual Observed Mort %[b]	Trees/Ac Cycle 3
2	381.953	0.011	0.391	2.286	384.592
4	130.578	0.024	0.851	1.102	118.281
6	59.799	0.040	1.414	0.542	61.196
8	36.070	0.058	2.044	0.355	32.860
10	20.369	0.082	2.877	0.524	22.284
12	12.631	0.097	3.394	0.576	14.359
14	5.900	0.112	3.909	0.802	8.117
16	2.456	0.129	4.489	1.156	3.470
18	1.092	0.143	4.963	1.392	1.485
20	0.551	0.163	5.638	2.595	0.700
22	0.213	0.176	6.073	2.676	0.311
24	0.086	0.203	6.972	4.419	0.124
26	0.058	0.213	7.302	1.552	0.048
28	0.056	0.226	7.730	2.500	0.049
30	0.016	0.243	8.287	1.250	0.037
32	0.006	0.263	8.938	10.000	0.022
Total:	658.552	0.062	2.183	1.582	647.935

[a] Annual Baseline Mortality % = A predictable level of relative mortality caused by biotic and abiotic factors interacting with stocking competition essential for maintenance of a balanced healthy forest. Baseline mortality is linked to forest structure (Law of de Liocourt, Manion and Griffin, 2001) and growth (measured diameter increment).

[b] Annual Observed Mortality % = Sum of the total number of dead trees per diameter size class observed in the field at any point in time divided by the initial live tree stocking, divided by the growth measurement period. Note that mortality is expressed in terms of diameter class rather than years.

Table 3—Calculated mortality rates (baseline versus observed) during the three measurement periods.

Measure period	Annual baseline mortality	Annual observed mortality
	percent	*percent*
1966–1976	2.183	1.582
1976–1986	2.981	3.267
1986–2001	2.974	3.324

growth measurement period. FIA cycle 3 to cycle 4 equates to the 1976 to 1986 growth period. Cycle 4 to cycle 5 spans the 1986 to 2001 measurement interval. Notice that the observed relative mortality exceeds baseline relative mortality during the past two FIA measurement cycles. This correlates well to the observed higher incidence of oak decline.

As a point of comparison, Manion and Griffin reported annual baseline mortality for Adirondack Park, New York, in 1996 at 3.0 percent. Buckman (1985) computed an annual measured mortality rate of 2.7 percent for National Forests in Michigan and Wisconsin. Based on these findings, and specifically on values obtained from the cycle 3 data set, for this study we chose a value of 2.0 percent annual mortality (in terms of trees per acre) from reconstructed cycle 2 to cycle 3 as the threshold to indicate stands of low mortality occurrence versus those of high mortality incidence.

Recall that three ecological strata were identified for this project based on aspect and site index: *poor*, *moderate*, and *good*. Using the 2.0 percent baseline relative mortality threshold to aid in determining low versus high mortality incidence, the plots represented in the FIA data set were distributed as shown in table 4. Thus, six combinations of ecological strata and mortality groups were identified for analysis.

Table 4—Distribution of the base FIA plots among productivity class and mortality group.

Productivity Class	Available number of stands	Number of stands in each mortality group: Low mortality (<2% per yr)	High mortality (>2% per yr)
Good	15	14	1
Moderate	49	34	15
Poor	36	26	10
Total:	100	74	26

Oak Decline Event Monitor

The Oak Decline Event Monitor (ODEM) addfile (Courter 2005) is an auxiliary keyword file that applies the effects of oak decline during FVS simulations of stand growth. Individual plots are evaluated with a probability/risk rating system to determine the susceptibility of the stand to the effects of oak decline. Based on research data from the southeastern United States (including the Missouri Ozarks), the likelihood of an oak decline event depends on many factors including proportion of basal area in the target species groups, condition of the stand, site quality, stand age, and occurrence of previous oak decline events (Oak and others 1996). These factors are used within the ODEM addfile to calculate the probability/risk of a decline event.

An oak decline event is scheduled in the FVS cycle if a drawn random number is less than or equal to the estimated probability in that cycle. If an event is scheduled, oak decline mortality is targeted for the red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), and hickory (*Carya* sp.) species groups at the end of that FVS cycle. Oak decline induced mortality is determined by the stand risk rating with greater mortality and crown reduction scheduled for stands with elevated risk. Within the ODEM addfile, mortality and crown reduction values are applied through use of the "FixMort" and "Prune" keywords.

