CHAPTER 5

Tree Mortality

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INTRODUCTION

Tree mortality is a natural process in all forest ecosystems. High rates of tree mortality can be an indicator of greater forest health problems. On a regional scale, high mortality levels may indicate widespread insect or disease impacts. High rates of tree 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 (e.g., regional) scales. In many cases, the proximate cause of mortality may be discernable. Understanding proximate causes of mortality may provide insight into whether the mortality level 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. 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, with Western States measured on a 10-year cycle and Eastern States measured on a 5-year or 7-year cycle.

An analysis of mortality rates 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 the West, plots are remeasured on a 10-year cycle. Thus, estimates of growth and mortality from several Western States are based on less than a complete cycle of remeasurement. Working from an incomplete cycle of remeasurement, the effective sampling intensity for growth and mortality estimates is lower than FIA's standard of one plot per 6,000 acres (table 5.1). Therefore, the sampling error percentage on growth and mortality estimates tends to be larger in States with the lowest effective sampling intensities. Results are not presented for ecoregions where fewer than 25 plots had been remeasured.

Due to the COVID-19 pandemic, FIA data collection slowed during 2020. As a result, no new data were available from many Eastern States (i.e., the available datasets are the same as those used for the 2020 FHM report). Therefore, for this report, we focus our analysis on Western and some South-central States. Figure 5.1 shows the States included in the analysis as well as the forested area in those States.

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

State	Time period	Effective sample intensity
Arizona	2001–2019	one plot: 6,667 acres
California	2001–2019	one plot: 6,667 acres
Colorado	2002–2019	one plot: 7,500 acres
Idaho	2004–2019	one plot: 10,000 acres
Kansas	2009–2019	one plot: 6,000 acres
Louisiana	2004–2018	one plot: 6,000 acres
Montana	2003–2019	one plot: 8,571 acres
Nevada	2004–2019	one plot: 10,000 acres
New Mexico	2005–2019	one plot: 12,000 acres
Oklahoma[a]	2010–2020	one plot: 6,000 acres
Oregon	2001–2019	one plot: 6,000 acres
Texas	2004–2020	one plot: 6,000 acres (eastern Texas)[b] one plot: 15,000 acres (western Texas)
Utah	2000–2019	one plot: 6,000 acres
Washington	2002–2019	one plot: 7,500 acres
Wyoming[c]	2000–2019	one plot: 6,667 acres

[a] Mortality data are only available for eastern Oklahoma. Eastern Oklahoma includes those counties in FIA Survey Units 1 and 2 (see Appendix B in Burrill and others 2018).

[b] Eastern Texas consists of those counties in FIA Survey Units 1 and 2 (see Appendix B in Burrill and others 2018).

[c] Mortality estimates for Wyoming are based on a comparison of annualized inventory data with data from the final periodic inventory.

METHODS

Forest Inventory and Analysis 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 8.0) (Burrill and others 2018). EVALIDator (version 1.8.0.01), an online tool for querying the FIA Database and generating area-based reports on forest characteristics (USDA Forest Service FIA program 2021), was used to obtain mortality rates over the most recent measurement cycle for each ecoregion section (Cleland and others 2007, McNab and others 2007). For most States, the most recent cycle of available data ran through 2018[1] (e.g., data collected from 2012 through 2018).

To compare mortality across forest types and climate zones, mortality as a percentage of live growing stock was calculated:

$$\text{Mortality percent} = m \,/\, v * 100$$

where

m = average annual mortality of sound bole volume of trees (at least 5 inches in diameter) on forest land (cubic feet per year)

v = sound bole volume of live trees (at least 5 inches in diameter) on forest land (cubic feet)

The temporal basis for all EVALIDator estimates is "Current."

To identify causal agents for the observed mortality, EVALIDator was also used to summarize mortality 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 section, EVALIDator also 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, it is possible to make reasonable assumptions about the particular insects or diseases that may be affecting 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 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, aerial survey information has been incorporated into the discussion by referencing State Forest Health Highlights, which reflect in large part the results of aerial surveys.

In addition, mortality rates were derived for each forest type group (Burrill and others 2018, USDA Forest Service 2008) for each ecoregion section. At times, identifying the forest type experiencing high mortality can be more useful than identifying the species group, especially when the cause of death is abiotic.

[1] *Overall, the most recent data available for any State ranged from 2016 to 2019.*

RESULTS AND DISCUSSION

Figure 5.2 shows the ratio of annual mortality to standing live tree volume for the United States. Results are not presented for ecoregions that had fewer than 25 remeasured plots. The majority of ecoregions omitted from the analysis were mostly nonforest (see fig. 5.1) (mostly desert or grassland, heavily urbanized, or converted to agriculture). Table 5.2 summarizes the mortality results for those ecoregion sections having the highest mortality relative to live tree volume (>2 percent), showing the species groups that had the highest mortality as well as the major causes of mortality, if they could be identified.

