USE OF USDA FOREST INVENTORY AND ANALYSIS DATA TO ASSESS OAK TREE HEALTH IN MINNESOTA

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ABSTRACT.—As a precursor to a regional assessment for the Upper Midwest, three variables were examined as measures of oak health in Minnesota between 1974 and 1990 using USDA Forest Service Inventory and Analysis data. Mortality was < 1 percent in the 1974-1977 inventory, but > 6 percent in the 1986-1990 inventory based on numbers of dead oaks per total oaks on plots with ≥ 25 percent oak in three forest types. Over two-thirds of the oaks measured during "leaf-on" period in both cycles were in relatively good condition based on live crown ratio (value > 30 percent). Damage incidence observed during "leaf-on" varied by forest type. Incidence of damage-free trees decreased with increasing tree size class and with increasing position in the canopy. Incidence of "decline-associated" damage increased with increased size and increased position in the canopy.

Oak (*Quercus*) species occur on over 5 million hectares of land in the seven states of the Upper Midwest (Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin), and the volume of oak growing stock covering all age classes on timberland in the region exceeds 503 million m^3 (Juzwik and Schmidt 2000). Oaks provide food and habitat for wildlife, landscape trees, and wood for lumber and veneer; thus, supporting the health and sustainability of the oak forest resource is important.

There have been several published reports of oak mortality within the North Central region since the 1960s (Millers and others 1989). Oak wilt, caused by the fungus *Ceratocystis fagacearum*, and oak decline, caused by a variety of biotic and abiotic factors, are diseases that cause mortality at the landscape level (Oak 2001). In a recent survey of state foresters, in five of the seven Upper Midwest states, either oak wilt or oak decline was considered the major disease of concern (Billings 2000). High levels of oak mortality are anticipated in areas of Missouri, given recent drought conditions and large populations of red oak borers (Gill and Wiggins 2001, Lawrence and Moltzan 2001). Although recently initiated efforts have begun monitoring and documenting specific information on oak tree health in the region (USDA Forest Service 2002, Witter and others 2000), information on historical trends in the condition of oak tree health across the region is lacking.

Regional Forest Inventory and Analysis (FIA) units within the USDA Forest Service have been collecting data from thousands of field plots in forested, non-urban areas since the 1930s (Miles and others 2001). Although sampling and collection efforts were primarily designed to extrapolate amounts and distribution of forest tree species across large landscapes, data on various types of damage to the measured trees were also recorded. In the late 1980s, Starkey and others (1992) used FIA data to identify and compare the numbers of plots with oak decline in bottomland versus upland sites in the southeastern USA. An oak decline atlas layer resulted from this effort. Further work explored the variables that were consistently related to high incidences of oak decline (Nebecker and others 1992, Oak and others 1996).

The overall goal of our research is to obtain a region-wide assessment of oak forest health in rural areas of seven states in the Upper Midwest, USA, using existing data sources.

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Results of such an assessment could provide a starting point from which to evaluate future changes and a framework to support effective management of our oak forests (Janz 1999, McWilliams and others 2002). USDA Forest Service FIA data offer the most complete and consistent data for the region, and the data were made available to us through a special agreement with the North Central Research Station FIA unit. Data for the two most recently completed inventory cycles for Minnesota were explored as a preliminary study in preparation for the regional evaluation.

The objectives of this study were to develop and evaluate modified FIA variables that would allow us to:

1) determine the distribution and levels of oak tree mortality over time,
2) estimate general tree crown conditions and changes based on recorded live crown ratio,
3) quantify decline-associated damage, and
4) explore relationships between these three variables and forest type, tree size class, and position of the tree in the canopy.

DATA ACQUISITION AND MANIPULATION

The two most recently completed periodic inventories for Minnesota for which electronic data are currently available are cycle 4, conducted between 1974 and 1977 (Jakes 1980) and cycle 5, conducted between 1986 and 1990 (Miles and others 1995). The data are stored in FIA databases organized for the Oracle Database Management System, and are accessible with the Structured Query Language (Miles and others 2001). The plot database provides plot and stand-level information such as the date of measurement, plot location, condition, and surroundings. The condition class database documents the overall status or condition of the trees as well as the plot area itself. Finally, the tree database contains the data on the condition of each individual tree at the time of measurement. Variables considered most relevant to the study objectives were selected from these databases. Data were extracted, using SQL Navigator (Quest Software Inc., Newport Beach, CA), and were exported to a spreadsheet program for manipulation and summarization.

