CHAPTER 2

Broad-Scale Patterns of Insect and Disease Activity across the 50 United States from the National Insect and Disease Survey, 2020

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INTRODUCTION

Forest insects and diseases have widespread ecological and economic impacts on the forests of the United States and may represent the most serious threats to the Nation's forests (Logan and others 2003, Lovett and others 2016, Tobin 2015). U.S. law therefore authorizes the Forest Service, U.S. Department of Agriculture, to "conduct surveys to detect and appraise insect infestations and disease conditions and man-made stresses affecting trees and establish a monitoring system throughout the forests of the United States to determine detrimental changes or improvements that occur over time, and report annually concerning such surveys and monitoring" (FHP 2021). Insects and diseases cause changes in forest structure and function, species succession, and biodiversity, which may be considered negative or positive depending on management objectives (Edmonds and others 2011). Nearly all native tree species of the United States are affected by at least one injury-causing insect or disease agent, with exotic agents on average considerably more severe than native ones (Potter and others 2019a). Additionally, the genetic integrity of several native tree species is highly vulnerable to exotic diseases and insects (Potter and others 2019b).

An important task for forest managers, pathologists, and entomologists is recognizing and distinguishing between natural and excessive mortality, a task that relates to ecologically based or commodity-based management objectives (Teale and Castello 2011). The impacts of insects and diseases on forests vary from natural thinning to disruption of valued ecosystem processes as a result of tree mortality, but insects and diseases are not necessarily enemies of the forest because they kill trees (Teale and Castello 2011). If disturbances, including insects and diseases, are viewed in their full ecological context, then some amount can be considered "healthy" to sustain the structure of the forest (Manion 2003, Zhang and others 2011) by facilitating a sanitation role, that is, causing tree mortality that culls weak competitors and releases resources that are needed to support the growth of surviving trees (Teale and Castello 2011).

Analyzing patterns of forest insect infestations, disease occurrences, forest declines, and related biotic stress factors is necessary to monitor the health of forested ecosystems and their potential impacts on forest structure, composition, biodiversity, and species distributions (Castello and others 1995). In particular, introduced insects and diseases can extensively damage the biodiversity, ecology, and economy of affected areas (Brockerhoff and others 2006, Mack and others 2000). Few forests remain unaffected by invasive species, and their devastating impacts in forests are undeniable, including, in some cases, wholesale changes to the structure and function of an ecosystem (Parry and Teale 2011).

Examining insect pest occurrences and related stress factors from a landscape-scale perspective is useful, given the regional extent of many infestations and the large-scale complexity of interactions between host distribution, stress factors, and the development of outbreaks (Holdenrieder and others 2004, Liebhold and

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others 2013). One such landscape-scale approach is detecting geographic patterns of disturbance, which allows for the identification of areas at greater risk of significant ecological and economic impacts and for the selection of locations for more intensive monitoring and analysis. National Insect and Disease Survey (IDS) data (FHP 2021), coordinated by the Forest Health Protection (FHP) program of the Forest Service, provide an important source of information about forest disturbances and their causal agents across broad regions. Recent long-term analyses of these data underscored that insects have been much more widespread agents of mortality than diseases, with bark beetles consistently the most important mortality agents across regions and over time (Potter and others 2020a). Additionally, the tree canopy area affected by nonnative invasive agents of mortality and defoliation has remained relatively consistent over time (with a larger relative impact on forests in the North), and tree canopy area affected by defoliation agents has usually exceeded or equaled the area affected by mortality agents (Potter and others 2020a).

Efforts to monitor the extent of insect and disease mortality and defoliation damage in U.S. forests continued in 2020 despite the challenges posed by the global COVID-19 pandemic. Because aerial survey flights were curtailed or not possible in many States, forest health specialists in those States quickly adopted other approaches, relying heavily on other sources of remotely sensed data.

METHODS

Data

In a typical year, IDS data (FHP 2021) consist of information from low-altitude aerial survey and ground survey efforts by FHP and partners in State agencies. These data can be used to summarize insect and disease activity by regions in the conterminous States (CONUS), Alaska, and Hawaii (Potter 2012, 2013; Potter and Koch 2012; Potter and Paschke 2013, 2014, 2015a, 2015b, 2016, 2017; Potter and others 2018, 2019c, 2020b, 2021). The global COVID-19 pandemic in 2020, however, precluded the ability of many State and regional Forest Service personnel to conduct aerial survey flights because of the risks posed by spending extended periods of time in the confined space of an aircraft. Instead, a group of forest health specialists had to work together to generate new workflows, training materials, and help sessions to address this challenge (Hanavan and others 2021). Specifically, many forest health specialists used a method called "pan and sketch" to outline damage polygons and points directly on base imagery, mostly from the National Agriculture Imagery Program (NAIP) 2020 or WorldView (FHP 2020). Some users collected features using the Digital Mobile Sketch Mapping (DMSM) tablet application, which allowed them to use common shortcut Quick Keys to capture the standard attributes. Others used the DMSM Desktop Tools Add-In to ArcMap® to capture features and attribute them.

The IDS data identify areas with mortality and defoliation caused by insect and disease activity, although some important forest insects (such as emerald ash borer [*Agrilus planipennis*] and hemlock woolly adelgid [*Adelges tsugae*]), diseases (such as laurel wilt [*Raffaelea lauricola*], Dutch elm disease [*Ophiostoma novo-ulmi*], white pine blister rust [*Cronartium ribicola*], and thousand cankers disease [*Geosmithia morbida*]), and mortality complexes (such as oak decline) are not easily detected or thoroughly quantified through aerial detection and other remote sensing methods. Such pests may attack hosts that are widely dispersed throughout forests with high tree species diversity or may cause mortality or defoliation that is otherwise difficult to detect. A pathogen or insect might be considered a mortality-causing agent in one location and a defoliation-causing agent in another, depending on the level of damage to the forest in an area and the convergence of other stress factors such as drought. In some cases, the identified agents of mortality or defoliation are actually complexes of multiple agents summarized under an impact label related to a specific host tree species (e.g., "beech bark disease complex" or "yellow-cedar decline"). Additionally, differences in data collection, attribute recognition, and coding procedures among States and regions can complicate data analysis and interpretation of the results. A comparison of aerial survey data with ground presence/absence observations found that the accuracy of the aerial survey data exceeded 70 percent, and that damage type observations for tree mortality and defoliation had high levels of accuracy, but that accuracy declined for severity estimates and as the specificity for observations went from genera to species level for tree species and damage agents (Coleman and others 2018).

In 2020, IDS surveys of the CONUS covered about 98.34 million ha of both forested and unforested area (fig. 2.1), of which approximately 68.34 million ha was forested, or about 21.6 percent of the 315.99-million-ha tree canopy area of the CONUS. This was less than half the percentage of tree-canopied area surveyed in 2018 (46.6 percent) and 2019 (49.2 percent) (Potter and others 2020b, 2021). Meanwhile, about 2.8 percent (2.18 million ha) of Alaska's 77.78 million ha of forest or shrubland was surveyed in 2020, out of a total of 2.70 million ha surveyed across land cover types. This compares to 12.7 percent in 2018 and 10.8 percent in 2019. Meanwhile, Hawaiian surveyors covered about 710 000 ha of that State during 2020. Approximately 520 000 ha of that area had tree canopy cover, or about 60.3 percent of the 861 000 ha total, compared to 69.4 percent in 2018 and 63.9 percent in 2019.

Digital Mobile Sketch Mapping includes tablet hardware, software, and data support processes that allow trained aerial surveyors in light aircraft, as well as ground observers and those using other remote sensing data, to record forest disturbances and their causal agents. Digital Mobile Sketch Mapping enhances the quality and quantity of forest health data while having the potential to improve safety by integrating with programs such as operational remote sensing (ORS), which uses satellite imagery to monitor disturbances in areas of higher aviation risk (FHP 2019). Geospatial data collected with DMSM are stored in the national IDS database. In an important change from the legacy Digital Aerial Sketch Mapping (DASM) approach, the DMSM platform allows surveyors to both define the extent of