In the South-central part of the country, ecoregion section 255C–Oak Woods and Prairies in Texas had the highest mortality relative to live volume. About 49 percent of the mortality occurred in the red and white oak species groups,[2] and another 15 percent occurred in the loblolly and shortleaf pine species group. The majority (67 percent) of mortality in this ecoregion section was identified as weather-related (table 5.2). Weather was responsible for 65 percent of oak mortality and 44 percent of pine mortality. Disease was the reported cause of another 21 percent of mortality (table 5.2). Disease was reported as responsible for 32 percent of oak mortality. Fire was responsible for 51 percent of loblolly and shortleaf pine mortality.

Similarly, in ecoregion 255A–Cross Timbers and Prairies in Kansas, Oklahoma, and northern Texas, most (43 percent) of the mortality occurred in oaks (red and white oak species groups). Thirty-two percent of overall mortality was due to diseases, 31 percent was due to adverse weather, and 13 percent was due to fire (table 5.2).[3]

A record-setting drought in 2011 affected Oklahoma and Texas (Oklahoma Forestry Services 2014, 2015, 2016). It was reported as weakening both pines and hardwoods in Texas, making them susceptible to a variety of pests and pathogens (McBride and Appel 2016; Smith 2013, 2014). 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 mortality. 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).

In ecoregion section 321B–Stockton Plateau in southwestern Texas, 74 percent of mortality was related to adverse weather and another 25 percent was due to fire (table 5.2). About 92 percent of mortality occurred in the western woodland softwoods species group (i.e., pinyon pines [*Pinus* spp.] and junipers [*Juniperus* spp.]). Presumably, the fire as well as the direct weather-induced

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[2] Overall mortality of the FIA select red oaks, select white oaks, other red oaks, and other white oaks species groups have been combined.

[3] Mortality data were not available from a large portion of ecoregion section 255A because much of the ecoregion is in western Oklahoma (as designated by FIA). Nevertheless, enough data were available from the portions of the ecoregion in Kansas, Texas, and eastern Oklahoma that we are able to report results for the ecoregion section.