Because a number of plots in cycle 5 were modeled, only data from plots that were field measured were used. Since a significant number of oak trees occur in several forest types, the incidence of oaks in all forest plots was first explored. Three forest types (oak-hickory, maple-beech-birch, aspen) were found to contain 90 percent of all the FIA inventoried oaks in the state (Kromroy, unpub. data). FIA plots within this subset of data were then examined and those with ≥ 25 percent oak stems per total number of tree stems on the plots were identified and selected for further analyses.

VARIABLE SELECTION AND MODIFICATION

FIA field crews used numerous variables to document tree mortality and assess tree condition, including health, in cycles 4 and 5 (USDA Forest Service 1989, USDA Forest Service 1999). For this study, three variables were selected: Mortality, Live Crown Ratio (LCR), and Damage. Definitions and descriptions of subcategories within each variable were carefully reviewed and served as the basis for elimination, combination or other modifications in the creation of the specific variables for this investigation.

Mortality was defined by FIA as whether a tree was alive or dead at the time of field measurement. Live trees included those that had a recorded history of a new live tree (a remeasured living tree) or a living tree that grew into the plot since the previous cycle. Subcategories of “dead” included trees determined to be a dead-salvable tree, dead standing, stump of a dead-salvable tree, or a tree that had grown into the plot since the previous cycle and had died.

Live Crown Ratio (LCR) is recorded by FIA field crews as an estimate of the percentage of total tree height that supported live green foliage for each tree measured in each cycle. Only data collected during the growing season (May to September) were extracted for use and classification for this study. The LCR values (1 to 9) were grouped into three new classes representing 1 to 30 percent, 31 to < 60 percent, and ≥ 60 percent LCR. In using LCR as a coarse measure of tree health for this study, values greater than 30 percent were considered an indicator of good tree health.

Damage was assessed by FIA field crews for each measured tree for the presence of damage due to any type of biotic or abiotic agent or environmental stress. If the tree appeared healthy, with no apparent damage, “0” was recorded; any other number indicated presence of some type of damage (USDA Forest Service 1989, USDA Forest Service 1999). In cycle 4, 22 damage codes were available for crew use, compared to 52 codes in cycle 5 (some were host-species specific). For this study, damage codes were utilized in two different ways. Incidence of any damage (presence/absence) was considered first. Further exploration of this variable involved grouping assigned damage codes according to their known association with forest tree decline ("decline-associated") (as defined by Manion 1991), and specifically, biotic and abiotic agents associated with oak decline (Wargo 1983, Tainter and Baker 1996) versus "all other damage" (non-decline associated) (table 1). Data for live and dead trees measured during the growing season were used.

DATA ANALYSIS AND SUMMARIZATION

Data on the three measures of tree health (Mortality, LCR, Damage) were analyzed for total populations of trees measured in cycle 4 and in cycle 5. When appropriate, subsets of these data were created to include information on individual oaks measured in both cycle 4 and cycle 5 ("remeasured trees"). Data for each study variable were grouped in several ways (i.e., by forest type, tree size class, and position in the canopy) and summarized for the state. Tree size classes were based on tree diameter at breast height (dbh) and categorized as: seedling-sapling (< 13 cm dbh), poletimber (13 to 28 cm dbh), and sawtimber (> 28 cm dbh). Position in the canopy, or "crown class" (Miles and others 2001), was grouped as intermediate and over-topped, codominant, and dominant trees. Mortality was further summarized at the county level.

Graphical presentations of the data were visually analyzed for apparent differences and/or trends. Changes in condition were considered only for remeasured trees. Tracking of individual trees may be critical to interpreting plot level changes in decline (Oak and others 1990). As a result, data used to calculate change were from substantially fewer plots and trees than were available in each individual inventory.

RESULTS

Less than 1 percent of 11,517 oaks measured during cycle 4 (1977) in Minnesota were dead, while 6.5 percent of cycle 5 (1990) measured trees (9,876) were dead. Due to the extremely low level of mortality found in the earlier inventory, no further summarization or analyses were done with the cycle 4 data. For cycle 5, the distribution of oak mortality in oak-hickory, maple-beech-birch, and aspen forest plots with ≥ 25 percent oak (656 plots) was summarized on a county basis (fig. 1).

