CHAPTER 2.

Large-Scale Patterns of Insect and Disease Activity in the Conterminous United States, Alaska, and Hawaii from the National Insect and Disease Survey, 2013

Kevin M. Potter

Jeanine L. Paschke

INTRODUCTION

Diseases and insects 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 which 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). One such landscape-scale approach is the detection of 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; Potter 2013; Potter and Koch 2012; Potter and Paschke 2013, 2014, 2015). In 2013, IDS surveys covered about 152.48 million ha of the forested area in the conterminous United States (approximately 59.8 percent of the total), 8.09 million ha of Alaska's forested area (approximately 15.7 percent of the total), and about 666 000 ha of forest in Hawaii (approximately 14 percent of the total) (fig. 2.1).

These surveys identify areas of mortality and defoliation caused by insect and pathogen 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 2013 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 and Hawaii. Because of the insect and disease aerial sketchmapping process, 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

A Getis-Ord hot spot analysis (Getis and Ord 1992) was employed in ArcMap® 10.1 (ESRI 2012) to identify surveyed forest areas with the greatest exposure to the detected mortality-causing and defoliation-causing agents and complexes. The units of analysis were 9,810 hexagonal cells, each approximately 834 km^2 in area, generated in a

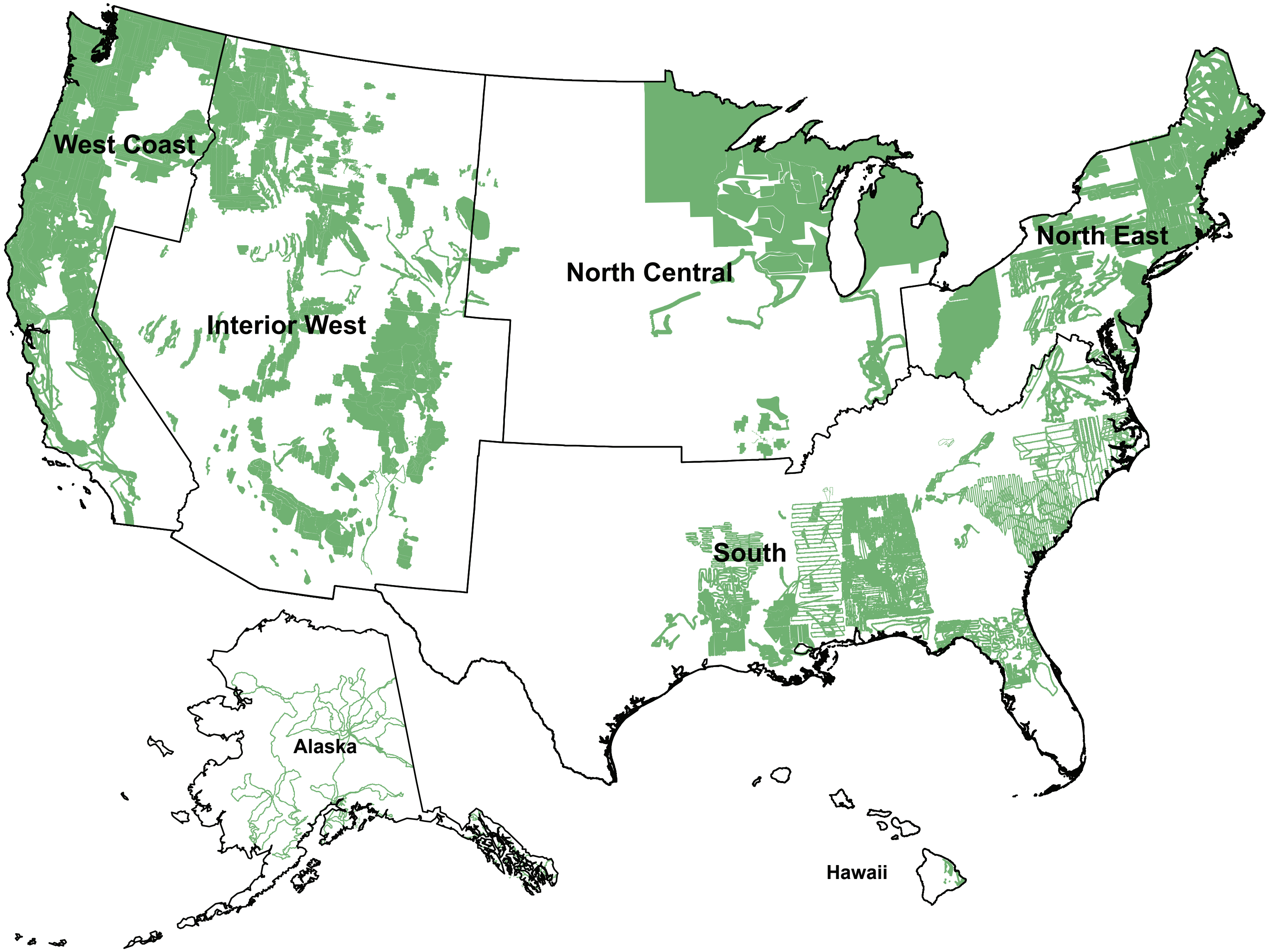

Figure 2.1—The extent of surveys for insect and disease activity conducted in the conterminous United States, Hawaii, and Alaska in 2013. The black lines delineate Forest Health Monitoring regions. Note: Alaska and Hawaii are not shown to scale with the conterminous United States. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

