CHAPTER 4

Tree Mortality

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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 impacts of one or more factors, including insects, disease, fire, drought, or major storms. Regionally high mortality may also occur if a large proportion of the forest in a particular region is made up of older, senescent stands. The approach presented here seeks to detect mortality patterns that might reflect changes to ecosystem processes at large scales that could affect long-term forest sustainability. 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

Forest Inventory and Analysis (FIA) Phase 2 (P2) data were the basis of the mortality analysis. 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). The most recent cycle of remeasurements for each State was used in this analysis. Ecoregion sections were omitted from this analysis if the dataset did not have at least 50 remeasured plots.

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Due to the COVID-19 (coronavirus) 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 2021 Forest Health Monitoring (FHM) report (Potter and Conkling 2022)). Similarly, no new data were available from most of the Great Plains States, (i.e., the available datasets are the same as those used for the 2022 FHM report). Therefore, for this report, the analysis is limited to States in the Eastern and Central United States shown in figure 4.1. That figure also shows the forested area in those States,[1,2] which can be important for interpreting the extent of the observed mortality.

METHODS

FIA calculates the 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). FIA's EVALIDator (ver. 2.0.6) is an online tool for querying the FIA Database and generating area-based reports on forest characteristics (USDA Forest Service, FIA Program 2023). EVALIDator was used to obtain net growth rates and mortality rates over the most recent measurement cycle for each of 96 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 2021[3] (e.g., each plot was most recently measured between 2015 and 2021), and growth and mortality were calculated from the previous measurement of each plot, usually 5, 7, or 10 years prior to the most recent plot measurement.

To compare mortality across forest types and climate zones, the ratio of annual mortality to gross growth (MRATIO) was used 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 with high uncertainty to growth estimates.

[1] For the latest analysis of mortality that includes Western States, see Ambrose and others (2022).
[2] For the latest analysis of mortality that includes the Plains States, see Ambrose (2023).
[3] Overall, the most recent data available for any State ranged from 2018 to 2022.