In four counties in southeastern Minnesota (Fillmore, Houston, Wabasha, and Winona), where the number of plots ranged from 21 to 44, between 5 and 10 percent oak mortality was observed. In 11 north central counties, where 16 to 51 plots per county were measured, mortality ranged from < 1 to 5 percent for Aitkin, Becker, Todd, and Wadena Counties, 5 to < 10 percent for Cass, Crow Wing, Hubbard, Morrison, and Otter-tail Counties, and > 10 percent for Beltrami County. In 22 other counties, where ≥ 5 percent mortality was found, the numbers of measured plots in each were relatively low (1 to 15) and county estimated mortality values could be misleading.

Table 1.—*USDA Forest Service Forest Inventory and Analysis (FIA) damage codes recorded for oak trees in Minnesota's cycle 5 (1990) inventory and their use in the creation of three damage type classes*

FIA reported damage by: Category	Code(s)	Number of trees	Damage type class[1]
Healthy	0	1,329	None
Insects	100's	75	Decline-associated
Diseases	200's	269	Decline-associated
Weather	300's	203	Decline-associated
Selected unknowns	900's	366	Decline-associated
Sub-group total		913	
Animal	400's	13	All other
Fire	500	8	All other
Suppression	600	43	All other
Logging-related	800, 820	22	All other
Abnormal growth	905, 908	300	All other
Miscellaneous or unknown	700's, 900	124	All other
Sub-group total		510	
All damage combined		1,423	

[1] Variable created for this study.

Because the number of oaks measured differed by forest type in the cycle 5 inventory (78 percent of total in oak-hickory, 14 percent in aspen, 8 percent in maple-beech-birch) mortality was examined within forest type. Mortality averaged 6 percent on 446 oak-hickory and 125 aspen forest type plots, and 10 percent on 85 maple-beech-birch plots. Mortality differed by tree size class within each forest type (fig. 2). In the oak-hickory and aspen forest type plots mortality was highest (8 to 10 percent) for the poletimber class. Mortality was highest and similar (11.0, 10.7 percent) for both poletimber and sawtimber size oaks in the maple-beech-birch type. Data on tree position in the canopy were not recorded for dead-standing or dead-salvable trees.

Live Crown Ratio (LCR)

The proportion of oak trees with different classes of LCR were similar for the two inventory cycles based on the total number of live oaks measured between May and September in each inventory (3,775 trees on 334 plots, cycle 4; 2,963 trees on 203 plots, cycle 5). Specifically, the percentages of trees in each LCR class were: 33 and 29 for 1 to 30 percent LCR, 62 and 64 for 31 to 60 percent LCR, and 5 and 7 for > 60 percent LCR for cycle 4 and 5, respectively (data not shown). The patterns of frequencies of trees across the three LCR classes were similar for forest type within a cycle, and general trends for the forest types were similar for both cycles, (fig. 3). In both cycles and all three forest types, the LCR class with the majority (58 to 74 percent) of the oaks was 31 to 60 percent.

Furthermore, the majority of oaks within each of the three tree size classes (seedling-sapling, poletimber, sawtimber) fell within the 31 to 60 percent LCR class (data not shown). Differences were found, however, when the distribution of oaks by position in the canopy (intermediate or overtopped, codominant, dominant) was considered. The frequencies of trees within canopy position class were similar for both inventory cycles, but differences in patterns were found across canopy position within each cycle (fig. 4). Not surprisingly, the intermediate and overtopped trees had the highest percent of trees in the lowest LCR category (1 to 30 percent LCR) and the dominant oaks were most commonly represented in the higher crown ratio classes (i.e., > 30 percent LCR).

Change in LCR class for individual trees between the two inventory cycles was examined based on 866 oak trees in 193 plots that were measured in both cycles. Of this subset, 124 oaks (14.3 percent) were classified as dead standing or dead salvable, 70 of which had