lattice across the conterminous United States using intensification of the Environmental Monitoring and Assessment Program (EMAP) North American hexagon coordinates (White and others 1992). 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 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 data set, 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 was 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 and Hawaii in 2013 (fig. 2.1) precluded the use of Getis-Ord hot spot analyses for these States. Instead, Alaska mortality and defoliation data were summarized by ecoregion section (Nowacki and Brock 1995), calculated as the percentage 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.) No corresponding ecoregion treatment exists for Hawaii, however, so it was not possible to summarize mortality and defoliation for that State similarly. 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 73 different mortality-causing agents and complexes on approximately 1.53 million ha across the conterminous United States in 2013, slightly larger than the combined land area of Connecticut and Rhode Island. (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 2013, detected on 653 700 ha (table 2.1), continuing a downward trend in the area affected by this insect in recent years, from 3.47 million ha in 2009 (Potter 2013), to 2.77 million ha in 2010 (Potter and Paschke 2013), to 1.54 million ha in 2011 (Potter and Paschke 2014), and to 969 037 ha in 2012 (Potter and Paschke 2015). The total footprint, or nonoverlapping sum of areas, of detected mountain pine beetle mortality from 2000 through 2013 exceeds 9.54 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.

Three other mortality agents and complexes were detected on more than 100 000 ha in

Table 2.1—Mortality agents and complexes affecting more than 5000 ha in the conterminous United States during 2013

Agents/complexes causing mortality, 2013	Area
	ha
Mountain pine beetle[a]	653 700
Spruce beetle	216 296
Ips engraver beetles	105 449
Fir engraver	103 755
Subalpine fir mortality complex[a]	98 594
Western pine beetle	94 047
Douglas-fir beetle	91 565
Five-needle pine decline[a]	89 865
Emerald ash borer	70 974
Pinyon ips	39 187
Sudden oak death	19 231
Jeffrey pine beetle	17 668
Spruce budworm	15 463
Pine engraver	13 333
Unknown	10 530
Eastern larch beetle	10 329
Multidamage (insect/disease)	10 026
Balsam woolly adelgid	9 952
Armillaria root disease	9 877
Flatheaded fir borer	6 723
Western balsam bark beetle[b]	5 947
Bark beetles	5 462
Twig beetles	5 336
Other mortality agents (50)	40 197
Total, all mortality agents	**1 529 050**

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 (FHM) region, from 2000 through 2013

FHM region	Area
	ha
Interior West	7 481 640
West Coast	1 900 240
North Central	161 616
Total, all regions	**9 543 496**

2013: spruce beetle (*Dendroctonus rufipennis*), ips engraver beetles (*Ips* spp.), and fir engraver (*Scolytus ventralis*). Mortality from the western bark beetle group was detected on more than 1.35 million ha in 2013, representing a large majority of the total area on which mortality was recorded across the conterminous States. This group encompasses 24 different agents in the IDS data (table 2.3).

The Interior West region had approximately 992 000 ha on which mortality-causing agents and complexes were detected in 2013, an area far greater than that of any other FHM region (table 2.4). About 43 percent of this was associated with mountain pine beetle, although spruce beetle (20 percent), ips engraver beetles (11 percent), subalpine fir (*Abies lasiocarpa*) mortality complex (10 percent), and Douglas-fir beetle (*Dendroctonus pseudotsugae*) (8 percent) also constituted a considerable portion of the entire area. A total of 27 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, the most intense was centered on the border between eastern Idaho and western Montana, especially in ecoregions M332B–Northern Rockies and Bitterroot Valley and M332E–Beaverhead Mountains. Mortality in this area was attributed almost entirely to mountain pine beetle in lodgepole pine (*Pinus contorta*) and ponderosa pine (*Pinus ponderosa*) forests, although smaller areas of mortality were associated with Douglas-fir beetle and white pine blister rust (caused by *Cronartium ribicola*). The hot spot extended beyond those ecoregions into several others, including M332A–Idaho Batholith, M332D–Belt Mountains, and M333D–Bitterroot Mountains. A smaller hot spot, a short distance to the east and also associated with mountain pine beetle mortality, was centered on 331K–North Central Highlands and M332D–Belt Mountains.

In M331E–Uinta Mountains of northeastern Utah, a high-intensity hot spot was mainly associated with mountain pine beetle infestations in lodgepole pine stands, with spruce beetle-caused mortality in Engelmann spruce (*Picea engelmannii*) stands, and with subalpine fir mortality complex in subalpine fir stands (fig. 2.2).