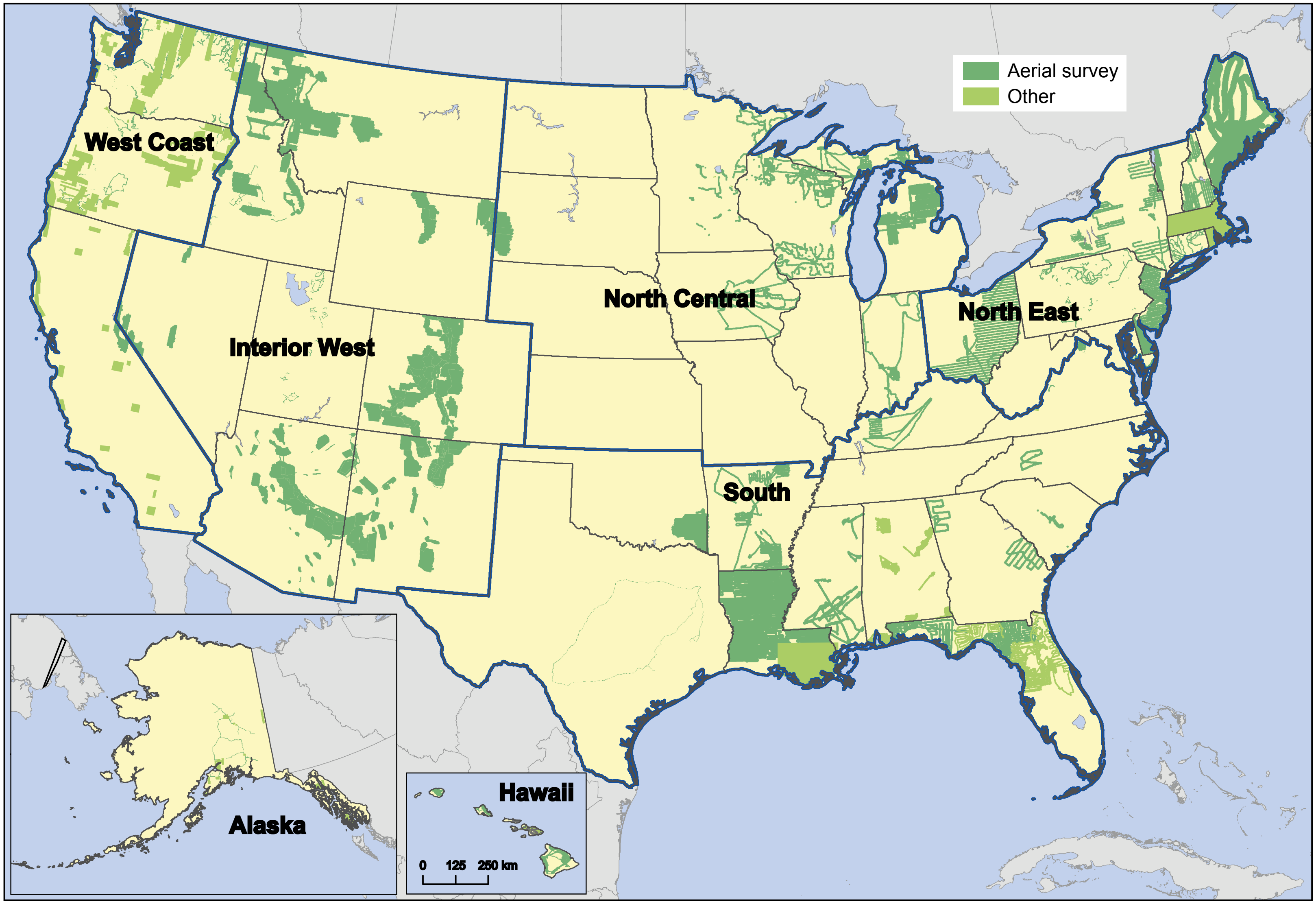

Figure 2.1—The extent of surveys for insect and disease activity conducted in the conterminous United States (CONUS), Alaska, and Hawaii in 2020. The blue lines delineate Forest Health Monitoring regions. Note: Alaska and Hawaii are not shown to scale with map of the CONUS. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

an area experiencing damage and to estimate percent range of the area within the polygon that is affected (Berryman and McMahan 2019). While additional validation will be required for this new metric, it is expected to increase the accuracy of derived damage metrics because it potentially corrects for previous overestimation caused by "lassoing" areas of undamaged trees into large areas of damage (Coleman and others 2018, Slaton and others 2021). For this reason, FHM reports before 2019 did not incorporate any derived damage estimates beyond the areal footprint damage with mortality or defoliation polygon boundaries, but these are now possible because of the inclusion of damage percentage estimates within polygons (see "Analyses" below).

Digital Mobile Sketch Mapping includes both polygon geometry, used for damage areas where boundaries are discrete and obvious, and point geometry, used for small clusters of damage where the size and shape of the damage are less important than recording the location of damage, such as for sudden oak death (caused by the pathogen *Phytophthora ramorum*), southern pine beetle (*Dendroctonus frontalis*), and some types of bark beetle damage in the West. For the 2020 data, these points were assigned an area of 0.8 ha (about 2 acres). Additionally, DMSM allows for the use of grid cells (240-, 480-, 960-, or 1920-m resolution) to estimate the percentage of trees affected by damages that may be widespread and diffuse, such as those associated with spongy moth (*Lymantria dispar dispar*, formerly known as European gypsy moth) and emerald ash borer. When calculating the total areas affected by each damage agent, we used the entire areas of these grid cells (e.g., 240-m cell = 5.76 ha).

Analyses

To estimate the extent of damaging insect and disease agents in 2020, we conducted two types of analyses. In the first, we reported the most widely detected mortality and defoliation agents in a series of tables. Specifically, the 2020 mortality and defoliation polygons were used to identify the select mortality and defoliation agents and complexes causing damage on >5000 ha of forest in the CONUS in that year. Similarly, we listed the five most widely reported mortality and defoliation agents and complexes within each of five FHM regions within the CONUS (West Coast, Interior West, North Central, North East, and South), as well as for Alaska and Hawaii where data were available.

Because of the insect and disease aerial sketch-mapping process (i.e., digitization of polygons by a human interpreter aboard aircraft or by a forest health specialist applying the "pan and sketch" approach with remotely sensed data), all quantities are approximate "footprint" areas for each agent or complex, delineating areas of visible damage within which the agent or complex is present. Unaffected trees may exist within the footprint, and the amount of damage within the footprint is not reflected in the estimates of forest area affected. The sum of areas affected by all agents and complexes is not equal to the total affected area as a result of overlapping polygons and the reporting of multiple agents per polygon in some situations.

In our second set of analyses, we used the IDS data for 2020 to more directly estimate the impacts of insect- and disease-related mortality and defoliation on U.S. forests. These results are reported in a set of figures describing the percentage of surveyed tree canopy cover area with insect- and disease-related mortality or defoliation within ecoregions across the United States. As an indicator of the extent of damaging insect and disease agents, we summarized the percentage of surveyed tree canopy cover area experiencing mortality or defoliation for ecoregions within the CONUS and Hawaii, and for surveyed forest and shrubland in Alaska ecoregions. This is a change from FHM reports before 2019, in which we reported on the percentage of regions *exposed to* mortality and defoliating agents based only on the footprint with mortality or defoliation polygon boundaries (masked by forest cover) because information on the percentage of damage within polygons was not yet completely available. As noted above, DMSM now allows surveyors to both define the extent of an area experiencing damage and to estimate percent range of the area within the polygon that is affected (specifically, 1–3 percent, 4–10 percent, 11–29 percent, 30–50 percent, and >50 percent). By multiplying the area of damage within each polygon (after masking by tree canopy cover) by the midpoint of the estimated percent-affected range, it is possible to generate an adjusted estimate of the area affected by each mortality or defoliation agent detection (Berryman and McMahan 2019). These individual estimates can be summed for all the polygons within an ecoregion (intersected and dissolved) and divided by the total surveyed tree canopy cover area within the ecoregion to generate an estimate of the percentage of its canopy cover area affected by defoliating or mortality-causing agents. (Digital Mobile Sketch Mapping point data are also included in this estimate. Surveyors have the option to estimate the number of trees affected at a point and are required to assign an area value associated with each point, which is assumed to be 100 percent affected by its mortality or defoliation agent. For simplicity, we transformed each point into a 2-acre [0.809-ha] polygon. These areas for all the points in an ecoregion were then added to the polygon-adjusted affected area estimates for the ecoregion.)

For the CONUS, percentage of surveyed tree canopy area with mortality or defoliation was calculated within each of 190 ecoregion sections (Cleland and others 2007). Similarly, the mortality and defoliation data were summarized for each of the 32 ecoregion sections in Alaska (Spencer and others 2002). In Hawaii, the percentage of surveyed tree canopy area affected by mortality and defoliation agents was calculated by 34 ecoregion subunits on each of the major islands of the archipelago (Potter 2020). Statistics were not calculated for analysis regions in the CONUS with ≤2.5 percent of the tree canopy cover area surveyed (which is less than the ≤5 percent in a typical year because of the reduced extent of survey area resulting from the global COVID-19 pandemic), nor in Alaska with ≤1 percent of the forest and shrubland area surveyed (≤2.5 percent in a typical year), nor Hawaii with ≤5 percent of the tree canopy cover area surveyed (as in a typical year).