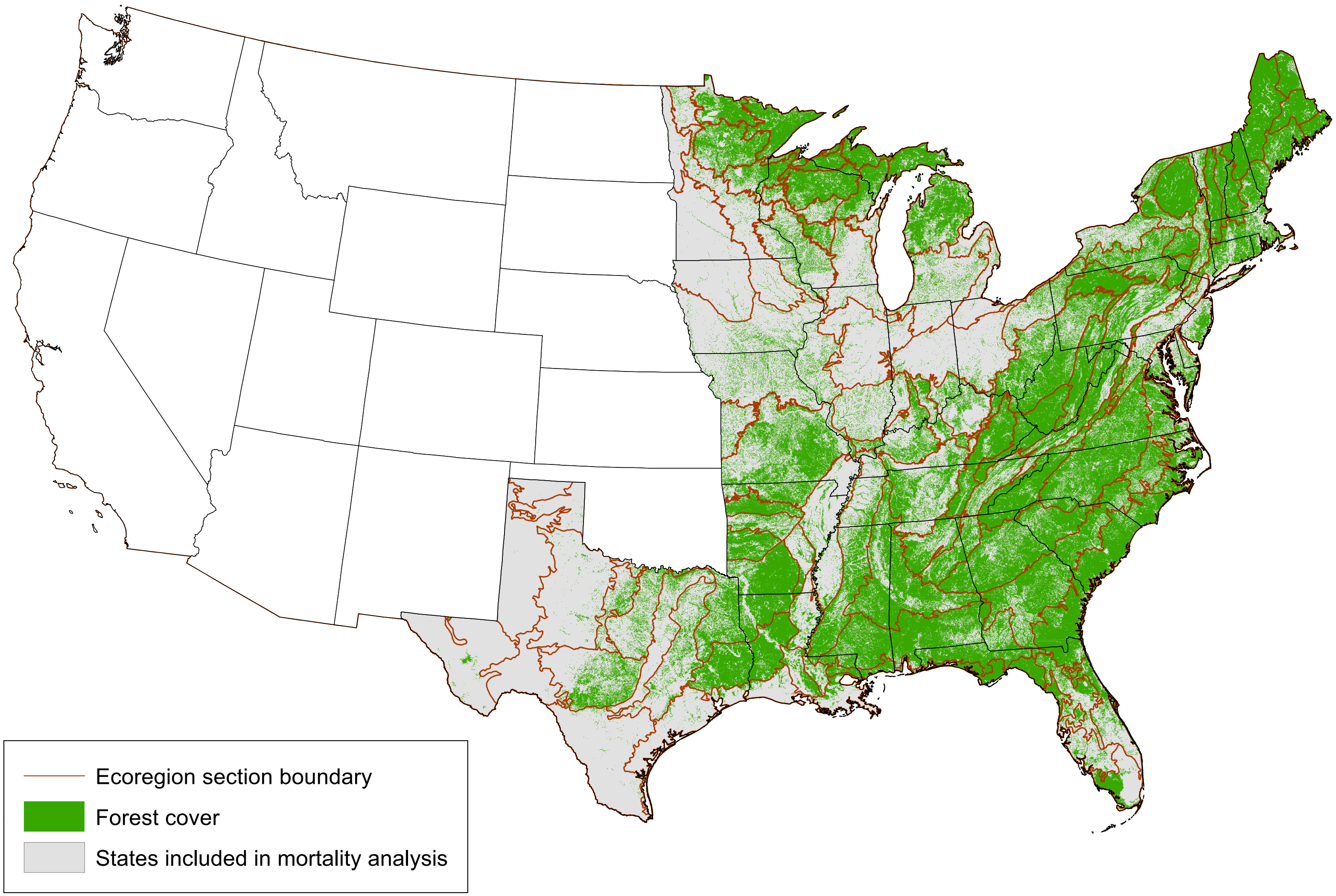

Figure 4.1—Forest cover in the States where mortality was analyzed by ecoregion section (Cleland and others 2007). Forest cover was derived from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery (USDA Forest Service 2008).

To identify causal agents for the observed mortality, EVALIDator was also used to summarize by the reported "cause of death" associated with the observed mortality. Causes of death are reported as general categories (e.g., insects, fire, weather). For each ecoregion with a high MRATIO, EVALIDator was used to generate a table of annual mortality volume by FIA species group (Burrill and others 2018) and cause of death. From these tables, one can make reasonable assumptions about the particular insects or diseases that may be affecting particular tree species in particular 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 aerial and ground surveys of insects and disease (see ch. 2 in this report). Directly matching survey data to mortality observed on FIA plots is challenging due to both the difference in timing when mortality is recorded and difficulty matching plot locations with aerial survey mortality polygons. However, insect and disease survey information has been incorporated into the discussion by referencing State "Forest Health Highlights," which reflect in large part the results of aerial and ground surveys of insects and diseases.

RESULTS AND DISCUSSION

The MRATIO values are shown in figure 4.2. The MRATIO can be large if an old 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. The ecoregion sections with the highest MRATIOs are labeled on the map. In the discussion that follows, the focus is placed on the ecoregions having MRATIOs >0.6.

Ecoregion section 321B–Stockton Plateau in western Texas (fig. 4.2), which had the highest MRATIO in the region covered in this analysis (MRATIO = 0.89), is a region of extremely low forest cover (fig. 4.1). There, about 67 percent of mortality was related to adverse weather and another 32 percent was due to fire (table 4.1). About 92 percent of mortality occurred in the western woodland softwoods species group, i.e., pinyon pines (*Pinus* spp.) and junipers (*Juniperus* spp.). About 68 percent of western woodland softwoods mortality was due to weather and 31 percent was due to fire. Most of this mortality was probably related to a record-setting drought that affected Texas and Oklahoma beginning in 2011. Note that western Texas is on a 10-year FIA remeasurement cycle, so data used in this analysis extend back up to 20 years.

