CHAPTER 5.

Tree Mortality

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INTRODUCTION

Tree mortality is a natural process in all forest ecosystems. However, extremely high mortality can also be an indicator of forest health issues. On a regional scale, high mortality levels may indicate widespread insect or disease problems. High mortality may also occur if a large proportion of the forest in a particular region is made up of older, senescent stands.

In early national reports (2001–04) of the Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, mortality was analyzed using phase 3 data from the FHM and Forest Inventory and Analysis (FIA) programs of the Forest Service. Those data spanned a relatively long time period (for some States, up to 12 years), but the sample was not spatially intense (approximately 1 plot per 96,000 acres). In the 2008 FHM national report (Ambrose 2012), the same method was applied to FIA phase 2 data, which were more spatially intense (approximately 1 plot per 6,000 acres) but came from the relatively small number of States in the Eastern United States where repeated plot measurements had been taken. In the 2009 and 2010 FHM reports, the method was applied to larger areas, using increasing numbers of plots. For this report, the repeated phase 2 data cover much of the Central and Eastern United States, and we can begin to use data from a third cycle of measurements, i.e., a third measurement of the plots.

The mission of the FHM program is to monitor, assess, and report on the status, changes, and long-term trends in forest ecosystem health in the United States (USDA Forest Service 1994). Thus, the aim of this mortality analysis contrasts with how mortality might be approached in other reports, such as FIA State reports or State Forest Health Highlights. The approach to mortality presented here seeks to detect mortality patterns that might reflect subtle changes to fundamental ecosystem processes (due to such large-scale factors as air pollution, global climate change, or fire-regime change) that transcend individual tree species-pest/pathogen interactions. However, sometimes the proximate cause of mortality may be discernible. In such cases, the cause of mortality is reported, both because it is of interest in and of itself to many readers and because understanding such proximate causes of mortality might provide insight into whether the mortality is within the range of natural variation or reflects more fundamental changes to ecological processes.

A mortality baseline is still being established for most of the United States. To discern trends in mortality rates, at least three complete cycles of FIA data are required. With the data currently available, it is only possible to do a spatial comparison of ecoregion sections and identify regions of higher than average mortality (relative to growth) for further study.

DATA

FIA phase 2 inventory data are collected using a rotating panel sample design (Bechtold and Patterson 2005). Field plots are divided into spatially balanced panels, with one panel measured each year. A single cycle of measurements consists of measuring all panels. This "annualized" method of inventory was adopted, State by State, in 1999. An analysis of mortality requires data collected at a minimum of two points in time from any given plot. Therefore, mortality analysis was possible for areas where data from repeated plot measurements using consistent sampling protocols were available, i.e., where one cycle of measurements had been completed and at least one panel of the next cycle had been measured, and where there had been no changes to the protocols affecting measurement of trees or saplings.

Because the data used here are collected using a rotating panel design and all available annualized data are used, most of the data used in this mortality analysis were also used in the analysis presented in the previous FHM national report. Using the data in this way, it would be unusual to see any great changes in mortality patterns from one annual report to the next. Nevertheless, it is important to look at mortality patterns every year so as not to miss detecting changes in mortality patterns as soon as they may become discernible.

Table 5.1 shows the 36 States from which consistent, repeated phase 2 measurements were available, the time period spanned by

Table 5.1—States from which repeated Forest Inventory and Analysis (FIA) phase 2 measurements were available, the time period spanned by the data, and the effective sample intensity (based on plot density and on proportion of plots that had been re-measured) in the available data sets