The tree canopy data used for the CONUS and Hawaii were resampled to 240 m from a 30-m raster dataset that estimates percentage of tree canopy cover (0–100 percent) for each grid cell; this dataset was generated from the 2011 National Land Cover Database (NLCD)

(Homer and others 2015) through a cooperative project between the Multi-Resolution Land Characteristics Consortium and the Forest Service Geospatial Technology and Applications Center (GTAC) (Coulston and others 2012). For our purposes, we treated any cell with >0-percent tree canopy cover as forest. Comparable tree canopy cover data were not available for Alaska, so we instead created a 240-m-resolution layer of forest and shrub cover from the 2011 NLCD.

In previous years, we used the Spatial Association of Scalable Hexagons (SASH) analytical approach to identify statistically significant geographic hot spots of mortality or defoliation in the CONUS (Potter and others 2016). This method consists of dividing an analysis area into scalable equal-area hexagonal cells within which data are aggregated, followed by identifying statistically significant geographic clusters of hexagonal cells within which mean values are greater or less than those expected by chance. To identify these clusters, we employ a Getis-Ord (G_i^*) hot spot analysis (Getis and Ord 1992) in ArcMap® 10.3 (ESRI 2017). The low density of survey data in 2020 from both the CONUS and Alaska, as well as the small spatial extent of Hawaii (fig. 2.1), precluded the use of Getis-Ord G_i^* hot spot analyses, so we were not able to include these analyses in this report.

RESULTS AND DISCUSSION

Conterminous United States Mortality

The national IDS data in 2020 identified 45 mortality-causing agents and complexes across the CONUS on approximately 1.17 million ha, an area slightly less than the land area of Connecticut. In comparison, forests cover approximately 257 million ha of the CONUS (Oswalt and others 2019). Thirteen of the agents were detected on >5000 ha. All these numbers were lower than in a typical year (e.g., Potter and others 2020b), in large part because of the challenge of collecting insect and disease damage data during the COVID-19 pandemic. About 211 000 ha with mortality were detected using remotely sensed data other than from aerial surveys, or 18 percent of the total for the CONUS.

In 2020, the most widely detected mortality agent was emerald ash borer, identified on approximately 716 000 ha (table 2.1), or about 61 percent of the total mortality area in the CONUS. The next most widespread agent was fir engraver (*Scolytus ventralis*), detected on 150 000 ha; this mortality agent was the most widespread in 2018 and 2019 (Potter and others 2020b). No other mortality agents or complexes were detected on >100 000 ha. Mortality from the western bark beetle group, including 15 different agents in the IDS data (table 2.2), encompassed about 31 percent of all the 2020 mortality area across the CONUS, much less than during a typical year.

The North Central FHM region in 2020 had the largest area on which mortality agents and complexes were detected, about 702 000 ha (table 2.3). All but 700 ha of this was attributed to emerald ash borer. Another nine agents totaled about 0.1 percent of the mortality area. The North Central ecoregion sections with the highest mortality of surveyed tree canopy cover were 251C–Central Dissected Till Plains of southern Iowa (10.93 percent) and 251B–North

Table 2.1—Mortality agents and complexes affecting >5000 ha in the conterminous United States during 2020, including area and percentage of area surveyed by remote sensing methods other than aerial surveys

Agents/complexes causing mortality, 2020	Total area	Remotely sensed area	
	ha	*ha*	*percent*
Emerald ash borer	715 518	0	0.0
Fir engraver	149 776	100 197	66.9
Unknown	81 057	54 189	66.9
Douglas-fir beetle	52 042	16 786	32.3
Spruce beetle	38 844	0	0.0
Mountain pine beetle	31 379	16 349	52.1
Unknown bark beetle[a]	30 508	0	0.0
Western pine beetle	26 954	14 494	53.8
Balsam woolly adelgid	10 685	0	0.0
Ips engraver beetles	9309	0	0.0
Western balsam bark beetle	9053	0	0.0
Pinyon ips	6571	0	0.0
Flatheaded fir borer	5167	0	0.0
Other (32)	21 544	0	0.0
Total, all mortality agents	**1 166 528**	**211 110**	**18.1**

Note: All values are "footprint" areas for each agent or complex. The sum of the individual agents is not equal to the total for all agents due to the reporting of multiple agents per polygon.

[a] In the Interior West, this is primarily damage on ponderosa pines. The group of bark beetles is known and varied but not distinguishable from the air. Regions have characterized it as "Southwest bark beetle complex" consisting mainly of damage caused by roundheaded pine beetle, western pine beetle, and ips beetles.

Table 2.2—Beetle taxa included in the "western bark beetle" group

Western bark beetle mortality agents	
Cedar and cypress bark beetles	*Phloeosinus* spp.
Douglas-fir beetle	*Dendroctonus pseudotsugae*
Fir engraver	*Scolytus ventralis*
Flatheaded borer	Buprestidae
Ips engraver beetles	*Ips* spp.
Jeffrey pine beetle	*Dendroctonus jeffreyi*
Mountain pine beetle	*Dendroctonus ponderosae*
Pine engraver	*Ips pini*
Pinyon ips	*Ips confusus*
Roundheaded pine beetle	*Dendroctonus adjunctus*
Silver fir beetle	*Pseudohylesinus sericeus*
Spruce beetle	*Dendroctonus rufipennis*
Unknown bark beetle	—
Western balsam bark beetle	*Dryocoetes confusus*
Western pine beetle	*Dendroctonus brevicomis*

Table 2.3—The top five mortality agents or complexes for each Forest Health Monitoring region and for Alaska and Hawaii in 2020, including area and percentage of area surveyed by remote sensing methods other than aerial surveys

Mortality agents and complexes, 2020	Total area	Remotely sensed area	
	ha	*ha*	*percent*
Interior West			
Spruce beetle	38 774	0	0.0
Unknown bark beetle[a]	30 457	12	0.0
Douglas-fir beetle	26 002	262	1.0
Fir engraver	12 265	4	0.0
Mountain pine beetle	9699	0	0.0
Other mortality agents (10)	28 423	31	0.1
Total, all mortality agents and complexes	**144 341**	309	0.2
North Central			
Emerald ash borer	701 656	0	0.0
Spruce budworm	326	0	0.0
Oak decline	229	0	0.0
Unknown	36	0	0.0
Dutch elm disease	25	0	0.0
Other mortality agents (5)	52	0	0.0
Total, all mortality agents and complexes	**702 310**	0	0.0
North East			
Emerald ash borer	8407	0	0.0
Southern pine beetle	3843	0	0.0
Unknown	1236	0	0.0
Black turpentine beetle	1218	0	0.0
White pine needle damage	315	0	0.0
Other mortality agents (10)	583	0	0.0
Total, all mortality agents and complexes	**15 585**	0	0.0

Mortality agents and complexes, 2020	Total area	Remotely sensed area	
	ha	*ha*	*percent*
South			
Emerald ash borer	5455	0	0.0
Unknown	2036	0	0.0
Laurel wilt	1774	0	0.0
Ips engraver beetles	1054	0	0.0
Southern pine beetle	19	0	0.0
Other mortality agents (2)	1	0	0.0
Total, all mortality agents and complexes	**10 339**	0	0.0
West Coast			
Fir engraver	137 511	100 193	72.9
Unknown	75 132	54 165	72.1
Western pine beetle	26 565	14 493	54.6
Douglas-fir beetle	26 040	16 525	63.5
Mountain pine beetle	21 680	16 349	75.4
Other mortality agents (20)	27 593	12 396	44.9
Total, all mortality agents and complexes	**293 952**	210 801	71.7
Alaska			
Spruce beetle	45 826	43 408	94.7
Hemlock sawfly	32 202	32 201	100.0
Yellow-cedar decline	4177	4067	97.4
Brown crumbly rot (red belt fungus)	1	0	0.0
Unknown canker, diffuse	1	0	0.0
Other mortality agents (7)	1	0	0.0
Total, all mortality agents and complexes	**82 204**	79 673	96.9
Hawaii			
Unknown[b]	32 297	0	0.0
Total, all mortality agents and complexes	**32 297**	0	0.0

Note: The total area affected by other agents is listed at the end of each section. All values are "footprint" areas for each agent or complex. The sum of the individual agents is not equal to the total for all agents due to the reporting of multiple agents per polygon.

[a] In the Interior West, this is primarily damage on ponderosa pines. The group of bark beetles is known and varied but not distinguishable from the air. Regions have characterized it as "Southwest bark beetle complex" consisting mainly of damage caused by roundheaded pine beetle, western pine beetle, and ips beetles.

[b] Most of the mortality recorded in Hawaii is coded as "unknown" mortality on ʻōhiʻa lehua. Damage is likely attributed to rapid ʻōhiʻa death but has not been confirmed in all cases.

Central Glaciated Plains of northwestern Iowa and southwestern Minnesota (6.02 percent), where emerald ash borer was detected killing white, green, and black ash (*Fraxinus americana*, *F. pennsylvanica*, and *F. nigra*) (fig. 2.2). Two adjacent ecoregions also experienced extensive mortality associated with emerald ash borer: 222M–Minnesota and Northeast Iowa Morainal-Oak Savannah (4.36 percent) and 222L–North Central U.S. Driftless and Escarpment of southwestern Wisconsin, northeastern Iowa, and southeastern Minnesota (3.99 percent).