Analysis Process

After the data were prepared and the various processing components assembled, we were able to use FVS in two ways: (1) to capture static information from the data sets; and, (2) to project the existing data sets into the future. We compared measured changes in basal area and species composition to FVS predicted changes in basal area and species composition over the three periods of remeasurement. We compared different combinations of processing components (i.e., with and without model adjustments and the ODEM addfile) to determine which resulted in stand projection closest to measured trends. We then selected the "best" combination of processing components and used FVS to project poor sites 100 years into the future.

Analysis and Discussion

Static Use from Three Measurement Cycles

FVS was used to summarize various growth parameters for the base plot set from the three ecological strata and two mortality groups. The "good site/high mortality" category had only one stand. Strata based inferences could not be drawn for this site-mortality combination, so it was excluded from further consideration (fig. 1).

For low mortality plots, measured trends indicate that basal area per acre steadily increased from cycle 3 to 4 to 5. For high mortality stands, basal area per acre remained mostly constant from cycle 3 to 4 but then rebounded for cycle 5. On these sites, tree mortality made space for associated species to fill in the gaps over the 25-year period. Recall that we used the reconstructed cycle 2 to cycle 3 mortality rate to distinguish stands of observed high mortality versus those of low mortality occurrence. Thus by our definition of mortality groupings, the "high mortality" sites were already experiencing increased casualty at the beginning of cycle 3

In order to observe how the distribution of species changed over time, we calculated the basal area within seven species groups of particular interest. We considered scarlet

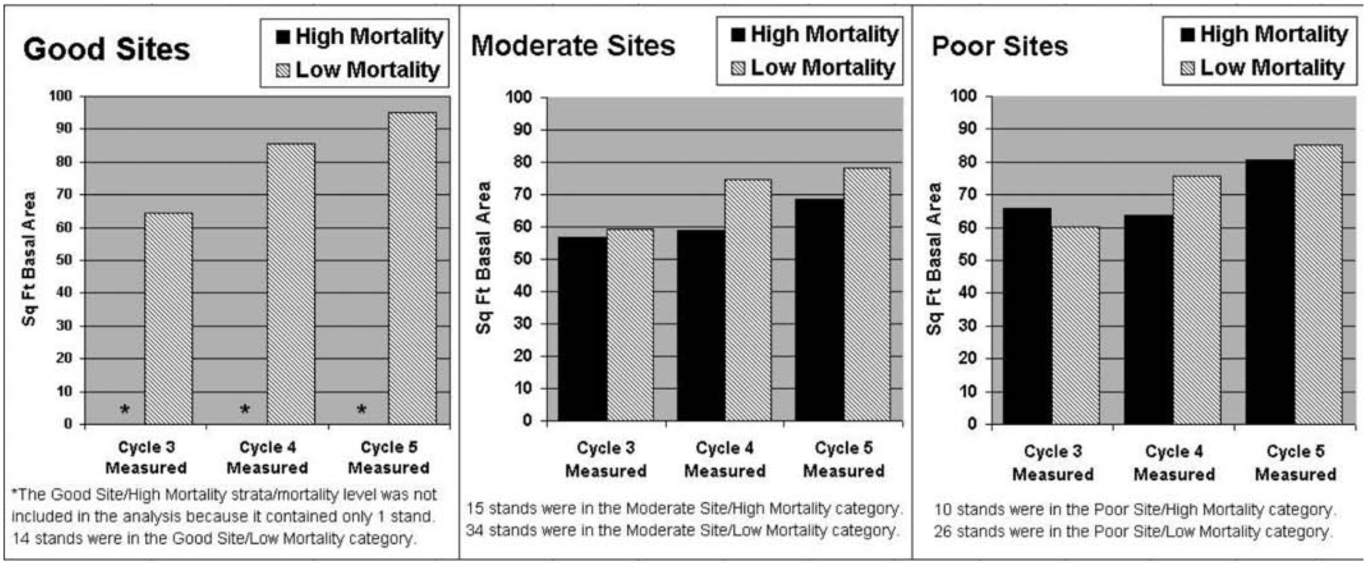

Figure 1—Measured basal area per acre of all trees equal to or greater than 5 inches dbh on good, moderate, and poor sites over three FIA inventory cycles. The bar for sites with high mortality is beside the bar for sites with low mortality for each cycle.

