CHAPTER 5

Tree Mortality

Mark J. Ambrose

INTRODUCTION

Tree mortality is a natural process in all forest ecosystems. High mortality can be an indicator of forest health problems. On a regional scale, high mortality levels may indicate widespread insect or disease impacts. Regionally high mortality may also occur if a large proportion of the forest in a particular region is made up of older, senescent stands. I present an approach that seeks to detect mortality patterns that might reflect changes to ecosystem processes at large scales. In many cases, the proximate cause of mortality may be discernable. Understanding proximate causes of mortality *may* provide insight into whether the mortality is within the range of natural variation or reflects more fundamental changes to ecological processes.

DATA

I used the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) Phase 2 (P2) data as the basis of the mortality analysis. The FIA P2 data are collected across forested land throughout the United States, with approximately one 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 being 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. The cycle length (i.e., number of years required to measure all plot panels) ranges from 5 to 10 years.

An analysis of mortality requires data collected at a minimum of two points in time. 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 measurements of trees or saplings). In this analysis, I used the most recent cycle of remeasurements for each State and omitted ecoregion sections if there were not at least 50 remeasured plots in the dataset.

Due to the COVID-19 pandemic, FIA data collection slowed during 2020 and 2021. Therefore, although mortality analyses were possible for all of the conterminous United States, no new data were available from any Western States (i.e., the available datasets are the same as those used for the Forest Health Monitoring: National Status, Trends, and Analysis 2021 report). Therefore, for this report, I limited the analysis to States in the Eastern and Central United States. Figure 5.1 shows the States included in the analysis as well as the forested area in those States.[1]

METHODS

The FIA program calculates tree growth, mortality, and removal volume on each plot over the interval between repeated measurements. These values are stored in the FIA Database (version 9.0.1) (Burrill and others 2021). EVALIDator (ver. 1.8.0.01) is FIA's online tool for querying the FIA Database

How to cite this chapter:

Ambrose, Mark J. 2023. Tree mortality. In: Potter, Kevin M.; Conkling, Barbara L., eds. Forest Health Monitoring: national status, trends, and analysis 2022. Gen. Tech. Rep. SRS-273. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 91–101. https://doi.org/10.2737/SRS-GTR-273-Chap5.

---

[1] *For the latest analysis of mortality that includes Western States, see Ambrose and others 2022.*