In 2020, the West Coast FHM region had the second-largest area on which mortality agents and complexes were detected, about 294 000 ha (table 2.3). A little less than half of this area (138 000 ha) was associated with fir engraver mortality. The next most commonly detected and known mortality agents were western pine beetle (*D. brevicomis*) on 27 000 ha (9.0 percent of the mortality area), Douglas-fir beetle (*D. pseudotsugae*) on 26 000 ha (8.9 percent), and mountain pine beetle (*D. ponderosae*) on 22 000 ha (7.4 percent). Another 20 mortality-causing agents and complexes accounted for 9.4 percent of the mortality area in the West Coast region.

Most of the sufficiently surveyed ecoregions in the West Coast region had at least a moderate amount of mortality in their surveyed area (>0.25 percent) (fig. 2.2). For example, the M261A–Klamath Mountains ecoregion section in northwestern California and southwestern Oregon had 1.35-percent mortality in surveyed canopy area, the result of fir engraver mortality in Pacific silver fir (*Abies amabilis*), grand fir (*A. grandis*), California red fir (*A. magnifica* var. *shastensis*), and noble fir (*A. procera*) forests, and of flatheaded fir borer (*Phaenops drummondi*) in Douglas-fir (*Pseudotsuga menziesii*) forests. In 261A–Central California Coast (1.20-percent mortality in surveyed areas), an unknown agent was causing mortality in California live oak (*Quercus agrifolia*) stands. Western pine beetle in stands of ponderosa pine (*Pinus ponderosa*) and fir engraver in stands of white fir (*A. concolor*) were issues in M261D–Southern Cascades (0.89-percent mortality of surveyed areas), while a long list of agents caused mortality in M333A–Okanogan Highland (0.92 percent), including ips engraver beetles and western pine beetle in ponderosa pine; Douglas-fir beetle in Douglas-fir; fir engraver and balsam woolly adelgid (*Adelges piceae*) in Pacific silver fir, noble fir, and grand fir; and mountain pine beetle in lodgepole pine (*P. contorta*). Similarly, several agents caused mortality in the M262B–Southern California Mountain and Valley ecoregion section (0.63 percent): fir engraver in white fir stands; Jeffrey pine beetle (*D. jeffreyi*) in Jeffrey pine (*P. jeffreyi*) stands; western pine beetle in ponderosa pine stands; and goldspotted oak borer (*A. auroguttatus*) in valley oak (*Q. lobata*), interior live oak (*Q. wislizeni*), canyon live oak (*Q. chrysolepis*), Engelmann oak (*Q. engelmannii*), and California black oak (*Q. kelloggii*). Finally, the M332G–Blue Mountains ecoregion section of northeastern Oregon had 0.58-percent mortality of surveyed areas due to mountain pine beetle-caused mortality in lodgepole pine, western pine beetle in ponderosa pine, and fir engraver in various firs.

In the Interior West FHM region, damage from 15 mortality agents and complexes was identified across 144 000 ha (table 2.3). As in 2018, spruce beetle (*D. rufipennis*) was the most

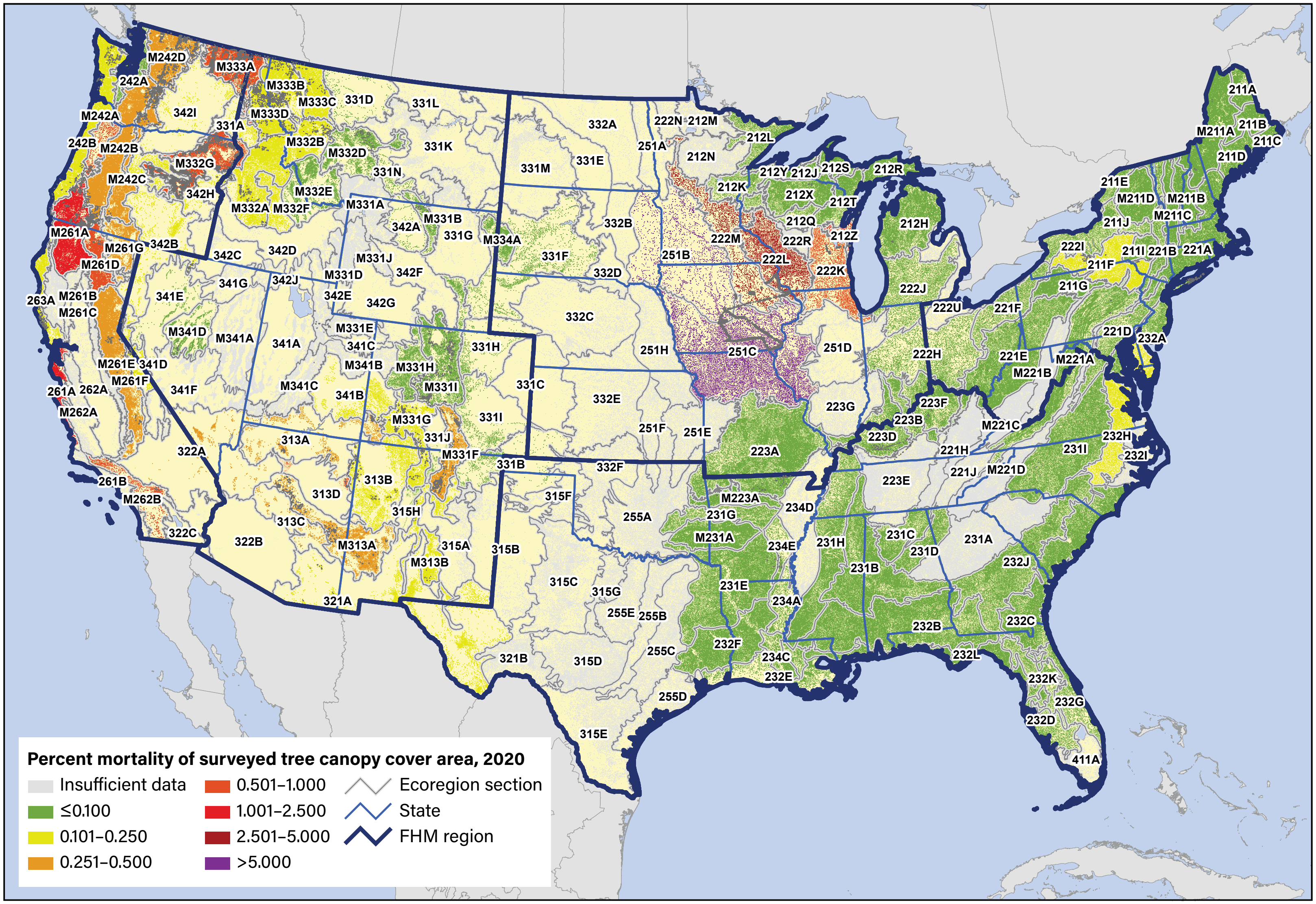

Figure 2.2—The percentage of surveyed tree canopy cover area with insect and disease mortality, by ecoregion section within the conterminous United States, for 2020. The gray lines delineate ecoregion sections (Cleland and others 2007). The 240-m tree canopy cover is based on data from a cooperative project between the Multi-Resolution Land Characteristics Consortium (Coulston and others 2012) and the Forest Service Geospatial Technology and Applications Center using the 2011 National Land Cover Database. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

widely detected agent, recorded on about 39 000 ha, or 26.9 percent of the total mortality area. Next, unknown bark beetles affected 21.1 percent of the total mortality area, or 30 000 ha. This was primarily damage in ponderosa pine forests by a group of known and varied bark beetles that are not possible to distinguish using remotely sensed data. This also has been characterized as "Southwest bark beetle complex" consisting mainly of damage caused by roundheaded pine beetle (*D. adjunctus*), western pine beetle, and ips beetles. Other widespread mortality agents in the region were Douglas-fir beetle detected on 26 000 ha (18.0 percent), fir engraver beetle on 12 000 ha (8.5 percent), and mountain pine beetle on 10 000 ha (6.7 percent) (table 2.3).

