CHAPTER 2.

Large-Scale Patterns of Insect and Disease Activity in the Conterminous United States and Alaska from the National Insect and Disease Survey, 2014

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INTRODUCTION

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). 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 extraordinary levels 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 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). Introduced nonnative insects and diseases, in particular, can extensively damage the diversity, 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 insect pest outbreaks (Holdenrieder and others 2004, Liebhold and 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.

METHODS

Data

Forest Health Protection (FHP) national Insect and Disease Survey (IDS) data (FHP 2014) 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 identify forest landscape-scale patterns associated with geographic hot spots of forest insect and disease activity in the conterminous 48 States and to summarize insect and disease activity by ecoregion in Alaska (Potter 2012, 2013; Potter and Koch 2012; Potter and Paschke 2013, 2014, 2015a, 2015b). In 2014, IDS surveys covered about 159.27 million ha of the forested area in the conterminous United States (approximately 62.5 percent of the total), and about 7.74 million ha of Alaska's forested area (approximately 15.1 percent of the total) (fig. 2.1).

These surveys identify areas of 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, Dutch elm disease, white pine blister rust, and thousand cankers disease), and mortality complexes (such as oak decline) are not easily detected or thoroughly quantified through aerial detection surveys. 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 a given 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., "subalpine fir mortality complex" or "aspen defoliation"). Additionally, differences in data collection, attribute recognition, and coding procedures among States and regions can complicate data analysis and interpretation of the results.

The 2014 mortality and defoliation polygons were used to identify the select mortality and defoliation agents and complexes causing damage on more than 5000 ha of forest in the conterminous United States in that year, and to identify and list the most widely detected mortality and defoliation agents for Alaska. Because of the insect and disease aerial sketch-mapping process (i.e., digitization of polygons by a human interpreter aboard the aircraft), 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 agents and complexes is not equal to the total affected area as a result of reporting multiple agents per polygon in some situations.

Analyses

We used the Spatial Association of Scalable Hexagons (SASH) analytical approach to identify surveyed forest areas with the greatest exposure to the detected mortality-causing and defoliation-causing agents and complexes. This method identifies locations where ecological phenomena occur at greater or lower occurrences than expected by random chance and is based on a sampling frame optimized for spatial neighborhood analysis, adjustable to the appropriate spatial resolution, and applicable to multiple data types (Potter and others 2016). Specifically, it consists of dividing an analysis area into scalable equal-area hexagonal cells

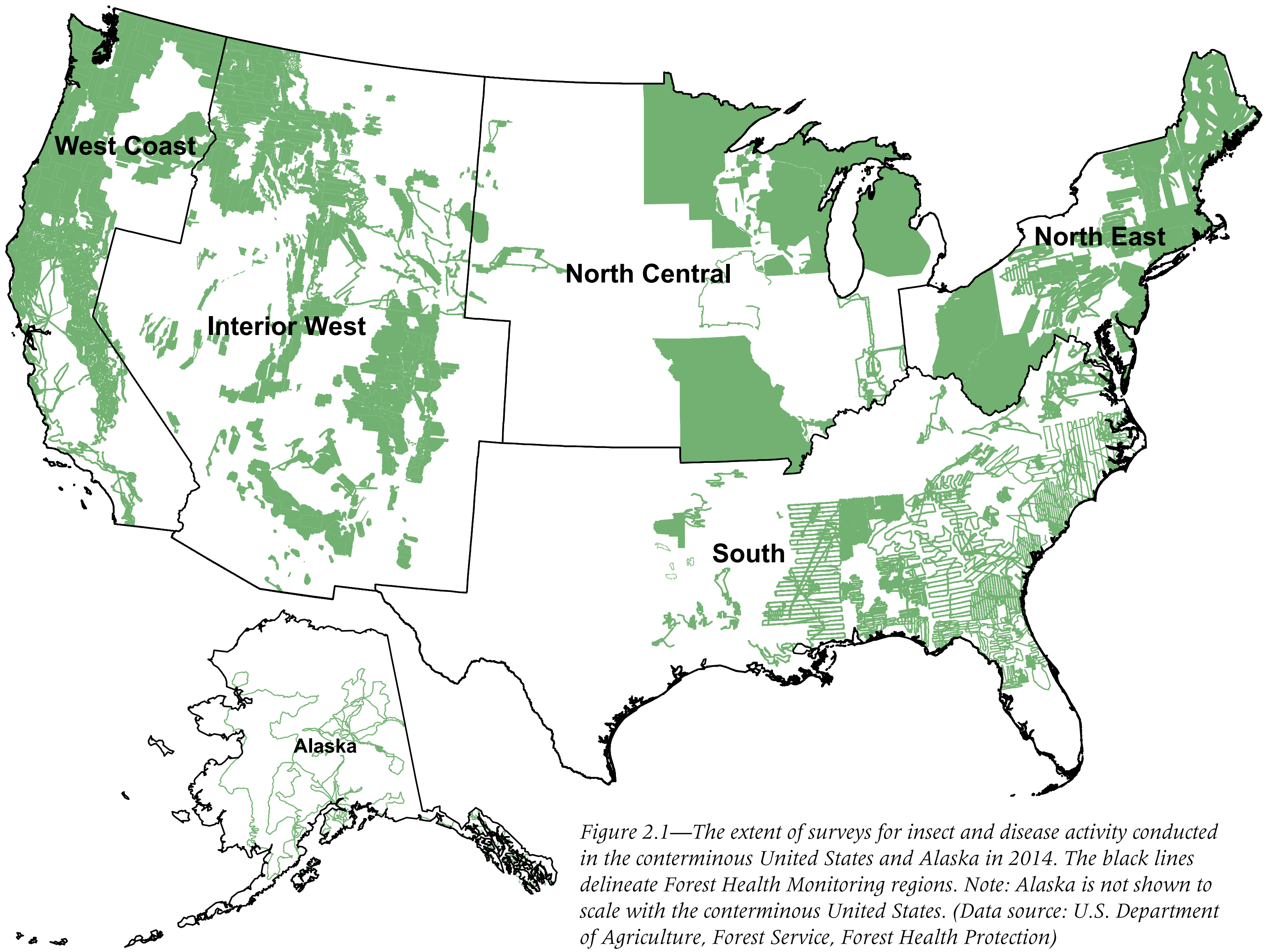

Figure 2.1—The extent of surveys for insect and disease activity conducted in the conterminous United States and Alaska in 2014. The black lines delineate Forest Health Monitoring regions. Note: Alaska is not shown to scale with the conterminous United States. (Data source: U.S. Department of Agriculture, Forest Service, Forest Health Protection)

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® 10.1 (ESRI 2012).