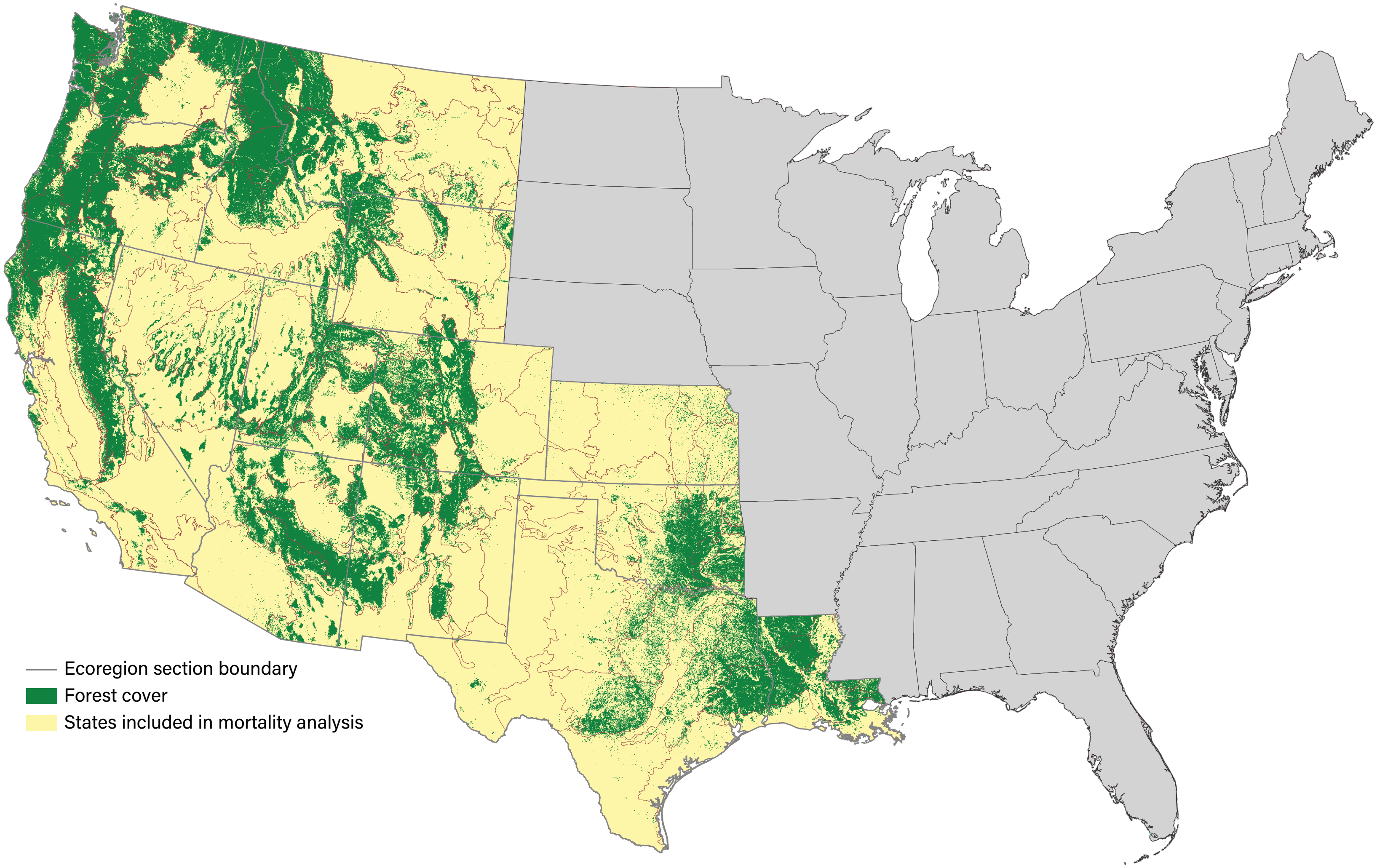

Figure 5.1—Forest cover in the States where mortality was analyzed by ecoregion section (Cleland and others 2007). Forest cover was derived from MODIS satellite imagery (U.S. Department of Agriculture Forest Service 2008).

Table 5.2—Ecoregion sections having the highest mortality relative to live tree volume, annual mortality rates, live volume, species groups having the highest mortality relative to growth, and associated causes of mortality

Ecoregion section	Average annual mortality	Live volume	Mortality relative to live volume	Species groups[a] having the highest mortality[b]	Major causes of mortality[c]
	cubic feet per year	*cubic feet*	*percent*		
341G–Northeastern Great Basin	6,684,440	100,898,913	6.62	True firs (57%)	Fire (55%), insects (30%)
M332F–Challis Volcanics	120,658,604	2,058,620,613	5.86	Douglas-fir (41%), lodgepole pine (26%)	Fire (49%), insects (40%)
M331J–Wind River Mountains	51,241,545	1,004,282,891	5.10	Lodgepole pine (50%), other western softwoods (26%)	Insects (69%), fire (18%)
M332D–Belt Mountains	198,200,487	4,864,386,519	4.07	Lodgepole pine (71%)	Insects (86%)
M331A–Yellowstone Highlands	321,755,288	8,122,990,167	3.96	Lodgepole pine (30%), Engelmann and other spruces (26%), other western softwoods (22%)	Insects (58%), fire (26%)
255C–Oak Woods and Prairies	128,117,245	3,344,147,442	3.83	Oaks[d] (49%), loblolly and shortleaf pine (15%)	Weather-related (67%), disease (21%)
M331I–Northern Parks and Ranges	467,198,325	12,353,152,165	3.78	Lodgepole pine (58%), Engelmann and other spruces (22%)	Insects (82%), disease (11%)
M331E–Uinta Mountains	104,048,591	2,802,315,890	3.71	Lodgepole pine (58%), Engelmann and other spruces (20%)	Insects (73%), disease (17%)
342A–Bighorn Basin	3,833,210	103,464,368	3.70	Lodgepole pine (66%)	Fire (67%), insects (17%), disease (15%)
M331G–South-Central Highlands	334,248,138	9,120,912,071	3.66	Engelmann and other spruces (65%)	Insects (69%), fire (13%), disease (10%)
M332B–Northern Rockies and Bitterroot Valley	202,003,412	5,865,620,498	3.44	Lodgepole pine (52%)	Insects (47%), fire (38%)
M262B–Southern California Mountain and Valley	29,449,257	916,788,218	3.21	Ponderosa and Jeffrey pine (26%), other western softwoods (18%), western woodland softwoods (13%)	Fire (65%), insects (12%), weather-related (11%)
M332A–Idaho Batholith	532,704,187	17,438,304,531	3.05	Lodgepole pine (32%), true firs (26%), Douglas-fir (23%)	Fire (54%), insects (26%), disease (12%)
M332E–Beaverhead Mountains	143,761,933	5,282,301,861	2.72	Lodgepole pine (55%), other western softwoods (18%)	Insects (79%), fire (13%)

(*Continued*)

Table 5.2 *(Continued)*—Ecoregion sections having the highest mortality relative to live tree volume, annual mortality rates, live volume, species groups having the highest mortality relative to growth, and associated causes of mortality

Ecoregion section	Average annual mortality	Live volume	Mortality relative to live volume	Species groups[a] having the highest mortality[b]	Major causes of mortality[c]
	cubic feet per year	*cubic feet*	*percent*		
321B–Stockton Plateau	9,297,589	384,623,307	2.42	Western woodland softwoods (92%)	Weather-related (74%), fire (25%)
M333C–Northern Rockies	189,675,948	7,885,114,636	2.41	Engelmann and other spruces (24%), lodgepole pine (23%), true firs (23%)	Fire (51%), disease (25%), insects (16%)
342F–Central Basin and Hills	3,847,809	165,862,120	2.32	Lodgepole pine (22%), cottonwood and aspen (22%), ponderosa and Jeffrey pine (19%)	Insects (64%), disease (16%), vegetation[e] (11%)
321A–Basin and Range	23,829,502	1,041,097,106	2.29	Western woodland hardwoods (48%), western woodland softwoods (22%)	Fire (56%), disease (15%), insects (12%)
331K–North Central Highlands	20,305,814	907,138,797	2.24	Ponderosa and Jeffrey pine (57%), lodgepole pine (27%)	Fire (54%), insects (27%)
331G–Powder River Basin	16,659,252	767,361,244	2.17	Ponderosa and Jeffrey pine (93%)	Fire (87%)
255A–Cross Timbers and Prairie	16,127,155	748,440,827	2.15	Oaks[d] (43%), other eastern soft hardwoods (28%)	Disease (32%), weather-related (31%), fire (13%)

[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 of the FIA select red oaks, select white oaks, other red oaks, and other white oaks species groups have been combined.
[e] Mortality caused by suppression, competition, vines/kudzu (Burrill and others 2018).