Interior West mortality was highest in the Four Corners States (fig. 2.2). The 313D–Painted Desert ecoregion section had the highest percentage of surveyed tree canopy area mortality (0.67) in the region, mostly the result of pinyon ips in two-needle pinyon (*P. edulis*) stands, as well as some mortality caused by cedar and cypress bark beetles in stands of Arizona cypress (*Cupressus arizonica*) and various junipers (*Juniperus* spp.) In the M331F–Southern Parks and Rocky Mountain Range ecoregion section, 0.43 percent of surveyed canopy area had mortality, the result of Engelmann spruce (*Picea engelmannii*) mortality by spruce beetle in the northern half of the ecoregion, and of Douglas-fir beetle in Douglas-fir stands and Southwest bark beetle complex in ponderosa pine stands (described above) in the southern half. Three other ecoregion sections, 313A–Grand Canyon (0.32 percent mortality), M313A–White Mountains-San Francisco Peaks-Mogollon Rim (0.31 percent), and 313C–Tonto Transition (0.28 percent), also experienced mortality from Southwest bark beetle complex in ponderosa pine. This was in addition to roundheaded pine beetle in ponderosa pine and pinyon ips in two-needle pinyon in 313A–Grand Canyon, as well as to spruce beetle in Engelmann spruce, Douglas-fir beetle in Douglas-fir, and western balsam bark beetle in corkbark fir (*Abies lasiocarpa* var. *arizonica*) in M313A–White Mountains-San Francisco Peaks-Mogollon Rim.

Approximately 16 000 ha in the North East FHM region had recorded damage from 15 mortality agents and complexes in 2020 (table 2.3). The most commonly detected was emerald ash borer, on 8000 ha (53.9 percent of the total mortality area in the region). Less commonly identified agents were southern pine beetle (4000 ha, 24.7 percent) and black turpentine beetle (*Dryocoetes terebrans*) (1000 ha, 7.8 percent). Two ecoregion sections had mortality exceeding 0.1 percent of the surveyed tree canopy area (fig. 2.2): 211F–Northern Glaciated Allegheny Plateau (0.12 percent) as a result of emerald ash borer and 232H–Middle Atlantic Coastal Plains and Flatwoods (also 0.12 percent) as a result of an unknown conifer mortality agent.

Finally, in the South FHM region, surveyors identified seven agents causing 10 000 ha with mortality (table 2.3). As with the North Central and North East regions, emerald ash borer was the most common mortality category (5000 ha, 52.8 percent), followed by "unknown" (2000 ha, 19.7 percent), laurel wilt (2000 ha, 17.2 percent), and ips engraver beetles (1000 ha, 10.2 percent).

Conterminous United States Defoliation

The national IDS in 2020 identified 59 defoliation agents and complexes affecting approximately 1.54 million ha across the CONUS (table 2.4), which is somewhat larger than the combined land area of Connecticut and Rhode Island. The most widespread defoliation agent was spruce budworm (*Choristoneura fumiferana*), detected on 496 000 ha, or approximately 32 percent of the total area with defoliation. In 2018 and 2019 (Potter and others 2020b, 2021), the most widespread defoliation agent was western spruce budworm (*C. freemani*), which was the third-most common in 2020, found on 220 000 ha or 14 percent of the total. Four additional agents were each detected on >100 000 ha: spongy moth on 388 000 ha, forest tent caterpillar (*Malacosoma disstria*) on 195 000 ha, and baldcypress leafroller (*Archips goyerana)* on 136 000 ha. About 14.5 percent of the total CONUS defoliation (223 000 ha) was detected

Table 2.4—Defoliation agents and complexes affecting >5000 ha in the conterminous United States in 2020, including area and percentage of area surveyed by remote sensing methods other than aerial surveys

Agents/complexes causing defoliation, 2020	Total area	Remotely sensed area	
	ha	*ha*	*percent*
Spruce budworm	496 493	0	0.0
Spongy moth	388 480	0	0.0
Western spruce budworm	219 735	0	0.0
Forest tent caterpillar	195 382	195 364	100.0
Baldcypress leafroller	135 709	135 709	100.0
Unknown defoliator	33 629	0	0.0
Douglas-fir tussock moth	31 958	0	0.0
Unknown	31 665	0	0.0
Gelechiid moths/needleminers	19 842	0	0.0
Browntail moth	17 943	0	0.0
Agromyzid fly	17 491	0	0.0
Fall webworm	14 839	0	0.0
Fall cankerworm	10 406	10 336	99.3
Maple leafcutter	8026	0	0.0
Pinyon needle scale	7350	0	0.0
Other (44)	38 141	5494	14.4
Total, all defoliation agents	**1 535 291**	**222 690**	**14.5**

Note: All values are "footprint" areas for each agent or complex. The sum of the individual agents is not equal to the total for all agents due to the reporting of multiple agents per polygon.

through remotely sensed methods other than the standard aerial surveys.

The North Central FHM region had the largest area on which defoliation was detected in 2020 (table 2.5). Surveyors identified 16 defoliation agents on approximately 924 000 ha, with slightly more than half of the defoliation area attributed to spruce budworm (496 000 ha). Spongy moth also caused widespread damage (385 000 ha, 41.6 percent).

Two ecoregion sections in the Great Lakes area exceed 5-percent defoliation of surveyed canopy cover (fig. 2.3): 212L–Northern Superior Uplands in northeastern Minnesota and 212H–Northern Lower Peninsula. In the former, the defoliation was by spruce budworm in spruce and fir forests, while it was by spongy moth in oak forests and spruce budworm in the latter. Other areas of extensive defoliation included 222J–South Central Great Lakes in southern Michigan (spongy moth), 251B–North Central Glaciated Plains of northwestern Iowa and southwestern Minnesota (Japanese beetle [*Popillia japonica*] and oak skeletonizer [*Bucculatrix ainsliella*]), and 223B–Interior Low Plateau-Transition Hills of south-central Indiana (unknown hardwood defoliator).

In the Interior West FHM region, 306 000 ha of damage was associated with 17 defoliators (table 2.5). Most of this area (71.7 percent) was affected by western spruce budworm (220 000 ha), as in recent years (Potter and others 2020b, 2021). Other widespread and known defoliators were Douglas-fir tussock moth (*Orgyia pseudotsugata*) which affected 30 000 ha (9.7 percent), Gelechiid moths/needleminers (*Coleotechnites* spp.) identified on 20 000 ha (6.5 percent), and pinyon needle scale (*Matsucoccus acalyptus*) detected on 7000 ha (2.4 percent).

Western spruce budworm caused extensive defoliation in areas of both the southern and northern Rockies, which was highest in M331F–Southern Parks and Rocky Mountain Range (4.99-percent defoliation of surveyed area) and M331G–South-Central Highlands (3.76 percent), both in south-central Colorado and north-central New Mexico (fig. 2.3). Western spruce budworm was also an issue in three adjacent ecoregion sections, M331I–Northern Parks and Ranges (0.78 percent) and M331H–North-Central Highlands and Rocky Mountains (0.61 percent) in north-central Colorado, and 313A–Grand Canyon (0.73 percent) in the Four Corners area. Meanwhile, it was also widespread in several ecoregion sections in northern Idaho, western Montana, and north-central Wyoming: M332B–Northern Rockies and Bitterroot Valley (0.85 percent), M333D–Bitterroot Mountains (0.73 percent), M332D–Belt Mountains (0.57 percent), and M331B–Bighorn Mountains (0.77 percent). Throughout the Interior West FHM region, western spruce budworm infested a variety of spruce (*Picea*) and fir (*Abies*) species, as well as Douglas-fir.

Additional defoliators were active in these ecoregion sections, usually to a lesser extent than western spruce beetle where it was present. For example, Douglas-fir tussock moth defoliated grand and subalpine fir (*A. lasiocarpa*) in M333D–Bitterroot Mountains and M332B–Northern Rockies and Bitterroot Valley. Quaking aspen

Table 2.5—The top five defoliation agents or complexes for each Forest Health Monitoring region and for Alaska and Hawaii in 2020, including area and percentage of area surveyed by remote sensing methods other than aerial surveys

Defoliation agents and complexes, 2020	Total area	Remotely sensed area	
	ha	*ha*	*percent*
Interior West			
Western spruce budworm	219 631	285	0.1
Unknown defoliator	32 868	98	0.3
Douglas-fir tussock moth	29 713	0	0.0
Gelechiid moths/needleminers	19 842	0	0.0
Pinyon needle scale	7350	0	0.0
Other defoliation agents (12)	4318	156	3.6
Total, all defoliation agents and complexes	**306 188**	540	0.2
North Central			
Spruce budworm	496 493	0	0.0
Spongy moth	384 605	0	0.0
Unknown	31 072	0	0.0
Japanese beetle	4478	0	0.0
Oak skeletonizer	2212	0	0.0
Other defoliation agents (11)	4698	0	0.0
Total, all defoliation agents and complexes	**923 557**	0	0.0
North East			
Browntail moth	17 943	0	0.0
Agromyzid fly	17 491	0	0.0
Fall webworm	14 839	0	0.0
Maple leafcutter	8026	0	0.0
Spongy moth	3875	31	0.8
Other defoliation agents (13)	11 246	2549	22.7
Total, all defoliation agents and complexes	**73 419**	2580	3.5

Defoliation agents and complexes, 2020	Total area	Remotely sensed area	
	ha	*ha*	*percent*
South			
Forest tent caterpillar	195 208	195 208	100.0
Baldcypress leafroller	135 709	135 709	100.0
Fall cankerworm	7787	7787	100.0
Sawflies	409	0	0.0
Unknown	7	0	0.0
Other defoliation agents (1)	<1	0	0.0
Total, all defoliation agents and complexes	**214 907**	214 491	99.8
West Coast			
Balsam woolly adelgid	3229	1855	57.5
Pandora moth	2929	0	0.0
Larch casebearer	2567	168	6.5
Lophodermium needle cast of pines	2343	0	0.0
Douglas-fir tussock moth	2245	2110	94.0
Other defoliation agents (15)	3957	947	23.9
Total, all defoliation agents and complexes	**17 219**	5079	29.5
Alaska			
Hemlock sawfly	49 407	42 492	86.0
Aspen leafminer	15 670	14 527	92.7
Unknown defoliator	1184	600	50.7
Birch leafminer	1152	0	0.0
Willow leaf blotchminer	169	122	72.4
Other defoliation agents (41)	108	0	0.0
Total, all defoliation agents and complexes	**67 683**	57 741	85.3
Hawaii			
'Ōhi'a / guava rust	5	0	0.0
Total, all defoliation agents and complexes	**5**	0	0.0

Note: The total area affected by other agents is listed at the end of each section. All values are "footprint" areas for each agent or complex. The sum of the individual agents is not equal to the total for all agents due to the reporting of multiple agents per polygon.