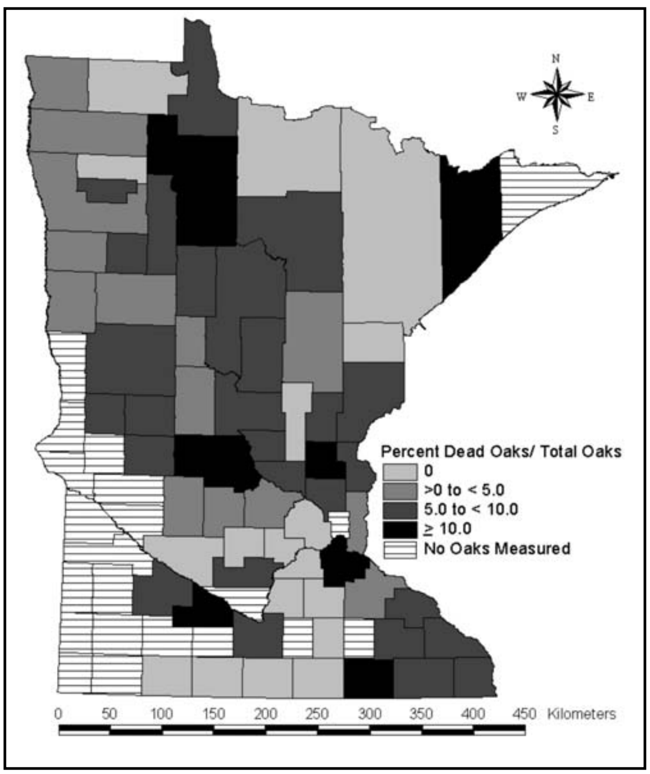

Figure 1.—*Percentages of dead oaks per total measured oaks per county in oak-hickory, maple-beech-birch, and aspen forest type plots with ≥ 25 percent oaks in cycle 5 inventory for Minnesota.*

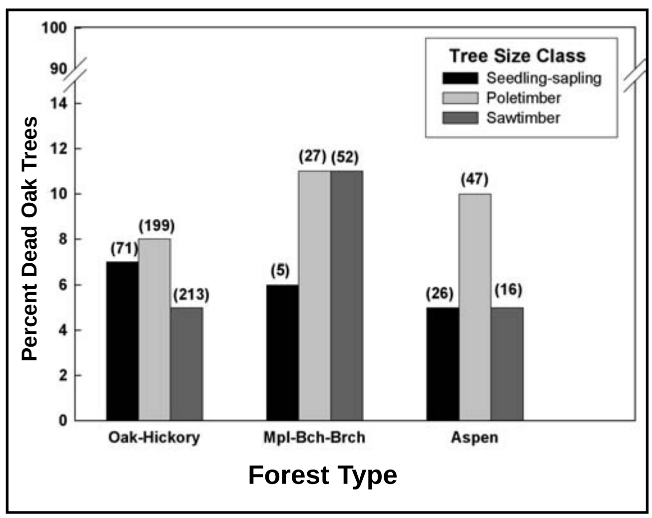

Figure 2.—*Percentages of dead oaks within three tree size classes in oak-hickory, maple-beech-birch, and aspen forest type plots for Minnesota cycle 5 inven-tory. Values in parentheses are actual numbers of dead oak trees.*

LCR's between 31 and 60 percent in the cycle 4 assessment. In addition, 111 oaks (12.8 percent) were recorded as stumps in cycle 5 (condition immediately prior to cutting unknown).

Incidence and degree of change in LCR was examined for the 631 trees that were recorded as live in both inventories (fig. 5). These changes were based on the LCR value recorded in the FIA database, not on the LCR categories that we created. No change in LCR was found for 38 percent of these trees between cycle 4 and cycle 5, while 43 percent of the trees had increases of 10 percent or more live crown, and 19 percent of the trees had decreases of 10 percent or more. For the live trees, differences were found by forest type, where 23 percent of oaks in aspen forests had some degree of loss of LCR between inventories, compared to 19 and 15 percent of oaks in maple-beech-birch and oak-hickory forests.

Conversely, over 50 percent of the oaks in oak-hickory forest type plots showed an increase in LCR. This compares to 37 and 40 percent of the oaks with a LCR increase in maple-beech-birch and aspen forest types. When considering changes in LCR by tree size class (for forest types combined), losses in LCR between the two cycles were similar (18 to 21 percent) across the classes, while increases in LCR were most common (49 percent) in the seedling-sapling size class and least common (38 percent) in the sawtimber trees. Finally, when considering changes in LCR by position of a tree in the canopy (for forest types combined) dominant