Time period	States	Effective sample intensity	Proportion of plots measured a third time
1999–2010	Indiana	1 plot: 6,000 acres	1/5
1999–2010	Wisconsin	1 plot: 3,000 acres[a]	1/5
1999–2009	Maine	1 plot: 6,000 acres	1/5
1999–2009	Minnesota	1 plot: 3,000 acres[a]	0
1999–2009	Missouri	1 plot: 6,000 acres[b]	0
2000–2009	Arkansas, Iowa, Pennsylvania	1 plot: 6,000 acres	0
2000–2010	Michigan	1 plot: 2,000 acres[c]	1/5
2000–2010	Virginia	1 plot: 7,500 acres	0
2001–2009	Illinois, Kansas, Nebraska, South Dakota	1 plot: 7,500 acres	0
2001–2009	Ohio	1 plot: 10,000 acres	0
2001–2010	Alabama	1 plot: 8,400 acres	0
2001–2010	Georgia, North Dakota, Tennessee	1 plot: 6,000 acres	0
2001–2010	Texas[d]	1 plot: 6,000 acres	2/5
2002–2009	Florida	1 plot: 30,000 acres	0
2002–2009	Kentucky	1 plot: 10,000 acres	0
2002–2009	New York	1 plot: 15,000 acres	0
2002–2010	New Hampshire	1 plot: 10,000 acres	0
2002–2010	South Carolina	1 plot: 7,500 acres	0
2003–2009	Massachusetts, Rhode Island	1 plot: 15,000 acres	0
2003–2010	North Carolina	1 plot: 21,000 acres	0
2003–2010	Connecticut, Vermont	1 plot: 10,000 acres	0
2004–2009	Delaware, Maryland, New Jersey, West Virginia	1 plot: 30,000 acres	0

[a] In Minnesota and Wisconsin, the phase 2 inventory was done at twice the standard FIA sample intensity, approximately one plot per 3,000 acres.
[b] In Missouri the phase 2 inventory was done at twice the standard FIA sample intensity, approximately one plot per 3,000 acres on national forest lands, and at the standard intensity on all other lands.
[c] In Michigan the phase 2 inventory was done at triple the standard FIA sample intensity, approximately one plot per 2,000 acres.
[d] Annualized growth and mortality data were only available for eastern Texas.

the data, and the number of panels of data available. Additional measurements of any plot, beyond the minimum of two required for a single mortality estimate, improves the mortality estimate. At present, third plot measurements have been taken in some States (table 5.1). The States included in this analysis, as well as the forest cover within those States, are shown in figure 5.1.

METHODS

FIA phase 2 tree and sapling data were used to estimate average annual tree mortality in terms of tons of biomass per acre. The biomass represented by each tree in tons was calculated by FIA and provided in the FIA Database-version 4.0 (USDA Forest Service 2010). To compare mortality rates across forest types and climate zones, the ratio of annual mortality to gross growth (MRATIO) is used as a standardized mortality indicator (Coulston and others 2005a). Gross growth rate and mortality rate, in terms of tons of biomass per acre, were independently calculated for each ecoregion section (Cleland and others 2007, McNab and others 2007) using a mixed modeling procedure where plot to plot variability is considered a random effect and time is a fixed effect. The mixed modeling approach has been shown to be particularly efficient for estimation using data where not all plots have been measured over identical time intervals (Gregoire and others 1995). In the estimation procedure, within plot temporal correlation was based on a covariance matrix modeled using a Toeplitz matrix. MRATIOs were then calculated from the growth and mortality rates. For details on the method, see appendix A (Supplemental Methods) in both the 2001 and the 2003 FHM national reports (Coulston and others 2005b, Coulston and others 2005c).

The MRATIO can be large if an over-mature forest is senescing and losing a cohort of older trees. If forests are not naturally senescing, a high MRATIO (> 0.6) may indicate high mortality due to some acute cause(s), e.g., insects, pathogens, drought, or due to generally deteriorating forest health conditions. An MRATIO value greater than 1 indicates that mortality exceeds growth and live standing biomass is actually decreasing.

In addition, the ratio of average dead tree diameter to average surviving live tree diameter (DDLD ratio) was calculated for each plot where mortality occurred. Low DDLD ratios (much less than 1) usually indicate competition-induced mortality typical of young, vigorous stands, while high ratios (much greater than 1) indicate mortality associated with senescence or some external factors such as insects, disease, or severe drought stress (Smith and Conkling 2004). Intermediate DDLD ratios can be hard to interpret because a variety of stand conditions can produce such DDLD values. The DDLD ratio is most useful for analyzing mortality in regions that also have high MRATIOs. High DDLD values in regions with very low MRATIOs may indicate small areas experiencing high mortality of large trees or locations where the death of a single large tree (such as a remnant pine in a young hardwood stand) has produced a deceptively high DDLD.