The units of analysis were 9,810 hexagonal cells, each approximately 834 km^2 in area, generated in a lattice across the conterminous United States using intensification of the Environmental Monitoring and Assessment Program (EMAP) North American hexagon coordinates (White and others 1992). These coordinates are the foundation of a sampling frame in which a hexagonal lattice was projected onto the conterminous United States by centering a large base hexagon over the region (Reams and others 2005, White and others 1992). This base hexagon can be subdivided into many smaller hexagons, depending on sampling needs, and serves as the basis of the plot sampling frame for the Forest Inventory and Analysis (FIA) Program (Reams and others 2005). Importantly, the hexagons maintain equal areas across the study region regardless of the degree of intensification of the EMAP hexagon coordinates. In addition, the hexagons are compact and uniform in their distance to the centroids of neighboring hexagons, meaning that a hexagonal lattice has a higher degree of isotropy (uniformity in all directions) than does a square grid (Shima and others 2010). These are convenient and highly useful attributes for spatial neighborhood analyses. These scalable hexagons also are independent of geopolitical and ecological boundaries, avoiding the possibility of different sample units (such as counties, States, or watersheds) encompassing vastly different areas (Potter and others 2016). We selected hexagons 834 km^2 in area because this is a manageable size for making monitoring and management decisions in analyses that are national in extent (Potter and others 2016).

The variable used in the hot spot analysis was the percentage of surveyed forest area in each hexagon exposed to either mortality-causing or defoliation-causing agents. This required first separately dissolving the mortality and defoliation polygon boundaries to generate an overall footprint of each general type of disturbance, then masking the dissolved polygons using a forest cover map (1-km^2 resolution) derived from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery by the U.S. Forest Service Remote Sensing Applications Center (USDA Forest Service 2008). The same process was undertaken with the polygons of the surveyed area. Finally, the percentage of surveyed forest within each hexagon exposed to mortality or defoliation agents was calculated by dividing the total forest-masked damage area by the forest-masked surveyed area.

The Getis-Ord G_i* statistic was used to identify clusters of hexagonal cells in which the percentage of surveyed forest exposed to mortality or defoliation agents was higher than expected by chance. This statistic allows for the decomposition of a global measure of spatial association into its contributing factors, by location, and is therefore particularly suitable for detecting nonstationarities in a dataset, such as when spatial clustering is concentrated in one subregion of the data (Anselin 1992).

The Getis-Ord G_i^* statistic for each hexagon summed the differences between the mean values in a local sample, determined by a moving window consisting of the hexagon and its 18 first- and second-order neighbors (the 6 adjacent hexagons and the 12 additional hexagons contiguous to those 6) and the global mean of all the forested hexagonal cells in the conterminous 48 States. It is then standardized as a z-score with a mean of 0 and a standard deviation of 1, with values > 1.96 representing significant ($p < 0.025$) local clustering of high values and values < -1.96 representing significant clustering of low values ($p < 0.025$), since 95 percent of the observations under a normal distribution should be within approximately 2 (exactly 1.96) standard deviations of the mean (Laffan 2006). In other words, a G_i^* value of 1.96 indicates that the local mean of the percentage of forest exposed to mortality-causing or defoliation-causing agents for a hexagon and its 18 neighbors is approximately 2 standard deviations greater than the mean expected in the absence of spatial clustering, while a G_i^* value of -1.96 indicates that the local mortality or defoliation mean for a hexagon and its 18 neighbors is approximately 2 standard deviations less than the mean expected in the absence of spatial clustering. Values between -1.96 and 1.96 have no statistically significant concentration of high or low values. In other words, when a hexagon has a G_i^* value between -1.96 and 1.96, mortality or defoliation damage within it and its 18 neighbors is not statistically different from a normal expectation.

It is worth noting that the -1.96 and 1.96 threshold values are not exact because the correlation of spatial data violates the assumption of independence required for statistical significance (Laffan 2006). The Getis-Ord approach does not require that the input data be normally distributed because the local G_i^* values are computed under a randomization assumption, with G_i^* equating to a standardized z-score that asymptotically tends to a normal distribution (Anselin 1992). The z-scores are reliable, even with skewed data, as long as the distance band used to define the local sample around the target observation is large enough to include several neighbors for each feature (ESRI 2012).

The low density of survey data from Alaska in 2014 (fig. 2.1) precluded the use of Getis-Ord hot spot analyses for this State. Instead, Alaska mortality and defoliation data were summarized by ecoregion section (Nowacki and Brock 1995), calculated as the percent of the forest within the surveyed areas affected by agents of mortality or defoliation. (As with the mortality and defoliation data, the flown area polygons were first dissolved to create an overall footprint.) For reference purposes, ecoregion sections (Cleland and others 2007) were also displayed on the geographic hot spot maps of the conterminous 48 United States.

RESULTS AND DISCUSSION

Conterminous United States Mortality

The national IDS survey data identified 88 different mortality-causing agents and complexes on approximately 1.75 million ha across the conterminous United States in 2014, slightly less than the combined land area of Connecticut and Delaware. (Three of these mortality-cause categories were "rollups" of multiple agents.) By way of comparison, forests are estimated to cover approximately 252 million ha of the conterminous 48 States (Smith and others 2009).

Mountain pine beetle (*Dendroctonus ponderosae*) was the most widespread mortality agent in 2014, detected on 707 649 ha (table 2.1), reversing a downward trend in the area affected by this insect in recent years; this area declined from 3.47 million ha in 2009 (Potter 2013) to 653 700 ha in 2013 (Potter and Paschke 2015b). The total footprint, or nonoverlapping sum of areas, of detected mountain pine beetle mortality from 2000 through 2014 exceeds 9.84 million ha, with the large majority occurring in the Forest Health Monitoring (FHM) Program Interior West region (as defined by the FHM Program) (table 2.2). This footprint is slightly larger than the State of Indiana.

