Using Forest Service Forest Inventory and Analysis Data to Estimate Regional Oak Decline and Oak Mortality

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ABSTRACT

Damage and mortality data are collected as part of the US Forest Service, Forest Inventory and Analysis (FIA) ongoing assessments of the nation's timberlands. The usefulness and value of FIA tree data in assessing historical levels of oak decline and oak mortality were investigated for seven Midwestern states. The data were collected during two periodic inventories conducted between the early 1970s and the mid-1990s. One-tenth to one-third of the oak trees had decline-associated damage in a given inventory, but no trends over time were apparent across the states. The percentages of dead trees ranged from less than 1 to 11 across all inventories and states; mortality was higher in the late inventory than the early inventory for all states. This is the first reported attempt to quantify oak decline across the Midwestern Region and it was accomplished using FIA tree data. The major concerns of the approach used are the subjective nature of the damage codes used to tabulate declining oaks and the inconsistencies and inherent subjectivities in the FIA recorded codes. The major drawback for non-FIA researchers is the time required to understand the intricacies of the FIA system.

Keywords: *Quercus* spp., forest inventory and analysis, oak decline, oak mortality

The Forest Inventory and Analysis (FIA) research and development staff of the US Forest Service is charged by the US Congress and required in the Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974, PL 93-378 88, Stat. 4765, to report information on the nation's forest resources. Periodic surveys conducted by this entity provide the information needed to assess the current status and performance of resources and to support estimates of their future condition. These are the subjects of FIA's published reports, e.g., Smith et al. (2004). The surveys are conducted in all 50 states of the nation. Historically (before the late1990's), surveys have been on an approximately 10-year cycle with starting and ending date differing by state. In the late 1990s, the FIA data collection protocol was changed to a continuous annual survey of a state's resources, with the periodic report provided after 5–7 years of data collection and subsequent analyses (Bechtold and Patterson 2005).

In the first phase of the FIA periodic system for developing estimates of timber inventories, amounts of forestland by county are estimated using aerial images. The second phase of the FIA system involves collection of detailed field measurements taken on randomly selected plots (Bechtold and Patterson 2005). Estimates of variables of interest, such as mortality, are often projected with a model based on trees measured in the field sampled plots in combination with modeled plots. Such estimates are then extrapolated to county and state levels for each inventory using the estimates of amounts of forestland determined in the first phase. These tree and plot data can be accessed using the FIA Database Retrieval System (US Forest Service 2005b). For the inventories included in our study, measured trees were assessed for the presence/absence of damage due to insects or pathogens that was severe enough to reduce tree vigor (FIA variable AGENTCD; US Forest Service Forest Inventory and Analysis Program [2006]). These tree records could be potentially valuable in assessing historical levels and trends of particular insect and disease damage across multiple states or even a region.

Oak decline is a disease complex (Manion 1991) common in the dominant oak-hickory forest of the eastern United States. The disease complex results from the interaction of predisposing stress factors (e.g., soil depth or texture and aspect), triggering factors (e.g., defoliation by insects, and drought events), and contributing factors (e.g., *Armillaria* root disease). The levels of oak mortality associated with this decline disease varied over the decades of the 20th century, largely depending on the occurrence of triggering events such as extended droughts and buildup of biotic agent populations such as wood-boring insects (Millers et al. 1989). Other diseases (e.g., oak wilt caused by *Ceratocystis fagacearum*) and oak mortality associated with them are found also in the oak-hickory forests of the Midwestern states, but generally are not as uniformly distributed or cause as high a level of damage as oak decline.

FIA data have been used previously to estimate or model and explain levels of oak decline on a state (Woodall et al. 2004) or a regional scale (Starkey et al. 1992). Plot level data, i.e., presence versus absence of oak decline occurrence in an FIA field plot, was

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used to develop an oak decline atlas layer for multiple states in the southern and southeastern United States (Starkey et al. 1992). More recently, individual tree data from FIA field plots in Missouri were used to determine variables that are significant predictors of oak tree mortality (Woodall et al. 2004). Measures of individual tree vigor were found to be more significant predictors of mortality than site or stand attributes. Non-FIA data have been the basis for small-scale, disjoint reports of oak decline and mortality published by forest health specialists in the region (e.g., Walters and Munson [1980] and Heyd [1994]). Reports documenting oak decline and mortality on a regional scale in the Midwest are lacking. FIA data are the most logical sources of this information because of their availability for every state, dating from the early 1970s for some states, and the relative consistency in data collection methods. Rate of oak mortality, based on volume, is regularly reported by the FIA and is used as an indicator of resource sustainability. These mortality estimates are based on numbers and volume of dead trees from a combination of samples of plots that are measured in the field and plots for which volume is projected with a model; samples are extrapolated to county and state levels for each inventory (Miles et al. 2001).