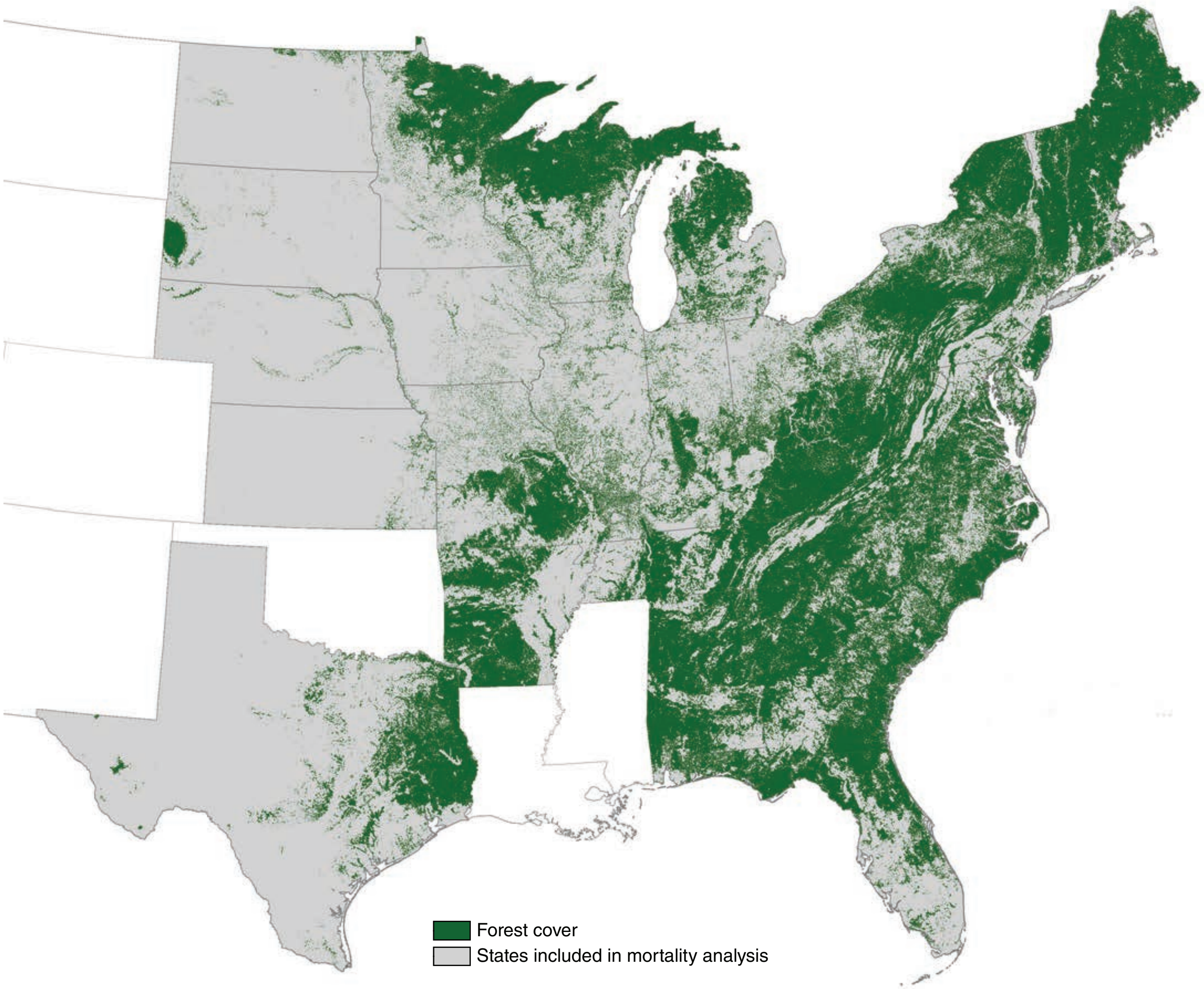

Figure 5.1—Forest cover in the States where mortality was analyzed. Forest cover was derived from Advanced Very High Resolution Radiometer satellite imagery (Zhu and Evans 1994).

To further analyze tree mortality, the number of stems and the total biomass of trees that died also were calculated by species within each ecoregion section. Identifying the tree species experiencing high mortality in an ecoregion is a first step in identifying what forest health issue may be affecting the forests. Although determining particular causal agents associated with all the observed mortality is beyond the scope of this report, often there are well-known insects and pathogens that are "likely suspects" once the affected tree species are identified.