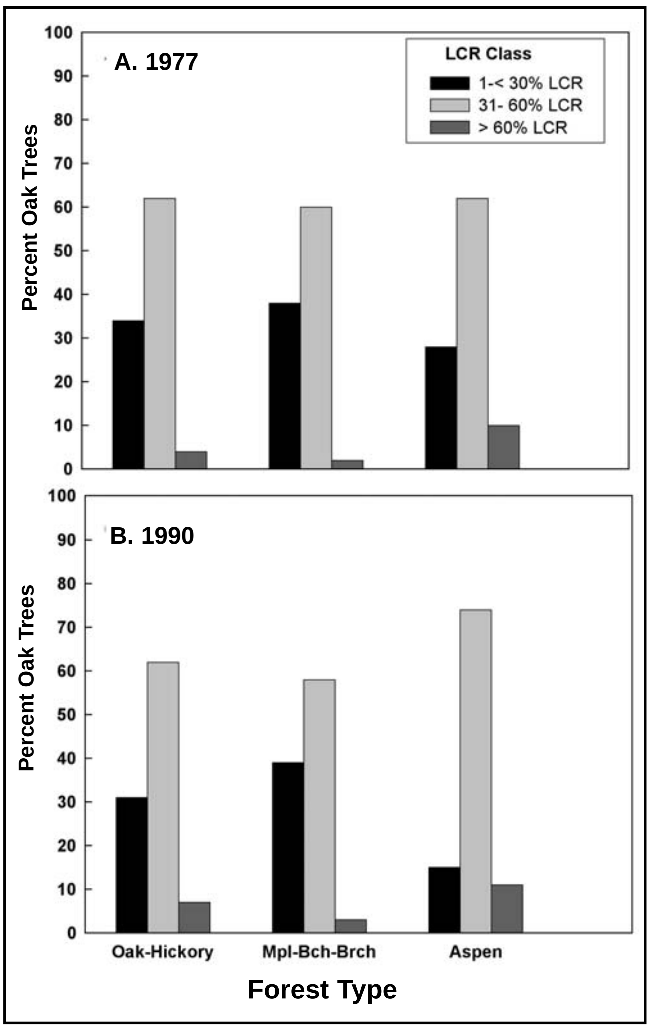

Figure 3.—*Percentages of oak trees among three live crown ratio classes (LCR), within oak-hickory, maple-beech-birch, and aspen forest types for two Minnesota forest inventories. A. 1977 = cycle 4, B. 1990 = cycle 5. Values are based on total number of oaks within each forest type.*

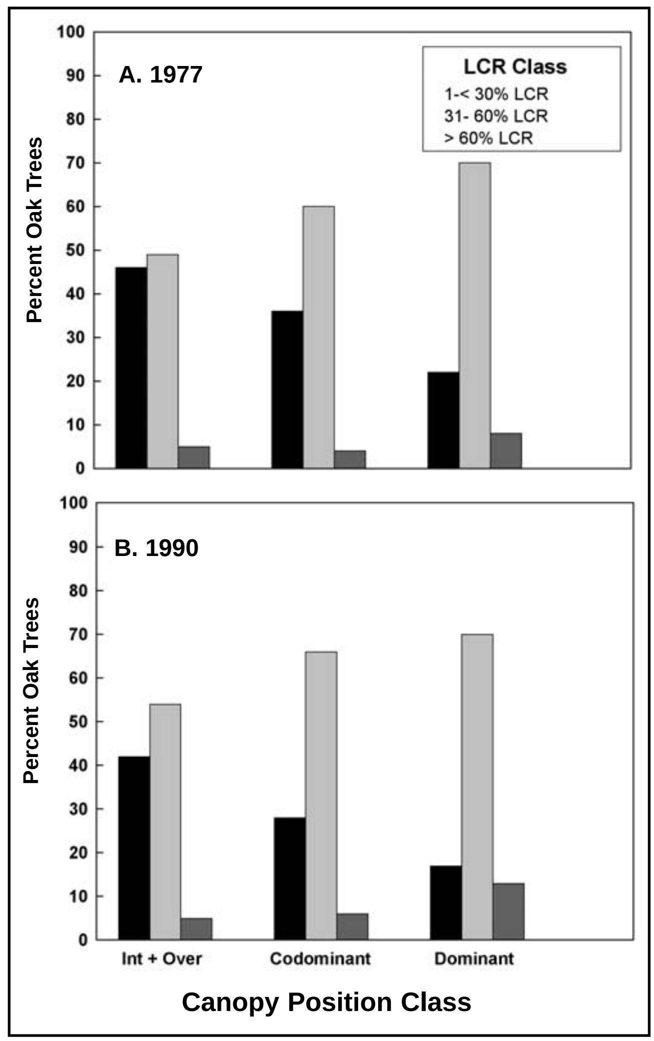

Figure 4.—*Percentages of oak trees among three live crown ratio classes (LCR), within intermediate and overtopped, codominant, and dominant positions for two Minnesota forest inventories. A. 1977 = cycle 4, B. 1990 = cycle 5. Values are based on total number of oaks within each forest type.*

trees had the highest occurrence of loss in live crown ratio, while intermediate and overtopped trees had the highest occurrence of increase in LCR values.