The purpose of this research was to investigate the usefulness and value of FIA individual tree data, coupled with plot data, in assessing historical levels of oak decline and oak mortality in Midwestern states. Our specific objectives were to (i) devise an approach, including identification of which FIA variables to use and how to do so; (ii) estimate the levels of oak decline and oak mortality in seven states of the Midwestern region using the developed approach; and (iii) compare our results to others' assessments of oak decline and/or mortality and determine the value and usefulness of our approach. A preliminary report on the first objective has been published (Kromroy et al. 2003).

Description of Analysis Approach

For each inventory, we selected measured, and remeasured plots based on forest types or forest type groups (a more general category than forest type) and included a total number of plots necessary to account for at least 90% of the measured oak trees. From the included forest types, we selected plots on which at least 25% of the stems were oak and then analyzed the individual tree data for those plots. For damage estimates, we used data from live trees measured during the growing season: April–October for Missouri and Indiana; May–October for Illinois and Iowa; and May–September for Michigan, Minnesota, and Wisconsin. FIA codes (Miles et al. 2001) for damage known to be associated with oak decline (Manion 1991) were grouped into the damage type "decline-associated damage" (DAD). These were the codes used for damage due to insects, diseases, weather, and selected unknowns (breakage, canker, decline/dieback, and defoliation). Types of damage generally not associated with oak decline were called "other damage." These were the codes used for damage due to animals, fire, suppression, logging related and other mechanical damage, and selected miscellaneous damages (e.g., dead or missing top and vine damage). Trees that were coded for "poor form" were not counted as damaged, but they were included in the total numbers of trees measured. For each inventory we calculated the percentage of oak trees with DAD and other damage based on the total number of oak trees measured.

For oak tree mortality we used data that were collected year-round and calculated the percentage of oak trees that were dead at the time of field measurement. Based on the tree history this percentage was out of all the trees measured. "Live" included remeasured living trees and living trees that grew into the plot since the previous measurement cycle. "Dead" included trees coded as dead salvable, dead standing, stumps of dead-salvable trees, and trees that had grown into the plot since the previous cycle and died. Stumps of cut trees were not included in the mortality calculations.

We aggregated dead and damaged oaks by forest type group, species group, size class, and position in the canopy for each inventory. The red oak group, subgenus *Erythrobalanus* (Stein et al. 2003) included FIA species groups "selected red oaks" and "other red oaks" (Miles et al. 2001). Red oak species were northern red oak (*Quercus rubra* L.), black oak (*Quercus velutina* Lam.), blackjack oak (*Quercus marilandica* Münchh.), scarlet oak (*Quercus coccinea* Münchh.), northern pin oak (*Quercus ellipsoidalis* E. J. Hill), shingle oak (*Quercus imbricaria* Michx.), shumard oak (*Quercus shumardii* Buckley), pin oak (*Quercus palustris* Münchh.), southern red oak (*Quercus falcata* Michx.), cherrybark oak (*Quercus pagoda* Raf.), and willow oak (*Quercus phellos* L.). The white oak group, subgenus *Leucobalanus*, included FIA species groups "selected white oaks" and "other white oaks" (Miles et al. 2001). White oak species were white oak (*Quercus alba* L.), post oak (*Quercus stellata* Wangenh.), bur oak (*Quercus macrocarpa* Michx.) chinkapin oak (*Quercus muehlenbergii* Engelm.), chestnut oak (*Quercus montana* Willd.), overcup oak (*Quercus lyrata* Walter), swamp chestnut oak (*Quercus michauxii* Nutt.), and swamp white oak (*Quercus bicolor* Willd.). Tree size classes were seedling-sapling (2.5–13 cm dbh); poletimber (13–28 cm dbh); and sawtimber (more than 28 cm dbh). Trees less than 2.5 cm dbh were not included in our assessment. Position in the canopy was not recorded for dead trees so we evaluated this factor for DAD only. Positions in the canopy were dominant, codominant, intermediate, and overtopped (Miles et al. 2001). We combined intermediate and overtopped into a single category.

Differences in the percentages of dead and damaged trees among forest type groups, tree species groups, and tree size classes were evaluated with the likelihood ratio test. Exact *P* values were calculated, or estimates of exact *P* values were obtained using the Monte Carlo enumeration algorithms (Mehta and Patel 1995). Statistical tests for differences over time were not conducted because of methodological variations. Because we were working at a regional scale, we combined inventories for some comparisons.

