CHAPTER 4.
Tree Mortality

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INTRODUCTION

Tree mortality is a natural process in all forest ecosystems. However, extremely high mortality also can 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 forests in a region is made up of older, senescent stands.

In early national reports by 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 (nearly 10 years for some States), but the sample was not spatially intense (approximately one plot per 96,000 acres). In the 2008 and 2009 FHM national reports (Ambrose 2012a, Ambrose 2012b), the same method was applied to FIA phase 2 data from the relatively small number of States in the Eastern United States where repeated plot measurements had been taken. In this report, the method is applied to most of the Central and Eastern United States, using phase 2 data from repeated measurements in a much larger number of States.

The FHM mission 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 nonspecific or multiple-host 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 or direct concern over forest resource production and availability.

At this point a mortality baseline is still being established for most of the United States using the first two cycles of annualized data (i.e., the first two measurements of each plot). To discern trends in mortality rates, a minimum of three cycles of FIA data are required.[2] With at most two cycles of data currently available, it is only possible to do a spatial comparison of ecoregions and identify regions of higher than average mortality (relative to growth) for further study.

[2] In theory, one could estimate changes or trends in mortality rates using just two cycles of data by comparing, for example, plots measured in 2000 and 2005 with those measured in 2001 and 2006, those measured in 2002 and 2007, and so on. However, we choose not to do so because estimating mortality rates independently for each panel of data reduces the effective sample intensity by a factor of five and because an analysis of mortality rates using heavily overlapping time periods will be unlikely to detect subtle changes in mortality rates.

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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 being measured each year. A single cycle of measurements consists of measuring all panels. This annualized method was phased in, State by State, beginning in 1999. Initially, a 5-year measurement cycle was instituted in the East and a 10-year cycle in the West. However, some Southeastern States later adopted a 7-year cycle. Any analysis of mortality requires data collected for at least 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).

Once all phase 2 plots have been remeasured in a State, mortality estimates generally will be based on a sample intensity of approximately 1 plot for 6,000 acres of forest.[3] However, at this time not all plots have been remeasured in most of the States included in this analysis. When not all plots have been remeasured, mortality estimates are based on a lower effective sample intensity. Table 4.1 shows the 28 States from which consistent, repeated FIA phase 2 measurements

[3] In some States, more intensive sampling has been implemented. See table 4.1 for details.

Table 4.1—States from which repeated Forest Inventory and Analysis (FIA) phase 2 measurements were available, the time period spanned by the data, and the number of panels of data available. Each panel represents approximately one-fifth of the plots in a State[a]

Time period	States	Number of phase 2 panels
1999-2008	ME	5
1999-2008	MN, MO, WI	4[b, c, d]
2000-2008	IA, IN, MI, PA	4
2000-2008	VA	3[e]
2001-2007	GA, TN	2
2001-2008	OH	2
2001-2008	AL, IL, KS, NE, ND, SD, TX[f]	3
2002-2007	AR, KY, SC	1
2002-2008	NY	1
2002-2008	NH	2
2003-2008	CT, MA, RI, VT	1

[a]States are listed by standard abbreviation.
[b]In Minnesota and Wisconsin, the phase 2 inventory was done at twice the standard FIA sample intensity, approximately 1 plot per 3,000 acres when the full five panels are measured.
[c]In Missouri, the phase 2 inventory was done at twice the standard FIA sample intensity, approximately one plot per 3,000 acres when the full five panels are measured, on national forest lands and at the standard intensity on all other lands.
[d]In Minnesota, Missouri, and Wisconsin, the field season often begins late in the calendar year, so while the earliest data are from 1999, they do not represent a separate panel but are part of the panel mostly measured in 2000.
[e]Only a small proportion of the plots measured in Virginia in 2000 used the current national standard plot design, so just slightly more than three full panels of remeasurement data were available for this analysis.
[f]Annualized growth and mortality data were only available for eastern Texas.

were available, the time period spanned by the data, and the effective sample intensity, based on the cycle length and the number of remeasured panels. The States included in this analysis, as well as the forest cover within those States, are shown in figure 4.1.