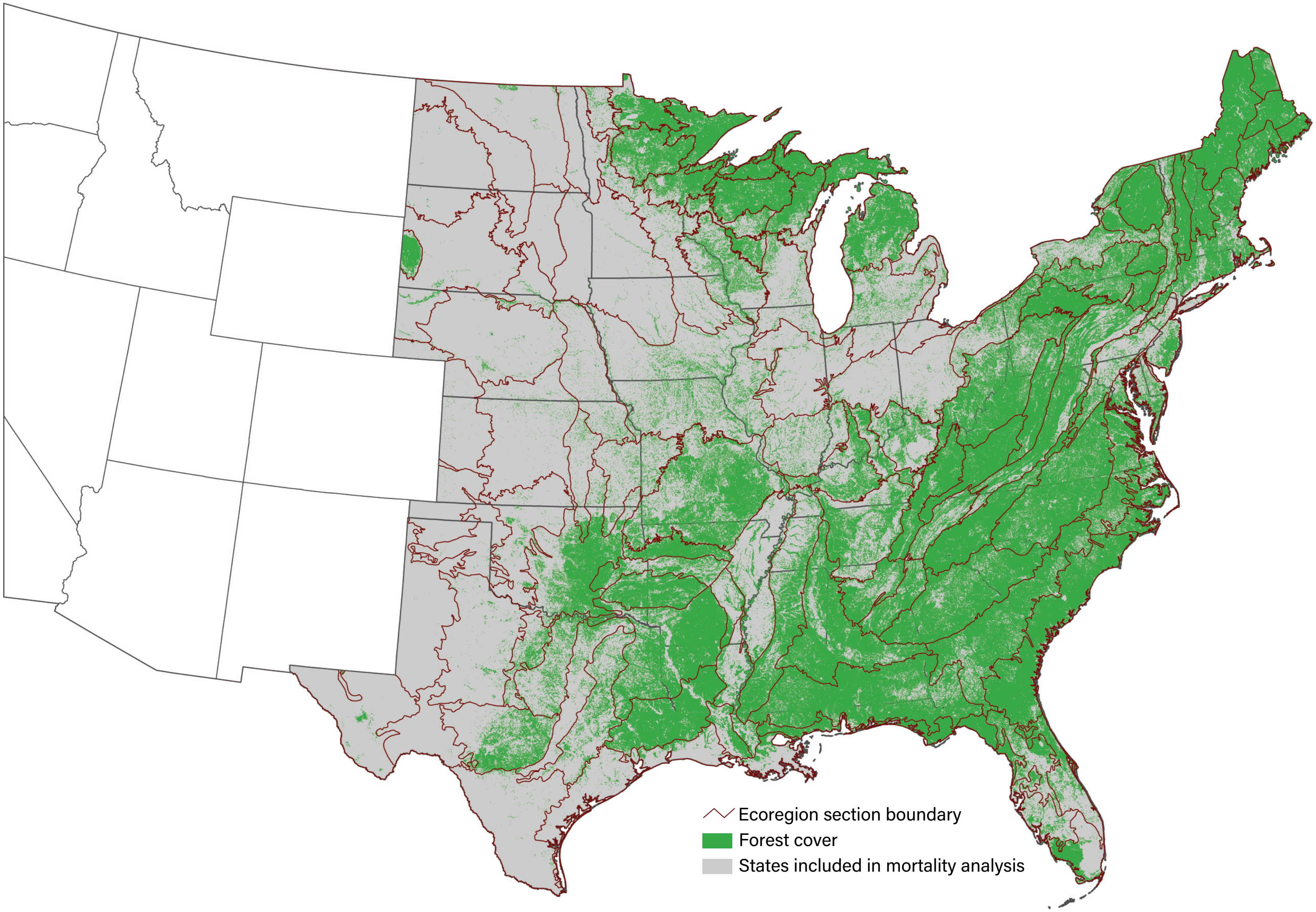

Figure 5.1—Forest cover in the States where mortality was analyzed by ecoregion section (Cleland and others 2007). Forest cover was derived from Moderate Resolution Imaging Spectrometer (MODIS) satellite imagery (USDA Forest Service 2008).

and generating area-based reports on forest characteristics (USDA Forest Service FIA 2019). EVALIDator was used to obtain net growth rates and mortality rates over the most recent measurement cycle for each of 113 ecoregion sections (Cleland and others 2007, McNab and others 2007) covering the Eastern and Central United States. For most States, the most recent cycle of available data ran through 2020[2] (e.g., data collected from 2014 through 2020).

To compare mortality across forest types and climate zones, I used the ratio of annual mortality to gross growth (MRATIO) as a standardized mortality indicator (Coulston and others 2005). The MRATIO has proven to be a useful indicator of forest health, but it can be a problematic indicator, especially when growth rates are very low. The MRATIO can also be difficult to interpret when there is high uncertainty associated with growth estimates.

To identify causal agents for the observed mortality, I also used EVALIDator to summarize mortality by the reported "cause of death" associated with the observed mortality. FIA records causes of death as general categories (e.g., insects, fire, weather). For each ecoregion with a high MRATIO, I used EVALIDator to generate a table of annual mortality volume by FIA species group (Burrill and others 2018) and cause of death. From these tables, it is possible to make reasonable assumptions about the particular insects or diseases that may be affecting certain regions. Care must be used in interpreting these causes because tree mortality may actually be caused by a combination of factors, such as drought and insects. Further information about the causes of mortality is provided by the aerial survey of insects and disease (see ch. 2 in this report). It is difficult to directly match aerial survey data to mortality observed on FIA plots due to both the difference in timing when mortality is recorded and difficulty matching plot locations with aerial survey mortality polygons. However, I have incorporated aerial survey information into the discussion by referencing State Forest Health Highlights, which reflect in large part the results of aerial surveys.

RESULTS AND DISCUSSION

The MRATIO values are shown in figure 5.2. The MRATIO can be large if an overmature 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 (e.g., insects or diseases) or due to generally deteriorating forest health conditions. The ecoregion sections with the highest MRATIOs are labeled on the map in figure 5.2. In the discussion that follows, I focus on the ecoregion sections having MRATIOs >0.6.

The highest MRATIO occurred in ecoregion section M334A–Black Hills (MRATIO = 1.29). The MRATIO was also extremely high in adjacent 331F–Western Great Plains (MRATIO = 0.92) in South Dakota and Nebraska. Other areas of high mortality relative to growth on the Great Plains were in 332A–Northeastern Glaciated Plains (MRATIO = 0.64) in North

---

[2] *Overall, the most recent data available for any State ranged from 2018 to 2021.*