Nearly all of central Colorado constituted a mortality hot spot, with the highest intensities occurring in M331G–South-Central Highlands and M331I–Northern Parks and Ranges. The hot spots extended into M331F–Southern Parks and Rocky Mountain Range, M331H–North-Central

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

Western bark beetle mortality agents	Genus and species
California fivespined ips	*Ips paraconfusus*
Cedar and cypress bark beetles	*Phloeosinus* spp.
Douglas-fir beetle	*Dendroctonus pseudotsugae*
Douglas-fir engraver	*Scolytus unispinosus*
Fir engraver	*Scolytus ventralis*
Five-needle pine decline	—
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*
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*
Subalpine fir *(Abies lasiocarpa)* mortality complex	—
True fir *(Abies)* pest complex	—
Western balsam bark beetle	*Dryocoetes confusus*
Western cedar bark beetle	*Phloeosinus punctatus*
Western pine beetle	*Dendroctonus brevicomis*
Bark beetles (nonspecific)	—

— = not applicable.

Table 2.4—The top five mortality agents or complexes for each Forest Health Monitoring region, and for Alaska and Hawaii, in 2013

2013 mortality agents and complexes	Area
	ha
Interior West	
Mountain pine beetle [a]	421 829
Spruce beetle	202 728
Ips engraver beetles	104 135
Subalpine fir mortality complex [a]	97 315
Douglas-fir beetle	78 492
Other mortality agents and complexes (22)	126 636
Total, all mortality agents and complexes	**992 139**
North Central	
Emerald ash borer	70 561
Spruce budworm	15 463
Mountain pine beetle [a]	13 263
Eastern larch beetle	10 329
Pine engraver	9 766
Other mortality agents and complexes (21)	24 612
Total, all mortality agents and complexes	**133 303**
North East	
Forest tent caterpillar	2 726
Beech bark disease	2 560
Southern pine beetle	2 284
Balsam woolly adelgid	1 525
Unknown	1 508
Other mortality agents and complexes (23)	5 561
Total, all mortality agents and complexes	**15 371**

2013 mortality agents and complexes	Area
	ha
South	
Hemlock woolly adelgid	197
Unknown	191
Southern pine beetle	186
Black turpentine beetle	54
Ips engraver beetles	23
Bark beetles (nonspecific)	2
Total, all mortality agents and complexes	**654**
West Coast	
Mountain pine beetle [a]	218 608
Fir engraver	61 261
Western pine beetle	58 339
Sudden oak death	19 231
Jeffrey pine beetle	17 664
Other mortality agents and complexes (22)	63 809
Total, all mortality agents and complexes	**387 584**
Alaska	
Spruce beetle	10 932
Yellow-cedar decline	5 403
Northern spruce engraver	3 259
Total, all mortality agents and complexes	**19 594**
Hawaii	
Unknown	15
Total, all mortality agents and complexes	**15**