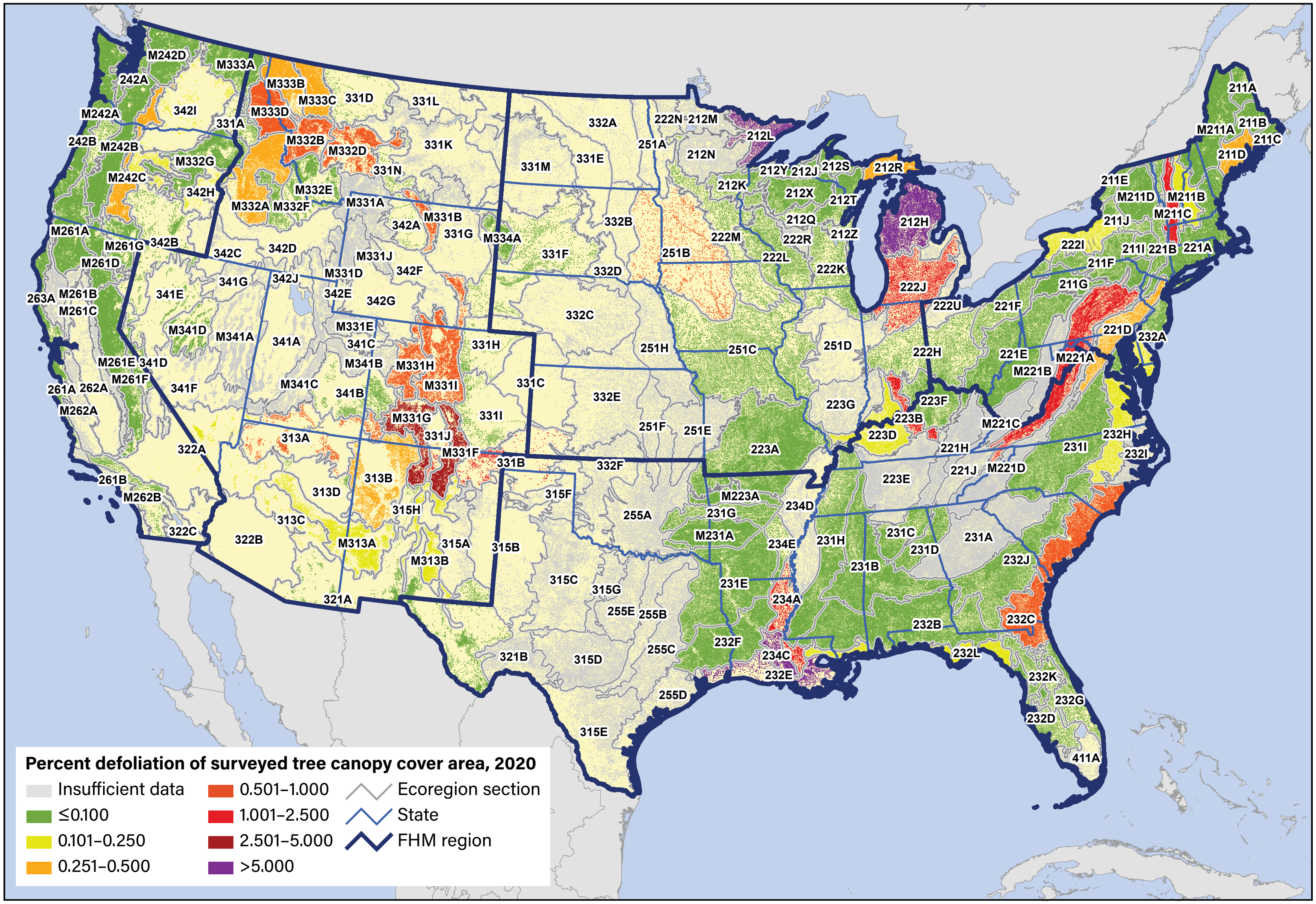

Figure 2.3—The percentage of surveyed tree canopy cover area with insect and disease defoliation, by ecoregion section within the conterminous United States, for 2020. The gray lines delineate ecoregion sections (Cleland and others 2007). The 240-m tree canopy cover is based on data from a cooperative project between the Multi-Resolution Land Characteristics Consortium (Coulston and others 2012) and the Forest Service Geospatial Technology and Applications Center using the 2011 National Land Cover Database. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

(*Populus tremuloides*) was defoliated by Marssonina blight in M331G–South-Central Highlands and by unknown defoliators there and in M331F–Southern Parks and Rocky Mountain Range (where Gelechiid moths/needleminers also defoliated ponderosa pine), M331I–Northern Parks and Ranges, and 313A–Grand Canyon (where pinyon needle scale also defoliated two-needle pinyon).

In the South FHM region, two of six agents were the most widely identified: forest tent caterpillar on about 195 000 ha (90.8 percent of the regional total) and baldcypress leafroller on about 136 000 ha (63.1 percent). The two co-occurred on large areas of surveyed tree canopy cover. Fall cankerworm (*Alsophila pometaria*) defoliation was detected on an additional 8000 ha (3.6 percent).

The combination of forest tent caterpillar (in a variety of southern hardwoods) and baldcypress leafroller (in baldcypress [*Taxodium distichum*]) resulted in high levels of defoliation in southern and eastern Louisiana: 232E–Louisiana Coastal Prairie and Marshes (8.83 percent defoliation of surveyed canopy area) and 234C–Atchafalaya and Red River Alluvial Plains (2.27 percent) (fig. 2.3). The 232C–Atlantic Coastal Flatwoods ecoregion section, which stretches along the Atlantic Coast from North Carolina to northern Florida, also had relatively high defoliation (0.51 percent) as a result of forest tent caterpillar.

Surveyors in 2020 documented about 73 000 ha with defoliation in the North East FHM region (table 2.5), with browntail moth (*Euproctis chrysorrhoea*) detected on about 18 000 ha (24.4 percent of the area with defoliation), agromyzid fly (*Agromyza viridula*) on about 17 000 ha (23.8 percent), and fall webworm (*Hyphantria cunea*) on about 15 000 ha (20.2 percent). Among the other 15 defoliating agents detected in the region, maple leafcutter (*Paraclemensia acerifoliella*) and spongy moth were recorded on an additional 8000 ha and 4000 ha, respectively.

The North East ecoregion section with the highest proportion of defoliation was M221A–Northern Ridge and Valley in east-central Pennsylvania (2.12 percent), where locust leafminer (*Odontota dorsalis*) infested black locust (*Robinia pseudoacacia*) and where fall webworm impacted various hardwoods (fig. 2.3). A relatively high proportion of defoliated surveyed canopy area (1.26 percent) was caused in M211C–Green-Taconic-Berkshire Mountains in Vermont and Massachusetts by maple leafcutter in stands of sugar maple (*Acer saccharum*) and red maple (*A. rubrum*). Meanwhile, fall webworm was an issue in the 221D–Northern Appalachian Piedmont of southeastern Pennsylvania and northern New Jersey (0.33-percent defoliation), and browntail moth was an issue in northern red oak (*Quercus rubra*) stands in 211D–Central Maine Coastal and Embayment (0.31 percent).

Finally, 20 defoliating agents were recorded in the West Coast FHM region on 17 000 ha (table 2.5), with no single agent responsible for a majority of the defoliation. Five agents each represent between 13 and 19 percent of defoliation: balsam woolly adelgid (3000 ha), pandora moth (*Coloradia pandora*) (3000 ha), larch casebearer (*Coleophora laricella*) (2600 ha), Lophodermium needle cast of pines (*Lophodermium* spp.) (2000 ha), and Douglas-fir tussock moth (2000 ha).