Oak Trees across the Region

More than 198,000 tree records from over 11,000 plot visits were analyzed (Table 1). Because of our growing season date restriction, there were fewer trees in the assessment for damage than for mortality (Table 1). In each of the seven states, at least 75% of the oak trees occurred on plots in the oak-hickory forest type group (Table 2). In four states from 5 to 9% of the oak trees were found in the maple-beech-birch forest type group in one or both inventories. Oaks in the aspen-birch forest type group accounted for 4–13% (average by inventory) of all the oaks in the three Lake States (Minnesota, Michigan, and Wisconsin). Wisconsin was the only state where oaks occurred in sufficient numbers on plots in pine forest types such that these types were included in the analysis.

Trees in the red oak group accounted for 54% of the total number of oak tree records in the assessment (Table 3). Five states (Missouri, Iowa, Minnesota, Illinois, and Indiana) had less than a 17% difference between the ratios of oaks in the white versus red group across both inventories. In Michigan and Wisconsin, there were 44 and 50% more red oaks than white oaks, respectively. Changes in

Table 1. Numbers of plots and oaks trees (>2.5 cm dbh) from two US Forest Service FIA periodic inventories of seven Midwestern states used to estimate decline-associated damage and mortality frequencies.

State	Inventory[a]	No. for decline associated damage[b]		No. for mortality[c]		Reference
		Plots	Oak trees	Plots	Oak trees	
Missouri	1972	1,148	22,073	2,193	43,681	Spencer and Essex 1976
	1989	1,531	28,944	2,751	58,542	Spencer et al. 1992
Iowa	1974	127	1,852	229	3,341	Spencer and Jakes 1980
	1990	75	1,107	109	1,843	Brand and Walkowiak 1991
Minnesota	1977	—[d]	—	992	11,507	Jakes 1980
	1990	202	2,587	652	9,876	Miles et al. 1995
Michigan	1980	319	4,666	712	10,124	Raile and Smith 1983
	1993	129	2,054	581	8,984	Leatherberry and Spencer 1996
Wisconsin	1983	443	5,822	768	11,425	Spencer et al. 1988
	1996	127	1,988	772	12,660	Schmidt 1997
Illinois	1985	231	3,370	457	6,841	Raile and Leatherberry 1988
	1998	151	2,764	344	6,840	Schmidt et al. 2000a
Indiana	1986	187	2,789	432	7,370	Smith and Golitz 1988
	1998	117	2,328	229	5,148	Schmidt et al. 2000b
All		4,787	82,344	11,221	198,182	

[a] Completion year of inventory.
[b] Data collected only during months when foliage was present.
[c] Data collected during any month of the year.
[d] Data not used because of an apparent miscoding error.

Table 2. Occurrence of oak trees within major forest type groups in two US Forest Service FIA periodic inventories in seven Midwestern states.

State	Forest type group		Average oaks in type group (%)
	Name	Types included	
Missouri	Oak-hickory	Black-scarlet oak, post-blackjack oak, white oak	93
Iowa	Oak-hickory	White-red oak-hickory, white oak, bur oak	93
Minnesota	Oak-hickory	Oak-hickory	75
	Aspen-birch	Aspen	13
	Maple-beech-birch	Maple-basswood	8
Michigan	Oak-hickory	Oak-hickory	77
	Maple-beech-birch	Maple-birch	9
	Aspen-birch	Aspen	5
Wisconsin	Oak-hickory	Post-blackjack oak, white-red oak-hickory, northern red oak, bur oak, white oak, mixed-upland hardwoods	76
	Oak-pine	Other pine-hardwood	7
	White-Red-Jack	Jack pine	5
	Aspen-birch	Aspen	4
Illinois	Oak-hickory	White-red oak-hickory, mixed-upland hardwoods, white oak, post-blackjack oak, northern red oak, chestnut-black-scarlet oak, bur oak	90
	Maple-beech-birch	Maple-basswood, maple-beech-yellow birch	8
Indiana	Oak-hickory	White-red oak-hickory, white oak, chestnut-black-scarlet oak, chestnut oak, northern red oak, yellow poplar-white-red oak	87
	Maple-beech-birch	Sugar maple-beech-yellow birch, maple-basswood, cherry-ash-yellow poplar	5

the ratio of red to white oaks within states between repeated inventories were less than 3% except for Minnesota, where there was a 7% decrease in the ratio of red oaks measured between the 1977 and 1990 inventories. Within a single state, the number of species ranged from 6 (Minnesota and Wisconsin) to 17 (Illinois). The distribution of oak trees among the three size classes varied among the states, but within each state the size class distributions were very similar for white and red oaks (Figure 1).