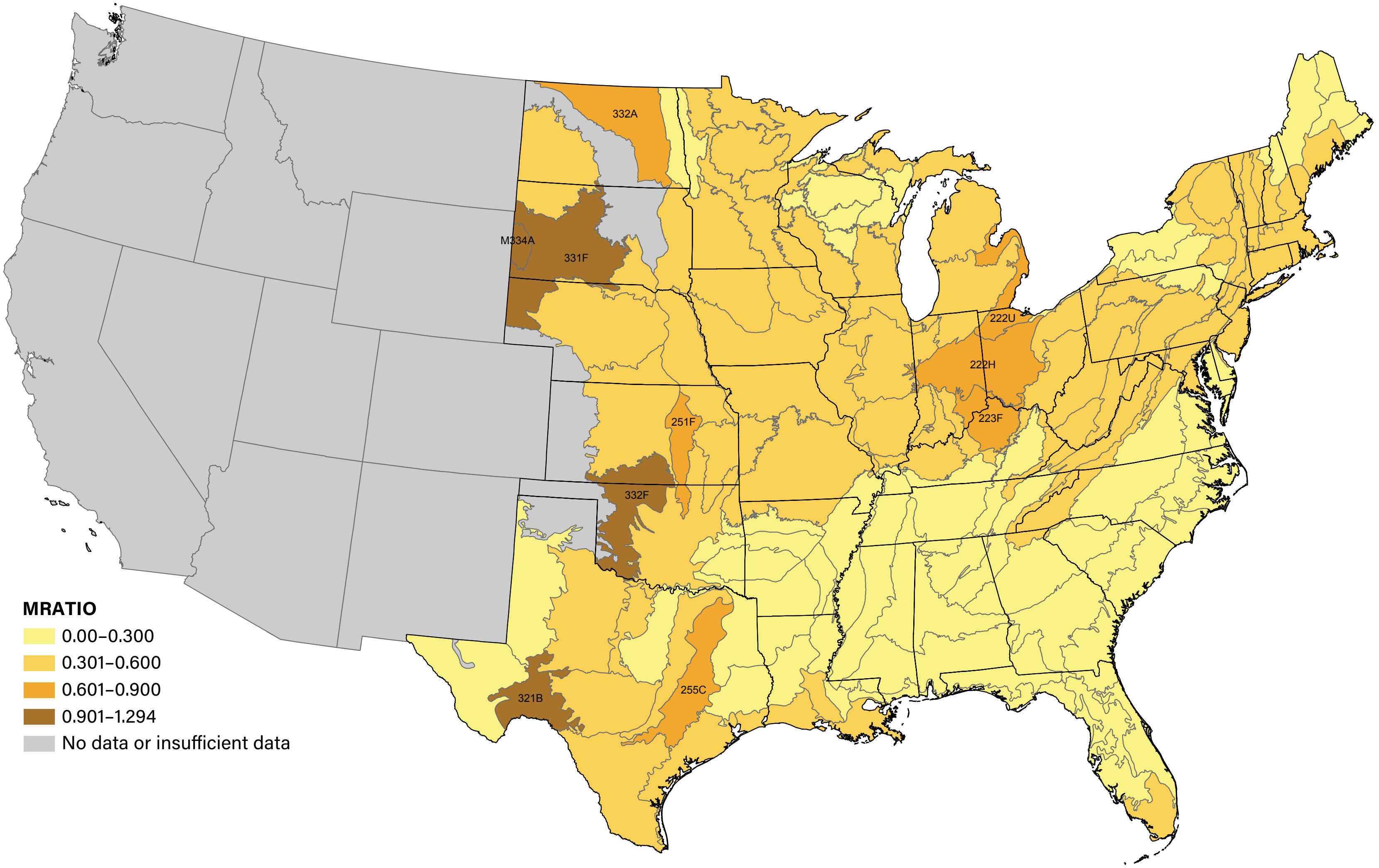

Figure 5.2—Tree mortality expressed as the ratio of annual mortality volume to gross annual growth volume (MRATIO), by ecoregion section (Cleland and others 2007). (Data source: U.S. Department of Agriculture, Forest Service Forest Inventory and Analysis program)

Dakota. In these Great Plains ecoregion sections where mortality is high relative to growth, the predominant vegetation is grassland. Although the ecoregions are quite large, there was relatively little forest land to measure. In the Great Plains, tree growth is generally slow because of naturally dry conditions. Where the number of sample plots is small and tree growth is naturally slow, care must be taken in interpreting mortality relative to growth.

In ecoregion section M334A–Black Hills (MRATIO = 1.29), the vast majority (94 percent) of mortality occurred in the ponderosa and Jeffrey pines species group. For the entire ecoregion section, 75 percent of mortality was caused by insects, while 14 percent was caused by fire (table 5.1); for the ponderosa and Jeffrey pine species group, insects and fire were responsible for 78 percent and 14 percent of mortality, respectively. Mortality in this ecoregion section is most likely related to mountain pine beetle (*Dendroctonus ponderosae*). There had been an ongoing mountain pine beetle outbreak in the Black Hills region (Ball and others 2015, 2016; South Dakota Department of Agriculture 2011, 2012, 2013, 2014). Mountain pine beetle activity has declined dramatically in the region since 2015 (Ball and others 2017, Wyoming State Forestry Division 2017). The pine beetle outbreak has ended, but reported mortality remains high because results reported, based on the most recent cycles of FIA data, reflect mortality over the period that includes the peak of the outbreak in 2015.

In ecoregion section 331F–Western Great Plains (MRATIO = 0.92), fire caused 61 percent of mortality; another 20 percent of mortality was weather-related (table 5.1). In this ecoregion section, most of the mortality (about 87 percent) occurred in the ponderosa and Jeffrey pines species group. In this species group, 62 percent of mortality was due to fire and 22 percent was due to adverse weather; only 8 percent of mortality was related to insects.