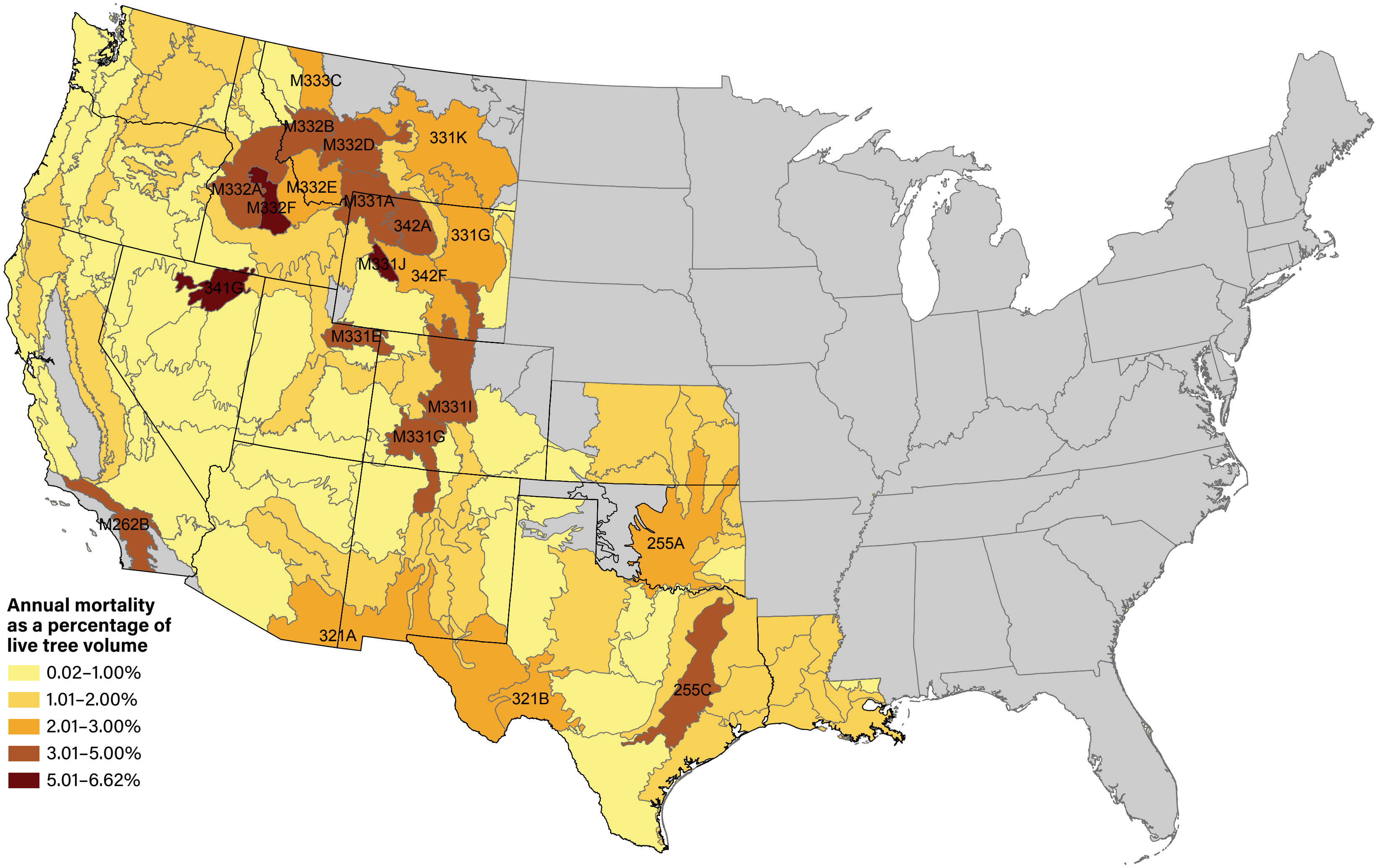

Figure 5.2—Annual tree mortality expressed as a percentage of live tree volume by ecoregion section (Cleland and others 2007). (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis program). Areas shown in gray are States not analyzed for this report and ecoregion sections with too few remeasured forested plots to include in the analysis.

mortality were related to the droughts that have affected much of Texas over the past decade.

As mentioned above, in most Western States, less than the full cycle of plots have been remeasured, reducing the precision of mortality estimates. Also, one must be aware that, because of the longer 10-year measurement cycle in the West, results shown represent mortality that may have occurred any time during the period spanned by the data (see table 5.1), which may have been as long as 20 years.