DAD of Oaks across the Region

Minnesota 1990 and Michigan 1993 were the inventories with the highest percentages of oak trees with DAD—31 and 33, respectively—as well as with all damage types combined—35 and 36, respectively (data not shown). The lowest percentage of oaks with DAD (less than 11) occurred in Indiana 1998, which also was lowest (16) for both damage types combined. We did not summarize damage for the 1977 Minnesota inventory because this variable was apparently miscoded for a significant number of tree records. Within the three forest type groups with the most oak, the percentages of oak trees with DAD were similar ($P = 0.56$) when we combined the data from all the inventories (Table 4). The percentages of oak trees with other damage varied by forest type group ($P < 0.001$), ranging from a low of 5.5 in aspen-birch to a high of 8.9 in oak-hickory. We found no significant differences between the two pine forest type groups in percentages of oak trees with DAD or other damage. Changes in the percentage of trees with DAD by forest type group over time within a state were variable.

Across all the inventories combined, the percentage of red oaks with DAD (21) was higher than the percentage of white oaks with DAD (13; $P < 0.001$; Figure 2A). At the same time, the percentage of white oaks with other damage (12) was higher than the percentage of red oaks with other damage (8; $P < 0.001$). Two inventories, Michigan 1980 and Wisconsin 1983 were exceptions to these trends.

Table 3. Percentages of trees by oak species group for two (combined) US Forest Service FIA periodic inventories of timberland in seven Midwestern states.[a]

State	Percentage of trees by oak species group[b]	
	Red	White
Missouri	46	54
Iowa	42	58
Minnesota	50	50
Michigan	72	28
Wisconsin	75	25
Illinois	50	50
Indiana	44	56

[a] Refer to Table 1 for inventories used.
[b] Based on total number of oaks by state for combined inventories (see Table 1, no. oak trees used for mortality).

Across all the inventories combined, sawtimber size oaks had a higher percentage with DAD than poletimber size oaks ($P < 0.001$) whereas a significantly greater percentage of those in the poletimber size class had other damage compared with the sawtimber size class ($P < 0.001$; Figure 2B). The percentages of oaks with both damage types in the seedling-sapling size class were variable, ranking above the other two size classes in some inventories and below both size classes in other inventories. The contribution of DAD to the damage types combined was less for the seedling-saplings than for poletimber or sawtimber tree. Trends in percentages of oaks with DAD and other damage based on position in the canopy were very similar to those based on size class (data not shown). Dominant trees had a higher percentage with both damage types than codominant trees, and DAD accounted for higher percentages of damaged trees in dominant positions compared with trees in codominant positions. In several inventories, the trees in the combined category of intermediate and overtopped positions had the highest percentages of damage types combined but the lowest percentages of trees with DAD.

Oak Mortality across the Region

Percentages of dead oak trees ranged from less than 1 in the Minnesota 1977 inventory to 11 in the Illinois 1998 inventory (data not shown). Mortality was higher in the late inventory than in the early inventory for all seven states. The percentage of dead oak trees was higher in the oak-hickory forest type group (6) than in the maple-beech-birch forest type group (5; $P = 0.030$) and the aspen-birch forest type group (4; $P < 0.001$) when we combined data from all the inventories (Table 4). The percentages of dead trees in the two pine forest type groups in Wisconsin across both inventories were similar (8 and 9 for white-red-jack pine and oak-pine, respectively; $P = 0.62$), and higher than in the other three forest type groups (data not shown). Because Wisconsin was the only state with enough oak trees in the white-red-jack pine and oak-pine forest type groups to be included in the analysis, mortality in these two groups was statistically compared with mortality in the other three forest type groups.

Across all states and inventories, the percentage of dead red oaks (7.6) was higher than the percentage of dead white oaks (4.6; $P < 0.001$; Figure 3A). Michigan was the exception to this trend. There was a significantly higher percentage of dead poletimber oaks (4.6) than sawtimber size oaks (4.2; $P < 0.001$), with Missouri 1972 the exception to this trend (Figure 3B).