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 2005) 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 making estimates with data for which not all plots have been measured over identical time intervals (Gregoire and others 1995). MRATIOs were then calculated from the growth and mortality rates. For details on the method, see appendix A—Supplemental Methods in Coulston and others (2005b), and see appendix A—Supplemental Methods in 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 (insects or pathogens) 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 live tree diameter (DDLD ratio) was calculated for each plot where mortality occurred. Low DDLD ratios (much less than 1), i.e., small dead trees compared with the surviving trees, usually indicate competition-induced mortality typical of young, vigorous stands, while high ratios (much greater than 1), i.e., large dead trees compared with the surviving trees, indicate mortality associated with senescence or some external factors such as insects or disease (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 (plot-level) 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.

To further analyze tree mortality, the number of stems and the total biomass of trees that

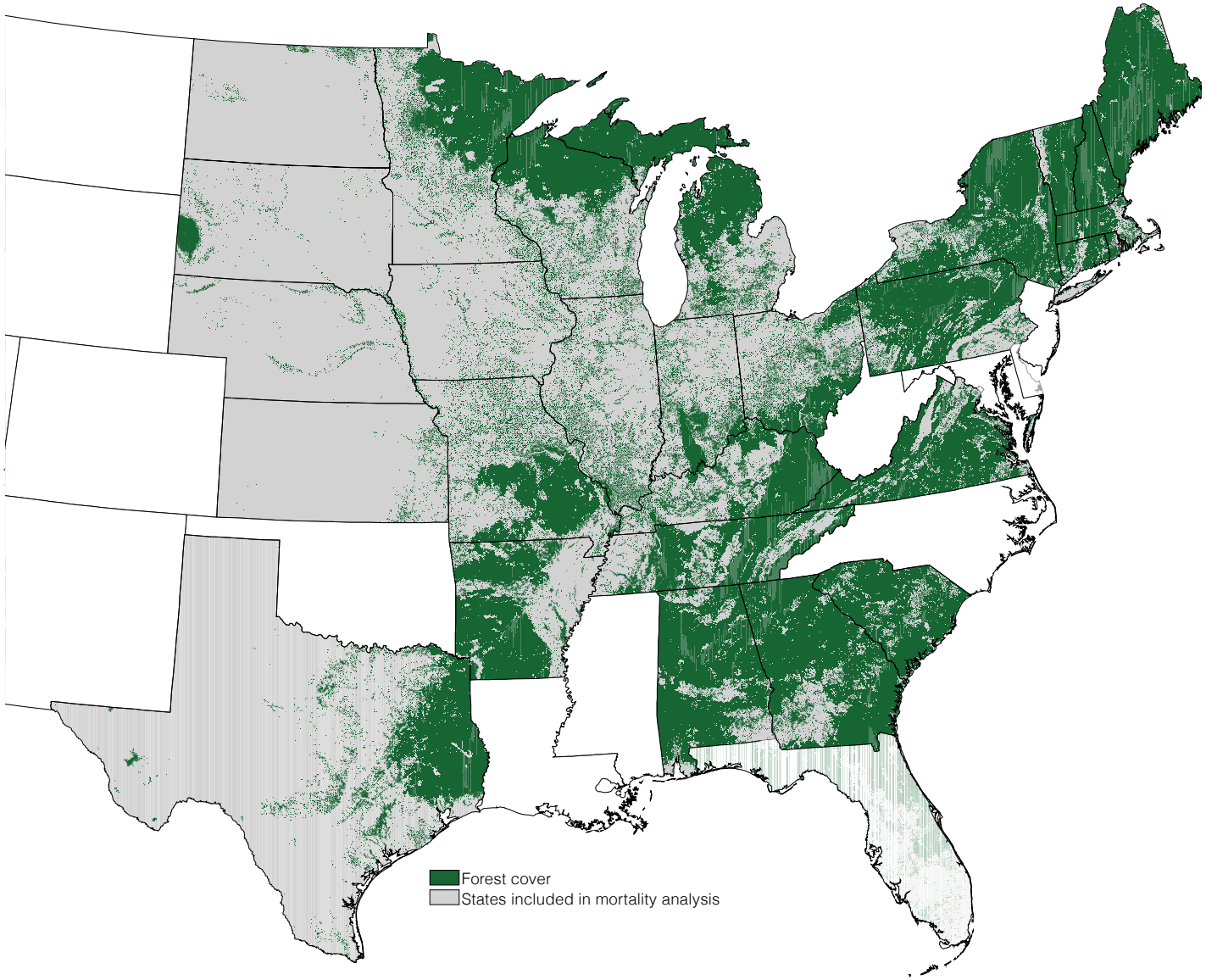

Figure 4.1—Forest cover in the States where mortality was analyzed. Forest cover was derived from Advanced Very High Resolution Radiometer satellite imagery (Zhu and Evans 1994).

died also were calculated by species within each ecoregion. Identifying the tree species experiencing high mortality in an ecoregion is a first step in identifying what forest health issue or issues 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.

RESULTS

The MRATIO values are shown in figure 4.2. The highest MRATIOs occurred in ecoregion sections 332C-Nebraska Sand Hills (MRATIO = 1.38) and 331F-Western Great Plains (MRATIO = 1.36), where mortality exceeded growth. Other areas of extremely high mortality relative to growth occurred in 332A-Northeastern Glaciated Plains (MRATIO = 0.98), 251B-North