Also, a biomass weighted mean mortality age was calculated by ecoregion section and species. For each species experiencing mortality in an ecoregion section the mean stand age was calculated, weighted by the dead biomass on the plot. This value gives a rough indicator of the average age of trees that died. However, the age of individual trees may differ significantly from the age assigned to a stand by FIA field crews, especially in mixed species stands. When the age of trees that die is relatively low compared with the age at which trees of a particular species usually become senescent, it suggests that some pest, pathogen, or other forest health problem may be affecting the forest.

RESULTS AND DISCUSSION

The MRATIO values are shown in figure 5.2. Table 5.2 shows the tree species experiencing the greatest mortality in ecoregion sections having MRATIOs of 0.6 or greater.

The highest MRATIO occurred in ecoregion section 331F-Western Great Plains (MRATIO = 1.98) in South Dakota and Nebraska, where mortality actually exceeded growth. Other areas of high mortality relative to growth were ecoregion sections 332D-North-Central Great Plains, also in South Dakota and Nebraska, (MRATIO = 0.82), 232D-Florida Coastal Lowlands (MRATIO = 0.72), 255D-Central Gulf Prairie and Marshes in eastern Texas (MRATIO = 0.70), and 251B-North Central Glaciated Plains, which stretch from southeastern North Dakota to central Iowa (MRATIO = 0.62).

The results of the analysis of the relative sizes of trees that died to those that lived, the DDLD ratio, are shown in table 5.3. The DDLD ratio is a plot-level indicator, so we obtained summary statistics for the ecoregions where mortality relative to growth was highest. In all cases the mean and median DDLDs were rather close to one, meaning that the trees that died were similar in size to the trees that survived. However, there were some plots with extremely high DDLD values. Interestingly, the same pattern of mean and median DDLD close to one and some high DDLD values was observed in nearly all ecoregion sections, regardless of the overall mortality level. So the DDLD analyzed at the ecoregion scale is not very revealing.

In three of the ecoregion sections exhibiting highest mortality relative to growth (331F-Western Great Plains, 332D-North-Central Great Plains, and 251B-North Central Glaciated Plains), the predominant vegetation is grassland, and there were few forested plots measured. Tree growth rates in these regions (especially in ecoregion section 331F) are quite low, so

