CHAPTER 5.
Tree Mortality

Mark J. Ambrose

INTRODUCTION

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

The mission of the Forest Health Monitoring (FHM) Program is to monitor, assess, and report on the status, changes, and long-term trends in forest ecosystem health in the United States (FHM 1994). Thus, 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 discernable. 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.

DATA

Mortality is analyzed using Forest Inventory and Analysis (FIA) phase 2 (P2) data. FIA P2 data are collected across forested land throughout the United States, with approximately 1 plot per 6,000 acres of forest, 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, beginning in 1999. Any 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). For this report, the repeated P2 data were available for all of the Central and Eastern States, and data for some States include a third cycle of measurements (i.e., a third measurement of the plots).

Once all P2 plots have been remeasured in a State, mortality estimates generally will be based on a sample intensity of approximately 1 plot per 6,000 acres of forest.[1] However, at this time not all plots have been remeasured in all the States included in this analysis. When not all plots have been remeasured, mortality estimates are based on a lower effective sample intensity. Table 5.1 shows the 37 States from which consistent, repeated P2 measurements were available,

[1] In some States more intensive sampling has been implemented. See table 5.1 for details.

Table 5.1—States from which repeated Forest Inventory and Analysis (FIA) phase 2 measurements were available in 2013, the time period spanned by the data, and the effective sample intensity (based on plot density and proportion of plots that had been remeasured) in the available data sets

Time period	States	Effective sample intensity	Proportion of plots measured three times
1999–2012	IN	1 plot: 6,000 acres	3/5
1999–2012	ME	1 plot: 6,000 acres	4/5
1999–2012	WI	1 plot: 3,000 acres[a]	3/5
1999–2012	MN	1 plot: 3,000 acres[a]	3/5
1999–2012	MO	1 plot: 6,000 acres[b]	3/5
2000–2012	PA, VA	1 plot: 6,000 acres	3/5
2000–2012	IA	1 plot: 6,000 acres	3/5
2000–2012	MI	1 plot: 2,000 acres[c]	3/5
2000–2012	AR	1 plot: 6,000 acres	2/5
2001–2012	OH	1 plot: 6,000 acres	1/5
2001–2012	TX[d]	1 plot: 6,000 acres	4/5
2001–2012	GA, KS, NE	1 plot: 6,000 acres	2/5
2001–2011	TN	1 plot: 6,000 acres	1/5
2001–2012	LA	1 plot: 10,500 acres	0
2001–2012	AL	1 plot: 6,000 acres	0
2001–2012	IL, ND, SD	1 plot: 6,000 acres	2/5
2002–2012	FL	1 plot: 7,500 acres	0
2002–2012	SC	1 plot: 6,000 acres	1/5
2002–2011	KY	1 plot: 7,500 acres	0
2002–2012	NY	1 plot: 6,000 acres	0
2002–2012	NH	1 plot: 6,000 acres	0
2003–2012	CT, MA, RI, VT	1 plot: 6,000 acres	0
2003–2012	NC	1 plot: 10,500 acres	0
2004–2012	DE, MD, NJ, WV	1 plot: 7,500 acres	0
2006–2012	MS	1 plot: 10,500 acres	0
2008–2012	OK[e]	1 plot: 15,000 acres	0

[a] In Minnesota and Wisconsin, the phase 2 inventory was done at twice the standard FIA sample intensity, approximately 1 plot per 3,000 acres.

[b] In Missouri, the phase 2 inventory was done at twice the standard FIA sample intensity, approximately 1 plot per 3,000 acres, on national forest lands, and at the standard intensity of 1 plot per 6,000 acres on all other lands.

[c] In Michigan, the phase 2 inventory was done at triple the standard FIA sample intensity, approximately 1 plot per 2,000 acres.

[d] Annualized growth and mortality data were only available for eastern Texas.

[e] Annualized growth and mortality data were only available for eastern Oklahoma.

the time period spanned by the data, and the effective sample intensity. Also shown is the proportion of plots measured for a third time. The States included in this analysis, as well as the forest cover within those States, are shown in figure 5.1.

Because the data used here are collected using a rotating panel design and all available annualized data are used, the majority of data used in this mortality analysis were also used in the analysis presented in the previous FHM national report (Ambrose 2015). Using the data in this way, it would be very 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 mortality patterns that may be indicative of forest health problems as soon as they become discernable.