The majority of the mortality in ecoregion section 332A–Northeastern Glaciated Plains (MRATIO = 0.64) of North Dakota was split between the cottonwood and aspen (69 percent) and select white oaks (19 percent) species groups. About 30 percent of the mortality overall (table 5.1), 39 percent of mortality in the select white oaks species group, and 26 percent of mortality in the cottonwood and aspen species group was related to adverse weather. North Dakota experienced both drought (North Dakota Forest Service 2017) and heavy precipitation that waterlogged tree root systems (North Dakota Forest Service 2020) during the monitoring period, both of which severely stressed trees. In addition, North Dakota experienced numerous storm events over the past several years, including 435 hail events and 66 tornadoes during the 2015 and 2016 growing seasons. Damage due to hailstorms can make trees susceptible to a number of fungal diseases (North Dakota Forest Service 2015, 2016). Cottonwood canker fungi have been identified as a problem throughout North Dakota (North Dakota Forest Service 2014, 2015); these fungi may be contributing to the observed mortality in the cottonwood and aspen species group. About 18 percent of mortality was attributed to animals; almost all of this occurred in the cottonwood and aspen species group.

Table 5.1—Ecoregion sections in the Eastern and Central United States having the highest mortality relative to growth (MRATIO), annual mortality and growth rates, species groups having the greatest mortality relative to growth, and associated causes of mortality

Ecoregion section	Average annual mortality	Average annual gross growth	MRATIO	Species groups[a] having the highest mortality[b]	Major causes of mortality[c]
	--- cubic feet per year ---				
M334A–Black Hills	47,840,846	36,971,471	1.29	Ponderosa and Jeffrey pines (94%)	Insects (75%), fire (14%)
332F–South Central and Red Bed Plains	18,476,189	19,195,108	0.96	Other eastern soft hardwoods (38%), other eastern softwoods (25%), other eastern hard hardwoods (13%)	Fire (54%), disease (23%), weather-related (23%)
321B–Stockton Plateau	8,830,859	9,587,071	0.92	Western woodland softwoods (92%)	Weather-related (68%), fire (30%)
331F–Western Great Plains	11,539,479	12,592,299	0.92	Ponderosa and Jeffrey pines (87%)	Fire (61%), weather-related (20%)
255C–Oak Woods and Prairie	118,181,937	150,755,567	0.78	Oaksd (46%), loblolly and shortleaf pines (13%)	Weather-related (64%), disease (23%)
223F–Interior Low Plateau-Bluegrass	104,017,750	156,580,166	0.66	Ash (59%), other eastern soft hardwoods (15%)	Insects (55%), vegetation (13%)[e]
222U–Lake Whittlesey Glaciolacustrine Plain	44,342,544	67,606,692	0.66	Ash (65%), other eastern soft hardwoods (13%)	Insects (66%)
332A–Northeastern Glaciated Plains	5,877,224	9,133,469	0.64	Cottonwood and aspen (69%), select white oaks (19%)	Weather-related (30%), animals (18%)
251F–Flint Hills	11,607,118	18,076,691	0.64	Oaks[d] (44%), other eastern soft hardwoods (33%)	Weather-related (39%), insects (14%), disease (14%)
222H–Central Till Plains-Beech-Maple	111,213,566	175,798,966	0.63	Ash (57%), other eastern soft hardwoods (16%)	Insects (55%)

[a] For the species included in each species group, see Appendices E and F in Burrill and others 2018.

[b] The value in parentheses is the proportion of average annual mortality volume in the ecoregion section occurring in the species group.

[c] The value in parentheses is the proportion of average annual mortality volume in the ecoregion section attributed to the causal agent.

[d] Overall mortality has been combined for the Forest Inventory and Analysis select red oaks, select white oaks, other red oaks, and other white oaks species groups.

[e] Mortality caused by suppression, Competition, vines/kudzu (Burrill and others 2018).

Ecoregion section 332F–South Central and Red Bed Plains in Kansas and Oklahoma had the second highest observed MRATIO (0.96). Fifty-four percent of mortality was due to fire, while 23 percent of mortality was attributed to disease and another 23 percent to adverse weather (table 5.1). The region was affected by a severe drought in 2011 as well as additional droughty periods in years that followed (Kansas Forest Service 2012, 2013, 2014; Oklahoma Forestry Services 2014, 2015, 2016, 2020). The species groups in which most of the mortality occurred (other eastern soft hardwoods, other eastern softwoods, and other eastern hard hardwoods) include a large number of unrelated species. Thus, understanding the specific impacts of weather and disease on particular species in this ecoregion would require a more detailed analysis beyond the scope of this report.

In ecoregion section 251F–Flint Hills (MRATIO = 0.64), also in Kansas and Oklahoma, 39 percent of mortality was weather-related, while insects and disease were each responsible for about 14 percent of mortality (table 5.1). The region frequently experiences adverse weather events. In addition to drought, these include hail, tornadoes, high winds, and ice storms (Kansas Forest Service 2020). The highest mortality occurred in the combined oaks species groups (44 percent of the ecoregion section's mortality). Eighty-two percent of mortality in this species group was attributed to adverse weather.