Damage and Decline

Because 85 percent of the oaks determined to have some type of damage in cycle 4 were assigned codes for which definitions could not be found, no further summarization or analyses involving cycle 4 damage data were done. In the cycle 5 databases, only a small percentage of trees with damage were assigned codes for which no definitions existed; such trees were omitted prior to data summarization.

Of 2,752 oak trees measured on 203 plots between May-September during cycle 5, 52 percent had some type of damage. Of the 52 possible codes, 32 were used to describe damage on the oak trees (only one used per tree); 10 of these 32 codes were used for less than five trees each. Damage incidence (presence/absence) varied by forest type with the highest incidence (55 percent) found in oak-hickory forest type plots compared to 42 and 43 percent in the maple-beech-birch and aspen plots, respectively (data not shown). Within each of the three forest types, "decline-associated" damage occurred more frequently than "all other" damage (fig. 6).

Differences in damage type occurrences were found among the three size classes within each forest type (fig. 7). The incidence of "no damage" decreased with the increase in tree size class (i.e., from seedling-sapling to poletimber to sawtimber). For example, incidence of "no damage" ranged from 90 percent in seedling-saplings to 42 percent in sawtimber size oaks in maple-birch-beech forest type plots.

Furthermore, the incidence of decline-associated damage increased with increasing tree size. For example, decline-associated damage ranged from 11 percent for seedling-saplings to 43 percent for sawtimber size oaks within oak-hickory forest plots. The incidence of "all other" damage did not show any trends with tree size, and levels were less than 25 percent within each size class and forest type.

Differences in damage type occurrence were also found among position in the canopy classes; the incidence of "no damage" decreased with increasing position of the trees in the canopy (fig. 8). For example, incidence of no damage ranged from 74 percent in intermediate and overtopped oaks combined, to 37 percent in dominant oaks on maple-beech-birch forest plots. Furthermore, the incidence of "decline-associated" damage increased with increasing position in the canopy. For example, "decline-associated" damage ranged from 19 percent in intermediate and overtopped oaks to 46 percent in dominant oaks within oak-hickory forest type plots. No positively- or negatively-correlated trends were evident for incidence of "all other" damage.

DISCUSSION AND SUMMARY

The utility and value of each of our variables in measuring oak health varied. Mortality, based on numbers of dead oaks per total oaks, was very low (< 1 percent) in the earlier inventory

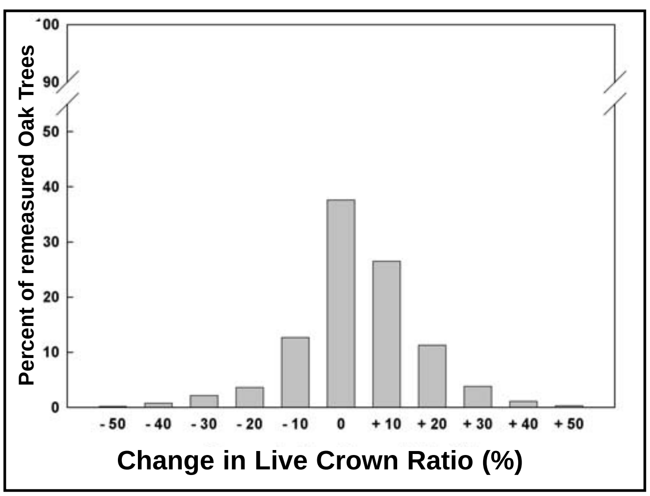

Figure 5.—*Frequency distribution by amount of change in live crown ratio (LCR) for live trees measured in May to September in Minnesota forest inventories cycle 4 and cycle 5 (n = 868).*