METHODS

The methods used in this analysis were developed for earlier FHM national reports (2001–04) using FHM and FIA phase 3 (P3) data. FIA P2 tree (≥5 inches d.b.h.) and sapling (1 inch ≤ d.b.h. < 5 inches) data were used to estimate average annual tree mortality in terms of tons of aboveground biomass per acre. The data were obtained from the public FIA Database-version 5.1 (USDA Forest Service 2011). The biomass represented by each tree was calculated by FIA and provided in the FIA Database (USDA Forest Service 2013). 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 2005b). 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). MRATIOs were then calculated from the growth and mortality rates. For details on the method, see appendix A—Supplemental Methods in the Forest Health Monitoring 2001 National Technical Report (Coulston and others 2005c) and appendix A—Supplemental Methods in the Forest Health Monitoring 2003 National Technical Report (Coulston and others 2005a).

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 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 DDLD values in regions with very low MRATIOs may indicate small

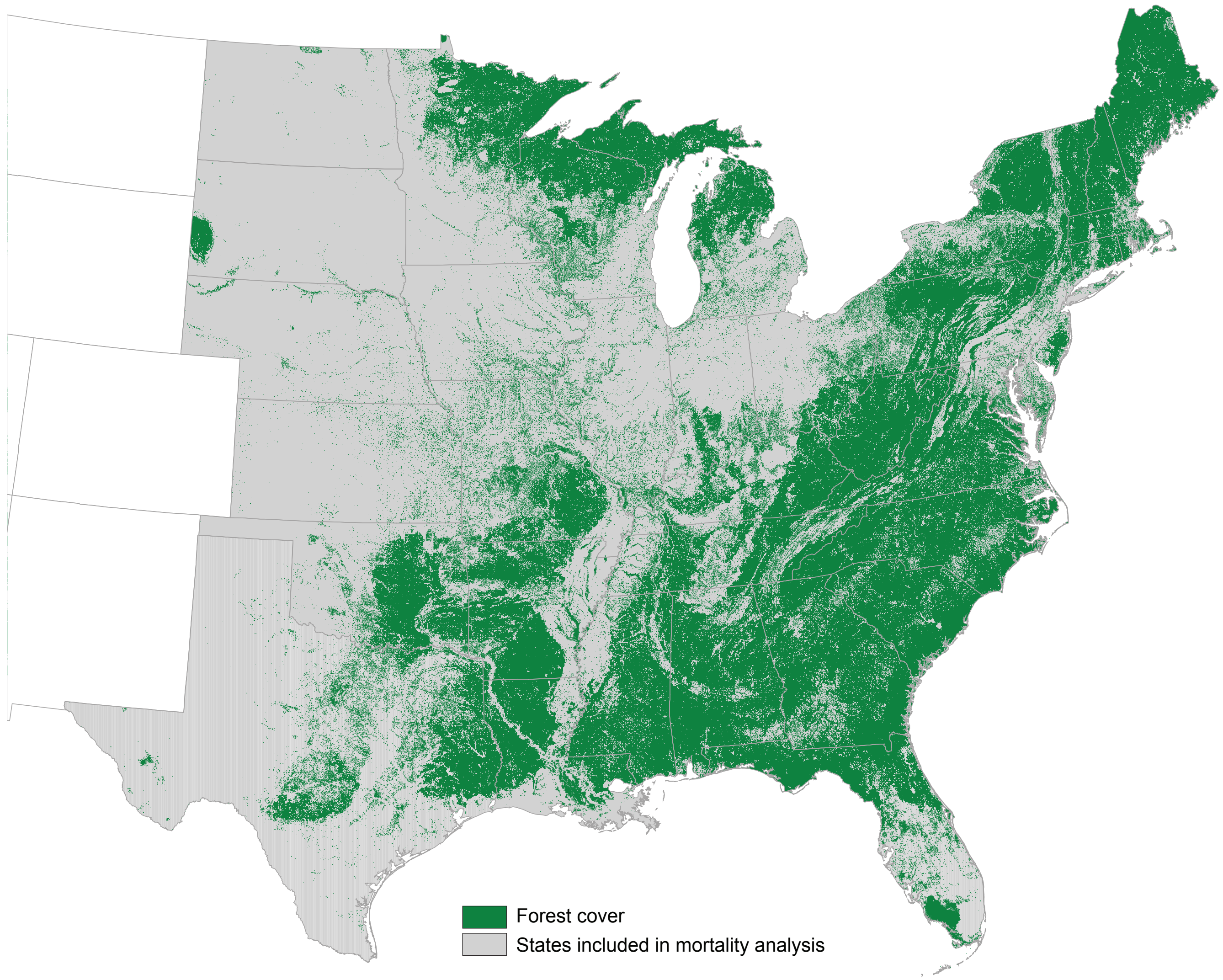

Figure 5.1—Forest cover in the States where mortality was analyzed. Forest cover was derived from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery (USDA Forest Service 2008).