Of the ecoregions of the West Coast States, ecoregion section M262B–Southern California Mountain and Valley stands out, with an annual mortality rate of 3.21 percent. Fire was responsible for 65 percent of this mortality (table 5.2). About 57 percent of the mortality in this ecoregion section occurred in the Western Oak forest type group, and most of that mortality (79 percent) was due to fire. Fire was also responsible for most of the mortality (76 percent) in the Pinyon/juniper forest type group, where 7 percent of the ecoregion's mortality occurred. This ecoregion was severely impacted by the Thomas fire, which started in late 2017 and burned into 2018. At the time, it was the largest fire in the history of California (Chavez 2017), covering 281,893 acres (440 square miles). Other smaller fires have also affected the region.

While fire was the major cause of mortality within the region, ecoregion section M262B–Southern California Mountain and Valley was also impacted significantly by insects and diseases (12 percent of mortality) and adverse weather (11 percent of mortality). Insects were responsible for almost all the mortality in the Ponderosa Pine forest type group and about 43 percent of the mortality in the California Mixed Conifer forest type group; they were responsible for about 21 percent of the mortality in the ponderosa and Jeffrey pine species group and about 17 percent of the other western softwoods species group. Bark and engraver beetle outbreaks related to drought conditions and overstocked stands resulted in considerable conifer mortality in the past 20-year period. Seventeen percent of pine mortality was caused by insects. The ecoregion has also been a center of nonnative insect and insect/disease complex activities in California. The goldspotted oak borer (*Agrilus auroguttatus*) has killed various oak (*Quercus* spp.) species within the ecoregion, and the invasive shot hole borer complexes (two species of *Euwallacea* ambrosia beetles combined with their associated *Fusarium* species) have attacked and killed oaks and many other species of hardwoods. Although most activity was in urban forests and riparian zones, the invasive shot hole borer complexes have spread into woodlands and neighboring forested areas, leading to mortality.

In much of California, tree mortality has often been related to a combination of prolonged drought (2011–2015 statewide; 2011–2017 in parts of the State), bark beetles, and fire (California Forest Pest Council 2015, 2016, 2017). These factors have interacted, leading to high mortality, especially in southern California. Overstocked stands have contributed to the drought stress and susceptibility of forests to insects and wildfires (California Forest Pest Council 2015, 2016, 2017, 2018).

Turning to the Interior West, we see two clusters of ecoregion sections where mortality is high relative to standing live volume: a cluster of mountain ecoregions in western Montana, central Idaho, and northwestern Wyoming (M331A–Yellowstone Highlands, M331J–Wind River Mountains, M332A–Idaho Batholith, M332B–Northern Rockies and Bitterroot Valley, M332D–Belt Mountains, M332E–Beaverhead Mountains, and M332F–Challis Volcanics), together with the Northeastern Great Basin in northern Nevada (341G–Northeastern Great Basin), and a cluster including the Front Range of Colorado and southern Wyoming (M331I–Northern Parks and Ranges) and the South-Central Highlands of Colorado and northern New Mexico (M331G–South-Central Highlands) together with the Uinta Mountains of Utah (M331E–Uinta Mountains). In all of these regions, except M332E–Beaverhead Mountains, annual mortality exceeded 3 percent of live volume (table 5.2, fig. 5.2).

Spruce beetle (*Dendroctonus rufipennis*) epidemics have continued to expand over the last 20 years in the spruce (*Picea* spp.) forests of these ecoregions, particularly near areas of recent blowdown in Colorado, Idaho, Utah, New Mexico, and Wyoming. Spruce beetle-attacked trees tend to fade from green (healthy) to red (dying) more slowly than those attacked by other bark beetles, and damage estimates can be underestimated as a result. Chronic drought and repeated years of heavy western spruce budworm (*Choristoneura freemani*) defoliation have stressed Douglas-fir (*Pseudotsuga menziesii*) forests, making them more susceptible to bark beetle attacks. This has resulted in an increase in Douglas-fir beetle (*D. pseudotsugae*) in the Douglas-fir forests of these regions, which, in turn, is associated with the high Douglas-fir mortality observed in several of these ecoregions (table 5.2).

In Colorado and Wyoming, 58 percent of the mortality in ecoregion section M331I–Northern Parks and Ranges was in the lodgepole pine species group, and another 22 percent was in the Engelmann and other spruces species group; most (82 percent) of the mortality was attributed to insects. Western spruce budworm continued to cause significant defoliation in the Bighorn Mountains. Major outbreaks of mountain pine beetle (*D. ponderosae*) as well as spruce beetle (Colorado State Forest Service 2016, 2020; Wyoming State Forestry Division 2016, 2017, 2020; USDA Forest Service 2020) have occurred in the region over the last 20 years. These same pests have been affecting ecoregion section M331E–Uinta Mountains, (USDA Forest Service [N.d]; Utah Department of Natural Resources, Forestry, Fire, & State Lands 2016, 2019) where 58 percent of mortality was in the lodgepole pine species group and 20 percent was in the Engelmann and other spruces species group. Here, also, most (73 percent) of the mortality was caused by insects.