Ecoregion section 255C–Oak Woods and Prairie in Texas also had relatively high mortality (MRATIO = 0.78). About 46 percent of the mortality occurred in the combined oaks species groups, and another 13 percent occurred in the loblolly and shortleaf pines species group. The majority (64 percent) of mortality in this ecoregion section was identified as weather-related (table 5.1). Weather was responsible for 60 and 36 percent of mortality in the combined oaks and loblolly and shortleaf pines species groups, respectively. A record-setting drought in 2011 affected Oklahoma and Texas, and additional droughty periods occurred in following years (Oklahoma Forestry Services 2014, 2015, 2016, 2020). Drought was reported as weakening both pines (*Pinus* spp.) and hardwoods in Texas, making them susceptible to a variety of pests and pathogens (Smith 2013, 2014). Disease was the reported cause of another 23 percent of mortality (table 5.1). Disease was reported as responsible for 36 percent of mortality in the combined oaks species groups; fire was responsible for 57 percent of pine mortality. Oak wilt has been a major problem in oak woodlands in central Texas (Smith 2014; Texas A&M Forest Service 2015, 2016, 2019) and probably contributed to the red and white oak (*Quercus* spp.) mortality in the combined oak species group. Pine engraver beetle (*Ips* spp.) has been a problem in Texas' pine forests and may have contributed to mortality in the loblolly and shortleaf pines species group (Smith 2014; Texas A&M Forest Service 2015, 2016, 2017).

Ecoregion section 321B–Stockton Plateau (MRATIO = 0.92) is a region of extremely low forest cover (fig. 5.1). There, about 68 percent of mortality was related to adverse weather and another 30 percent was due to fire (table 5.1). About 92 percent of mortality occurred in the western woodland softwoods species group; about 70 percent of mortality in this species group was due to weather and 29 percent was due to fire. Most of this mortality probably was related to the previously discussed drought that affected Texas beginning in 2011.

Mortality relative to growth was also rather high (MRATIO = 0.66) in ecoregion section 222U–Lake Whittlesey Glaciolacustrine Plain. There, the majority of the mortality (65 percent) was in the ash species group. About 66 percent of mortality in that ecoregion section was caused by insects (table 5.1), and insects were responsible for 98 percent of ash (*Fraxinus* spp.*)* mortality. Most of this mortality was due to emerald ash borer (*Agrilus planipennis*), which has produced extremely high ash mortality throughout Ohio and Michigan (Michigan Department of Natural Resources 2014, 2015, 2016, 2017; Ohio Department of Natural Resources, Division of Forestry 2014, 2015, 2020). Indeed, emerald ash borer has been "the most devastating forest pest in Ohio in recent years" (Ohio Department of Natural Resources, Division of Forestry 2020) and has caused the death of the "vast majority" of native ash in northwestern Ohio (Ohio Department of Natural Resources, Division of Forestry 2016, 2017).

Similarly, in the adjacent ecoregion section 222H–Central Till Plains-Beech-Maple (MRATIO = 0.63) in Ohio and Indiana, much of the mortality (57 percent) was in the ash species group and 97 percent of ash mortality was due to emerald ash borer[3] (table 5.1). Indeed, emerald ash borer has been confirmed throughout the ecoregion as well as throughout Indiana (Marshall 2017, 2018, 2020; Ohio Department of Natural Resources, Division of Forestry 2016, 2017).

The situation is similar in ecoregion section 223F–Interior Low Plateau-Bluegrass (MRATIO = 0.66) in southern Indiana and Ohio and north-central Kentucky. There, about 54 percent of mortality was in the ash species group. Fifty-five percent of overall mortality in the ecoregion section was attributed to insects, but almost all (94 percent) of ash mortality was due to emerald ash borer.[4] Emerald ash borer has been confirmed throughout the portion of the ecoregion section that is in Kentucky at least since 2016 (Kentucky Division of Forestry 2016).

CONCLUSIONS

This analysis shows that in most of the Eastern and Central United States, mortality is low relative to tree growth. The areas of highest mortality occur in the forests and woodlands of the Great Plains ecoregions. A common

---

[3] *Personal communication. 2022. Philip Marshall, Forest Health Specialist and Director of the Division of Entomology & Plant Pathology, Indiana Division of Forestry, 402 W. Washington St., Indianapolis, IN 46204; Tom Macy, Forest Health Program Manager, Ohio Division of Forestry, 2045 Morse Road Building H1, Columbus, OH 43229.*

[4] *Personal communication. 2022. Philip Marshall, Forest Health Specialist and Director of the Division of Entomology & Plant Pathology, Indiana Division of Forestry, 402 W. Washington St., Indianapolis, IN 46204; Tom Macy, Forest Health Program Manager, Ohio Division of Forestry, 2045 Morse Road Building H1, Columbus, OH 43229; Alexandra Blevins, Forest Health Specialist, Kentucky Division of Forestry, 300 Sower Blvd, Frankfort, KY 40601.*

characteristic of most of the ecoregions having high mortality is that they are on the margins of land suitable for forest growth, being very dry. Thus, they tend to be extremely vulnerable to changes in weather patterns that might produce prolonged and/or extreme drought. Drought, combined with a variety of other biotic and/or abiotic stressors, is responsible for much of the mortality observed.