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

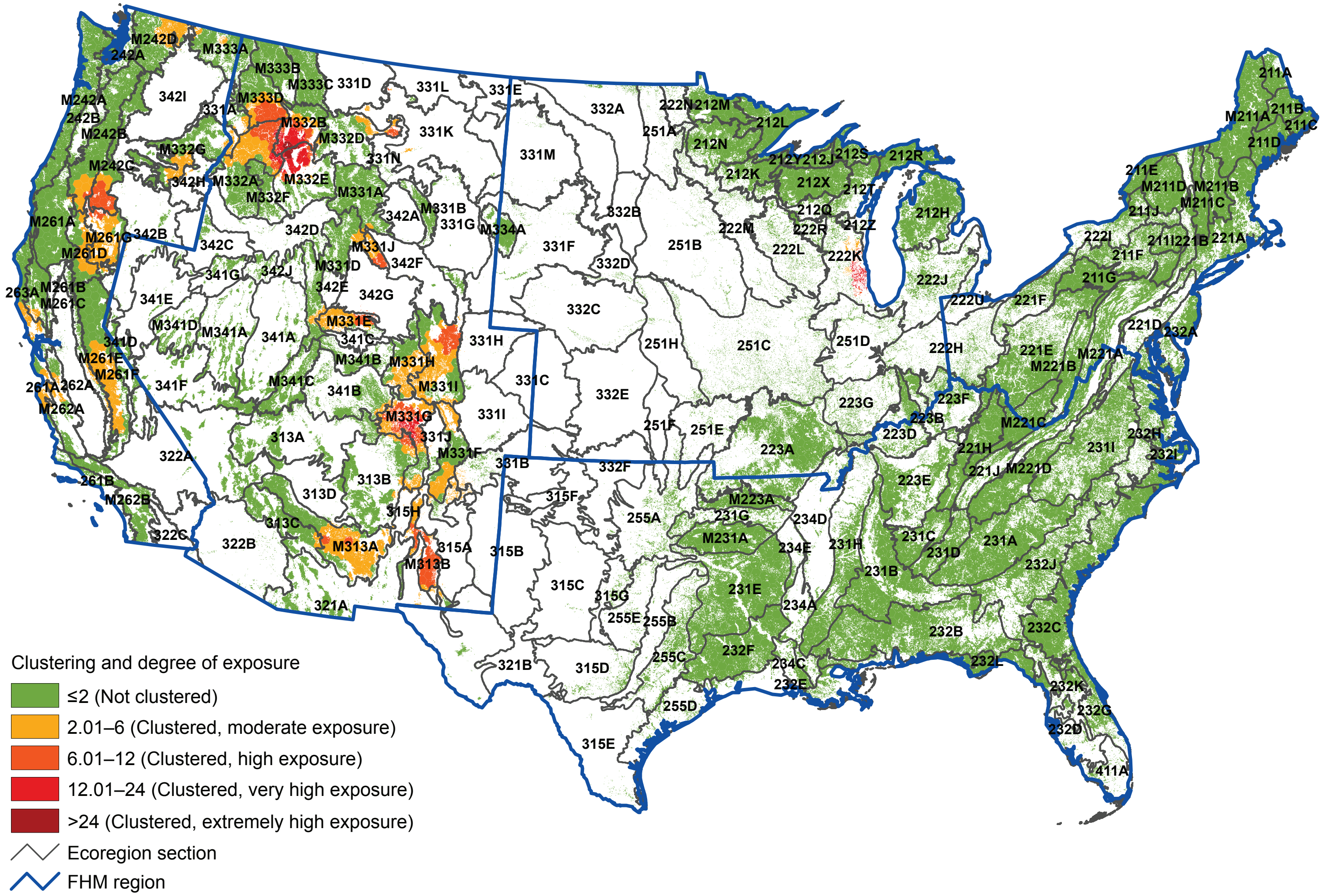

Figure 2.2—Hot spots of exposure to mortality-causing insects and diseases in 2013. Values are Getis-Ord G_i** scores, with values >2 representing significant clustering of high percentages of forest area exposed to mortality agents. (No areas of significant clustering of low percentages of exposure, <-2, were detected.) The gray lines delineate ecoregion sections (Cleland and others 2007), and the blue lines delineate Forest Health Monitoring (FHM) regions. Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)*

Highlands and Rocky Mountains, 313B–Navaho Canyonlands, and 331J–Northern Rio Grande Basin. Most of the mortality in this area was caused by spruce beetle in Engelmann spruce stands, although mortality was also associated with fir engraver in white fir (*Abies concolor*) forests, with subalpine fir mortality complex in subalpine fir forests, and with Douglas-fir beetle in Douglas-fir forests. Another hot spot of high mortality was located to the south in New Mexico, centered in M313B–Sacramento-Monzano Mountains and extending into 315H–Central Rio Grande Intermontaine, M331G–South-Central Highlands, and M331F–Southern Parks and Rocky Mountain Range. Mortality in this area was associated with a mixture of several mortality agents, including ips engraver beetles, western pine beetle (*Dendroctonus brevicomis*), western balsam bark beetle (*Dryocoetes confusus*), Douglas-fir beetle, fir engraver, and pinyon ips (*Ips confusus*). Moderate-to-high mortality extended west through New Mexico into Arizona 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 388 000 ha (table 2.4). Of the 27 agents and complexes detected, mountain pine beetle was the leading cause of mortality. It was identified on about 219 000 ha, approximately 56 percent of the entire area. Other bark beetles, including fir engraver, western pine beetle, and Jeffrey pine beetle (*Dendroctonus jeffreyi*), were also widespread causes of mortality in the region, as was sudden oak death (caused by *Phytophthora ramorum*).

Bark beetles were the primary agent associated with four large hot spots of mortality in the West Coast region. The largest of these encompassed much of four ecoregions in northern California and south-central Oregon: M242C–Eastern Cascades, M261G–Modoc Plateau, M242B–Western Cascades, and M261D–Southern Cascades (fig. 2.2). Here, the most common mortality agents were mountain pine beetle in stands of lodgepole pine, ponderosa pine, and western white pine (*Pinus monticola*); western pine beetle in ponderosa pine stands; fir engraver in white fir stands; and Jeffrey pine beetle in Jeffrey pine (*Pinus jeffreyi*) stands. The mortality causes were similar in a hot spot to the northeast in M332G–Blue Mountains.

A hot spot of mortality in M261E–Sierra Nevada and M261F–Sierra Nevada Foothills was associated primarily with mountain pine beetle in stands of lodgepole pine, western white pine, whitebark pine (*Pinus albicaulis*), and sugar pine (*Pinus lambertiana*); with western pine beetle in ponderosa pine forests; with Jeffrey pine beetle in Jeffrey pine forests; and with fir engraver in stands of California red fir (*Abies magnifica*) and white fir (fig. 2.2). A pair of mortality hot spots in north-central Washington State (in M242D–Northern Cascades and M333A–Okanogan Highland) was caused by infestations of spruce beetle in spruce (*Picea* spp.) forests and mountain pine beetle in lodgepole pine forests.