In ecoregion section M331G–South-Central Highlands, about 69 percent of mortality overall was caused by insects. In this ecoregion, about 65 percent of mortality was in the Engelmann and other spruces species group; 88 percent of spruce mortality was due to insects. In this area, spruce beetle has caused significant mortality (Colorado State Forest Service 2016, 2017; Formby 2020;

USDA Forest Service 2019, 2020; Zegler 2015, 2016; Zegler and Formby 2017). Also, severe drought is starting to cause visible discoloration in ponderosa pine (*Pinus ponderosa*) in this region with no visible signs of insects or diseases yet. Bark beetle-induced mortality, across most host species, is expected to increase in this ecoregion over the next few years (Formby 2020).

In most of the areas of high mortality in Montana, Idaho, and northwestern Wyoming (ecoregion sections M331A, M331J, M332A, M332B, M332D, M332E, and M332F) as well as the Northeastern Great Basin (341G) of Nevada, insects and fire were the most significant causes of mortality (table 5.2). This region includes areas suffering outbreaks of mountain pine beetle (Idaho Department of Lands 2010, 2019; Montana Department of Natural Resources and Conservation 2014, 2016) as well as major fires (Idaho Department of Lands 2014). However, several other insect and disease issues have been identified in this region and may have contributed to the mortality. In most of these ecoregion sections (M331A, M331J, M332A, M332B, M332D, M332E), lodgepole pine was the species group suffering the highest mortality, mostly from mountain pine beetle attacks. However, many other species groups, including Douglas-fir, true firs, and Engelmann and other spruces also suffered nontrivial mortality. Douglas-fir beetle is the primary causal agent impacting Douglas-fir in these regions while the nonnative balsam woolly adelgid (*Adelges piceae*) and fir engraver are impacting the true firs (Idaho Department of Lands 2017, 2018, 2019, 2020; Montana Department of Natural Resources and Conservation 2019, 2020). In contrast with the other ecoregions in this cluster, in ecoregion section M332F–Challis Volcanics in Idaho, most mortality occurred in the Douglas-fir species group (41 percent) rather than lodgepole pine (26 percent). However, the causes of mortality were the same—fire and insects, especially Douglas-fir beetle and mountain pine beetle.

The highest mortality in the Interior West occurred in occurred in ecoregion section 341G–Northeastern Great Basin in northern Nevada, where mortality was 6.62 percent of live volume. Here, fire was responsible for 55 percent of mortality while insects caused another 30 percent of mortality. Most (57 percent) of this mortality occurred in the true firs species group. In this ecoregion, forested area is very low (fig. 5.1); all of this is high-elevation forest (Bryce and others 2003). Only 31 forested plots were included in the analysis (only slightly above our cut-off of 25 plots). It is hard to interpret how important this high mortality rate is. While it affects a relatively small area of forest, that forest may be very important ecologically because of the rarity of forested ecosystems in this region.

Though it is difficult to point to particular, major fires associated with much of the observed mortality in the Interior West, the cumulative impact of fires in the region cannot be overstated. Over the past decade, the Interior West has experienced numerous extreme fire seasons with large, high-severity fires. The year 2017 stands out, with over 4.4 million acres burned in wildfires across the region (National Interagency Fire Center 2017). In 2018 and 2019, another 2.9

million and 1.1 million acres burned (National Interagency Fire Center 2018, 2019). Fires not only kill trees directly but also leave trees near the fire perimeter stressed and damaged, making them susceptible to bark beetle attacks. These beetle populations can then reach levels high enough that the outbreak spreads to undamaged stands.

SUMMARY

Throughout the portions of the United States analyzed for this report, drought and fire have been primary drivers of mortality. They have been directly responsible for mortality in many areas. They have also stressed forests, leaving them susceptible to the insect and disease outbreaks responsible for much of the observed mortality.

Based on current trends, we expect that fire and drought will continue to cause significant mortality throughout many of the areas analyzed. California and Colorado experienced their largest fires in history in 2020 when the August Complex in California burned 1,032,648 acres and the Cameron Peak Fire in Colorado burned 208,913 acres. Extended periods of drought are now causing significant mortality, apparently as a direct result of moisture stress, from Arizona up through Colorado, Nevada, and Utah.

The analyses presented in this chapter alone do not tell the complete story regarding tree mortality. Mortality that occurred in highly fragmented forest or treed areas adjacent to or circumscribed by human development may not have been detected because the FIA inventory does not cover most urban areas or other places not defined as forest by FIA.[4] 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.

To gain a more complete understanding of mortality, one should consider the results of this analysis together with other indicators of forest health. Forest Inventory and Analysis tree damage data (Burrill and others 2018), as well as Evaluation Monitoring projects that focus on particular mortality-causing agents (ch. 7–13 in this report) can provide insight into smaller scale or species-specific mortality issues. Large-scale analyses of forest stressors, including insect and disease activity (ch. 2), fire (ch. 3), and drought (ch. 4) are also important for understanding mortality patterns.

[4] *For a detailed explanation of FIA's definition of forest, see Burrill and others 2018, section 2.4.*

LITERATURE CITED

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.

Bryce, S.A.; Woods, A.J.; Morefield, J.D. [and others]. 2003. Ecoregions of Nevada [color poster with map, descriptive text, summary tables, and photographs]. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. Map presentation scale 1:1,350,000. https://gaftp.epa.gov/EPADataCommons/ORD/Ecoregions/nv/nv_front.pdf. [Date accessed: October 1, 2021].