oak (*Q. coccinea* Muenchh.) and black oak (*Q. velutina* L.) as one unique species group, white oak as another species group, and all other oaks (*Quercus* sp.) as a third group. All hickories were considered in the hickory group. All other hardwoods, such as cherry (*Prunus sp.*), ash (*Fraxinus sp.*), dogwood (*Cornus sp.*), etc., were grouped together. Shortleaf pine was the predominant conifer recorded; however, eastern redcedar was observed in cycle 5. Pine and cedar were kept as separate species groups. In figure 2, the proportion of total basal area in each of these species groups is shown for the "poor" sites at each of the three measurement periods.

On poor sites with high mortality, the proportion of basal area in scarlet and black oak decreased in successive measurement cycles. Conversely, the proportion of basal area in white oak increased. This trend is consistent with the silvicultural predictions

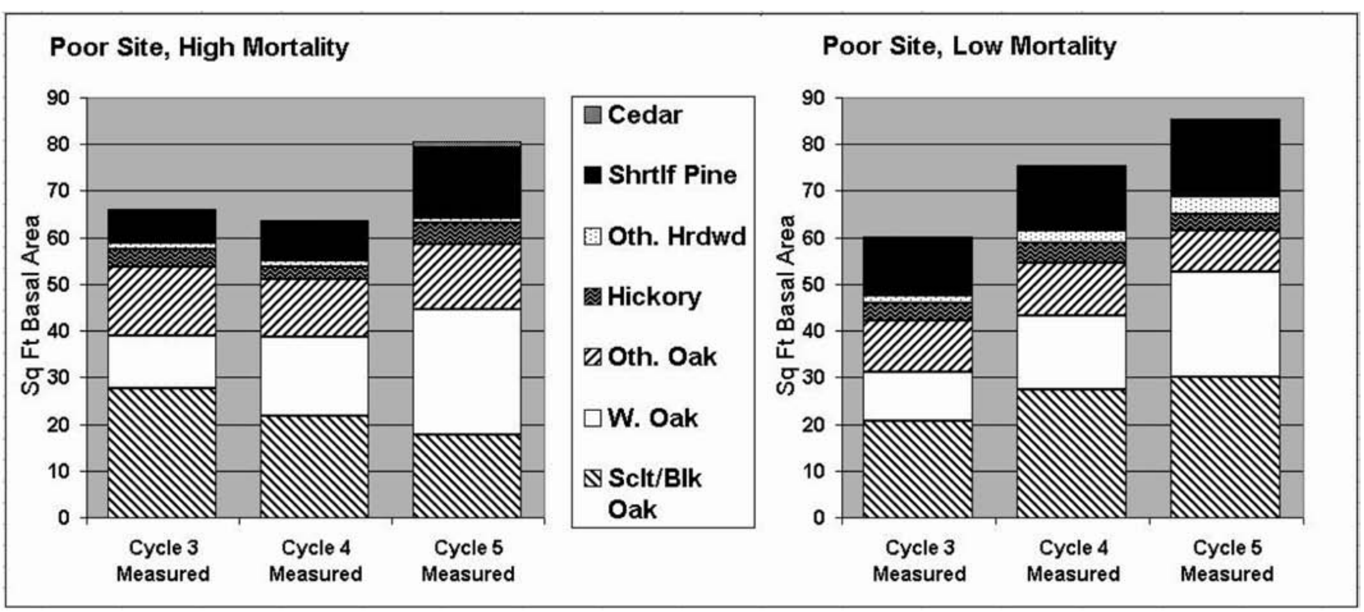

Figure 2—Measured basal area per acre of all trees equal to or greater than 5 inches dbh on poor quality sites over three FIA inventory cycles displayed by tree species representation.

of tree species response to oak decline (Shifley and other 2006). On poor sites with low mortality, basal area in scarlet and black oak increased during each cycle. White oak also increased. The identifiable differences in response pattern between the high and low mortality groups indicate that the criteria we used to distinguish mortality groups were meaningful.