Value and Usefulness of Approach

We were able to develop estimates of oak decline and oak mortality over time for seven Midwestern states. One-tenth to one-third of the oak trees had DAD in a given inventory, but no trends over time were apparent across the states. Rates of oak tree mortality increased from 9 to 800% between the two inventories in the seven states. Annual mortality rates based on volume that were estimated for these inventories using Forest Inventory Mapmaker version 1.7 (US Forest Service 2005) also showed increases from the early to the late inventory for all states. All FIA estimates of mortality have uncertainty associated with them, caused by in part, perhaps, to the low numbers of trees used for such estimates. Mortality estimates often are based on many fewer trees than the numbers used to estimate annual growth, and lower than the numbers we used in our study (Luppold and McWilliams 2004). Our estimation of percentages of dead oak trees is based on cumulative mortality of trees that were measured in the field at a specific time. Our use of tree history to determine these percentages was straightforward, and we did not consider all levels of this variable to be appropriate for the study, e.g., cut stumps. Although damaged trees often are cut in some managed stands to make use of them before they reach the point of no wood value, there is no way for an FIA field crew to know if this is the reason for removal when a stump is found.

Our approach allowed us to estimate decline and death, of oaks growing on plots of forest types other than those in the oak-hickory forest type group. This information may be important in areas where other forest types are significant or predominant and for understanding the role of forest type in decline.

We investigated relationships between DAD or mortality and forest type group, oak species group, size class, and position in the canopy. A consistent relationship was not found between percentages of trees with DAD and percentages of dead trees by forest type group or size class, but both DAD and mortality were higher among red oak species than white oak species. White oaks, in general, have a longer lifespan than red oaks (Burns and Honkala 1990). Red oaks also are more susceptible and more readily killed by oak decline and oak wilt (Johnson and Law 1989, Tainter and Baker 1996), two major diseases of oaks in the region (Billings 2000). One factor that may contribute to the different results for DAD and mortality is that the two measures are based on somewhat different populations of trees—the oak trees included in the damage estimation were a subset of the oak trees in the mortality assessment because of our date restrictions for damage data collection. Another explanation for the difference between DAD and mortality is that although the likelihood of a tree sustaining DAD increases as it ages, DAD does not necessarily cause tree death. Once an oak tree reaches sawtimber size, unless it is already stressed, death may not occur for decades (Pederson 1998). Woodall et al. (2004), on the other hand, showed that from 1972 to 1989 in Missouri, oak trees that were coded as having damage types associated with disease had a higher risk of mortality than undamaged oaks for all diameter classes.

This is the first report that uses FIA individual tree data to estimate oak decline over time for a region. There have been numerous reports of localized oak decline and mortality throughout the region in the latter quarter of the 20th century (Hanson et al. 1976, Walters and Munsen 1980, Rush 1986). All these events are likely reflected in FIA data. Although there has been an increased emphasis on the health of various species groups with the establishment of the Forest Health Monitoring (FHM) Program (Steinman 2004), there has