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. http://fia.fs.fed.us/library/database-documentation/. [Date accessed: July 16, 2019].

California Forest Pest Council. 2015. 2015 California forest health highlights. 21 p. https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: May 9, 2018].

California Forest Pest Council. 2016. 2016 California forest health highlights. 31 p. https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: May 9, 2018].

California Forest Pest Council. 2017. 2017 California forest health highlights. 38 p. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd578578.pdf. [Date accessed: May 9, 2018].

California Forest Pest Council. 2018. 2018 California forest health highlights. 32 p. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd617798.pdf. [Date accessed: May 19, 2021].

Chavez, N. 2017. Thomas Fire is now the largest blaze in California history. https://www.cnn.com/2017/12/23/us/thomas-fire-california/index.html. [Date accessed: September 1, 2021].

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.

Colorado State Forest Service. 2016. 2015 report on the health of Colorado's forests: 15 years of change. Fort Collins, CO: Colorado State Forest Service. 32 p. https://csfs.colostate.edu/media/sites/22/2016/02/ForestHealthReport-2015.pdf. [Date accessed: July 30, 2019].

Colorado State Forest Service. 2017. 2016 report on the health of Colorado's forests: fire and water. Fort Collins, CO: Colorado State Forest Service. 36 p. https://csfs.colostate.edu/media/sites/22/2017/02/CSU_304464_ForestReport-2016-www.pdf. [Date accessed: July 30, 2019].

Colorado State Forest Service. 2020. 2020 report on the health of Colorado's forests: protecting our future after a historic wildfire year. Fort Collins, CO: Colorado State Forest Service. 36 p. https://csfs.colostate.edu/forest-management/forest-health-report/. [Date accessed: June 27, 2020].

Formby, J.P. 2020. New Mexico forest health conditions 2020. 20 p. http://www.emnrd.state.nm.us/SFD/FWHPlan/documents/2020NMForestHealthReport.FINAL.pdf. [Date accessed: June 30, 2020].

Idaho Department of Lands. 2010. 2010 forest health highlights. 5 p. https://www.fs.fed.us/foresthealth/docs/fhh/ID_FHH_2010.pdf. [Date accessed: May 26, 2020].

Idaho Department of Lands. 2014. 2014 forest health highlights. 7 p. https://www.fs.fed.us/foresthealth/docs/fhh/ID_FHH_2014.pdf. [Date accessed: May 26, 2020].

Idaho Department of Lands. 2017. 2017 forest health highlights. 9 p. https://www.fs.fed.us/foresthealth/docs/fhh/ID_FHH_2017.pdf. [Date accessed: May 29, 2020].

Idaho Department of Lands. 2018. 2018 forest health highlights. 9 p. https://www.idl.idaho.gov/wp-content/uploads/sites/2/2020/04/2018-Idaho-Forest-Health-Highlights.pdf. [Date accessed: May 29, 2020].

Idaho Department of Lands. 2019. 2019 forest health highlights. 9 p. https://www.idl.idaho.gov/wp-content/uploads/sites/116/2020/04/2019-Idaho-Forest-Health-Highlights.pdf. [Date accessed: May 29, 2020].

Idaho Department of Lands. 2020. 2020 forest health highlights. 9 p. https://www.idl.idaho.gov/wp-content/uploads/sites/116/2020/04/2019-Idaho-Forest-Health-Highlights.pdf. [Date accessed: June 24, 2020].

McBride, S.; Appel, D. 2016. Hypoxylon canker of oaks. College Station, TX: Texas A & M AgriLife Extension Service. 4 p. https://cdn-ext.agnet.tamu.edu/wp-content/uploads/2018/10/EPLP-030-hypoxylon-canker-of-oaks.pdf. [Date accessed: May 20, 2021].

McNab, W.H.; Cleland, D.T.; Freeouf, J.A. [and others], comps. 2007. Description of ecological subregions: sections of the conterminous United States. Gen. Tech. Report WO-76B. Washington, DC: U.S. Department of Agriculture Forest Service. 80 p. https://doi.org/10.2737/WO-GTR-76B.

Montana Department of Natural Resources and Conservation. 2014. Montana forest health highlights 2014. 4 p. https://www.fs.fed.us/foresthealth/docs/fhh/MT_FHH_2014.pdf. [Date accessed: May 28, 2021].

Montana Department of Natural Resources and Conservation. 2016. Montana forest health highlights 2016. 4 p. http://dnrc.mt.gov/divisions/forestry/docs/assistance/pests/conditions-highlights/fhh_2016.pdf. [Date accessed: May 28, 2021].

Montana Department of Natural Resources and Conservation. 2019. Montana forest health highlights 2019. 3 p. http://dnrc.mt.gov/divisions/forestry/docs/assistance/pests/conditions-highlights/fhh2019_compliant.pdf. [Date accessed: May 28, 2021].

Montana Department of Natural Resources and Conservation. 2020. Montana forest insect and disease conditions and program highlights 2020. 4 p. https://www.fs.fed.us/foresthealth/docs/fhh/MT_FHH_2020.pdf. [Date accessed: 5/28/2021].