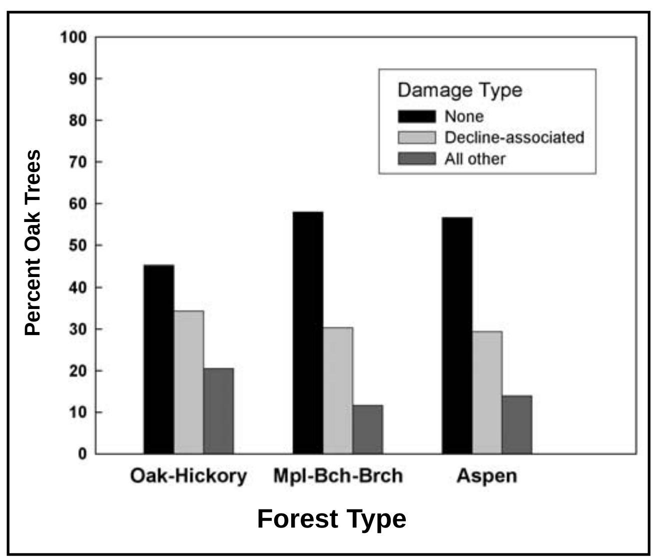

Figure 6.—*Percentages of oak trees within three damage classes.*

but apparently higher (> 6 percent) in the latter one and suggests that mortality increased over the time period considered. We consider mortality to be the most direct measure of oak forest health of the three variables used in this study. Mortality was a "straight-forward" calculation and required the least amount of interpretation of the FIA variables. In FIA published reports, the primary indicators of forest health are mortality estimates that are indexed as a percent of volume of the species (McWilliams and others 2002). The latter view of mortality gives a more direct estimate of economic impact, while our approach is more appropriate for oak health assessment.

In considering our results on the distribution of oak mortality across Minnesota it is important to keep in mind that the numbers of FIA plots and trees on which the mortality averages were calculated varied greatly. Our mortality estimates for the State may mask the impact of local mortality events such as those chronologically summarized by Millers and others (1989). However, it appears that greater than 5 percent mortality is common in the major oak growing areas of the State (fig. 1).

The damage variable provided a measure of the incidence of trees with damage as well as information on the type of damage, but only for the

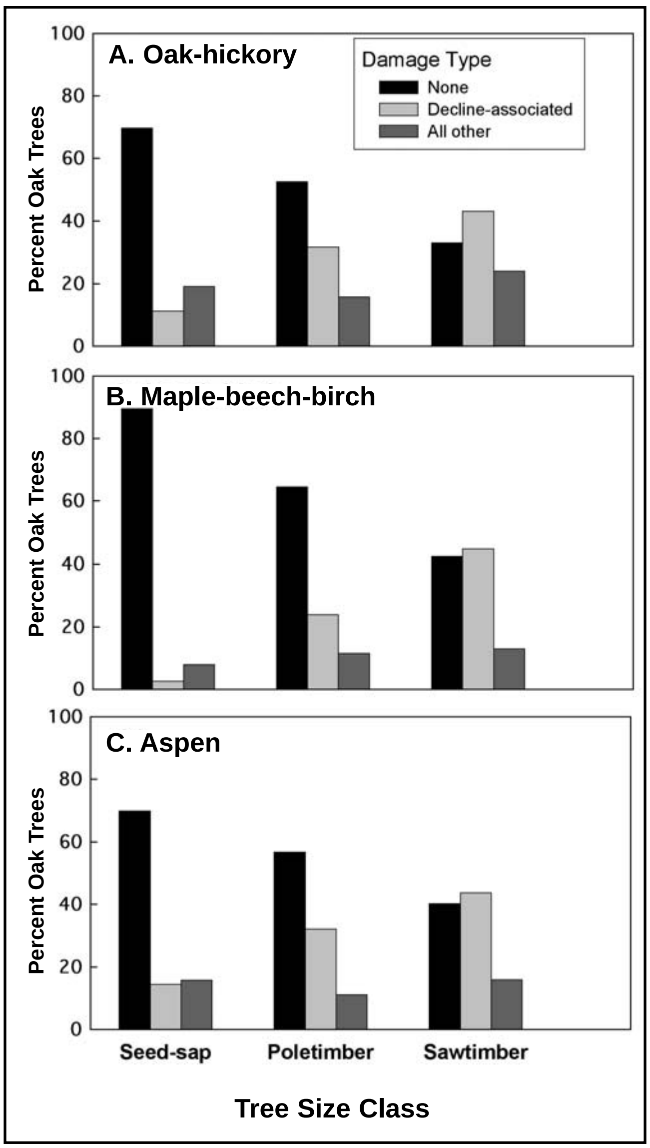

Figure 7.—*Percentages of oak trees among three damage classes within three tree size classes for Minnesota inventory cycle 5 for oak-hickory, maple-beech-birch, and aspen forest types.*