One insect pest issue, however, does stand out in the East. In ecoregion sections 222H–Central Till Plains-Beech-Maple, 222U–Lake Whittlesey Glaciolacustrine Plain, and 223F–Interior Low Plateau-Bluegrass, ash mortality due to emerald ash borer is extremely high.

It is also important to realize that the analyses presented in this chapter alone cannot tell the complete story regarding tree mortality. Mortality concentrated in highly fragmented forest or nonforest areas adjacent to human development may not be detected because the available FIA data do not cover most urban areas or other places not defined as forest by FIA. Also, these analyses are unlikely to detect a pest or pathogen attacking a particular tree species in a mixed-species forest where other species are growing vigorously. This is especially true of species (e.g., ash) that make up a relatively small proportion of many eastern forests. For example, it is known that emerald ash borer has been causing very high ash mortality in many Eastern and Central States in recent years (Ohio Department of Natural Resources, Division of Forestry 2016; USDA APHIS 2018). Yet, this mortality stands out only in ecoregion sections 222H–Central Till Plains-Beech-Maple, 222U–Lake Whittlesey Glaciolacustrine Plain, and 223F–Interior Low Plateau-Bluegrass. Elsewhere in the East, though ash mortality is known to be extremely high, the mortality currently is masked because ash is a relatively minor component of the forest.

To gain a more complete understanding of mortality, it is important to consider the results of this analysis together with other indicators of forest health. Forest Inventory and Analysis tree damage data (Burrill and others 2021), as well as Evaluation Monitoring projects that focus on particular mortality-causing agents (ch. 8, 10, and 11), can provide insight into smaller scale or species-specific mortality issues. Large-scale analyses of forest-damaging events, including insect and disease activity (ch. 2) and fire (ch. 3), are also important for understanding mortality patterns. This can be especially important in the West, where mortality data are limited.

LITERATURE CITED

Ambrose, M.J.; Hanavan, R.; Smith, T. 2022. Tree mortality. In: Potter, K.M.; Conkling, B.L., eds. Forest Health Monitoring: national status, trends, and analysis 2021. Gen. Tech. Rep. SRS-266. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 101–115. https://doi.org/10.2737/SRS-GTR-266-Chap5.

Ball, J.; Pyser, N.; Warnke, M. 2016. Forest health highlights in South Dakota 2016. Pierre: South Dakota Department of Agriculture, Division of Resource Conservation and Forestry. 6 p. https://www.fs.usda.gov/foresthealth/docs/fhh/SD_FHH_2016.pdf. [Date accessed: August 18, 2022].

Ball, J.; Seidl, A.; Warnke, M. 2017. State of South Dakota forest health highlights. Pierre: South Dakota Department of Agriculture, Division of Resource Conservation and Forestry. 8 p. https://sdda.sd.gov/conservation-forestry/forest-health/SDHighlights_2017-2.pdf. [Date accessed: July 23, 2019].

Ball, J.; Seidl, A.; Warnke, M. 2018. State of South Dakota forest health highlights. Pierre: South Dakota Department of Agriculture, Division of Resource Conservation and Forestry. 12 p. https://sdda.sd.gov/conservation-forestry/forest-health/SDHighlights_2018.pdf. [Date accessed: July 1, 2019].

Ball, J.; Warnke, M.; Garbisch, B. 2015. Forest health highlights in South Dakota 2015. Pierre: South Dakota Department of Agriculture, Division of Resource Conservation and Forestry. 9 p. https://www.fs.usda.gov/foresthealth/docs/fhh/SD_FHH_2015.pdf. [Date accessed: August 18, 2022].

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. https://doi.org/10.2737/SRS-GTR-80.

Burrill, E.A.; DiTommaso, A.M.; Turner, J.A. [and others]. 2021. The Forest Inventory and Analysis Database: database description and user guide for Phase 2 (version 9.0.1). Washington, DC: U.S. Department of Agriculture, Forest Service. 1026 p. https://www.fia.fs.usda.gov/library/database-documentation/. [Date last accessed: December 22, 2022].

Burrill, E.A.; Wilson, A.M.; Turner, J.A. [and others]. 2018. The Forest Inventory and Analysis Database: database description and user guide for Phase 2 (version 8.0). Washington, DC: U.S. Department of Agriculture, Forest Service. 946 p. https://www.fia.fs.usda.gov/library/database-documentation/. [Date last accessed: December 22, 2022].

Cleland, D.T.; Freeouf, J.A.; Keys, J.E. [and others]. 2007. Ecological subregions: sections and subsections for the conterminous United States. Gen. Tech. Rep. WO-76D. Washington, DC: U.S. Department of Agriculture, Forest Service. Map; Sloan, A.M., cartographer; presentation scale 1:3,500,000; colored. https://doi.org/10.2737/WO-GTR-76D.

Coulston, J.W.; Ambrose, M.J.; Stolte. K.S. [and others]. 2005. Criterion 3 – 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. 204 p.

Kansas Forest Service. 2012. Kansas forest health highlights 2012. 5 p. https://www.fs.usda.gov/foresthealth/docs/fhh/KS_FHH_2012.pdf. [Date accessed: August 18, 2022].