Five other mortality agents and complexes were detected on more than 100 000 ha in 2014: spruce beetle (*Dendroctonus rufipennis*), fir engraver (*Scolytus ventralis*), western pine beetle (*Dendroctonus brevicomis*), five-needle pine decline, and subalpine fir (*Abies lasiocarpa*)

Table 2.1—Mortality agents and complexes affecting more than 5000 ha in the conterminous United States during 2014

Agents/complexes causing mortality, 2014	Area
	ha
Mountain pine beetle[a]	707 649
Spruce beetle	291 086
Fir engraver	285 896
Western pine beetle	133 968
Five-needle pine decline[a]	133 143
Subalpine fir mortality complex[a]	113 538
Douglas-fir beetle	77 814
Ips engraver beetles	66 083
Pinyon ips	44 948
Emerald ash borer	41 571
Mortality (unclassified)	24 904
Eastern larch beetle	18 335
California flatheaded borer	18 263
Jeffrey pine beetle	17 964
Beech bark disease	12 646
Sudden oak death	11 606
Balsam woolly adelgid	9 900
Multi-damage (insect/disease)	9 821
California fivespined ips	8 133
Unknown	7 985
Pine engraver	7 033
Flatheaded fir borer	5 992
Western balsam bark beetle[b]	5 376
Other mortality agents (65)	43 167
Total, all mortality agents	**1 753 763**

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] Rollup of multiple agent codes from the Insect and Disease Survey database.

[b] Also included in the subalpine fir mortality rollup.

Table 2.2—Footprint area affected by mountain pine beetle *(Dendroctonus ponderosae)*, by Forest Health Monitoring region, from 2000 through 2014

FHM region	Area
	ha
Interior West	7 615 518
West Coast	164 877
North Central	2 063 866
Total, all regions	**9 844 261**

mortality complex. Mortality from the western bark beetle group was detected on approximately 1.60 million ha in 2014, representing a large majority of the total area on which mortality was recorded across the conterminous States. This group encompasses 28 different agents in the IDS data (table 2.3).

The Interior West region had approximately 1.02 million ha on which mortality-causing agents and complexes were detected in 2014, an area that exceeded that of all other FHM regions combined (table 2.4). About 41 percent of this was associated with mountain pine beetle; also constituting a considerable area were spruce beetle (27 percent), subalpine fir mortality complex (11 percent), fir engraver (7 percent), and ips engraver beetles (*Ips* spp.) (6 percent). A total of 28 mortality agents and complexes were detected in the region.

The Getis-Ord analysis detected several major hot spots of intense mortality exposure in the Interior West region (fig. 2.2). As in 2012 and 2013, the most intense was a hot spot of very

Table 2.3—Beetle taxa included in the "western bark beetle" group

Western bark beetle mortality agents	Taxonomic classification
Bark beetles (non-specific)	Family Curculionidae, subfamily Scolytinae
California fivespined ips	*Ips paraconfusus*
Cedar and cypress bark beetles	*Phloeosinus* spp.
Douglas-fir beetle	*Dendroctonus pseudotsugae*
Douglas-fir engraver	*Scolytus unispinosus*
Douglas-fir pole beetle	*Pseudohylesinus nebulosus*
Fir engraver	*Scolytus ventralis*
Five-needle pine decline	—
Flatheaded borer	Family Buprestidae
Ips engraver beetles	*Ips* spp.
Jeffrey pine beetle	*Dendroctonus jeffreyi*
Lodgepole pine beetle	*Dendroctonus murrayanae*
Mountain pine beetle	*Dendroctonus ponderosae*
Pine engraver	*Ips pini*
Pinyon ips	*Ips confuses*
Pinyon pine mortality	—
Red turpentine beetle	*Dendroctonus valens*
Roundheaded pine beetle	*Dendroctonus adjunctus*
Silver fir beetle	*Pseudohylesinus sericeus*
Southern pine beetle	*Dendroctonus frontalis*
Spruce beetle	*Dendroctonus rufipennis*
Tip beetles	*Pityogenes* spp.
True fir bark beetles	*Scolytus* spp.
True fir *(Abies)* pest complex	—
Twig beetles	*Pityophthorus* spp.
Western balsam bark beetle	*Dryocoetes confuses*
Western cedar bark beetle	*Phloeosinus punctatus*
Western pine beetle	*Dendroctonus brevicomis*

— = not applicable.

Table 2.4—The top five mortality agents or complexes for each Forest Health Monitoring region and for Alaska in 2014

2014 mortality agents and complexes	Area
	ha
Interior West	
Mountain pine beetle[a]	418 815
Spruce beetle	276 030
Subalpine fir mortality complex[a]	112 084
Fir engraver	73 786
Ips engraver beetles	56 542
Other mortality agents and complexes (23)	151 213
Total, all mortality agents and complexes	**1 018 930**
North Central	
Emerald ash borer	38 790
Eastern larch beetle	18 335
Mortality	15 824
Beech bark disease	11 676
Mountain pine beetle[a]	6 121
Other mortality agents (12)	7 976
Total, all mortality agents and complexes	**98 723**
North East	
Mortality	8 974
Balsam woolly adelgid	6 851
Fir needle cast[b]	4 825
True fir bark beetles[b]	4 825
Emerald ash borer	2 761
Other mortality agents (39)	10 886
Total, all mortality agents and complexes	**28 173**

2014 mortality agents and complexes	Area
	ha
South	
Unknown	5 282
Hemlock woolly adelgid	1 469
Southern pine beetle	382
Other root or butt disease (known)	380
Ips engraver beetles	247
Other mortality agents (8)	48
Total, all mortality agents and complexes	**7 806**
West Coast	
Mountain pine beetle[a]	282 712
Fir engraver	212 110
Western pine beetle	120 236
Douglas-fir beetle	22 112
California flatheaded borer	18 263
Other mortality agents (25)	106 909
Total, all mortality agents and complexes	**600 131**
Alaska	
Yellow-cedar decline	8 055
Spruce beetle	5 987
Northern spruce engraver	2 970
Western balsam bark beetle	75
Defoliators	39
Total, all mortality agents and complexes	**17 109**

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 because of the reporting of multiple agents per polygon.

[a] Rollup of multiple agent codes from the Insect and Disease Survey database.

[b] Fir needle cast and true fir bark beetles co-occurred along with balsam woolly adelgid.