Sudden oak death mortality in tanoak (*Lithocarpus densiflorus*) and coast live oak (*Quercus agrifolia*) forests was the leading agent of mortality associated with two other mortality hot spots along the California coast. The northern hot spot was located north of San Francisco Bay within 263A–Northern California Coast and M261B–Northern California Coast Ranges. Here, additional sources of mortality were pitch canker (caused by *Fusarium circinatum*) in bishop pine (*Pinus muricata*) stands, flatheaded fir borer (*Phaenops drummondi*) in Douglas-fir forests, and California flatheaded borer (*Phaenops californica*) in knobcone pine (*Pinus attenuata*) stands. The southern hot spot, south of San Francisco Bay, was located within 261A–Central California Coast and M262A–Central California Ranges. Other than sudden oak death, western pine beetle in Coulter pine (*Pinus coulteri*) stands, multiagent damage in gray pine (*Pinus sabaniana*), and flatheaded fir borer in bristlecone fir (*Abies bracteata*) were causes of mortality in this area.

In the North Central FHM region, mortality was recorded on more than 133 000 ha, with emerald ash borer the most widely identified causal agent, found on almost 71 000 ha (table 2.4). Of the 26 agents and complexes detected in the region, spruce budworm (*Choristoneura fumiferana*), mountain pine beetle, eastern larch beetle (*Dendroctonus simplex*), and pine engraver (*Ips pini*) each also affected areas exceeding 9000 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).

No geographic hot spots of mortality were detected in the North East and South FHM regions. In the North East region, the FHP survey recorded mortality-causing agents and complexes on approximately 15 000 ha (table 2.4). Forest tent caterpillar (*Malacosoma disstria*) was the most widely detected mortality agent, followed by beech bark disease, southern pine beetle (*Dendroctonus frontalis*), and balsam woolly adelgid (*Adelges piceae*). In the South, mortality was detected on about 700 ha, with hemlock woolly adelgid and southern pine beetle being the most commonly detected agents (table 2.4).

Conterminous United States Defoliation

In 2013, the national IDS survey identified 83 defoliation agents and complexes affecting approximately 2.94 million ha across the conterminous United States, slightly larger than the combined land area of Vermont and Delaware. (Two of these defoliation-cause categories were "rollups" of multiple agents.) The most widespread defoliator was fall cankerworm (*Alsophila pometaria*), detected on approximately 962 000 ha, followed by western and eastern spruce budworms (*Choristoneura occidentalis* and *C. fumiferana*), affecting slightly more than 728 000 ha (table 2.5). Three other insects—tent caterpillars (*Malacosoma* spp.), gypsy moth (*Lymantria dispar*), and baldcypress leafroller (*Archips goyerana*)—each also affected more than 100 000 ha.

The South FHM region had the largest area on which defoliating agents and complexes were detected in 2013, approximately 1.1 million ha

Table 2.5—Defoliation agents and complexes affecting more than 5000 ha in the conterminous United States in 2013

Agents/complexes causing defoliation, 2013	Area
	ha
Fall cankerworm	961 855
Spruce budworm (eastern and western)[a]	728 003
Tent caterpillars[a]	608 523
Gypsy moth	232 219
Baldcypress leafroller	117 768
Loopers	80 307
Phoberia moth	80 052
Aspen defoliation	54 597
Spruce budworm	52 367
Lophodermella needle cast of pines	42 046
Birch leaf fungus	32 649
Large aspen tortrix	28 971
Unknown defoliator	24 017
Pinyon needle scale	23 063
Anthracnose	22 354
Unknown	21 914
Leafroller/seed moth	11 310
Other defoliator (known)	11 092
Larch needle cast	10 335
Winter moth	9 724
Tent caterpillars	9 628
Larch casebearer	7 504
Pinyon sawfly	6 556
Other gallmaking insect (known)	5 899
Western blackheaded budworm	5 752
Other defoliation agents (57)	43 429
Total, all defoliation agents	**2 941 264**

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). Fall cankerworm affected the greatest area, approximately 922 000 ha, but forest tent caterpillar and baldcypress leafroller were also surveyed across large areas. A large area of mostly low-severity defoliation (≤50 percent) caused by fall cankerworm caused a hot spot of high-defoliation exposure in northern Virginia and southern Maryland (in the North East FHM region), centered on 231I–Central Appalachian Piedmont and 232H–Middle Atlantic Coastal Plains and Flatwoods (fig. 2.3). Defoliation by baldcypress leafroller and forest tent caterpillar, meanwhile, resulted in a high-defoliation hot spot in southern Louisiana in ecoregions 232E–Louisiana Coastal Prairies and Marshes and 234C–Atchafalaya and Red River Alluvial Plains.

Thirty defoliation agents and complexes were identified on about 327 000 ha in the North East FHM region, with gypsy moth the most widely detected on nearly 206 000 ha. Gypsy moth was the cause of the single defoliation hot spot in the region, centered on ecoregion 211G–Northern Unglaciated Allegheny Plateau in northwestern Pennsylvania and southwestern New York (fig. 2.3).