FVS Modeling: Choosing "Best" Combination

Because data were available for the same 100 base plots over a 25-year period, we were able to compare the actual measured basal area per acre values to the predicted basal area estimates when we projected the stands for 25 years under four different combinations of the FVS model. The combinations we compared were:

- FVS without adjustments
- FVS without adjustments, with the Oak Decline Event Monitor (ODEM) addfile
- FVS with adjustments as described in the methods section of this paper
- FVS with adjustments as described in the methods section, with the ODEM addfile

From this comparison (table 5), it was clear that FVS without adjustment consistently resulted in a considerable overestimation of basal area, even after a period as short as 25 years. When the ODEM addfile was applied, predicted values improved as compared to the observed values. For the best prediction of basal area attainment, adjustment alone for low mortality plots and adjustment plus the ODEM addfile for high mortality plots achieved those results. This indicates that even with adjustment, FVS cannot be expected to accurately predict the epidemic levels of mortality that will occur from an oak decline event. Ideally, FVS should be configured to adjust for an inherent level of tree mortality and the ODEM addfile should be used if you want to simulate the potential outcome of an oak decline event. Use of projected values with and without the ODEM addfile could indicate mortality bounds (endemic vs. epidemic). If climatic conditions such as drought exist, you would expect a pending oak decline event.

In order to determine which processing combination provided a better prediction of the future species composition, we compared the predicted basal area of the same species groups previously described to the measured basal area from cycle 5. The predicted basal area was derived from FVS projections of cycle 3 data forward 25 years to cycle 5 under the various adjustments to the base FVS model described above. The results of this comparison for the poor site/high mortality stratum are shown graphically in figure 3. The species composition that was measured in cycle 5 was quite different from the composition projected by any version of the model. Although a 25-year projection by various model configurations predicted different amounts of basal area, the proportion of

Table 5—Measured basal area per acre of all trees equal to or greater than 5 inches dbh in cycle 5 versus predicted basal area from cycle 3 data projected to cycle 5 by various versions of the FVS model.

Site grouping	Number of sites	Cycle 3 measured BA (ft²/acre)	Cycle 5 measured BA (ft²/acre)	Cycle 5—FVS without adj.[a] projected BA (ft²/acre)	Cycle 5—FVS without adj. + ODEM[b] projected BA (ft²/acre)	Cycle 5—FVS with adj.[c] projected BA (ft²/acre)	Cycle 5—FVS with adj. + ODEM[d] projected BA (ft²/acre)
Poor Site, High Mortality	10	66.0	80.5	110.8 (+30.3)[e]	96.6 (+16.1)	90.0 (+9.5)	82.1 (+1.6)
Moderate Site, High Mortality	15	56.8	68.4	94.0 (+25.6)	70.9 (+2.5)	78.5 (+10.1)	64.0 (–4.4)
Poor Site, Low mortality	26	60.3	85.3	104.0 (+18.7)	91.9 (+6.6)	86.4 (+1.1)	71.7 (–13.6)
Moderate Site, Low mortality	34	59.1	78.1	99.3 (+21.2)	89.6 (+11.5)	86.1 (+8.0)	72.5 (–5.6)
Good Site, Low mortality	14	64.6	95.2	108.7 (+13.5)	99.9 (+4.7)	92.2 (–3.0)	72.5 (–22.7)

[a] FVS base model without adjustments.
[b] FVS base model with Oak Decline Event Monitor (ODEM). Note that ODEM has a random component, so values vary from run to run.
[c] FVS base model with adjustments as described in the methods section of the paper.
[d] FVS base model with adjustments, with ODEM included as an addfile.
[e] The figures in parentheses represent the difference between the cycle 5 measured value and the cycle 5 value as predicted by that version of the model.