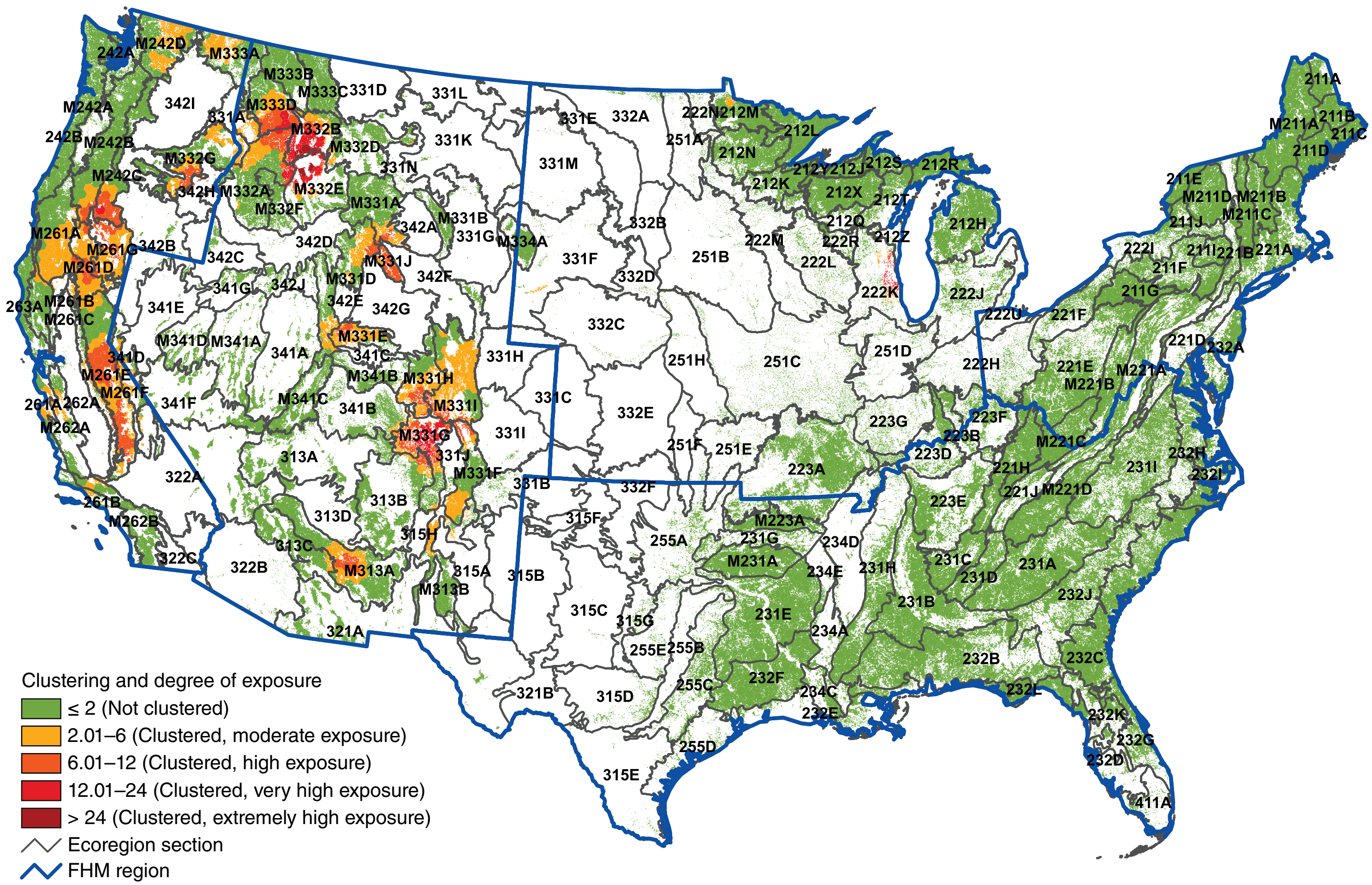

Figure 2.2—Hot spots of exposure to mortality-causing insects and diseases in 2014. Values are Getis-Ord G_i scores, with values >2 representing significant clustering of high percentages of forest area exposed to mortality agents. (No areas of significant clustering of low percentages of exposure, <-2, were detected.) The gray lines delineate ecoregion sections (Cleland and others 2007), and the blue lines delineate Forest Health Monitoring regions. Background forest cover is derived from Moderate Resolution Imaging Spectroradiometer (MODIS) imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture, Forest Service, Forest Health Protection)*

high and extremely high mortality exposure centered on the border between eastern Idaho and western Montana, especially in ecoregions M332B–Northern Rockies and Bitterroot Valley, M332E–Beaverhead Mountains, M332D–Belt Mountains, and M332A–Idaho Batholith. Mortality in this area was attributed almost entirely to mountain pine beetle in lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), and whitebark pine (*Pinus albicaulis*) forests, along with some fir engraver in grand fir (*Abies grandis*) stands and Douglas-fir beetle (*Dendroctonus pseudotsugae*) in Douglas-fir (*Pseudotsuga menziesii*) stands.

A hot spot of very high mortality exposure was also detected in southwestern Colorado, centered on M331G–South-Central Highlands and extending into M331H–North-Central Highlands and Rocky Mountains, M331I–Northern Parks and Ranges, and M331F–Southern Parks and Rocky Mountain Range (fig. 2.2). A large majority of the mortality here was caused by spruce beetle in Engelmann spruce (*Picea engelmannii*) stands, although mortality was also associated with subalpine fir mortality complex in subalpine fir forests, with fir engraver in white fir (*Abies concolor*) forests, and with mountain pine beetle in ponderosa pine forests. Meanwhile, a hot spot of high mortality exposure associated with five-needle pine decline in whitebark and limber pine (*Pinus flexilis*) stands, spruce beetle in Engelmann spruce stands, and mountain pine beetle in whitebark pine stands was detected in M331J–Wind River Mountains, M331A–Yellowstone Highlands, and M331D–Overthrust Mountains.

In M331E–Uinta Mountains of northeastern Utah, a high-intensity hot spot, was mainly associated with spruce beetle-caused mortality in Engelmann spruce and with subalpine fir mortality complex in subalpine fir (fig. 2.2). Finally, farther south in east-central Arizona and west-central New Mexico, fir engraver in white fir and ips engraver beetle in ponderosa pine caused a hot spot of high mortality exposure in M313A–White Mountains-San Francisco Peaks-Mogollon Rim.

The FHM West Coast region had the second largest area on which mortality agents and complexes were detected, about 600 100 ha (table 2.4). Of the 30 agents and complexes detected, mountain pine beetle was the leading cause of mortality and was identified on about 282 700 ha, approximately 47 percent of the entire area. Other bark beetles, including fir engraver, western pine beetle, and Douglas-fir beetle, were also widespread causes of mortality in the region, as was the California flatheaded borer (*Phaenops californica*).

Bark beetles, primarily mountain pine beetle in lodgepole and ponderosa pine stands, were the primary agent associated with a hot spot of very high mortality exposure in southern Oregon, centered on M242C–Eastern Cascades and extending into M261G–Modoc Plateau, M242B–Western Cascades, and M261D–Southern Cascades (fig. 2.2). To the south, a hot spot of high mortality in M261D–Southern Cascades in northern California was associated with fir engraver in white fir and California red fir (*Abies magnifica*) and with western pine beetle in ponderosa pine. To the northeast in eastern Oregon, a hot spot of high mountain pine beetle mortality in lodgepole pine was detected in M332G–Blue Mountains. Mountain pine beetle and spruce beetle also caused hot spots of moderate mortality exposure in northern Washington, in M242D–Northern Cascades and M333A–Okanogan Highland.