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 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 may be affecting the forests. Although determining particular causal agents associated with all 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.

Finally, a biomass-weighted mean mortality age was calculated by ecoregion and species. For each species experiencing mortality in an ecoregion, 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 the stands in which trees 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. 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 >1 indicates that mortality exceeds growth and live standing biomass is actually decreasing.

The highest MRATIOs occurred in ecoregion sections 331F–Western Great Plains (MRATIO = 1.35) in South Dakota and Nebraska and 332F–South-Central and Red Bed Plains (MRATIO = 1.16) in southern Kansas, where mortality actually exceeded growth. Other areas of high mortality relative to growth were sections 332D–North-Central Great Plains, also in South Dakota and Nebraska (MRATIO = 0.98); M334A–Black Hills (MRATIO = 0.87); 234A–Southern Mississippi Alluvial Plain in Louisiana, Mississippi, and Arkansas (MRATIO = 0.86); and 232E–Louisiana Coastal Prairies and Marshes (MRATIO = 0.69). Table 5.2 shows the tree species experiencing the greatest mortality in those ecoregions.

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 I 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 1, 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

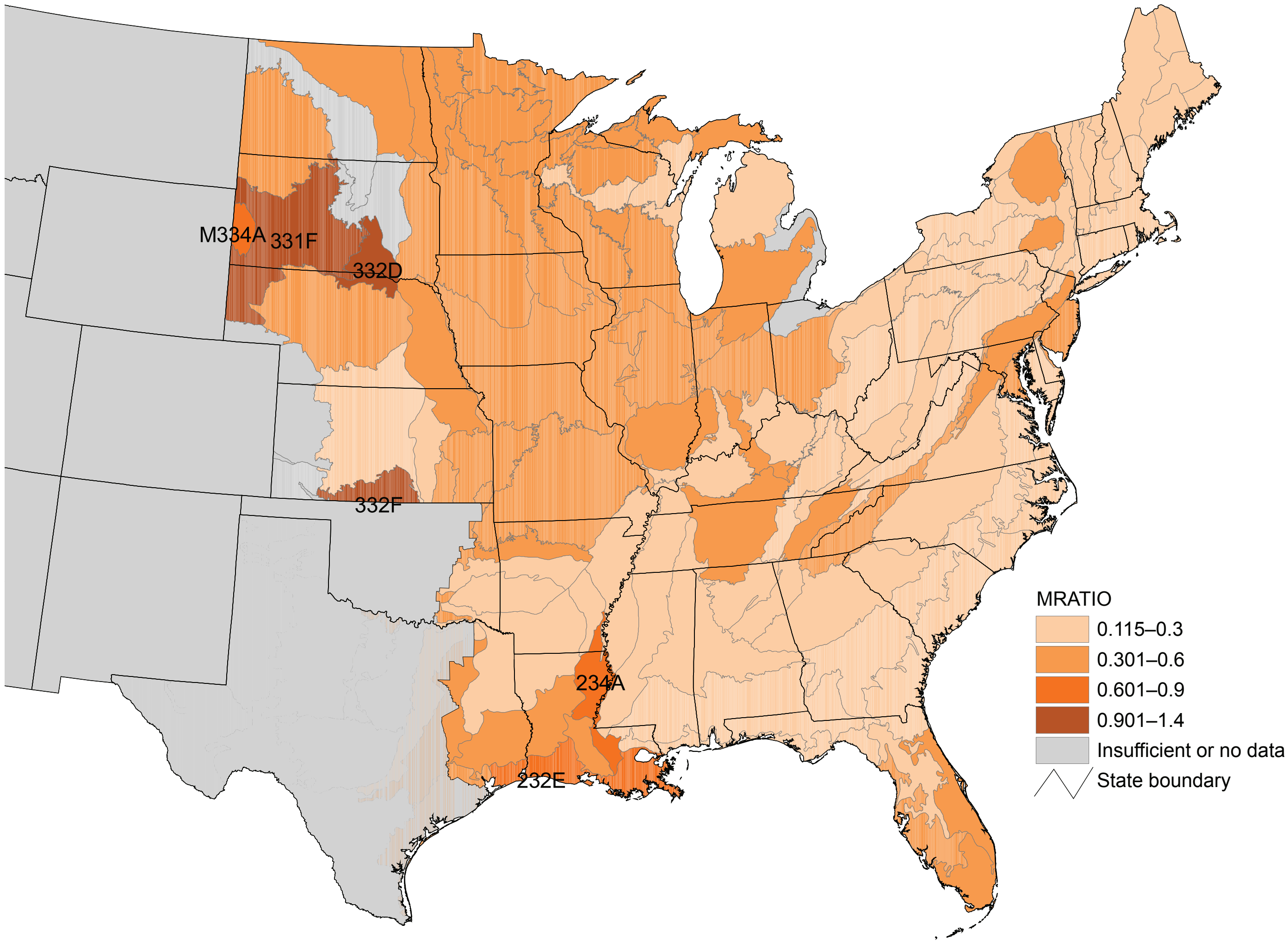

Figure 5.2—Tree mortality expressed as the ratio of annual mortality of woody biomass to gross annual growth in woody biomass (MRATIO) by ecoregion section (Cleland and others 2007). Ecoregions with high MRATIOs are identified by section number. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

Table 5.2—Tree species responsible for least 5 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)	Species percent mortality (stems)