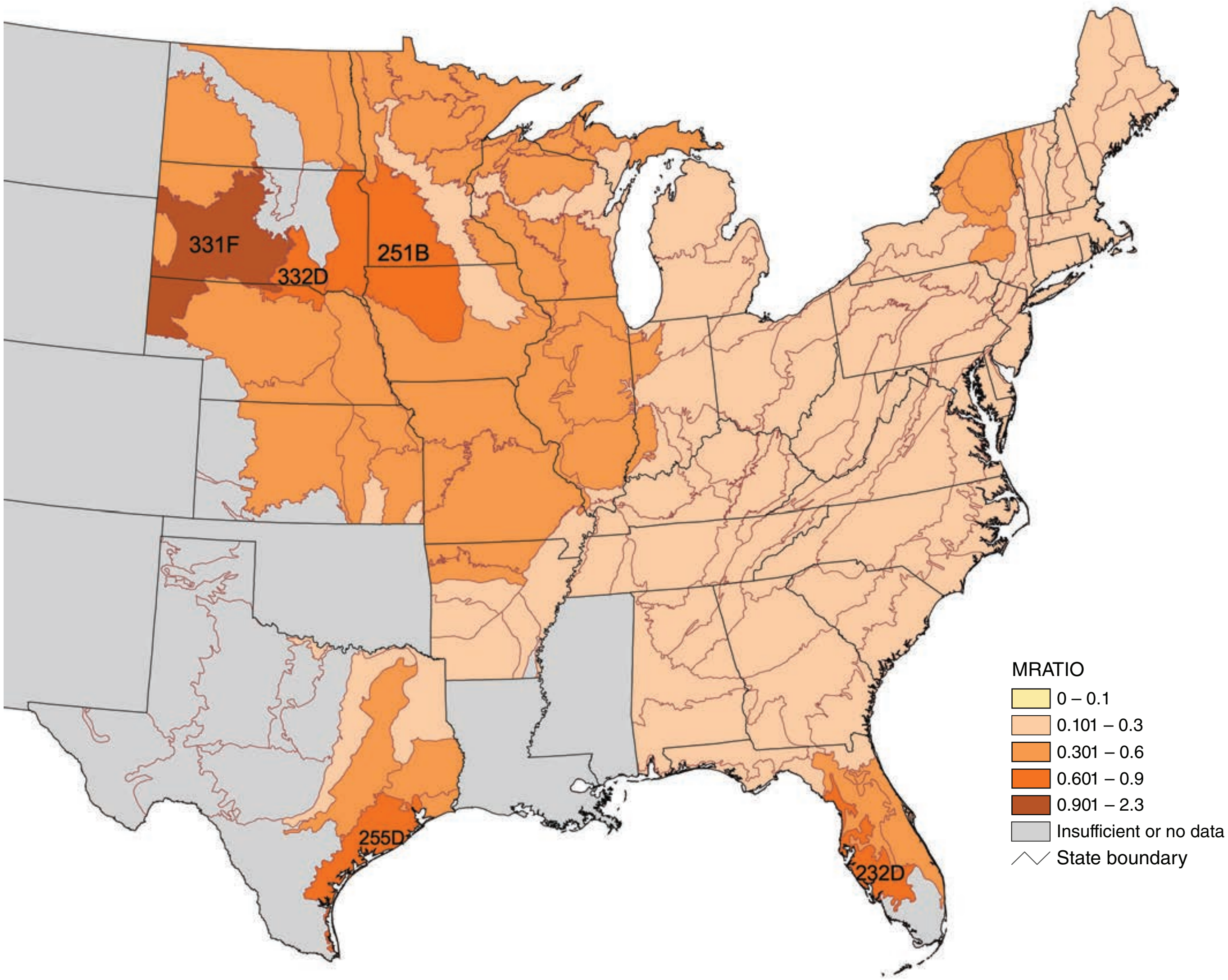

Figure 5.2—Tree mortality expressed as the ratio of annual mortality of woody biomass to gross annual growth in woody biomass (MRATIO) by ecoregion section (Cleland and others 2007). (Data source: USDA Forest Service, Forest Inventory and Analysis Program.)

Table 5.2—Tree species responsible for at least 10 percent of the mortality (in terms of biomass) for ecoregions where the MRATIO was 0.60 or greater

Ecoregion section	MRATIO	Tree species	Percent of total ecoregion mortality biomass	Mean age of dead trees[a]	Species percent mortality (biomass)	(stems)
331F-Western Great Plains	1.98	Ponderosa pine (*Pinus ponderosa*)	51.21	76	5.51	12.02
		Green ash (*F. pennsylvanica*)	25.48	42	21.80	22.48
332D-North-Central Great Plains	0.82	Bur oak (*Quercus macrocarpa*)	29.35	74	4.99	5.33
		Hackberry (*Celtis occidentalis*)	19.33	60	11.98	6.25
		Green ash (*F. pennsylvanica*)	15.26	77	13.21	19.68
		Ponderosa pine (*P. ponderosa*)	10.91	59	8.18	43.48
232D-Florida Coastal Lowlands	0.72	Live oak (*Quercus virginiana*)	12.44	56	14.42	15.19
		Slash pine (*Pinus elliotii*)	12.25	39	7.61	13.79
255D-Central Gulf Prairie and Marshes	0.70	Loblolly pine (*Pinus taeda*)	26.70	66	8.23	6.80
		Pecan (*Carya illinoensis*)	23.54	60	48.30	28.08
		Water oak (*Quercus nigra*)	21.37	48	21.32	21.48
251B-North Central Glaciated Plains	0.62	American elm (*Ulmus americana*)	35.43	54	32.24	26.12
		Bur oak (*Q. macrocarpa*)	12.30	106	4.65	4.30

[a]Ages are estimated from the stand age as determined by the FIA field crew. It is possible that the age of individual trees that died differed significantly from the stand age, especially in mixed-species stands.