Two hot spots of high mortality exposure were detected in M261E–Sierra Nevada, in California (fig. 2.2). The more northerly of these was associated with mortality caused by western pine beetle in ponderosa pine; mountain pine beetle in sugar pine (*Pinus lambertiana*), whitebark pine, and lodgepole pine; fir engraver in white fir and California red fir; and Jeffrey pine beetle (*Dendroctonus jeffreyi*) in Jeffrey pine (*Pinus jeffreyi*). The more southerly Sierra Nevada mortality hot spot was caused by California flatheaded borer in Jeffrey pine, western pine beetle in ponderosa pine, fir engraver in California red fir, pinyon ips (*Ips confusus*) in single-leaf pinyon (*Pinus monophylla*), and mountain pine beetle in lodgepole and sugar pine.

Meanwhile, sudden oak death mortality in tanoak (*Lithocarpus densiflorus*) forests and multiple insect and disease damage in grey pine (*Pinus sabaniana*) stands caused a hot spot of moderate mortality near the central California coast, in 261A–Central California Coast and M262A–Central California Coast Ranges. Farther south, pinyon ips in single-leaf pinyon and California fivespined ips (*Ips paraconfusus*) in Jeffrey pine resulted in a moderate mortality hot spot in M262B–Southern California Mountain and Valley.

In the North Central FHM region, mortality was recorded on nearly 99 000 ha, with emerald ash borer the most widely identified causal agent, found on almost 39 000 ha (table 2.4). Two more of the 17 agents and complexes detected in the region affected areas exceeding 10 000 ha: eastern larch beetle (*Dendroctonus simplex*) and beech bark disease complex. Mortality with unclassified causes also was detected on nearly 16 000 ha. Emerald ash borer was the cause of the single mortality hot spot in the region, in 222K–Southwestern Great Lakes Morainal, in southeastern Wisconsin (fig. 2.2).

In the North East FHM region, the FHP survey recorded mortality-causing agents and complexes on approximately 28 000 ha (table 2.4). Of the classified mortality agents and complexes, balsam woolly adelgid (*Adelges piceae*) was the most widely detected, followed by fir needle cast/true fir bark beetles, and emerald ash borer. Mortality with an unclassified cause was identified on nearly 9 000 ha. In the South, mortality was detected on about 7 800 ha, mostly with an unknown cause. Hemlock woolly adelgid was the most commonly identified agent (table 2.4). No geographic hot spots of mortality were detected in the North East and South FHM regions.

Conterminous United States Defoliation

In 2014, the national IDS survey identified 67 defoliation agents and complexes affecting approximately 1.73 million ha across the conterminous United States, an area slightly smaller than the combined land area of Connecticut and Delaware. The two most widespread defoliation causes were "rollups" of multiple agents: eastern and western spruce budworms (*Choristoneura occidentalis* and *C. fumiferana*), affecting nearly 954 000 ha, and tent caterpillars (*Malacosoma* spp.), detected on approximately 233 000 ha (table 2.5). Two other insects—gypsy moth (*Lymantria dispar*) and baldcypress leafroller (*Archips goyerana*)—each also affected more than 100 000 ha, and fall cankerworm (*Alsophila pometaria*) was detected on nearly 99 000 ha (table 2.5).

The Interior West FHM region had the largest area on which defoliating agents and complexes were detected in 2014, approximately 904 000 ha (table 2.6). Approximately 89 percent of this (about 804 000 ha) was attributed to western spruce budworm (*Choristoneura occidentalis*) (table 2.6). Unknown defoliators and aspen defoliation were the next most widely detected defoliation agents of the 21 that were identified.

All four defoliation hot spots in the region (fig. 2.3) were associated with western spruce budworm, along with other agents or complexes. The largest of these, caused by western spruce budworm in fir forests, was a hot spot of very high defoliation exposure that centered on M333B–Flathead Valley and M333C–Northern Rockies and extended into M332B–Northern Rockies and Bitterroot Valley and M332D–Belt Mountains. Similarly, western spruce budworm activity in Douglas-fir forests generated a hot

Table 2.5—Defoliation agents and complexes affecting more than 5000 ha in the conterminous United States in 2014

Agents/complexes causing defoliation, 2014	Area
	ha
Spruce budworm (eastern and western)[a]	953 918
Tent caterpillars[a]	233 259
Gypsy moth	158 965
Baldcypress leafroller	111 337
Fall cankerworm	98 680
Defoliators (unclassified)	81 149
Unknown defoliator	41 619
Jack pine budworm	41 271
Aspen defoliation	28 879
Large aspen tortrix	22 576
Oak leafroller	21 490
Winter moth	19 714
Douglas-fir tussock moth	12 633
Larch casebearer	10 352
Other defoliator (known)	8 974
Lophodermium needle cast of pines	8 353
Western blackheaded budworm	8 129
Larch needle cast	7 670
Leafroller/seed moth	7 278
Loopers	6 608
Pinyon needle scale	6 137
Other defoliation agents (46)	27 208
Total, all defoliation agents	**1 728 098**

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] Rollup of multiple agent codes from the Insect and Disease Survey database.

Table 2.6—The top five defoliation agents or complexes for each Forest Health Monitoring region and for Alaska in 2014

2014 defoliation agents and complexes	Area
	ha
Interior West	
Western spruce budworm[a]	804 123
Unknown defoliator	39 986
Aspen defoliation	28 879
Other defoliator (known)	8 974
Larch needle cast	7 099
Other defoliation agents and complexes (16)	22 658
Total, all defoliation agents and complexes	**903 617**
North Central	
Spruce budworm[a]	111 361
Defoliators (unclassified)	80 612
Forest tent caterpillar[b]	63 059
Jack pine budworm	41 271
Large aspen tortrix	22 576
Other defoliation agents and complexes (13)	36 168
Total, all defoliation agents and complexes	**355 046**
North East	
Gypsy moth	142 076
Fall cankerworm	75 587
Oak leafroller	21 490
Winter moth	19 714
Loopers	6 608
Other defoliation agents and complexes (22)	7 846
Total, all defoliation agents and complexes	**198 689**

2014 defoliation agents and complexes	Area
	ha
South	
Forest tent caterpillar[b]	163 675
Baldcypress leafroller	111 337
Fall cankerworm	23 093
Jumping oak gall wasp	359
Unknown	56
Other defoliation agents and complexes (7)	23
Total, all defoliation agents and complexes	**193 577**
West Coast	
Western spruce budworm[a]	38 413
Douglas-fir tussock moth	11 434
Western blackheaded budworm	8 129
Western tent caterpillar[b]	5 623
Lodgepole needleminer	3 667
Other defoliation agents and complexes (14)	10 107
Total, all defoliation agents and complexes	**77 170**
Alaska	
Defoliators (unclassified)	120 016
Aspen leafminer	50 048
Birch leafroller	48 987
Unknown	23 835
Willow leaf blotchminer	8 029
Other defoliation agents and complexes (7)	6 795
Total, all defoliation agents and complexes	**252 833**

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] Included in spruce budworm rollup.