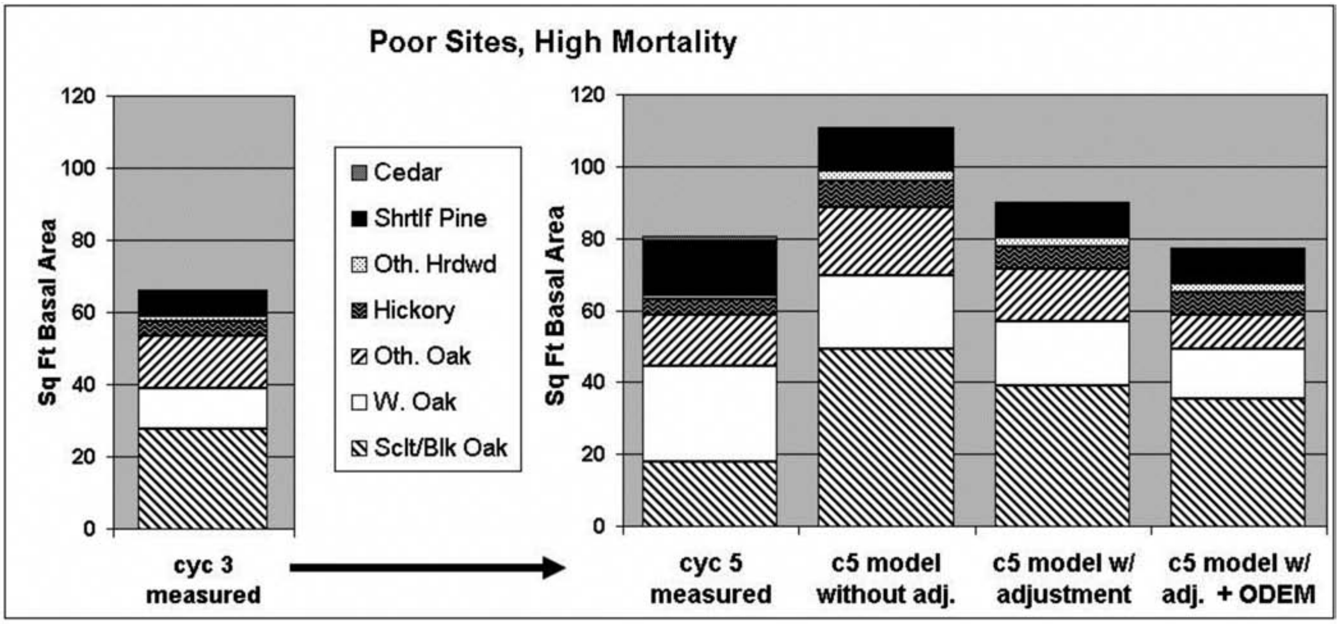

Figure 3—Comparison of measured to projected basal area representation of species distribution on poor quality, high mortality sites. Cycle 3 data was projected 25 years with the base FVS model and also with various versions of the model to compare the affect on the prediction of species composition.

the basal area in any species group was affected very little by the various combinations of the model. Similar results were obtained for the other ecological stratum.

Some of the differences between measured and modeled species composition may be due to the changes in sampling design from cycles 3 and 4 to cycle 5. Since the same center pin was used in all inventories, the trees measured in cycle 5 included some of the same trees measured in cycle 3 and 4. However, not all the trees were the same because the subplot configurations were different between the periodic and annual sampling designs. It is also worth noting that the species composition predicted by all combinations of the model is quite similar to the original composition in cycle 3. Over a 25-year projection, the various FVS combinations did not predict a major shift in species composition because most of the basal area of trees over 5 inches dbh is comprised of the original trees. Over a longer projection, we would expect to see diverging species composition by the various processing combinations of the FVS model due to the application of different mortality rates and regeneration inputs.

Future: Projecting Current Data 100 Years

After determining that the FVS model with adjustments provided reasonable estimates of stand growth, we simulated the development of the poor sites, with both high and low mortality levels, for 100 years into the future. The poor sites with high mortality were projected from cycle 5 for 100 years using the FVS model with adjustments (fig. 4). The Oak Decline Event Monitor addfile was not applied in this case under the assumption that these are "aftermath" stands that have already lost their vulnerable scarlet and black oak component. The adjusted FVS model predicts that these stands would increase in basal area to a maximum slightly above 120 ft^2. It predicts that the white oak and other hardwoods would occupy an increasingly large proportion of the basal area. Projecting data beyond 50 years is suspect, but if pressed to do so, it is encouraging to see that the adjusted model predicts a basal area level and species composition that are similar to measured trends. Note that we also produced an iteration of the FVS model without adjustments to determine what the predicted basal area would be after 100 years of growth. This simulation produced an unrealistically high prediction of basal area.