232E–Louisiana Coastal Prairies and Marshes	0.69	Chinese tallowtree *(Sapium sebiferum)*	20.22	29	11.54	13.20
		Laurel oak *(Quercus laurifolia)*	13.89	51	32.49	16.03
		Loblolly pine *(Pinus taeda)*	12.71	26	4.99	7.21
		Willow oak *(Quercus phellos)*	9.86	46	26.89	7.61
		Water oak *(Quercus nigra)*	8.99	35	9.45	15.06
		Swamp chestnut oak *(Quercus michauxii)*	6.73	45	58.53	6.25
234A–Southern Mississippi Alluvial Plain	0.86	Black willow *(Salix nigra)*	73.06	38	68.02	50.75
		Water oak *(Quercus nigra)*	10.41	25	22.19	29.12
331F–Western Great Plains	1.35	Ponderosa pine *(Pinus ponderosa)*	62.50	54	8.36	10.40
		Green ash *(Fraxinus pennsylvanica)*	14.98	44	15.13	12.83
		Eastern cottonwood *(Populus deltoides)*	10.22	61	4.31	21.89
332D–North-Central Great Plains	0.98	Eastern cottonwood *(Populus deltoides)*	23.88	85	10.80	4.50
		American elm *(Ulmus americana)*	19.46	49	26.49	22.00
		Ponderosa pine *(Pinus ponderosa)*	17.65	44	22.18	30.72
		Bur oak *(Quercus macrocarpa)*	12.93	63	3.21	4.87
		Green ash *(Fraxinus pennsylvanica)*	8.80	62	15.15	16.24
		Hackberry *(Celtis occidentalis)*	7.34	60	10.24	0.72
		Eastern redcedar *(Juniperus virginiana)*	5.54	43	3.89	6.90
332F–South-Central and Red Bed Plains	1.16	Eastern cottonwood *(Populus deltoides)*	22.53	37	9.95	5.78
		Black willow *(Salix nigra)*	21.57	55	57.59	62.50
		Black locust *(Robinia pseudoacacia)*	19.49	42	23.59	39.25
		American elm *(Ulmus americana)*	13.78	39	28.11	2.87
		Red mulberry *(Morus rubra)*	6.04	51	3.92	2.05
		Hackberry *(Celtis occidentalis)*	5.88	44	10.22	1.93
M334A–Black Hills	0.87	Ponderosa pine *(Pinus ponderosa)*	83.91	70	5.10	8.08
		Quaking aspen *(Populus tremuloides)*	7.83	74	28.74	28.06

MRATIO = ratio of annual mortality of woody biomass to gross annual growth in woody biomass.

[a] Ages (in years) are estimated from the stand age as determined by the 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.