Central Glaciated Plains (MRATIO = 0.85), 251C-Central Dissected Till Plains (MRATIO = 0.84), and 332E-South Central Great Plains (MRATIO = 0.78). Mortality was also very high in 255D-Central Gulf Prairies and Marshes in southeastern Texas (MRATIO = 0.64) and M211D-Adirondack Highlands in New York (MRATIO = 0.61). In interpreting these MRATIOs, one must remember that the MRATIO is an ecoregion-level indicator. The mortality which produces a high MRATIO may be spatially concentrated within a region.

The results of the analysis of the relative sizes of trees that died, the DDLD ratio, are shown in figure 4.3. The DDLD ratio is a plot-level indicator and is so represented in the figure. However, with the density of FIA phase 2 plots, overlap of plot values represented on a national-scale map can give a misleading impression, so close-up views of the Upper Midwest, the Northeast, and the Southeast are also provided.

These figures show that even in areas of high mortality relative to growth, there was no mortality on most sample plots. However, on the plots where mortality occurred, the trees were large compared with surviving trees, suggesting the mortality is related to either senescence of older stands or some insect or disease issue.

In the three ecoregion sections exhibiting highest mortality relative to growth [332C-Nebraska Sand Hills, 331F-Western Great Plains (South Dakota and Nebraska), and 332A-Northeastern Glaciated Plains (North Dakota)], the predominant vegetation is grassland, and there were very few forested plots measured. Tree growth rates in these regions (especially in 331F) are quite low, so 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, many of the species experiencing greatest mortality (table 4.2) are commonly found in riparian areas.

In ecoregion section 332C-Nebraska Sand Hills, where the MRATIO was highest, by far the largest amount of biomass that died was eastern cottonwood (table 4.2); more than half of the cottonwood biomass and more than one-third of the cottonwood stems had died by the end of the analysis period.