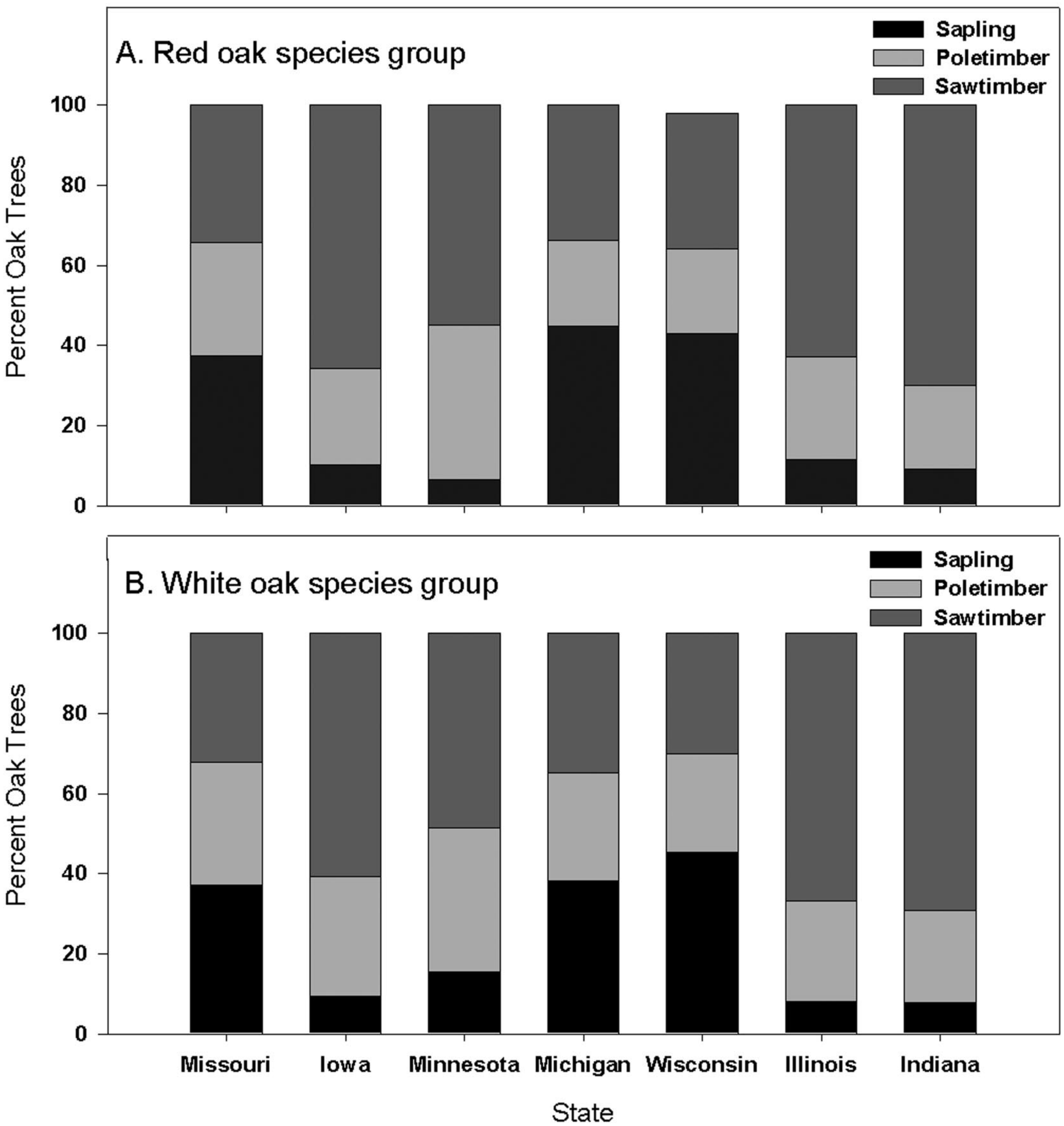

Figure 1. Percentages of different size class oak trees in regional study by oak species group, (A) red oak species, and (B) white oak species for two (combined) US Forest Service FIA periodic inventories of timberland in seven Midwestern states.

Table 4. Percentages of damaged and dead oak trees by forest type group for two (combined) US Forest Service FIA periodic inventories of timberland in seven Midwestern states.

Forest type group	Percentage of oaks by damage type[a]		Percentage of dead oaks[b]
	Decline associated	Other	
Oak-hickory	18.0x[d]	8.9 x	6.2 x
Maple-beech -birch	18.3 x	7.0xy	5.4xy
Aspen-birch	17.3 x	5.5 y	4.8 y
White-red-jack pine[c]	14.4	4.8	8.6
Oak-pine[c]	14.0	3.8	7.9

[a] Based on total number of red and white oaks surveyed during leaf-on season for combined inventories: 79,298, oak-hickory; 1,232, maple-beech birch; 950, aspen-birch; 291, white-red-jack pine; and 573, oak-pine.
[b] Based on total number of red and white oaks surveyed during entire year for combined inventories: 187,084, oak-hickory; 4,498, maple-beech birch; 4,562, aspen-birch; 1,304, white-red-jack pine; and 744, oak-pine.
[c] Wisconsin was the only state with enough oak trees in the white-red-jack pine and oak-pine forest type groups to be included in the analysis, so they were not statistically compared (see below) to the other three forest type groups. These two forest type groups in Wisconsin were not significantly different from each other for decline-associated or other damage, or dead oaks.
[d] Values followed by the same letter are not significantly different based on results of the likelihood ratio test and an estimate of an exact *P*-value of ≤0.01 based on the Monte Carlo enumeration algorithms (Mehta and Patel 1995).

been little attention focused on individual tree data. The use of such data at the state or the regional scale likely would yield different results than those obtained from extrapolated plot data.

The oak decline atlas layer produced from FIA plot data in the southeastern United States (Starkey et al. 1992) was used as a foundation to develop a system to rate the risk of oak decline (Nebecker et al. 1992, Oak et al. 1996). Results from our estimation could serve as the foundation for predictive modeling of oak decline-like symptoms and mortality at the state and regional scales in the Midwest. Data from selected FIA plot variables and summarized climatic and edaphic data from other sources could be included in such models. In a recent study of black ash decline in Minnesota, Ward et al. (in press) found relationships between ash dieback or decline and proximity to city, county, and state roads using FIA field plot data collected between 1977 and 2005.