Also in Texas, ecoregion section 255C–Oak Woods and Prairies had relatively high mortality (MRATIO = 0.64). About 45 percent of the mortality occurred in the red and white oak species groups, and another 11 percent occurred in the

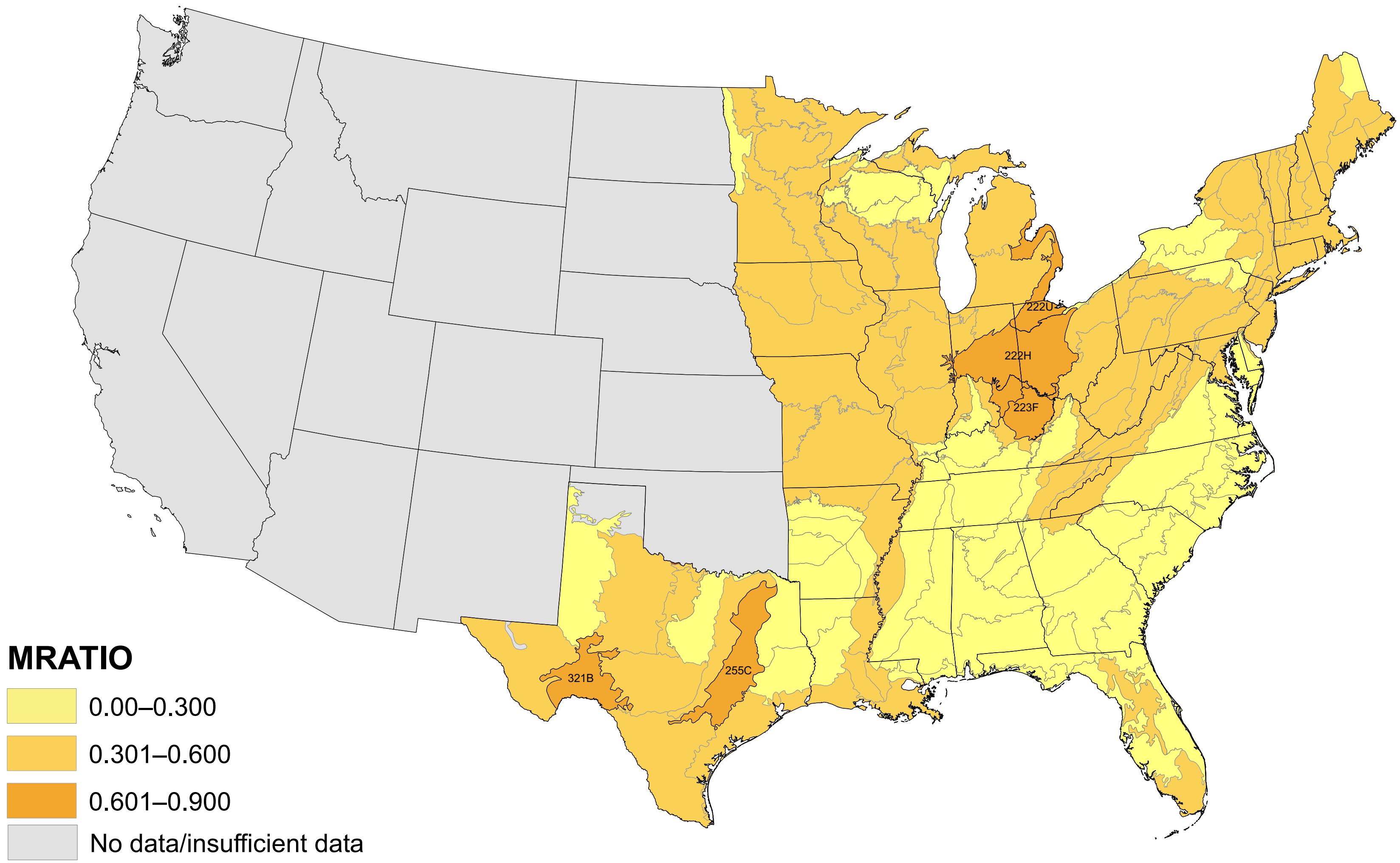

Figure 4.2—Tree mortality expressed as the ratio of annual mortality volume to gross annual growth volume (MRATIO), by ecoregion section (Cleland and others 2007). (Data source: U.S. Department of Agriculture, Forest Service Forest Inventory and Analysis program)

loblolly and shortleaf pine species group. The majority (61 percent) of mortality in this ecoregion section was identified as weather-related (table 4.1). Weather was responsible for 55 percent of mortality in the oaks and 30 percent of the loblolly and shortleaf pine species group mortality. In addition to the record-setting drought in 2011, other droughty periods occurred in following years (Oklahoma Forestry Services 2014, 2015, 2016, 2020). Drought was reported as weakening both pines and hardwoods in Texas, making them susceptible to a variety of pests and pathogens (Smith 2013, 2014). Disease was the reported cause of another 28 percent of mortality (table 4.1), responsible for 43 percent of oak mortality. Fire was responsible for 52 percent of pine mortality. Oak wilt, caused by the fungus *Bretziella fagacearum*, has been a major problem in oak (*Quercus* spp.) woodlands in central Texas (Smith 2014; Texas A & M Forest Service 2015, 2016, 2019) and probably contributed to mortality in the red and white oak species groups. Pine engraver beetle (*Ips* spp.) has been a problem in Texas' pine forests and may have contributed to mortality in the loblolly and shortleaf pine species group (Smith 2014; Texas A & M Forest Service 2015, 2016, 2017).

A cluster of ecoregions with high mortality relative to growth occurred in eastern Michigan, central Indiana, western Ohio, and northern Kentucky. Of these, mortality relative to growth was highest (MRATIO = 0.67) in ecoregion section 222U–Lake Whittlesey Glaciolacustrine Plain. There, the majority of the mortality (60 percent) was in the ash species group. About 61 percent of mortality in that ecoregion was caused by insects (table 4.1), and insects were responsible for 98 percent of ash 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 (*Fraxinus* spp.) 