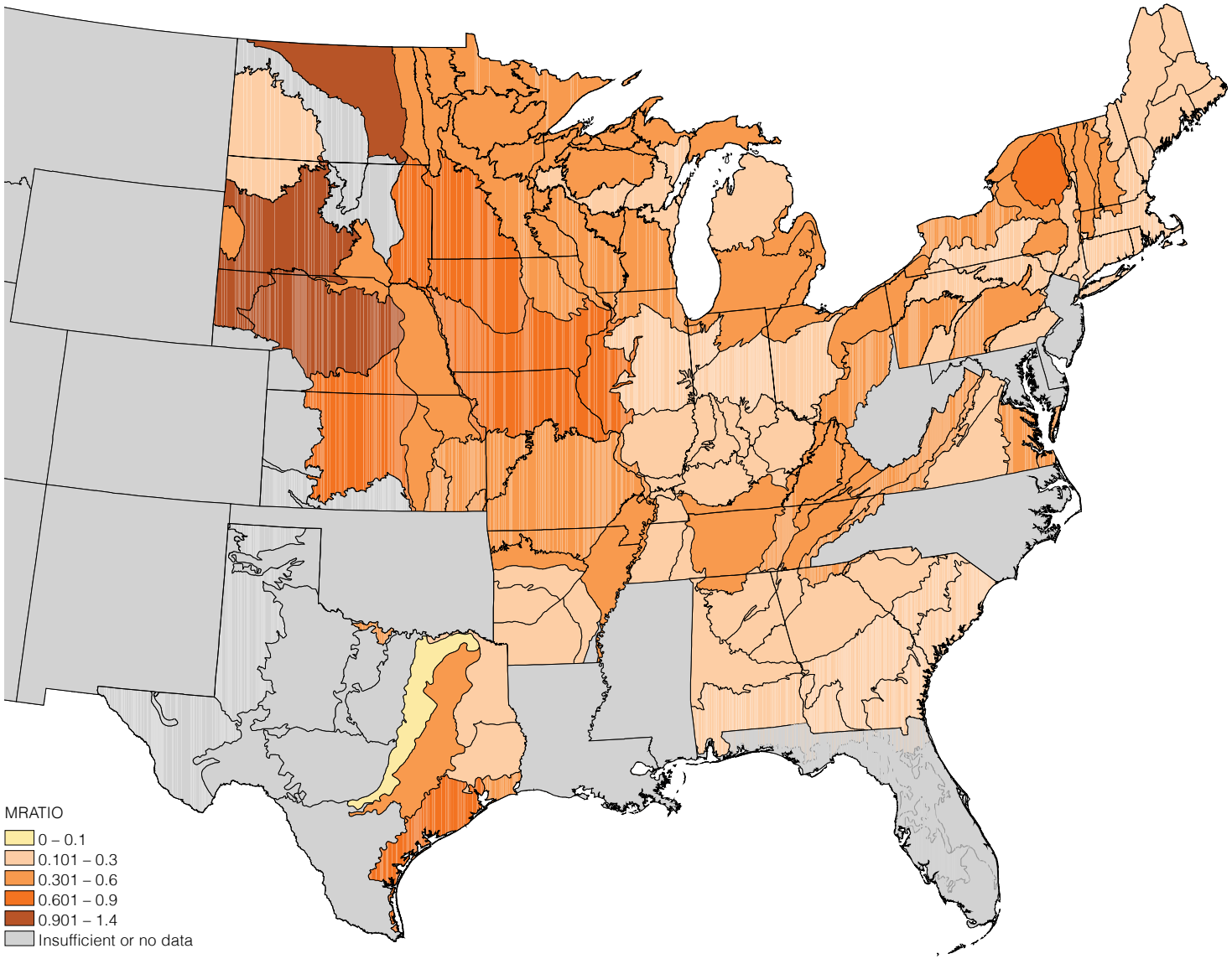

Figure 4.2—Tree mortality expressed as the ratio of annual mortality of woody biomass to gross annual growth in woody biomass (MRATIO) by ecoregion section (Cleland and others 2005). (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

Figure 4.3—The ratio of average dead tree diameter to average surviving tree diameter (DDLD) on each plot at the time of its last measurement: (A) Eastern United States, (B) upper Midwest, (C) Northeast, (D) Southeast. Dot sizes are scaled relative to the biomass that died on each plot. Plot locations are approximate. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