[b] Included in tent caterpillar rollup.

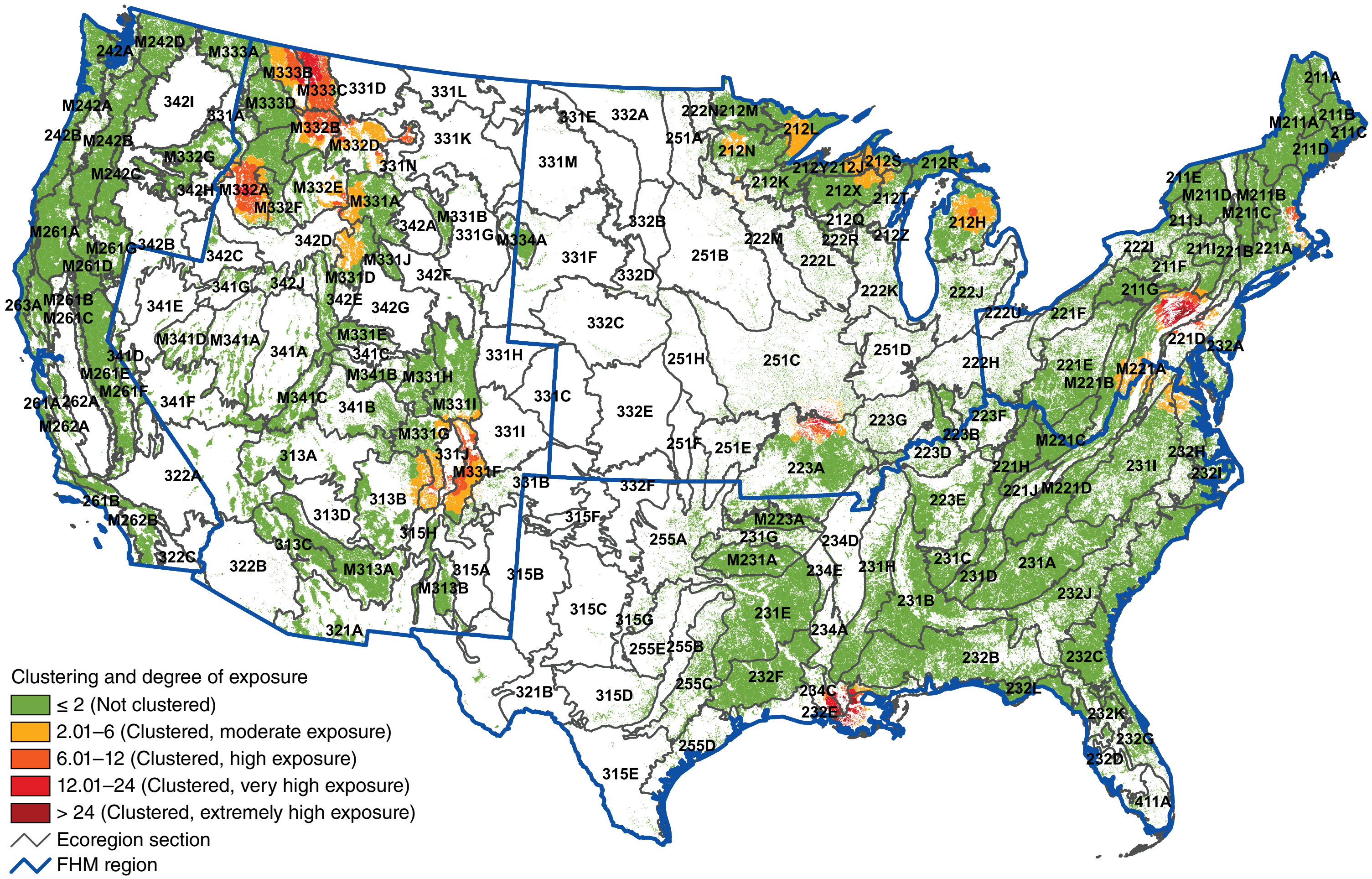

Figure 2.3—Hot spots of exposure to defoliation-causing insects and diseases in 2014. Values are Getis-Ord $G_i{}^*$ *scores, with values > 2 representing significant clustering of high percentages of forest area exposed to defoliation agents. (No areas of significant clustering of low percentages of exposure, < -2, were detected). The gray lines delineate ecoregion sections (Cleland and others 2007), and the blue lines delineate Forest Health Monitoring regions. Background forest cover is derived from Moderate Resolution Imaging Spectroradiometer (MODIS) imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture, Forest Service, Forest Health Protection)*

spot of very high defoliation exposure in central Idaho (M332A–Idaho Batholith). Western spruce budworm defoliation of fir and Douglas-fir resulted in a hot spot in M332E–Beaverhead Mountains and M331A–Yellowstone Highlands at the intersection of Montana, Idaho, and Wyoming. Finally, a hot spot in southern Colorado and northern New Mexico (M331F–Southern Parks and Rocky Mountain Range and M331G–South-Central Highlands) was associated with western spruce budworm defoliation of Douglas-fir and with aspen defoliation.

Western spruce budworm, meanwhile, accounted for about 50 percent of the approximately 77 200 ha of defoliation recorded in the FHM West Coast region (table 2.6). The other most commonly detected defoliators of the 19 recorded in the region were Douglas-fir tussock moth, western blackheaded budworm (*Acleris gloverana*), and western tent caterpillar (*Malacosoma californicum*). No geographic hot spots of defoliation were identified in the region.

Eighteen different defoliation agents and complexes resulted in the detection of about 355 000 ha of defoliation in the North Central FHM region. Eastern and western spruce budworm together represented the most commonly detected defoliation agent in the region, detected on more than 111 000 ha. After the spruce budworms, unclassified defoliators, forest tent caterpillar (*Malacosoma disstria*), jack pine budworm (*Choristoneura pinus*), and large aspen tortrix (*Choristoneura conflictana*) were the most commonly recorded defoliators, affecting approximately 80 600 ha, 63 000 ha, 41 300 ha, and 22 600 ha, respectively (table 2.6).