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
232E–Louisiana Coastal Prairies and Marshes	1.11	2.91	0.85	0.32
234A–Southern Mississippi Alluvial Plain	1.01	3.45	0.70	0.26
331F–Western Great Plains	0.99	3.29	0.92	0.08
332D–North-Central Great Plains	1.04	5.38	0.89	0.15
332F–South-Central and Red Bed Plains	1.17	3.11	1.20	0.14
M334A–Black Hills	1.04	7.02	0.77	0.16

MRATIO = ratio of annual mortality of woody biomass to gross annual growth in woody biomass.

mean and median DDLD close to 1 and some high DDLD values was observed in nearly all ecoregions, regardless of the overall mortality level.

In three of the ecoregion sections exhibiting highest mortality relative to growth (331F–Western Great Plains, 332D–North-Central Great Plains, and 332F–South-Central and Red Bed Plains), the predominant vegetation is grassland (see the forest cover in fig. 5.1), and there were relatively few forested plots measured (98 plots in region 331F, 58 plots in region 332D, and 26 plots in region 332F). Both ecoregions 331F and 332D have had high mortality relative to growth in recent years (Ambrose 2013, 2014, 2015), so the observed mortality is not a new phenomenon. Tree growth rates in these regions (especially in 331F) are quite low, so the high MRATIOs are due to a combination of low growth and high mortality. Much of the forest in these sections is riparian, 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 *(Pinus ponderosa)* mortality in ecoregion section 331F–Western Great Plains. Ponderosa pine is not a riparian tree species, but like the riparian species, it only occurs in a relatively small area of the ecoregion, on discontinuous mountains, plateaus, canyons, and breaks in the plains (Burns and Honkala 1990).

Within the three ecoregions exhibiting the highest mortality relative to growth, DDLD values vary widely. 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 M334A–Black Hills, 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 ecoregion (about 8 percent of ponderosa pine stems and 5 percent of biomass). This pine mortality is very likely related to mountain pine beetle (*Dendroctonus ponderosae*). There has been an ongoing pine beetle outbreak in the Black Hills (South Dakota Department of Agriculture 2011, 2012) and mountain pine beetle mortality has been reported in western Nebraska (Nebraska Forest Service 2011, 2012). In contrast, aspen (*Populus tremuloides*) mortality made up a much smaller portion of total mortality in the ecoregion, but it represented a much higher mortality rate in aspen (about 28 percent of aspen, in terms of both stems and biomass, died). This suggests that aspen may be affected by more serious forest health issues.

In the adjacent ecoregion section 331F–Western Great Plains, where the MRATIO was highest, ponderosa pine also made up the majority of trees that died (63 percent). Here, too, this mortality represented a relatively small proportion of the ponderosa pine (biomass and stems) in the region. Green ash (*Fraxinus pennsylvanica*), which made up less than one quarter of the ecoregion mortality as ponderosa pine, suffered a slightly larger proportional loss of the total ash stock.

In ecoregion section 332D–North-Central Great Plains, seven species experienced high total mortality in terms of biomass and together represent over 90 percent of the mortality in the ecoregion: eastern cottonwood (*Populus deltoides*), American elm (*Ulmus americana*), ponderosa pine, bur oak (*Quercus macrocarpa*), green ash, hackberry (*Celtis occidentalis*), and eastern redcedar (*Juniperus virginiana*) (table 5.2). Of these, ponderosa pine and American elm suffered the largest proportional loss in terms of both biomass and number of stems and, together with eastern cottonwood, made up the largest proportion of total mortality. In the case of hackberry, the mortality in terms of biomass (10.24 percent) was much higher than the mortality in terms of number of stems (0.72 percent), which means that the trees that died were a relatively small number of very large trees. A number of different factors may be responsible for the high mortality in the ecoregion. Drought in 2012, as well as associated winter desiccation, has been reported as affecting much of South Dakota and Nebraska. Dutch elm disease has been responsible for elm mortality in both States as well (South Dakota Department of Agriculture 2012, Nebraska Forest Service 2012). Cedar bark beetles (*Phloeosinus* spp.) and juniper blight have been reported as affecting eastern redcedar in South Dakota (South Dakota Department of Agriculture 2012). Green ash has been affected by ash/lilac borer (*Podosesia* *syringae*) in South Dakota (South Dakota Department of Agriculture 2012). In addition, a variety of insects and disease has been reported as affecting ponderosa pine in South Dakota and Nebraska; their activity may have produced increased mortality in trees stressed by drought conditions.