In the North Central FHM region, defoliators were identified on approximately 650 000 ha, with forest tent caterpillar the most widely detected on slightly more than 434 000 ha, followed by loopers and Phoberia moth (*Phoberia atomaris*). A total of 20 agents and complexes were identified in the region. Forest tent caterpillar was the cause of a high-exposure hot spot of defoliation in two ecoregions in northern Minnesota, 212N–Northern Minnesota Drift and

Table 2.6—The top five defoliation agents or complexes for each Forest Health Monitoring region, and for Alaska and Hawaii, in 2013

2013 defoliation agents and complexes	Area
	ha
Interior West	
Western spruce budworm	601 271
Aspen defoliation	54 597
Lophodermella needle cast of pines	42 046
Pinyon needle scale	23 040
Unknown defoliator	19 240
Other defoliation agents and complexes (26)	41 906
Total, all defoliation agents and complexes	**765 460**
North Central	
Forest tent caterpillar	434 032
Loopers	80 307
Phoberia moth	80 052
Spruce budworm	52 367
Large aspen tortrix	27 030
Other defoliation agents and complexes (15)	56 409
Total, all defoliation agents and complexes	**650 126**
North East	
Gypsy moth	205 585
Fall cankerworm	39 553
Birch leaf fungus	32 649
Anthracnose	22 354
Unknown	17 122
Other defoliation agents and complexes (25)	33 529
Total, all defoliation agents and complexes	**326 891**

2013 defoliation agents and complexes	Area
	ha
South	
Fall cankerworm	922 062
Forest tent caterpillar	161 973
Baldcypress leafroller	117 768
Unknown	932
Total, all defoliation agents and complexes	**1 098 609**
West Coast	
Western spruce budworm	72 922
Larch needle cast	5 849
Western blackheaded budworm	5 752
Douglas-fir tussock moth	2 600
Western tent caterpillar	2 469
Other defoliation agents and complexes (18)	10 610
Total, all defoliation agents and complexes	**100 178**
Alaska	
Birch leafroller	133 962
Defoliators	66 869
Western blackheaded budworm	49 041
Aspen leafminer	40 236
Willow leaf blotchminer	11 420
Other defoliation agents and complexes (8)	16 536
Total, all defoliation agents and complexes	**312 515**
Hawaii	
Koa looper moth	26 301
Total, all defoliation agents and complexes	**26 301**

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.