One West Coast ecoregion section, M242C–Eastern Cascades of south-central Washington and central Oregon, had a moderate proportion of defoliation (0.31 percent of surveyed canopy area) (fig. 2.3). This was the result of a suite of defoliating agents: pandora moth in ponderosa and lodgepole pines; lodgepole pine sawfly (*Neodiprion nanulus contortae*) in lodgepole stands; balsam woolly adelgid in Pacific silver, subalpine, and grand fir stands; and larch needle cast (*Rhabdocline laricis*) in western larch (*Larix occidentalis*).

Alaska and Hawaii

In 2020, surveyors detected 82 000 ha with mortality in Alaska, attributed to 12 agents (table 2.3), an increase from 2019. As in previous years, spruce beetle was the most widely detected mortality agent, encompassing 46 000 ha and 55.7 percent of total area with mortality. Other widespread mortality agents were hemlock sawfly (*Neodiprion tsugae*), identified on 32 000 ha (39.2 percent of the total) and yellow-cedar (*Chamaecyparis nootkatensis*) decline, on 4000 ha or 5.1 percent of the total.

Also as in recent years, spruce beetle mortality was concentrated in south-central Alaska (fig. 2.4). The 133A–Cook Inlet Basin ecoregion section had the highest mortality of surveyed forest and shrubland in the State (2.89 percent). Two neighboring ecoregion sections also had relatively high mortality: M241C–Chugach-St. Elias Mountains (0.47) and M133B–Alaska Range (0.38 percent). Additionally, mortality from hemlock sawfly in western hemlock (*Tsuga heterophylla*) stands resulted in 0.78-percent mortality of the surveyed forest and shrubland of M241D–Alexander Archipelago in the Alaska panhandle.

Meanwhile, 46 agents resulted in 68 000 ha of Alaskan defoliation detected in 2020 (table 2.5). Hemlock sawfly encompassed 73.0 percent of the total defoliation area (49 000 ha). Aspen leafminer (*Phyllocnistis populiella*) was detected on an additional 16 000 ha (23.2 percent of the total).

The highest levels of defoliation occurred in east-central Alaska and in the panhandle (fig. 2.5). The 2.03-percent defoliation of surveyed forest and shrubland in M241D–Alexander Archipelago, in the Alaska panhandle, was attributed to hemlock sawfly, which also generated a relatively high level of mortality in the area (see above). Farther north, aspen leafminer was the primary cause of defoliation in M132C–Yukon-Tanana Uplands (1.93 percent of surveyed forest and shrubland), M132F–North Ogilvie Mountains (1.06 percent), and 132C–Tanana-Kuskokwim Lowlands (0.53 percent).

In the pandemic year of 2020, >85 percent of Alaska mortality (table 2.3) and defoliation (table 2.5) were detected using alternative methods to the standard aerial detection surveys.

Finally, about 32 000 ha with mortality were detected in Hawaii during 2020 using standard aerial survey methods (table 2.3), compared to

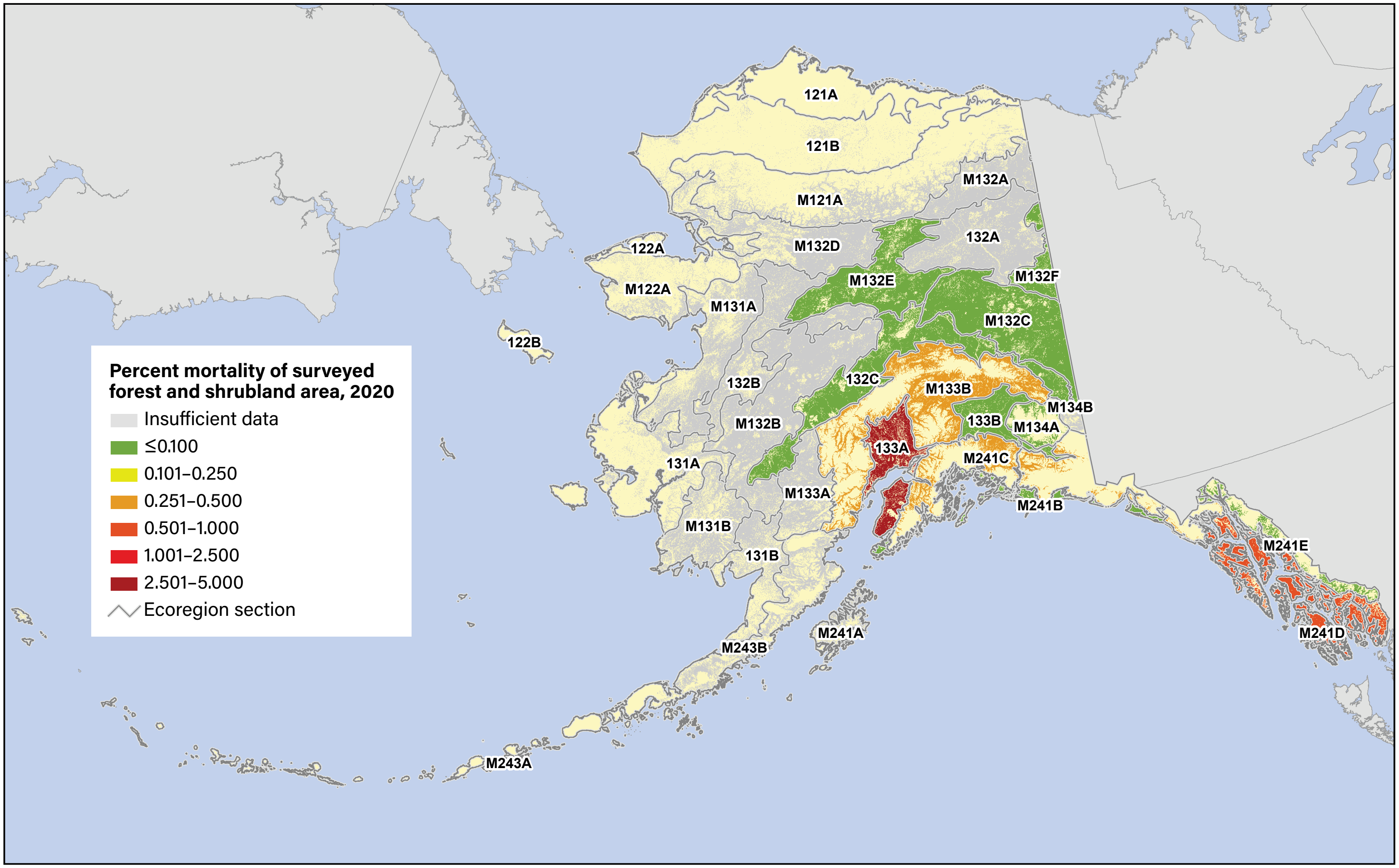

Figure 2.4—Percentage of 2020 surveyed Alaska forest and shrubland area within ecoregions with mortality caused by insects and diseases. The gray lines delineate ecoregion sections (Spencer and others 2002). Forest and shrub cover is derived from the 2011 National Land Cover Database. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