In ecoregion 332F–South-Central and Red Bed Plains in south-central Kansas, a wide range of species suffered high mortality, including eastern cottonwood, black willow (*Salix nigra*), black locust (*Robinia pseudoacacia*), American elm, red mulberry (*Morus rubra*), and hackberry. It is unlikely that a single pest or pathogen would produce mortality in this range of species. The most likely factor associated with this mortality is drought. Both 2011 and 2012 were extremely dry years in most of Kansas, with the areas of most severe drought including this ecoregion (Kansas Forest Service 2011, 2012). Such severe drought could lead to tree mortality either directly or by stressing the trees so that they succumb to pests or pathogens that would normally be nonlethal.

In section 232E–Louisiana Coastal Prairies and Marshes, the species experiencing the highest mortality was Chinese tallowtree (*Sapium sebiferum*). This species is an invasive exotic, so the tallowtree mortality is not necessarily a bad thing. However, the high mortality may indicate some stressors affecting the forest more generally that may be of concern in the future. The other species having high mortality in the ecoregion include loblolly pine *(Pinus taeda*) and several bottomland oak species. In ecoregion section 234A–Southern Mississippi Alluvial Plain, the species experiencing high mortality were also bottomland species: black willow and water oak (*Quercus nigra*).

Drought may be at least partially responsible for the mortality observed in these two ecoregions. During 2010 and 2011, much of Louisiana, including the areas of ecoregions 234A and 232E, suffered from severe drought (Koch and others 2014; National Climatic Data Center 2012a), and 2011 was the seventh driest year on record in Louisiana. In addition, 2011 was an extremely warm year across much of the continental United States, and Louisiana experienced its warmest summer on record in 2011 (National Climatic Data Center 2012b). Such severe and extended drought may be responsible for tree mortality either directly or by weakening trees so that they succumb to insects or disease that might otherwise be nonlethal.

This analysis shows that in most of the Eastern and Central United States, mortality has been low relative to tree growth. Mortality has been rather low in most of the areas for which data are available. The areas of highest recent mortality occurred in the mostly riparian forests of Great Plains ecoregions. A common characteristic of many of the ecoregions having high mortality, those on the Great Plains, is that they are on the margins of land suitable for forest growth, being very dry. Thus, they tend to be vulnerable to changes in weather patterns that might produce prolonged and/or extreme drought. Other areas having high mortality, those in the Gulf Coast, have much wetter climates but also experienced extreme drought conditions in recent years. A variety of other biotic or abiotic stressors, together with drought, likely have had a role in the mortality observed.

LITERATURE CITED

Ambrose, M.J. 2013. Tree mortality. In: Potter, K.M.; Conkling, B.L, eds. Forest Health Monitoring: national status, trends, and analysis 2011. Gen. Tech. Rep. SRS–185. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 59-68.

Ambrose, M.J. 2014. Tree mortality. In: Potter, K.M.; Conkling, B.L, eds. Forest Health Monitoring: national status, trends, and analysis 2012. Gen. Tech. Rep. SRS–198. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 73-83.

Ambrose, M.J. 2015. Tree mortality. In: Potter, K.M.; Conkling, B.L., eds. Forest Health Monitoring: national status, trends, and analysis 2013. Gen. Tech. Rep. SRS-207. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 71-81.

Bechtold, W.A.; Patterson, P.L., eds. 2005. The enhanced Forest Inventory and Analysis Program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS–80. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 85 p.

Burns, R.M.; Honkala, B.H., tech. coords. 1990. Silvics of North America: Vol. 1, conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture Forest Service. 675 p.

Cleland, D.T.; Freeouf, J.A.; Keys, J.E., Jr. [and others]. 2007. Ecological subregions: sections and subsections for the conterminous United States. In: Sloan, A.M., tech. ed. Gen. Tech. Rep. WO–76. Washington, DC: U.S. Department of Agriculture Forest Service. [Map, presentation scale 1:3,500,000; Albers equal area projection; colored]. [Also available as a Geographic Information System coverage in ArcINFO® format on CD-ROM or online at http://data.fs.usda.gov/geodata/edw/datasets.php. [Date accessed: July 20, 2015].

Coulston, J.W.; Ambrose, M.J.; Riitters, K.H. [and others]. 2005a. Supplemental methods. In: Forest Health Monitoring 2003 national technical report. Gen. Tech. Rep. SRS–85. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 87-92.