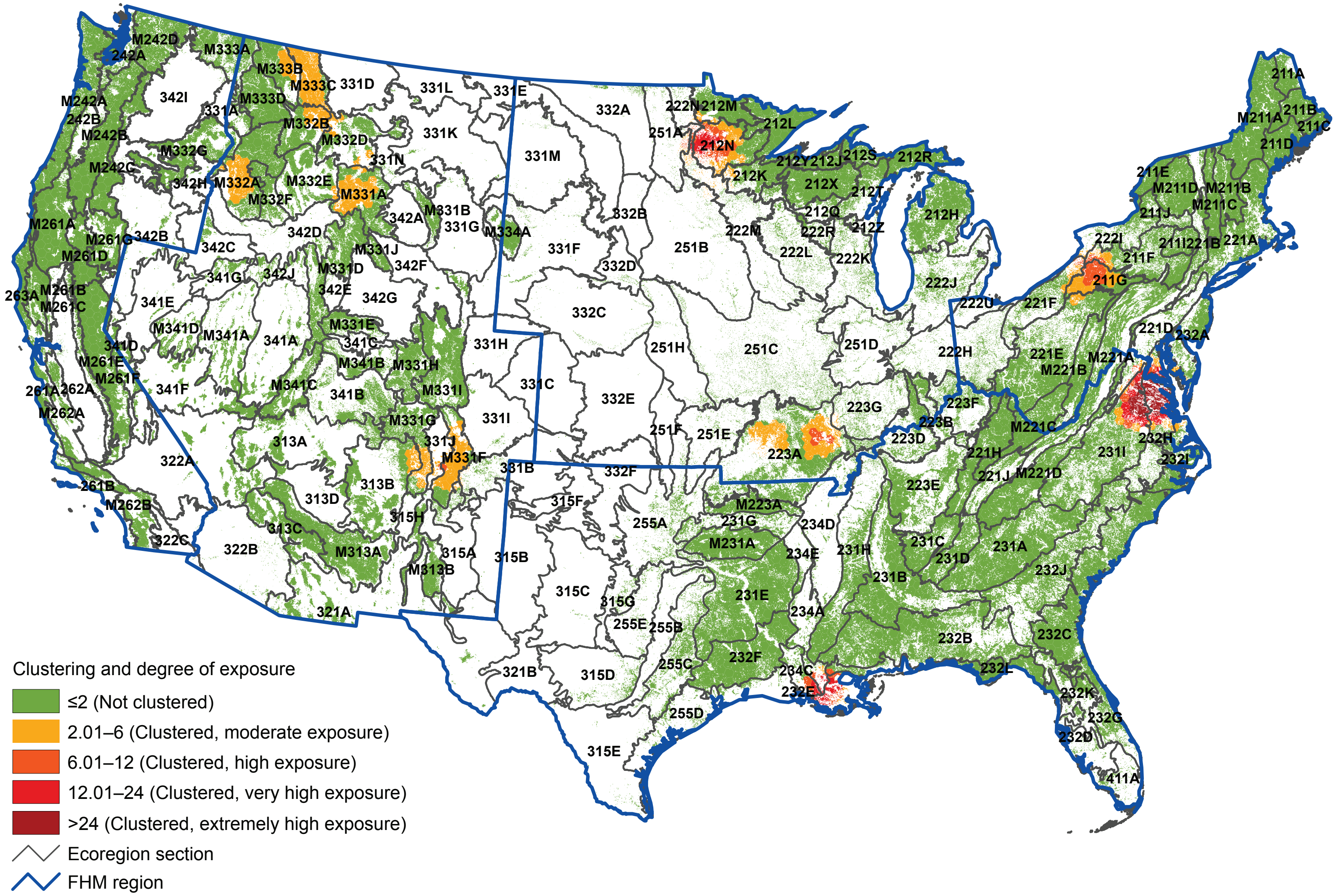

Figure 2.3—Hot spots of exposure to defoliation-causing insects and diseases in 2013. Values are Getis-Ord G_i^* scores, with values >2 representing significant clustering of high percentages of forest area exposed to defoliation agents. (No areas of significant clustering of low percentages of exposure, <-2, were detected.) The gray lines delineate ecoregion sections (Cleland and others 2007), and the blue lines delineate Forest Health Monitoring (FHM) regions. Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

Lake Plains and 222M–Minnesota and Northeast Iowa Morainal-Oak Savanna (fig. 2.3). Areas of looper infestation resulted in defoliation hot spots in 223A–Ozark Highlands in southern Missouri.

Of the approximately 765 000 ha of defoliation in the Interior West FHM region, 79 percent (about 601 000 ha) was attributed to western spruce budworm (table 2.6). Aspen defoliation and Lophodermella needle cast of pines (*Lophodermella* spp.) were the next most widely detected defoliation agents of the 31 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. In the northernmost of these hot spots, in M333B–Flathead Valley, M333C–Northern Rockies, and M332B–Northern Rockies and Bitterroot Valley, the primary defoliation agents were western spruce budworm in fir forests and larch needle cast (*Meria laricis*) in western larch (*Larix occidentalis*) stands. To the southeast in M331A–Yellowstone Highlands (southwestern Montana and northwestern Wyoming), a defoliation hot spot was caused by western spruce budworm in fir and Lophodermella needle cast of pines in lodgepole pine stands. To the southwest in M332A–Idaho Batholith, a defoliation hot spot was associated with western spruce budworm in subalpine fir and Douglas-fir stands.

Finally, a defoliation hot spot in northern New Mexico and southern Colorado (M331G–South-Central Highlands and M331F–Southern Parks and Rocky Mountain Range) was associated with western spruce budworm and aspen (*Populus tremuloides*) defoliation.

Western spruce budworm, meanwhile, accounted for about 73 percent of the approximately 100 000 ha of defoliation detected in the FHM West Coast region (table 2.6). The second and third leading defoliators in the region were larch needle cast and western blackheaded budworm (*Acleris gloverana*). No geographic hot spots of defoliation were identified in the region, where a total of 23 defoliation agents and complexes were detected.

Alaska and Hawaii

In Alaska, approximately 8 million ha of forested area was surveyed, 15.7 percent of the total forested land in the State. Mortality was recorded on nearly 20 000 ha in 2013, associated with three agents and complexes (table 2.4). This is a very small proportion (<1 percent) of the forested area surveyed. Spruce beetle was the most widely detected mortality agent, found on about 10 900 ha, mostly in the southern parts of the State. Yellow-cedar (*Chamaecyparis nootkatensis*) decline was identified on about 5400 ha in the Alaska panhandle, while northern spruce engraver (*Ips perturbatus*) was detected on about 3300 ha in the central and northern forested areas of the State. The percentage of surveyed forest exposed to mortality agents 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 2013, with