National Interagency Fire Center. 2017. National report of wildland fires and acres burned by State (2017). https://www.predictiveservices.nifc.gov/intelligence/2017_statssumm/fires_acres17.pdf. [Date accessed: August 29, 2021].

National Interagency Fire Center. 2018. National report of wildland fires and acres burned by State (2018). https://www.predictiveservices.nifc.gov/intelligence/2018_statssumm/fires_acres18.pdf. [Date accessed: August 29, 2021].

National Interagency Fire Center. 2019. National report of wildland fires and acres burned by State (2019). https://www.predictiveservices.nifc.gov/intelligence/2019_statssumm/fires_acres19.pdf. [Date accessed: August 29, 2021].

Oklahoma Forestry Services. 2014. Oklahoma forest health highlights 2014. 5 p. https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: April 2, 2018].

Oklahoma Forestry Services. 2015. Oklahoma forest health highlights 2015. 6 p. https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: April 3, 2018].

Oklahoma Forestry Services. 2016. Oklahoma forest health highlights 2016. 6 p. https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: April 2, 2018].

Smith, L.A. 2013. Forest health insects and diseases conditions Texas 2013. Longview, TX: Texas A & M Forest Service. 5 p. https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: April 27, 2018].

Smith, L.A. 2014. Forest health highlights in Texas 2014. Longview, TX: Texas A & M Forest Service. 1 p. https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: April 27, 2018].

Texas A & M Forest Service. 2015. Forest health highlights in Texas 2015. Longview, TX: Texas A & M Forest Service. 1 p. https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: April 20, 2018].

Texas A & M Forest Service. 2016. Forest health highlights in Texas 2016. Longview, TX: Texas A & M Forest Service. 1 p. https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: April 20, 2018].

Texas A & M Forest Service. 2017. Forest health highlights 2017. Longview, TX: Texas A & M Forest Service. 2 p. https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: May 21, 2018].

Texas A & M Forest Service. 2019. Forest health highlights 2019. Longview, TX: Texas A & M Forest Service. 2 p. https://www.fhm.fs.fed.us/foresthealth/docs/fhh/TX_FHH_2019.pdf. [Date accessed: May 21, 2020].

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, 2016].

U.S. Department of Agriculture (USDA) Forest Service. 2019. Forest insect and disease conditions in the Southwestern Region, 2018. Forest Health PR-R3-16-18. 49 p. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd663788.pdf. [Date accessed: August 10, 2021].

U.S. Department of Agriculture (USDA) Forest Service. 2020. Forest insect and disease conditions in the Rocky Mountain Region, 2019. Forest Health R2-RO-20-01. 40 p. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd700752.pdf. [Date accessed: July 25, 2021].

U.S. Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis (FIA) program. 2021. 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: May 20, 2021]

U.S. Department of Agriculture (USDA) Forest Service, Uinta-Wasatch-Cache National Forest. [N.d.]. Beetle activity on the Uinta-Wasatch-Cache National Forest. http://www.fs.usda.gov/detail/uwcnf/home/?cid=STELPRDB5145143. [Date accessed: July 25, 2017].

Utah Department of Natural Resources, Forestry, Fire, & State Lands. 2016. Utah forest health highlights 2016. 3 p. https://www.fs.fed.us/foresthealth/protecting-forest/forest-health-monitoring/monitoring-forest-highlights.shtml. [Date accessed: April 24, 2018].

Utah Department of Natural Resources, Forestry, Fire, & State Lands. 2019. Utah forest health highlights 2019. 3 p. https://ffsl.utah.gov/wp-content/uploads/StateHighlights2019-final.pdf. [Date accessed: June 20, 2020].

Wyoming State Forestry Division. 2016. 2016 Wyoming forest health highlights. 16 p. https://www.fs.fed.us/foresthealth/docs/fhh/WY_FHH_2016.pdf. [Date accessed: August 25, 2018].

Wyoming State Forestry Division. 2017. 2017 Wyoming forest health highlights. 17 p. https://www.fs.fed.us/foresthealth/docs/fhh/WY_FHH_2017.pdf. [Date accessed: August 25, 2018].

Wyoming State Forestry Division. 2020. 2020 Wyoming forest health highlights. 9 p. https://www.fs.fed.us/foresthealth/docs/fhh/WY_FHH_2020. [Date accessed: June 26, 2020].

Zegler, T. 2015. New Mexico forest health conditions, 2015. 17 p. http://www.emnrd.state.nm.us/SFD/FWHPlan/documents/2015_NMconditionsreport_low_shortIIpdf.pdf. [Date accessed: July 30, 2019].

Zegler, T. 2016. New Mexico forest health conditions, 2016. 18 p. http://www.emnrd.state.nm.us/SFD/FWHPlan/documents/2016_NMconditionsreport_short.pdf. [Date accessed: July 30, 2019].

Zegler, T.; Formby, J.P. 2017. New Mexico forest health conditions 2017. 35 p. http://www.emnrd.state.nm.us/SFD/FWHPlan/documents/NMForestHealthConditionsReportComplete.pdf. [Date accessed: July 30, 2019].