Coulston, J.W.; Ambrose, M.J.; Stolte, K.S. [and others]. 2005b. Health and vitality. In: Conkling, B.L.; Coulston, J.W.; Ambrose, M.J., eds. Forest Health Monitoring 2001 national technical report. Gen. Tech. Rep. SRS–81. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 39-82.

Coulston, J.W.; Smith, W.D.; Ambrose, M.J. [and others]. 2005c. Supplemental methods. In: Conkling, B.L.; Coulston, J.W.; Ambrose, M.J., eds. Forest Health Monitoring 2001 national technical report. Gen. Tech. Rep. SRS–81. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 123-140.

Forest Health Monitoring (FHM). 1994. Forest Health Monitoring: a national strategic plan. Research Triangle Park, NC: U.S. Department of Agriculture Forest Service, Forest Health Monitoring Program. 13 p.

Gregoire, T.G.; Schabenberger, O.; Barret, J.P. 1995. Linear modeling of irregularly spaced, unbalanced, longitudinal data from permanent-plot measurements. Canadian Journal of Forest Research. 25: 137-156.

Kansas Forest Service. 2011. Kansas forest health highlights 2011. 4 p. http://fhm.fs.fed.us/fhh/fhh_11/KS_FHH_2011.pdf. [Date accessed: June 10, 2014].

Kansas Forest Service. 2012. Kansas forest health highlights 2012. 5 p. http://fhm.fs.fed.us/fhh/fhh_12/KS_FHH_2012.pdf. [Date accessed: June 10, 2014].

Koch, F.H.; Smith, W.D.; Coulston, J.W. 2014. Drought patterns in the conterminous United States and Hawaii. In: Potter, K.M.; Conkling, B.L., eds. Forest Health Monitoring: national status, trends, and analysis 2012. Gen. Tech. Rep. SRS–198. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 49-72.

McNab, W.H.; Cleland, D.T.; Freeouf, J.A. [and others], comps. 2007. Description of ecological subregions: sections of the conterminous United States [CD-ROM]. Gen. Tech. Rep. WO–76B. Washington, DC: U.S. Department of Agriculture Forest Service. 80 p.

National Climatic Data Center. 2012a. State of the climate - drought - annual 2011. http://www.ncdc.noaa.gov/sotc/drought/2011/13. [Date accessed: July 10, 2012].

National Climatic Data Center. 2012b. State of the climate - national overview - annual 2011. http://www.ncdc.noaa.gov/sotc/national/2011/13. [Date accessed: July 10, 2012].

Nebraska Forest Service. 2011. Nebraska forest health highlights 2011. 5 p. http://fhm.fs.fed.us/fhh/fhh_11/NE_FHH_2011.pdf. [Date accessed: May 1, 2013].

Nebraska Forest Service. 2012. Nebraska forest health highlights 2012. 5 p. http://fhm.fs.fed.us/fhh/fhh_12/NE_FHH_2012.pdf. [Date accessed: June 10, 2014].

Smith, W.D.; Conkling, B.L. 2004. Analyzing forest health data. Gen. Tech. Rep. SRS–77. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 35 p.

South Dakota Department of Agriculture. 2011. South Dakota forest health highlights 2011. 4 p. http://fhm.fs.fed.us/fhh/fhh_11/SD_FHH_2011.pdf. [Date accessed: May 1, 2013].

South Dakota Department of Agriculture. 2012. South Dakota forest health highlights 2012. 5 p. http://fhm.fs.fed.us/fhh/fhh_12/SD_FHH_2012.pdf. [Date accessed: June 10, 2014].

U.S. Department of Agriculture (USDA) Forest Service. 2008. National forest type data development. http://data.fs.usda.gov/geodata/rastergateway/forest_type/index.php. [Date accessed: May 13, 2008].

U.S. Department of Agriculture (USDA) Forest Service. 2011. The Forest Inventory and Analysis database: database description and users manual version 5.1.4 for phase 2. Washington, DC: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program. http://fia.fs.fed.us/library/database-documentation/. [Date accessed: April 4, 2013].

U.S. Department of Agriculture (USDA) Forest Service. 2013. FIA DataMart FIADB version 5.1. [Online database]. Washington, DC: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program. Available: http://www.fia.fs.fed.us/tools-data/default.asp. [Date accessed: March 3, 2014].