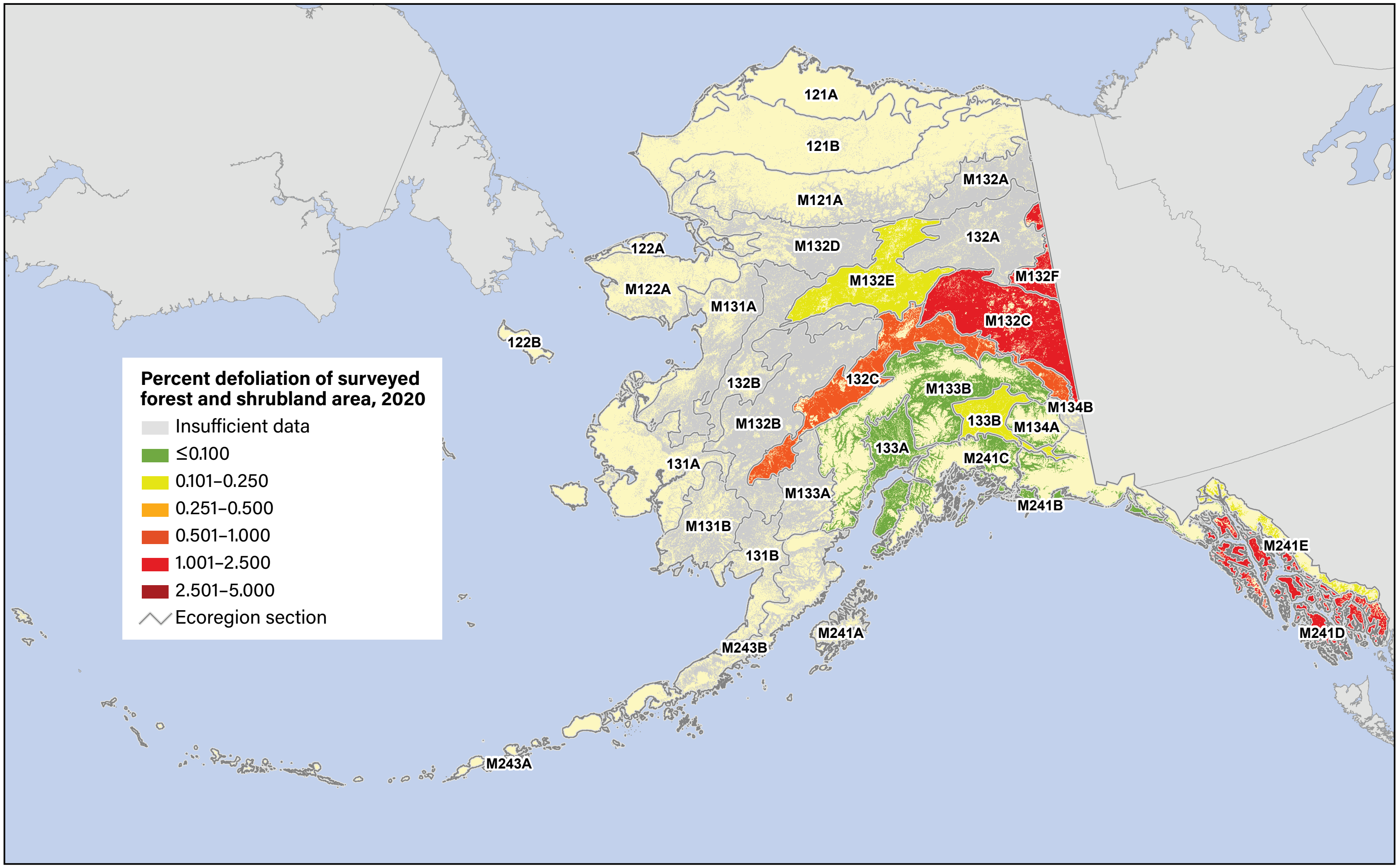

Figure 2.5—Percentage of 2020 surveyed Alaska forest and shrubland area within ecoregions with defoliation caused by insects and diseases. The gray lines delineate ecoregion sections (Spencer and others 2002). Forest and shrub cover is derived from the 2011 National Land Cover Database. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

27 000 ha in 2019 (Potter and others 2021). While all of this was coded as having an "unknown" mortality agent, at least some of the damage was likely caused by rapid ʻōhiʻa death, a wilt disease that affects ʻōhiʻa lehua (*Metrosideros polymorpha*). This endemic species is the most abundant native tree in Hawaii, where it is deeply woven into Hawaiian culture (University of Hawaiʻi 2021). Two fungal pathogens cause rapid ʻōhiʻa death, the more aggressive *Ceratocystis lukuohia* and the less aggressive *C. huliohia*, though both can kill ʻōhiʻa (Barnes and others 2018). Both pathogens have been confirmed on the islands of Hawaiʻi (the Big Island), where 90 percent of detections are of the more aggressive *C. lukuohia*, and Kauaʻi; meanwhile, in 2019 a small number of trees infected with *C. huliohia* were detected on Oʻahu and Maui (University of Hawaiʻi 2021).

All the montane wet ecoregions on the Island of Hawaiʻi had high levels of detected mortality in 2020 (fig. 2.6). The highest was Montane Wet-Hawaiʻi-Kona (MWh-ko) with 3.81-percent mortality of the surveyed tree canopy area, followed by Montane Wet-Hawaiʻi-Hilo-Puna (MWh-hp) with 1.72 percent, Montane Wet-Hawaiʻi-Kaʻū (MWh-ka) with 1.22 percent, and Montane Wet-Hawaiʻi-Kohala-Hāmākua (MWh-kh) with 0.90 percent.

CONCLUSIONS

Forest health specialists needed to quickly adapt new methods to monitor insect and disease damage in U.S. forests during 2020 as a result of the global COVID-19 pandemic. They were successful in surveying large areas of forest across the country, if not as much as in a typical year, despite the challenging circumstances. Caution is warranted, however, in comparing 2020 mortality and defoliation results to previous years because of the differences in the survey methods employed and in the proportion of forest surveyed.

Continued monitoring of insect and disease outbreaks across the United States will be necessary for determining appropriate followup investigation and management activities. Due to the limitations of survey efforts to detect certain important forest insects and diseases, the pests and pathogens discussed in this chapter do not include all the biotic forest health threats that should be considered when making management decisions and budget allocations. However, large-scale assessments of mortality and defoliation severity offer a useful approach for identifying geographic areas where the concentration of monitoring and management activities might be most effective.

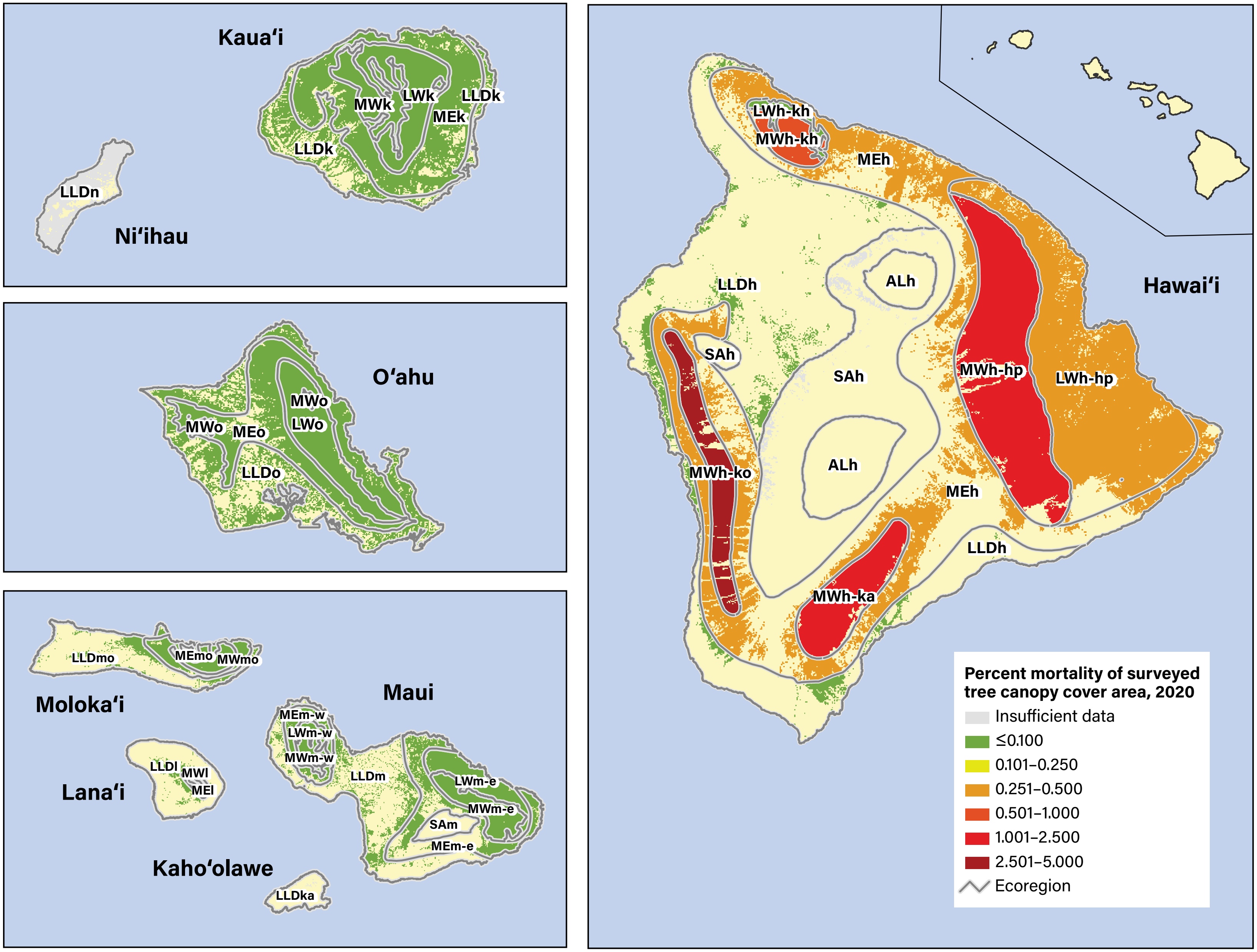

Figure 2.6—Percentage of 2020 surveyed Hawaii tree canopy area within island/ecoregion combinations with mortality caused by insects and diseases. Tree canopy cover is based on data from a cooperative project between the Multi-Resolution Land Characteristics Consortium (Coulston and others 2012) and the Forest Service Geospatial Technology and Applications Center using the 2011 National Land Cover Database. See table 1.1 for ecoregion identification. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

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