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 = 0.65) in Ohio and Indiana, much of the mortality (58 percent) was in the ash species group (table 4.1), and 97 percent of ash mortality was due to insects, i.e., emerald ash borer.[4] 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 = 0.67) in southern Indiana and Ohio and north-central Kentucky. There, about 59 percent of mortality was in the ash species group. Fifty-six

[4] Personal communication. 2022. Philip T. Marshall, Forest Health Specialist, Indiana Department of Natural Resources, Division of Forestry, 2782 W. Co. Rd. 540 S., Vallonia IN 47281.

Table 4.1—Ecoregion sections in the Eastern and Central United States having the highest mortality relative to growth (MRATIO), annual growth and mortality 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 ---				
321B–Stockton Plateau	7,918,664	8,929,419	0.89	Western woodland softwoods (92%)	Weather-related (67%), fire (32%)
222U–Lake Whittlesey Glaciolacustrine Plain	45,579,144	67,711,765	0.67	Ash (60%), other eastern soft hardwoods (13%)	Insects (61%), disease (10%)
223F–Interior Low Plateau-Bluegrass	105,866,216	158,460,432	0.67	Ash (59%), other eastern soft hardwoods (15%)	Insects (56%), vegetation (13%)
222H–Central Till Plains-Beech-Maple	114,530,445	175,830,480	0.65	Ash (58%), other eastern soft hardwoods (16%)	Insects (57%)
255C–Oak Woods and Prairies	103,150,455	161,311,759	0.64	Oaks[d] (45%), loblolly and shortleaf pine (11%)	Weather-related (61%), disease (28%)

[a] For the species included in each species group, see Burrill and others 2018, Appendices E and F.
[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 of the Forest Inventory and Analysis select red oaks, select white oaks, other red oaks, and other white oaks species groups have been combined.

percent of overall mortality in the ecoregion was attributed to insects, but almost all (94 percent) ash mortality was due to insects, i.e., emerald ash borer.[5] Emerald ash borer has been confirmed throughout the portion of the ecoregion section that is in Kentucky since at least 2016 (Kentucky Division of Forestry 2016).