Kansas Forest Service. 2013. Kansas forest health highlights 2013. 6 p. https://www.fs.usda.gov/foresthealth/docs/fhh/KS_FHH_2013.pdf. [Date accessed: August 18, 2022].

Kansas Forest Service. 2014. Kansas forest health highlights 2014. 6 p. https://www.fs.usda.gov/foresthealth/docs/fhh/KS_FHH_2014.pdf. [Date accessed: August 18, 2022].

Kansas Forest Service. 2020. Kansas forest health highlights 2020. 21 p. https://www.fs.usda.gov/foresthealth/docs/fhh/KS_FHH_2020.pdf. [Date accessed: August 18, 2022].

Kentucky Division of Forestry. 2016. Kentucky forest health highlights 2016. 12 p. https://www.fs.usda.gov/foresthealth/docs/fhh/KY_FHH_2016.pdf. [Date accessed: August 18, 2022].

Marshall, P.T. 2017. 2017 Indiana forest health highlights. Vallonia, IN: Indiana Department of Natural Resources. 17 p. https://www.in.gov/dnr/forestry/files/fo-Forest_Health_Highlights_2017.pdf. [Date accessed: June 20, 2019].

Marshall, P.T. 2018. 2018 Indiana forest health highlights. Vallonia, IN: Indiana Department of Natural Resources. 17 p. https://www.in.gov/dnr/forestry/files/fo-Forest_Health_Highlights_2018.pdf. [Date accessed: June 20, 2019].

Marshall, P.T. 2020. 2020 Indiana forest health highlights. Vallonia, IN: Indiana Department of Natural Resources. 17 p. https://www.fs.usda.gov/foresthealth/docs/fhh/IN_FHH_2020.pdf. [Date accessed: August 18, 2022].

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. https://doi.org/10.2737/WO-GTR-76B.

Michigan Department of Natural Resources. 2014. 2014 forest health highlights. 51 p. https://www.fs.usda.gov/foresthealth/docs/fhh/MI_FHH_2014.pdf. [Date accessed August 18, 2022].

Michigan Department of Natural Resources. 2015. 2015 forest health highlights. 50 p. https://www.fs.usda.gov/foresthealth/docs/fhh/MI_FHH_2015.pdf. [Date accessed August 18, 2022].

Michigan Department of Natural Resources. 2016. 2016 forest health highlights. 52 p. https://www.fs.usda.gov/foresthealth/docs/fhh/MI_FHH_2016.pdf. [Date accessed: August 18, 2022].

Michigan Department of Natural Resources. 2017. 2017 forest health highlights. 31 p. https://www.fs.usda.gov/foresthealth/docs/fhh/MI_FHH_2017.pdf. [Date accessed: August 18, 2022].

North Dakota Forest Service. 2014. North Dakota forest health highlights 2014. 24 p. https://www.ag.ndsu.edu/ndfs/documents/north-dakota-forest-health-highlights-2014.pdf. [Date accessed: August 18, 2022].

North Dakota Forest Service. 2015. North Dakota forest health highlights 2015. 24 p. https://www.ag.ndsu.edu/ndfs/documents/north-dakota-forest-health-highlights-2015-web.pdf. [Date accessed: August 18, 2022].

North Dakota Forest Service. 2016. Forest health highlights: North Dakota 2016. 4 p. https://www.ag.ndsu.edu/ndfs/documents/north-dakota-forest-health-highlights-2016.pdf. [Date accessed: August 18, 2022].

North Dakota Forest Service. 2017. Forest health highlights: North Dakota 2017. 12 p. https://www.ag.ndsu.edu/ndfs/documents/north-dakota-forest-health-highlights-2017.pdf. [Date accessed: August 18, 2022].

North Dakota Forest Service. 2020. Forest health highlights: North Dakota 2020. 8 p. https://www.fs.usda.gov/foresthealth/docs/fhh/ND_FHH_2020.pdf.[Date accessed: August 18, 2022].

Ohio Department of Natural Resources, Division of Forestry. 2014. 2014 Ohio forest health highlights. 7 p. Columbus, OH: Ohio Department of Natural Resources, Division of Forestry. https://www.fs.usda.gov/foresthealth/docs/fhh/OH_FHH_2014.pdf. [Date accessed August 18, 2022].

Ohio Department of Natural Resources, Division of Forestry. 2015. 2015 Ohio forest health highlights. 8 p. Columbus, OH: Ohio Department of Natural Resources, Division of Forestry. https://www.fs.usda.gov/foresthealth/docs/fhh/OH_FHH_2015.pdf. [Date accessed: August 18, 2022].

Ohio Department of Natural Resources, Division of Forestry. 2016. 2016 Ohio forest health highlights. 8 p. Columbus, OH: Ohio Department of Natural Resources, Division of Forestry. https://www.fs.usda.gov/foresthealth/docs/fhh/OH_FHH_2016.pdf. [Date accessed: August 18, 2022].