Poor sites, low mortality were also projected from cycle 5 for 100 years (fig. 5). In this example, we ran the model with and without the ODEM addfile in order to observe the effect of the ODEM addfile on the projection. When the FVS model with adjustments

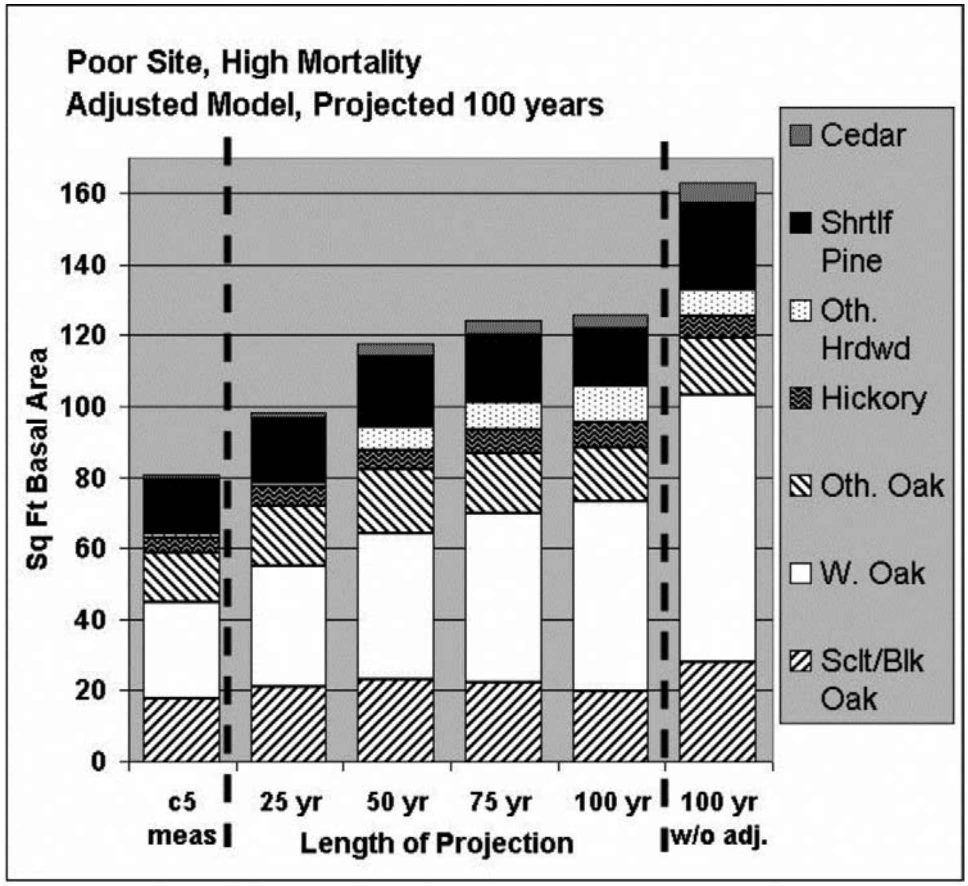

Figure 4—Projected basal area and species composition of poor sites with high mortality from cycle 5 for 100 years into the future, using the adjusted FVS model. Note that the 100-year projected value using FVS without adjustment is also shown for comparison.

was used, the predicted pattern of stand development was very similar to the pattern predicted for the high mortality stands (fig. 4). This is not surprising, since the average basal area of the stands in these two groups was actually quite similar by cycle 5. The interesting result here is the effect of including the ODEM addfile in the projection. Over a 100-year period, adding the ODEM addfile causes a fairly significant shift in species composition. It predicts a much lower proportion of the stand to be composed of either the “scarlet/black oak” or “white oak” species group and a much larger proportion of the stand in “other hardwoods.” It also holds the basal area below 100 ft^2/acre throughout the projection. Based on these findings, we recommend that the species related mortality impacts within the ODEM addfile be modified to apply a lower level to the “white oak” and a higher level to the ‘other hardwoods’ species group.