Table 5.3 —Dead diameter live diameter (DDLD) ratios for ecoregion sections where the MRATIO was 0.60 or greater

Ecoregion section	Mean DDLD	Maximum DDLD	Median DDLD	Minimum DDLD	MRATIO
255D-Central Gulf Prairies and Marshes	1.29	3.16	1.16	0.28	0.70
232D-Florida Coastal Lowlands	1.13	7.66	0.90	0.22	0.72
251B-North Central Glaciated Plains	1.00	4.44	0.74	0.12	0.62
331F-Western Great Plains	0.98	3.29	0.91	0.22	1.98
332D-North-Central Great Plains	0.89	1.83	0.96	0.29	0.82

the high MRATIOSs are due to a combination of low growth and high mortality. Most of the forest in these sections is riparian forest, and, indeed, most of the species experiencing greatest mortality (table 5.2) are commonly found in riparian areas. The one exception was high ponderosa pine mortality in ecoregion section 331F-Western Great Plains. Ponderosa pine is not typically a part of the plains ecosystem, so one suspects that the pine mortality is occurring on plots close to ecoregion section M334A-Black Hills (perhaps on plots actually in the Black Hills but included in ecoregion section 331F-Western Great Plains due to mapping error).

DDLD values vary widely within each of these sections. There are a small number of plots with high DDLDs, and these plots represent most of the biomass that died in these sections. However, on many of these plots the overall level of mortality is fairly low, as would be the case when remnant larger trees die, leaving young, vigorous stands behind. Tree growth is generally slow in these ecoregion sections because of naturally dry conditions. Where the number of sample plots is small and tree growth is slow, care must be taken in interpreting mortality relative to growth over short time intervals.

In ecoregion section 331F-Western Great Plains, where the MRATIO was highest (MRATIO = 1.98), by far the largest amount of biomass that died was ponderosa pine (table 5.2); however, this represented a relatively small proportion of the ponderosa pine in the ecorgion. Green ash, which made up only half as much of the ecoregion mortality as ponderosa pine, suffered a much larger proportional loss of the total ash stock (about 22 percent of both biomass and stems). This suggests that ash may be suffering from much more serious forest health issues than pine in this ecoregion.

In ecoregion section 332D-North-Central Great Plains, four species experienced the highest total mortality in terms of biomass and together represent about 75 percent of the mortality in the ecoregion: bur oak, hackberry, green ash, and ponderosa pine. Of these, hackberry and green ash suffered the greatest proportional loss of biomass (11.98 and 13.21 percent, respectively). The relatively high mean age of the dead trees suggests that the mortality is at least partially due to senescence of older stands.

One might be tempted to suspect the invasive insect, the emerald ash borer as the cause of the ash mortality in ecoregion sections 331F-Western Great Plains and 332D-North-Central Great Plains. However, this pest had not yet been reported in or near these regions as of the time that the mortality data were collected or the time of this writing (USDA Forest Service and others 2011, N.d.). More likely possible causes of the ash mortality include ash yellows (Pokorny and Sinclair 1994), environmental conditions, or simply senescence of older stands.

In ecoregion section 232D-Florida Coastal Lowlands, live oak and slash pine each represented about 12 percent of the mortality. The causes are unclear. Researchers in Florida are investigating pests that effect slash pine (southern pine beetle) and oak (variable oakleaf caterpillar). However, these research and monitoring efforts are focused in northern Florida, not in most of the area experiencing high mortality (Florida Department of Agriculture and Consumer, Division of Forestry 2009).

In ecoregion section 255D-Central Gulf Prairie and Marshes in eastern Texas, most of the mortality occurred in loblolly pine, pecan, and water oak. Of these, pecan suffered the largest proportional loss (48.3 percent of biomass and 28.08 percent of stems). The causes of this mortality are not readily apparent. In the case of water oak, one might suspect oak wilt, which is a major problem in much of Texas. However, oak wilt has not been confirmed in much of this ecoregion (Appel and others 2008).

In ecoregion section 251B-North Central Glaciated Plains, by far the largest amount of biomass that died was American elm. Elm also suffered the largest proportional loss, in terms of both biomass (32.24 percent) and number of stems (26.12 percent). Dutch elm disease is the suspected cause. The pathogen which causes it is known to occur throughout the Midwest, including every county of Iowa since 2002 (Feeley 2010). Dutch elm disease has severely affected riparian forests in North Dakota (North Dakota Forest Service 2007). The disease is also reported to be a problem in Minnesota (Minnesota DNR 2009) and nearby Illinois (Illinois DNR 2009).

The mortality pattern shown in these analyses do not immediately suggest large-scale forest health issues. Mortality is rather low in most of the areas for which data are available. The areas of highest mortality occur in the mostly riparian forests of several plains ecoregions. Further study of the health of these forests may be warranted. Further investigation may also be warranted into the causes of mortality in the Gulf Coast ecoregions of Florida and Texas.

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