Our approach for assessing mortality is quite different from that used by the FIA. Our estimated increases in mortality were much higher than FIA estimated increases for Missouri, Iowa, and Minnesota. We may have overestimated the increase in dead trees for these three states because they each had a higher ratio of new plots to

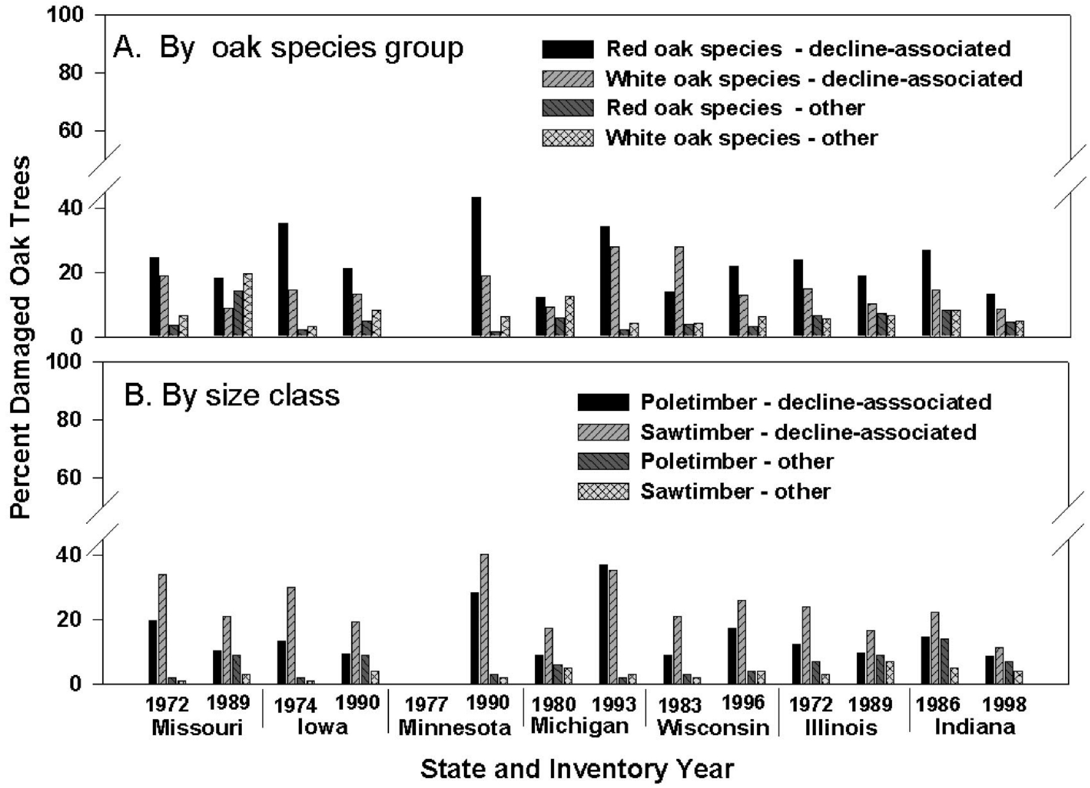

Figure 2. Percentages of oak trees with DAD (as defined in the Methods section) by (A) oak species group for each state and inventory and (B) tree size class for each state and inventory. Based on individual tree data from two US Forest Service FIA periodic inventories of timberland in seven Midwestern states.

remeasured plots for the earlier FIA inventory compared with the later inventory; our approach did not separate the two kinds of plots. In addition, volume mortality (FIA measure of mortality) is affected more by sawtimber trees than pole-sized ones, whereas when using total percentage of dead trees, all sizes have equal impact on the final percentage.

Concerns and Drawbacks to Approach

Our measure of decline-affected oaks is subjective and open to criticism. We consider DAD to be an estimate of the incidence of oak trees showing signs and symptoms of decline. The assignment of a tree to the DAD damage type was based on the damage code recorded for that tree by the FIA field crew. Although we assigned a tree to the DAD type, the tree may not have exhibited decline symptoms. Because no damage code existed for decline in the inventories used, we aggregated codes that logically could be related to factors triggering or contributing to oak decline. For the inventories used in this study, only one damage code could be recorded for each tree. Inconsistency in the definitions and use of damage codes was an issue for us in using the tree data; definitions for the codes varied among states and inventories (US Forest Service 1989, 1996), requiring some adjustments to allow for comparisons among inventories. Furthermore, the assignment of damage codes by field crews is much more subjective than assignment of tree history. Our study restricted DAD estimation to trees measured only during the growing season for each state because detection of damage relating to decline would be less visible or not apparent during the dormant season. Recently, the FIA has incorporated the FHM Program into the inventory program and methods for collecting damage data have been revised to provide more accurate and complete information than that obtained in the earlier inventories (Bechtold and Patterson 2005). No FIA variables were found to separate trees damaged by decline from nondeclining trees in a recent study of ash decline that used FIA tree data (Ward et al. in press).