Summary of Results

A study of this magnitude revealed several important findings. Regarding assembling data sources, access to FIA data has been streamlined in recent years. A simple truth concerning this finding is the more recent the inventory cycle, the more readily available the information. Retrieving past data from older periodic inventories can be challenging. Knowledge of FVS input files and their associated field formats may be required. As with our study, attempting to go back 20 or more years most likely will necessitate a high level of interaction with the raw data to produce FVS-ready files. Also, familiarity with FIA sampling techniques will be mandatory. Syncing inventory procedures is imperative when trying to draw inferences from varying survey designs.

When dealing with data collected from variable plot techniques to glean long-term trends, use aggregated stratum values, not per plot or per tree progressions. With

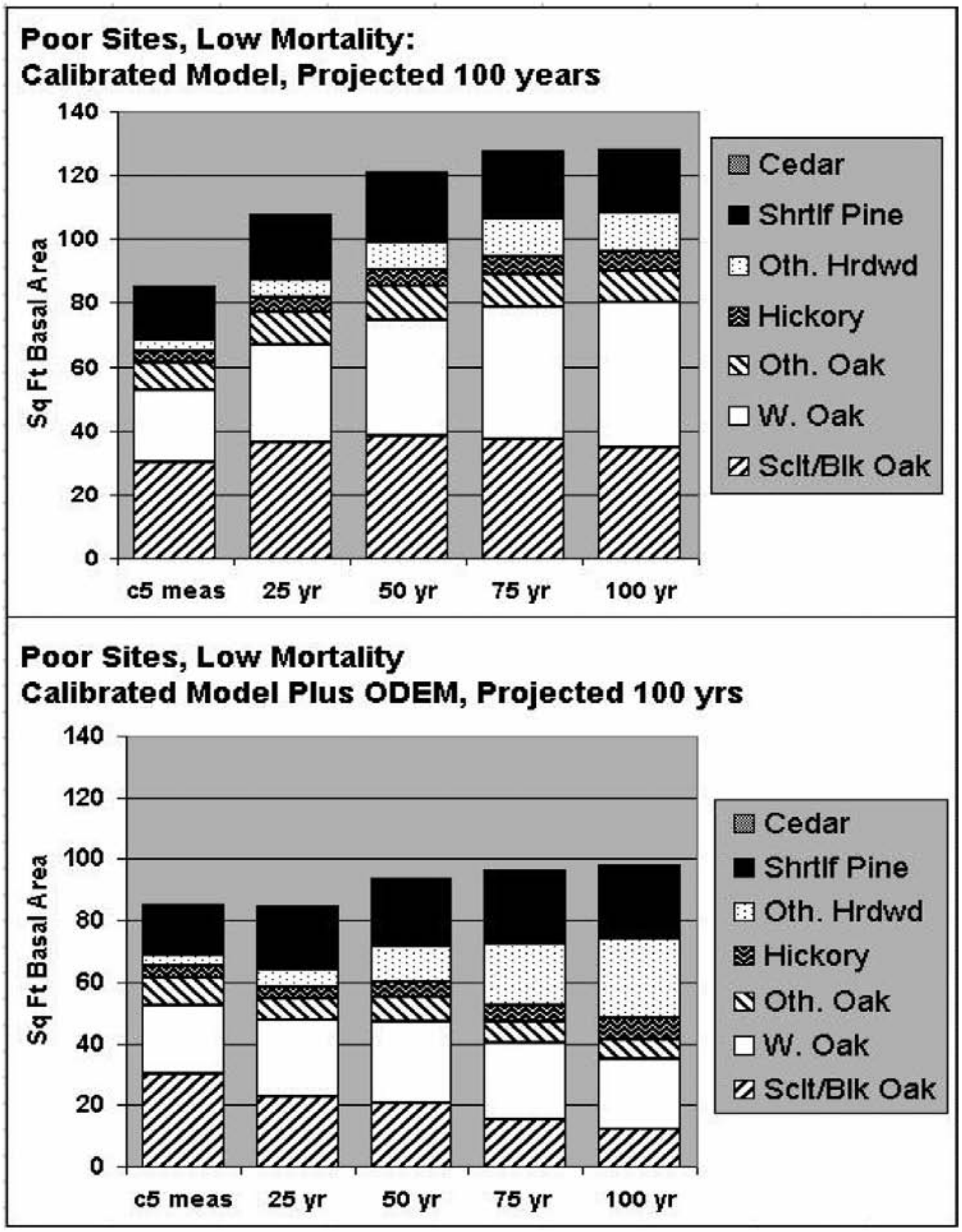

Figure 5—Projected basal area and species composition of poor sites with low mortality from cycle 5 for 100 years into the future using the FVS model with adjustments and the FVS model with adjustments with the ODEM addfile.

point sampling, tree expansion values change over time as a result of diameter growth. Consequently, per acre values differ when comparing repeat measurements. This adds complexity in interpreting trend information. Reliable monitoring estimates can only be made at the stratum level.