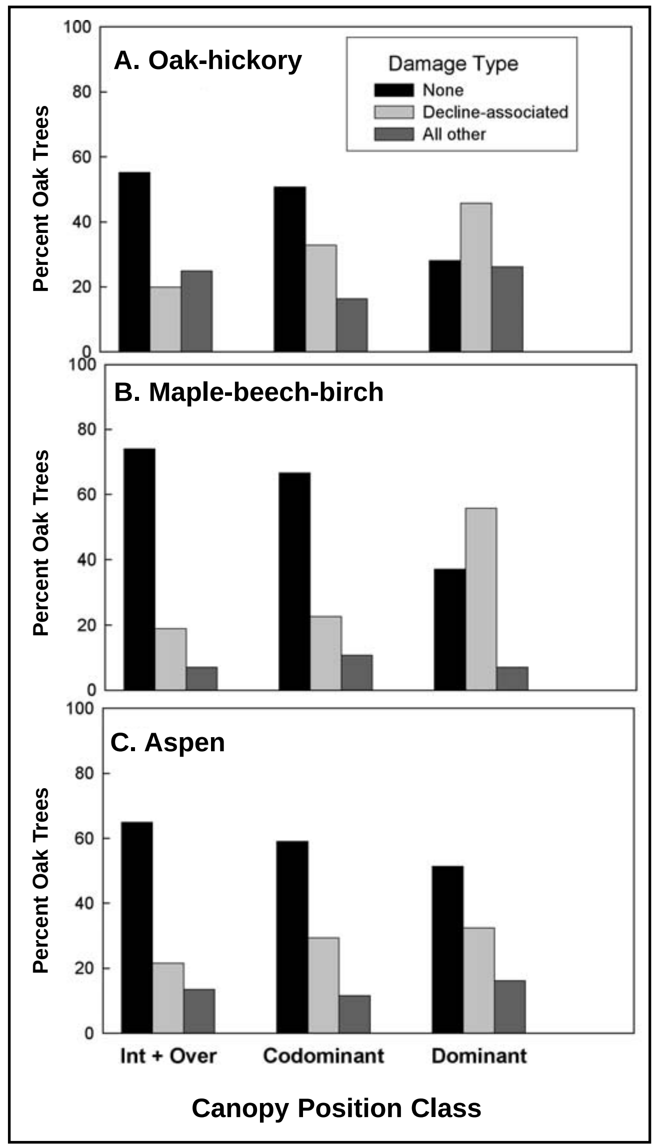

Figure 8.—*Percentages of oak trees among three damage classes within intermediate plus overtopped, codominant, and dominant canopy positions for Minnesota inventory cycle 5 for oak-hickory, maple-beech-birch, and aspen forest types.*

latter inventory due to prevalent errors in the earlier inventory. In cycle 5, over 50 percent of the oak trees had some type of damage, the majority of which (64 percent) are those commonly associated with oak decline. The incidence of trees with decline-associated damage increased both with increasing tree size and increasing position in the canopy. These observations generally agree with the theory that decline of oaks increases as trees age (Mueller-Dombois 1992).

Because the FIA damage data required considerable investigation and interpretation, we consider it of moderate value in measuring oak health. Starkey and others (1992) used some subjectivity in the identification of oak decline plots in the Southeast USA using FIA data. In our study the assignment of the various damage codes to "decline-associated" versus "all other" damage was somewhat arbitrary for several reasons, including the all-encompassing nature of oak decline and the interpretation required by the FIA field crew in assigning one damage code to a tree.

Based on LCR as a measure of oak health, more than 67 percent of the oak trees were in relatively good condition (LCR >30 percent) in both inventories. Furthermore, based on individual oaks measured in both inventories, 80 percent had either increases or no change in this attribute between inventories. This is the only variable for which change in condition of individual trees between cycles could be examined.

The most frequent LCR increases were in the smallest trees, which is expected because young trees divert proportionally more photosynthate to the crown than do older, larger ones (Kozlowski and others 1991). We consider LCR the variable least directly correlated to oak health. By itself, LCR is a very coarse measure of tree crown condition because it is based on the percentage of the total tree height that supports live green foliage and thus can vary in a forest stand because of tree density, adjacency to openings, and other factors unrelated to tree health. Compared to mortality, LCR may be more susceptible to observer variation (Ghosh and others 1995), although the three LCR classes we used in this study were quite general.

In summary, this preliminary study for Minnesota offers an approach to using FIA data to assess oak health. Mortality and damage data were found to be most useful measures of three variables considered and will be used to complete our regional historical assessment of oak health for the remaining six states in the Upper Midwest. The results of such analyses would complement information found in FIA forest inventory statistics publications for the states considered.

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