Ohio Department of Natural Resources, Division of Forestry. 2017. 2017 Ohio Forest Health Highlights. 7 p. Columbus, OH: Ohio Department of Natural Resources, Division of Forestry. https://www.fs.usda.gov/foresthealth/docs/fhh/OH_FHH_2017.pdf. [Date accessed: July 7, 2019].

Ohio Department of Natural Resources, Division of Forestry. 2020. Ohio Forest Health Highlights 2020. 8 p. Columbus, OH: Ohio Department of Natural Resources, Division of Forestry. https://www.fs.usda.gov/foresthealth/docs/fhh/OH_FHH_2020.pdf. [Date accessed: August 18, 2022].

Oklahoma Forestry Services. 2014. Oklahoma forest health highlights 2014. 5 p. https://www.fs.usda.gov/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: August 18, 2022].

Oklahoma Forestry Services. 2015. Oklahoma forest health highlights 2015. 6 p. https://www.fs.usda.gov/foresthealth/docs/fhh/OK_FHH_2015.pdf. [Date accessed: August 18, 2022].

Oklahoma Forestry Services. 2016. Oklahoma forest health highlights 2016. 6 p. https://www.fs.usda.gov/foresthealth/docs/fhh/OK_FHH_2016.pdf. [Date accessed: August 18, 2022].

Oklahoma Forestry Services. 2020. Oklahoma forest health highlights 2020. 9 p. https://www.fs.usda.gov/foresthealth/docs/fhh/OK_FHH_2020.pdf. [Date accessed: August 18, 2022].

Smith, L.A. 2013. Forest health insects and diseases conditions Texas 2013. Longview, TX: Texas A & M Forest Service. 5 p. https://www.fs.usda.gov/foresthealth/docs/fhh/TX_FHH_2013.pdf. [Date accessed: August 18, 2022].

Smith, L.A. 2014. Forest health highlights in Texas 2014. Longview, TX: Texas A & M Forest Service. 1 p. https://www.fs.usda.gov/foresthealth/docs/fhh/TX_FHH_2014.pdf. [Date accessed: August 18, 2022].

South Dakota Department of Agriculture. 2011. South Dakota forest health highlights 2011. Pierre: South Dakota Department of Agriculture, Division of Resource Conservation and Forestry. 4 p. https://www.fs.usda.gov/foresthealth/docs/fhh/SD_FHH_2011.pdf. [Date accessed: August 18, 2022].

South Dakota Department of Agriculture. 2012. South Dakota 2012 forest health highlights. Pierre: South Dakota Department of Agriculture, Division of Resource Conservation and Forestry. 5 p. https://www.fs.usda.gov/foresthealth/docs/fhh/SD_FHH_2012.pdf. [Date accessed: August 18, 2022].

South Dakota Department of Agriculture. 2013. South Dakota 2013 forest health highlights. Pierre: South Dakota Department of Agriculture, Division of Resource Conservation and Forestry. 5 p. https://www.fs.usda.gov/foresthealth/docs/fhh/SD_FHH_2013. [Date accessed: August 18, 2022].

South Dakota Department of Agriculture. 2014. South Dakota 2014 forest health highlights. Pierre: South Dakota Department of Agriculture, Division of Resource Conservation and Forestry. 7 p. https://www.fs.usda.gov/foresthealth/docs/fhh/SD_FHH_2014.pdf. [Date accessed: August 18, 2022].

Texas A & M Forest Service. 2015. Forest health highlights in Texas 2015. Longview, TX. 1 p. https://www.fs.usda.gov/foresthealth/docs/fhh/TX_FHH_2015.pdf. [Date accessed: August 18, 2022].

Texas A & M Forest Service. 2016. Forest health highlights in Texas 2016. Longview, TX. 1 p. https://www.fs.usda.gov/foresthealth/docs/fhh/TX_FHH_2016.pdf. [Date accessed: August 18, 2022].

Texas A & M Forest Service. 2017. Forest health highlights 2017. Longview, TX. 2 p. https://www.fs.usda.gov/foresthealth/docs/fhh/TX_FHH_2017.pdf. [Date accessed: August 18, 2022].

Texas A & M Forest Service. 2019. Forest health highlights 2019. Longview, TX. 2 p. https://www.fs.usda.gov/foresthealth/docs/fhh/TX_FHH_2019.pdf. [Date accessed: August 18, 2022].

U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS). 2018. Emerald ash borer. https://www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/the-threat/emerald-ash-borer/emerald-ash-borer-beetle. [Date accessed: August 31, 2018].

U.S. Department of Agriculture (USDA) Forest Service. 2008. National forest type dataset. http://data.fs.usda.gov/geodata//rastergateway/forest_type/index.php. [Date accessed: September 13, 2021].

U.S. Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis (FIA). 2019. Forest Inventory EVALIDator web-application. Version 1.8.0.01. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northern Research Station. http://apps.fs.fed.us/Evalidator/evalidator.jsp. [Date accessed: June 9, 2022].

Wyoming State Forestry Division. 2017. 2017 Wyoming forest health highlights. 17 p. https://www.fs.usda.gov/foresthealth/docs/fhh/WY_FHH_2017.pdf. [Date accessed March 6, 2022].