The overall spatial pattern (fig. 4.2) is that MRATIOs are lowest in the Southeast and higher to the north and west. Aside from specific forest health concerns, such as those discussed above, this pattern may be due to forest management practices as well as climate patterns across the Eastern United States. In general, forests in the Southeast are more highly managed than those farther north and west. Forest management may be directly reducing the impacts of certain stressors, such as reducing the likelihood of insect outbreaks. Also, forest management means that forests in the Southeast generally tend to be younger, and younger trees tend to be more resistant to many mortality-causing agents. Finally, because these forests are younger and located in areas with longer growing seasons, they have higher growth rates. Thus, MRATIOs, being the ratios of mortality to growth, will be lower simply due to higher productivity.

CONCLUSIONS

This analysis shows that in most of the Eastern and Central United States, mortality is low relative to tree growth. No ecoregion sections fall into the highest MRATIO class (>0.9). The areas of highest mortality relative to growth occur in Texas, where the impacts of a record-setting drought are still apparent. Drought, combined with a variety of other biotic and/or abiotic stressors, is responsible for much of the mortality observed there.

One insect pest issue 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.

Note 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, emerald ash borer is known to have caused very high ash mortality in many Eastern and Central States in recent years (USDA APHIS 2018; Ohio Department of Natural Resources, Division of Forestry 2016). Yet, this mortality stands out only in ecoregion sections 222H–Central Till Plains-Beech-Maple, 222U–Lake Whittlesey Glaciolacustrine Plain, and 223F–Interior Low

[5] Personal communication. 2022. Philip T. Marshall, Forest Health Specialist, Indiana Department of Natural Resources, Division of Forestry, 2782 W. Co. Rd. 540 S., Vallonia IN 47281.

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, the results of this analysis can be considered along with other indicators of forest health. FIA tree damage data (Burrill and others 2021), as well as FHM Evaluation Monitoring projects that focus on particular mortality-causing agents, 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. 2023. Tree mortality. In: Potter, K.M.; Conkling, B.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.

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.

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/current/ver90/FIADB%20User%20Guide%20P2_9-0-1_final.pdf. [Date accessed: May 18, 2023].

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/current/ver80/FIADB%20User%20Guide%20P2_8-0.pdf. [Date accessed: May 16, 2023].

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.

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 6, 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. Report 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].

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 30, 2024].

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/docs/fhh/OK_FHH_2014.doc. [Date accessed: September 10, 2023].

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: September 10, 2023].

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: September 10, 2023].

Oklahoma Forestry Services. 2020. Oklahoma forest health highlights 2020. 6 p. https://www.fs.usda.gov/foresthealth/docs/fhh/OK_FHH_2020.pdf. [Date accessed: September 10, 2023].

Potter, K.M.; Conkling, B.L., eds. 2022. 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. 193 p. https://doi.org/10.2737/SRS-GTR-266.

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].

Texas A & M Forest Service, 2015. Forest health highlights in Texas 2015. Longview, TX: Texas A & M Forest Service. 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: Texas A & M Forest Service. 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: Texas A & M Forest Service. 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: Texas A & M Forest Service. 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) Program. 2023. Forest inventory EVALIDator web-application version 2.0.6. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Northern Research Station. https://apps.fs.usda.gov/fiadb-api/evalidator. [Date accessed: April 18, 2023].