Summary and Conclusions

This is the first reported attempt to quantify oak decline across seven states in the Midwestern Region and it was accomplished using FIA individual tree data. The percentages of oak trees showing symptoms of decline were variable over time and not necessarily related to the trend in increased mortality. Additional analyses that are limited to trees measured in both inventories would provide more information on this relationship. The annual data collected since the late 1990s that uses FHM methods (Bechtold and Patterson 2005) might give more robust results. Our findings complement and add to the volume-based mortality estimates previously published by the FIA for the same inventories. Both methods show that oak tree mortality increased across the region from 1972 to 1998. Decline and mortality estimates derived from individual tree data could be used to investigate relationships between these variables and climatic, physiographic, and edaphic parameters and subsequently lead to predictive models for the region. The major concerns of our estimates are the subjective nature of the damage codes used to define declining oaks and the inconsistencies and inherent subjectivity in FIA recorded damage codes. The major drawback of our approach to using FIA individual tree data is the time required to understand the intricacies of the FIA system.

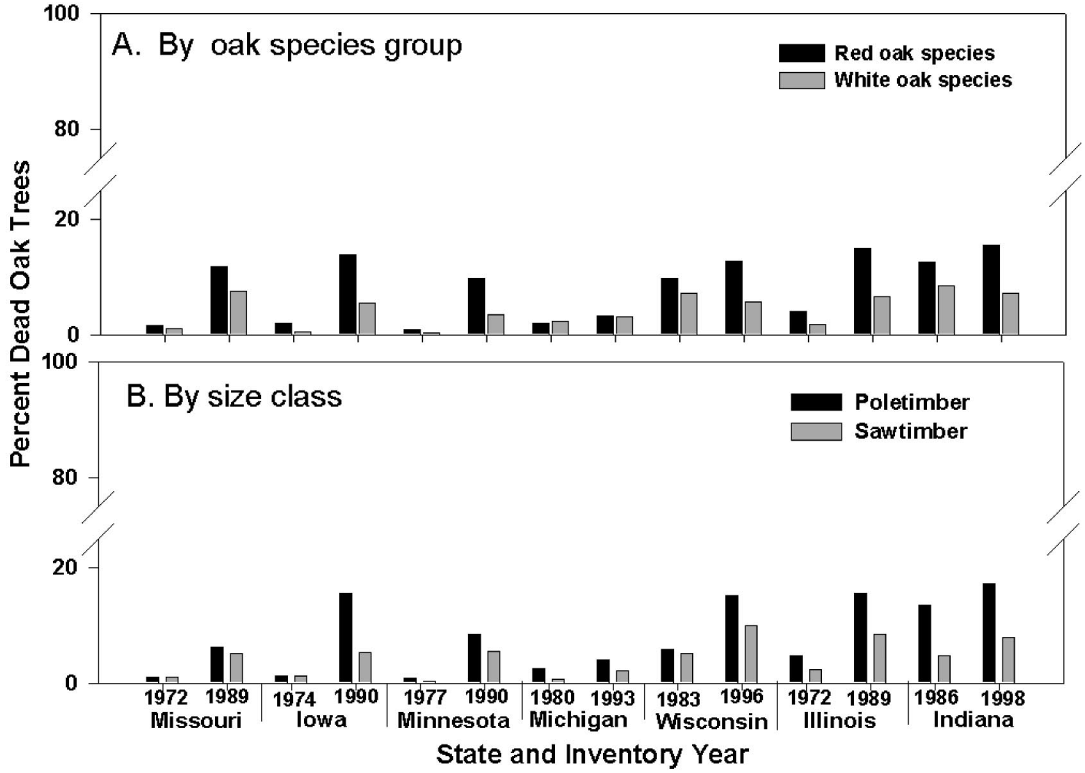

Figure 3. Percentages of dead oak trees by (A) oak species group for each state and inventory and (B) tree size class for each state and inventory. Based on individual tree data from two US Forest Service FIA periodic inventories of timberland in seven Midwestern states.

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