The ecological strata recognized by this study were correlated with differences in oak-hickory understory recruitment. We found that north aspects having high site productivity contained approximately half the oak-hickory small saplings as south aspects having low site quality. The ecotones between these (north aspect/low site and south aspect/high sites) had similar species compositions in the understory. They had more oak-hickory small saplings than the north aspect with high site potential but less than the south aspect with low site indices. Forest strata were defined by these ecological classes. These findings were valuable in development of regeneration estimation addfiles.

Since oak decline as a symptom was not recorded for the different FIA cycles, we needed to develop a method to infer the break-point between endemic and epidemic levels of mortality. We found the procedure suggested by Manion and Griffin useful insofar that it links forest structure to a predictable level of relative mortality. We applied their method for estimating baseline mortality per dbh class. Approximately 2 percent of the trees per acre per year die on the MTNF. This equates to about one-half of the trees surviving from a given 2-inch dbh class to the next larger class based on measured diameter growth and resultant tree survivorship. We used the 2 percent threshold to distinguish high from low mortality FIA plots.

In exploration of the data for regeneration estimation, we observed that north aspects of high site productivity did not commonly have a large amount of oak-hickory regeneration. Although these are good sites, they do not intrinsically favor oak-hickory tree species development. There is a high level of species diversity that would inherently be less susceptible to oak decline impacts. South aspects of low site quality are strongholds for oak-hickory development. We focused on these areas for comparing measured trends as revealed by three FIA cycles versus modeled effects as portrayed by FVS projections for the same time period.

Poor sites (south aspect, low site) with high mortality (>2% tpa/yr) as forecast by FVS demonstrated similar results in terms of stand basal area per acre as indicated by measured FIA data. Forecasts of species composition changes were less successful. Losses in the black oak species group (scarlet and black oak) were not as prevalent in the modeled runs as in the measured data. This was concluded over the 25-year period spanning 1976 to 2001. However, projecting this stand type forward 100 years demonstrated a greater loss in the black oaks and also in white oak. This may be an overstatement of the effects of oak decline on white oak. Measurement data revealed that white oak was less susceptible to oak decline agents and actually filled in the gaps resulting from mortality in the black oak species group.

Conclusions and Recommendations

Several conclusions can be drawn from our study of oak decline on the MTNF. The objective of this project was to investigate the utility of Forest Inventory Analysis data and the Forest Vegetation Simulator to address mortality impacts and resulting stand structure from impeding oak decline events. As indicated from our trials comparing the FVS model runs with and without adjustment techniques applied, it is recommended to pursue adjustment techniques: (1) perform FVS self-calibration, (3) obtain tree defect values, (3) derive maximums for stand density and tree attainment, and (3) develop a regeneration response. Each of these modifications contributes to crafting a FVS modeled run to perform similar to measurement trends. Future projections built on this basis can then be substantiated.

The Oak Decline Event Monitor addfile was developed specifically to induce effects of oak decline during a FVS model run. We found it to be particularly helpful in “scaling back” oak stocking when the FVS model was not adjusted, but less useful when the model had been fully adjusted to measured conditions. To obtain the most realistic results, we recommend always adjusting FVS. If the ODEM addfile is going to be used in conjunction with the adjustments, the user should consider reducing the levels of mortality it applies to white oak and increasing the level for other hardwoods.

As with the model runs for poor sites, the modeled runs for the moderate and good sites correlated well to actual measurements from cycle 3 to cycle 5. We hypothesize that the moderate and good sites would follow similar trends if forecast 100 years into the future. This would be a logical extension of this study. Also, calculation and comparison of net volume trends may provide additional information important to land managers.

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