Our hot spot analysis detected four main geographic clusters of defoliation exposure in the North Central FHM region (fig. 2.3). One in 212H–Northern Lower Peninsula of Michigan was associated with jack pine budworm in jack pine (*Pinus banksiana*), gypsy moth and large aspen tortrix in quaking aspen (*Populus tremuloides*), and spruce budworm in spruce. Meanwhile, spruce budworm in white spruce (*Picea glauca*) and balsam fir (*Abies balsamea*) forests caused a hot spot of moderate defoliation exposure on the Upper Peninsula of Michigan, at the intersection of four ecoregions: 212J–Southern Superior Highlands, 212S–Northern Upper Peninsula, 212T–Northern Green Bay Lobe, and 212X–Northern Highlands. A hot spot in 212L–Northern Superior Uplands of northeastern Minnesota was the result of spruce budworm defoliation in balsam fir stands. A short distance to the west, a hot spot of moderate defoliation exposure in north-central Minnesota (212N–Northern Minnesota Drift and Lake Plains) was associated with forest tent caterpillar activity in hardwood forests. Finally, low-severity unclassified defoliators in oak forests of east-central Missouri resulted in a hot spot in 223A–Ozark Highlands.

Twenty-seven defoliation agents and complexes were identified on about 199 000 ha in the North East FHM region, with gypsy moth the most widely detected on nearly 72 percent of this area (more than 142 000 ha). Fall cankerworm was recorded on nearly 75 600 ha, oak leafroller on 21 500 ha, and winter moth on 19 700 ha (table 2.6). A gypsy moth outbreak in eastern Pennsylvania caused a hot spot of extremely high defoliation exposure in M221A–Northern Ridge and Valley (fig. 2.3). Gypsy moth, fall cankerworm, and loopers together resulted in a hot spot of moderate defoliation in the same ecoregion, but farther south in eastern West Virginia. Finally, a hot spot of high defoliation exposure was caused by winter moth in 221A–Lower New England.

In the South FHM region, 12 defoliators were identified on approximately 193 600 ha, with forest tent caterpillar the most widely detected on nearly 163 700 ha, followed by baldcypress leafroller and fall cankerworm. In southern Louisiana, these two insects caused a hot spot of extremely high defoliation exposure in ecoregions 232E–Louisiana Coastal Prairies and Marshes and 234C–Atchafalaya and Red River Alluvial Plains (fig. 2.3). Meanwhile, fall cankerworm caused a hot spot of moderate defoliation exposure spanning two ecoregions in northern Virginia and southern Maryland (in the North East FHM region), 232H–Middle Atlantic Coastal Plains and Flatwoods and 231I–Central Appalachian Piedmont.

Alaska

In Alaska, approximately 7.74 million ha of forested area was surveyed, 15.1 percent of the total forested land in the State (approximately 51.36 million ha). Mortality was recorded on approximately 17 100 ha in 2014, associated with five agents and complexes (table 2.4). This is a very small proportion (> 1 percent) of the forested area surveyed. Yellow-cedar (*Chamaecyparis nootkatensis*) decline was the most widely detected mortality agent, found on about 8 100 ha in the Alaska panhandle, whereas spruce beetle was identified on almost 6 000 ha, mostly in southern parts of the State, and northern spruce engraver (*Ips perturbatus*) was detected on just under 3 000 ha mostly in the central and northern forested areas of Alaska. The percentage of surveyed forest exposed to mortality agents in 2014 did not exceed 1 percent in any of Alaska's ecoregions (fig. 2.4).

Meanwhile, defoliators were detected on a much larger area of Alaska during 2014, with 12 defoliating agents recorded on approximately 252 800 ha (table 2.6). Of this area, about 120 000 ha consisted of unclassified defoliators. Aspen leafminer (*Phyllocnistis populiella*) and birch leafroller (*Epinotia solandriana*) were both detected on about 50 000 ha, with aspen leafminer mostly in the central parts of the State and birch leafroller in the southwestern and central areas.

The Alaska ecoregions with the highest proportion of surveyed forest area affected by defoliators in 2014 were located in the west-central and south-central parts of the State (fig. 2.5). M131B–Nulato Hills had the highest proportion of surveyed area affected by defoliators (13.6 percent), followed by M213A–Northern Aleutian Range with 8 percent. Activity by general defoliators, mostly in willow (*Salix* spp.) stands, was the situation in the first of these, while activity by birch leafroller in birch (*Beluta* spp.) stands and general defoliators in red alder (*Alnus rubra*) forests caused the recorded defoliation in the latter ecoregion. Areas of moderately high defoliation (1–5 percent) extended across the middle of the State and along the southwestern coast.