Table 4.2—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
332C-Nebraska Sand Hills	1.38	Eastern cottonwood (*Populus deltoides*)	56.33	54	55.59	35.46
		Green ash (*Fraxinus pennsylvanica*)	10.22	67	14.65	13.67
331F-Western Great Plains	1.36	Ponderosa pine (*Pinus ponderosa*)	37.73	80	4.90	8.81
		Green ash (*F. pennsylvanica*)	32.77	42	21.80	22.48
332A-Northeastern Glaciated Great Plains	0.98	Quaking aspen (*Populus tremuloides*)	28.97	52	14.53	12.42
		American elm (*Ulmus americana*)	20.08	55	71.29	68.11
		Bur oak (*Quercus macrocarpa*)	19.88	101	7.15	2.25
		Green ash (*F. pennsylvanica*)	17.43	93	11.95	12.48
		Balsam poplar (*Populus balsamifera*)	10.86	45	53.03	74.00
251B-North Central Glaciated Plains	0.85	American elm (*U. americana*)	34.18	56	27.08	30.09
251C-Central Dissected Till Plains	0.84	American elm (*U. americana*)	13.98	52	18.82	22.39
332E-South Central Great Plains	0.78	Hackberry (*Celtis occidentalis*)	27.68	59	15.77	1.68
		Box elder (*Acer negundo*)	11.91	32	22.69	15.40
		Eastern cottonwood (*P. deltoides*)	11.64	62	7.25	17.65
		Green ash (*F. pennsylvanica*)	10.25	49	4.91	4.54
255D-Central Gulf Prairies and Marshes	0.64	Loblolly pine (*Pinus taeda*)	43.77	33	10.53	9.03
		Water oak (*Q. nigra*)	27.14	–	16.67	21.13
M211D-Adirondack Highlands	0.61	American beech (*Fagus americana*)	12.62	83	6.22	11.68
		Red maple (*A. rubrum*)	12.51	77	3.79	13.47
		Sugar maple (*A. saccharum*)	11.49	81	3.13	13.27
		Yellow birch (*Betula alleghaniensis*)	10.99	81	5.01	7.27

– = Data not available
[a]Ages are estimated from the stand age as determined by the Forest Inventory and Analysis (FIA) field crew. It is possible, especially in mixed-species stands, that the age of individual trees that died differed significantly from the stand age. Value may be missing if no stand age was given in the FIA data for most of the plots on which the mortality occurred.

In ecoregion section 331F-Western Great Plains, most of the mortality (37.73 percent in terms of biomass) was ponderosa pine. However this represented only 4.9 percent of the total ponderosa pine biomass. In contrast, green ash, which was 32.77 of total mortality (by biomass) in the ecoregion, suffered about 22 percent mortality, both in terms of biomass and number of stems. This suggests that there may be a more serious forest health issue affecting green ash than pine in that region.

Green ash also represented a large portion of the mortality in ecoregions 332A-Northeastern Glaciated Great Plains (17.43 percent), 332C-Nebraska Sand Hills (10.22 percent), and 332E-South Central Great Plains (12.25 percent). The cause of this mortality is not immediately apparent. One might be tempted to suspect the invasive insect, the emerald ash borer. However, this pest has not yet been reported in or near these regions (USDA Forest Service and others, N.d.). In ecoregion 332A-Northeastern Glaciated Great Plains, the age of the dead trees (table 4.2) suggests that older, senescent stands may be dying.

American elm was the only species that represented more than 10 percent of the mortality (by biomass) in ecoregions 251B-North Central Glaciated Plains (34.18 percent) and 251C-Central Dissected Till Plains (13.98 percent), which together stretch from southeastern North Dakota to western Illinois. American elm was also 20.08 percent of the mortality in ecoregion 332A-Northeastern Glaciated Great Plains. 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 Illinois (Illinois Department of Natural Resources 2009) and Minnesota (Minnesota Department of Natural Resources 2009).

The mortality pattern shown in these analyses does 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. The causes of the mortality of several of the tree species experiencing high mortality in these regions (including eastern cottonwood in ecoregion 332C-Nebraska Sand Hills and balsam poplar in ecoregion 332A-Northeastern Glaciated Great Plains) are not immediately apparent. Further study of the health of these forests is probably warranted.

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