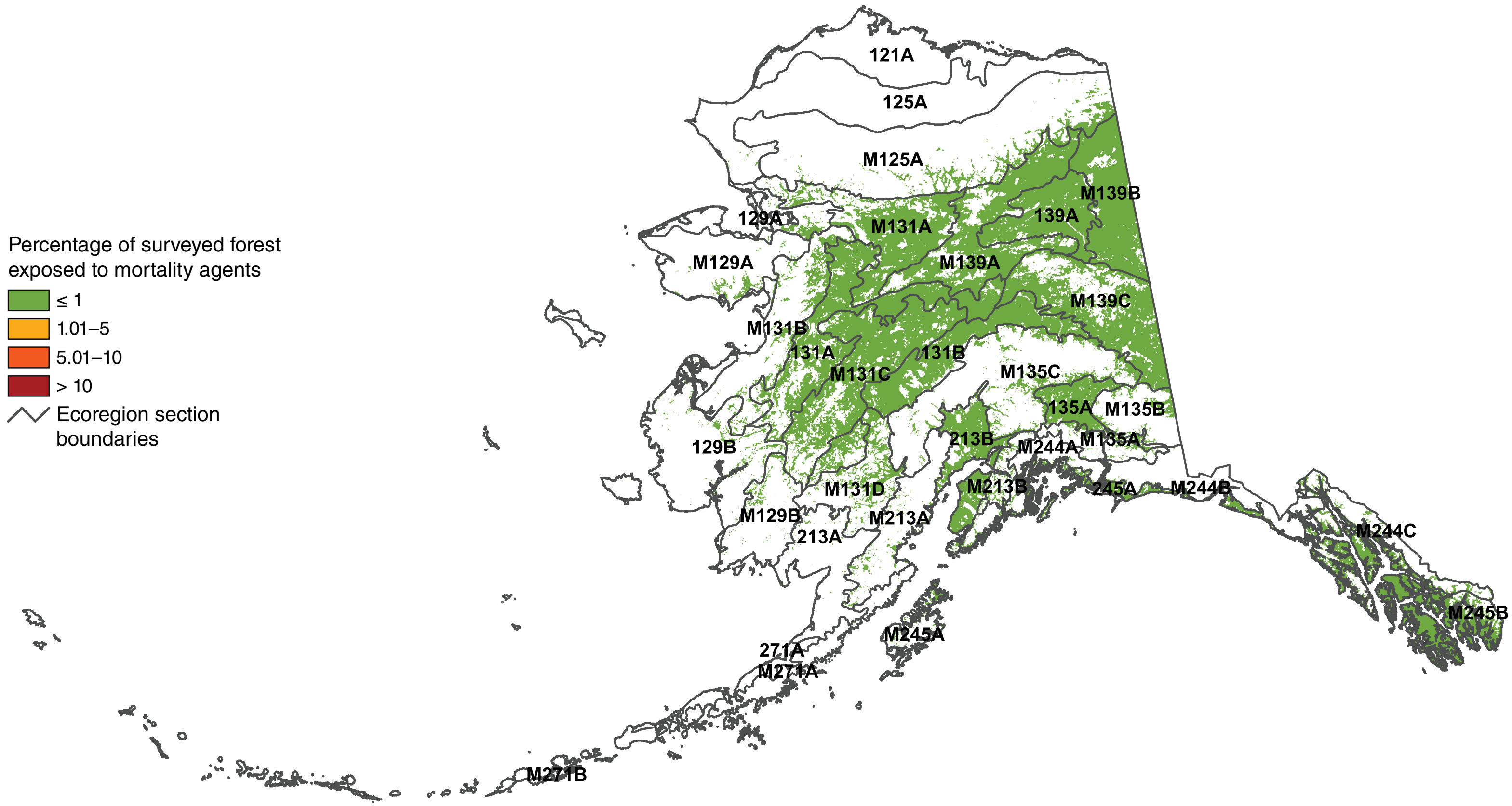

Figure 2.4—Percentage of surveyed forest in Alaska ecoregion sections exposed to mortality-causing insects and diseases in 2014. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from Moderate Resolution Imaging Spectroradiometer (MODIS) imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture, Forest Service, Forest Health Protection)

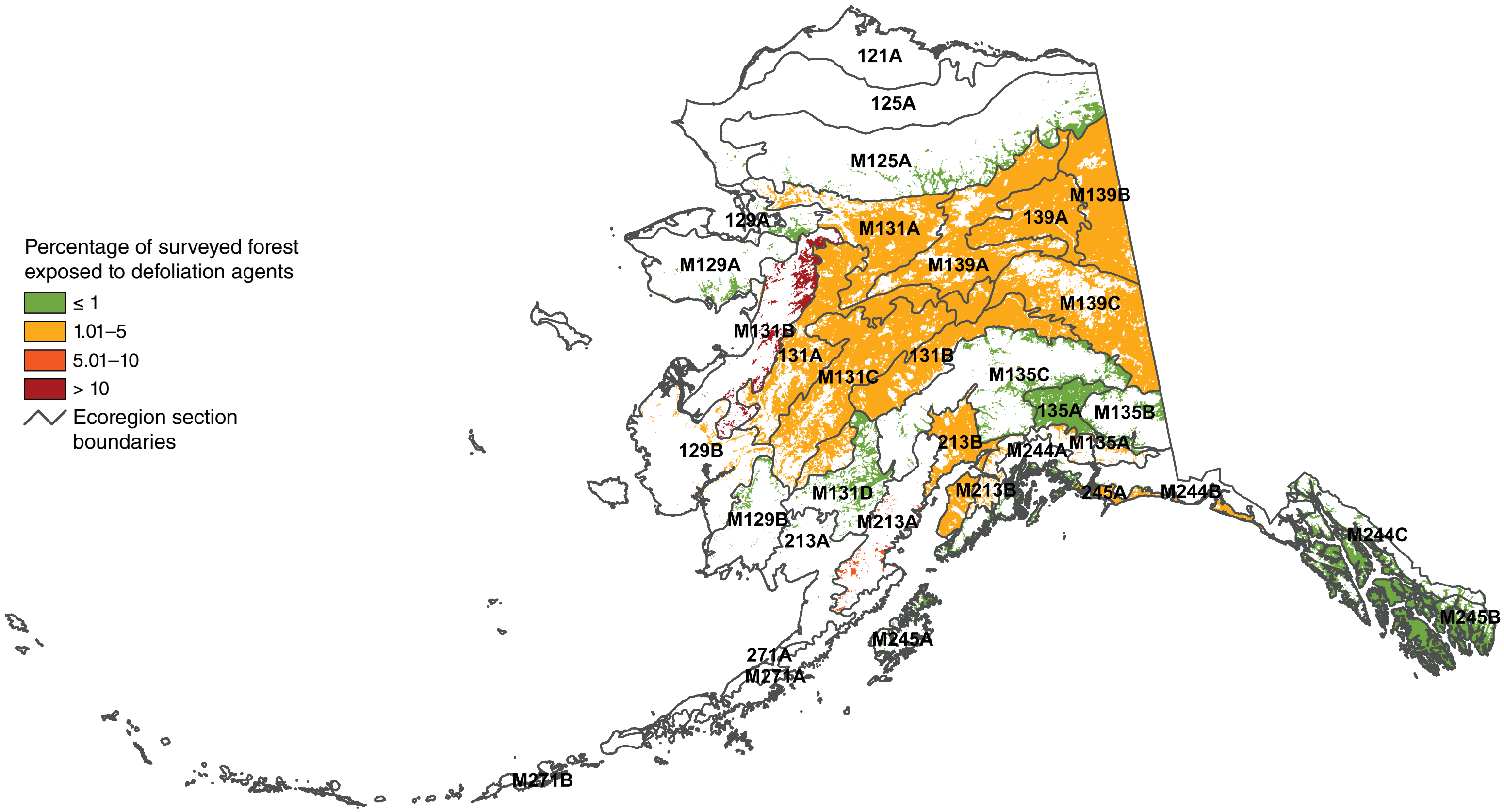

Figure 2.5—Percentage of surveyed forest in Alaska ecoregion sections exposed to defoliation-causing insects and diseases in 2014. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from Moderate Resolution Imaging Spectroradiometer (MODIS) imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture, Forest Service, Forest Health Protection)

CONCLUSION

Continued monitoring of insect and disease outbreaks across the United States will be necessary for determining appropriate follow-up investigation and management activities. Because of 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 exposure, including geographical hot spot detection analyses, offer a useful approach for identifying geographic areas where the concentration of monitoring and management activities might be most effective.

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