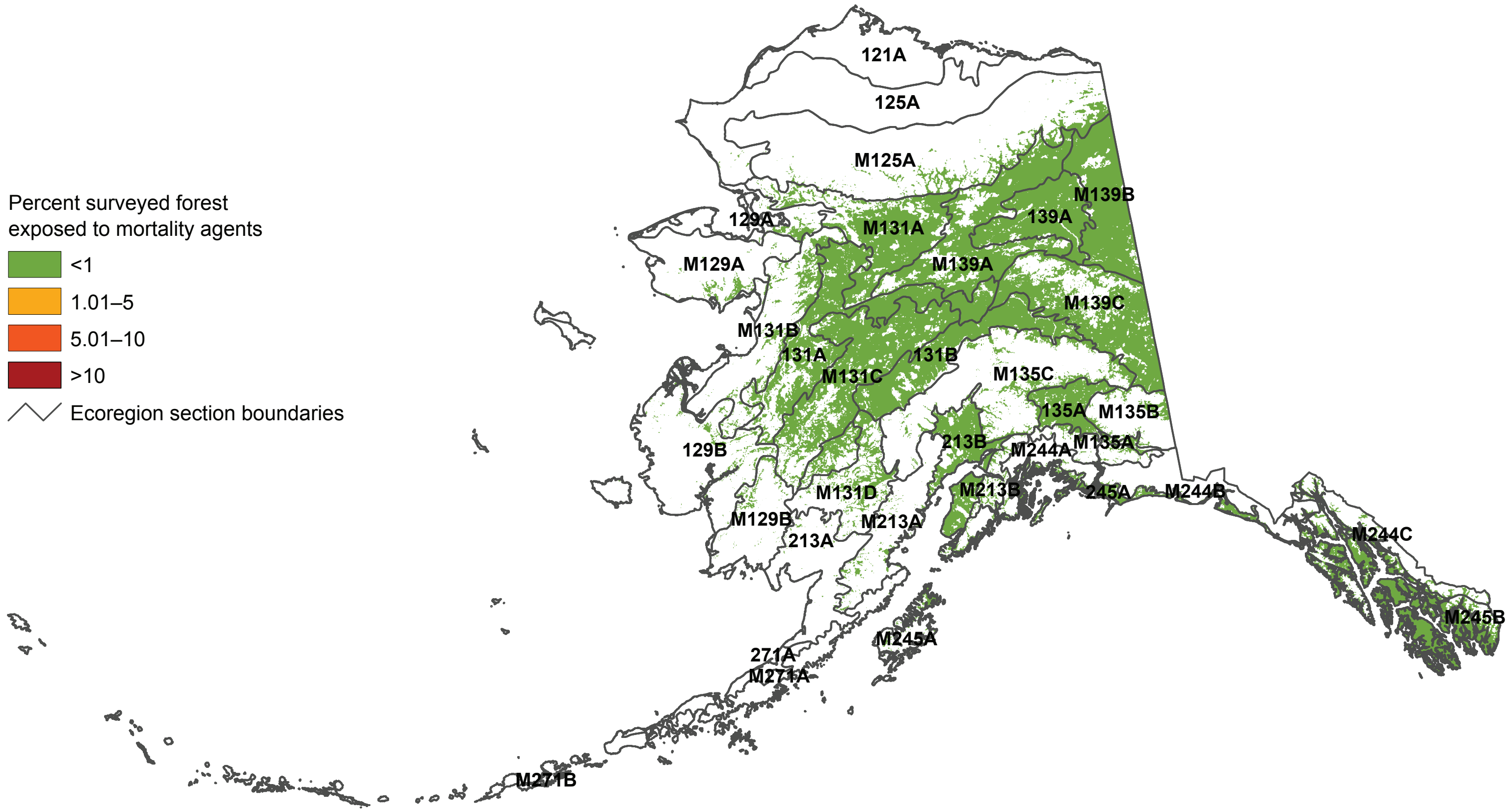

Figure 2.4—Percent of surveyed forest in Alaska ecoregion sections exposed to mortality-causing insects and diseases in 2013. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

13 defoliating agents recorded on more than 312 000 ha (table 2.6). Birch leafroller (*Epinotia solandriana*) was by far the most commonly recorded defoliator, recorded on approximately 134 000 ha. Nonspecific defoliators were the causal agent of defoliation on almost 67 000 ha. Western blackheaded budworm was detected on 49 000 ha, while aspen leafminer (*Phyllocnistis populiella*) was detected on 40 000 ha, mostly in the central parts of Alaska. Willow leaf blotchminer (*Micrurapteryx salicifoliella*) was found on approximately 11 000 ha.

The Alaska ecoregions with the highest proportion of surveyed forest area affected by defoliators in 2013 were located in the west-central and southwestern parts of the State (fig. 2.5). M131B–Nulato Hills had the highest proportion of area affected by defoliators (76.6 percent), but only a small proportion of this ecoregion section was surveyed. This was also the case for 213A–Bristol Bay Lowlands, where defoliators were detected on 32.1 percent of the surveyed area. Defoliators were detected on 13.4 percent of surveyed forest in M213A–Northern Aleutian Range and 11.9 percent of 129B–Yukon-Kuskokwim Delta. The primary agent of defoliation in these ecoregions was birch leafroller in stands of Alaska paper birch (*Betula neoalaskana*). A lower proportion of defoliation was identified in the central, east-central, and south-central portions of the State (between 1 and 5 percent).

Finally, almost no mortality was detected in Hawaii in 2013 (table 2.4), but more than 26 000 ha were identified as having been defoliated by koa looper moth (*Scotorythra paludicola*) (table 2.6). This was about 4 percent of the forested area surveyed in the State.

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.

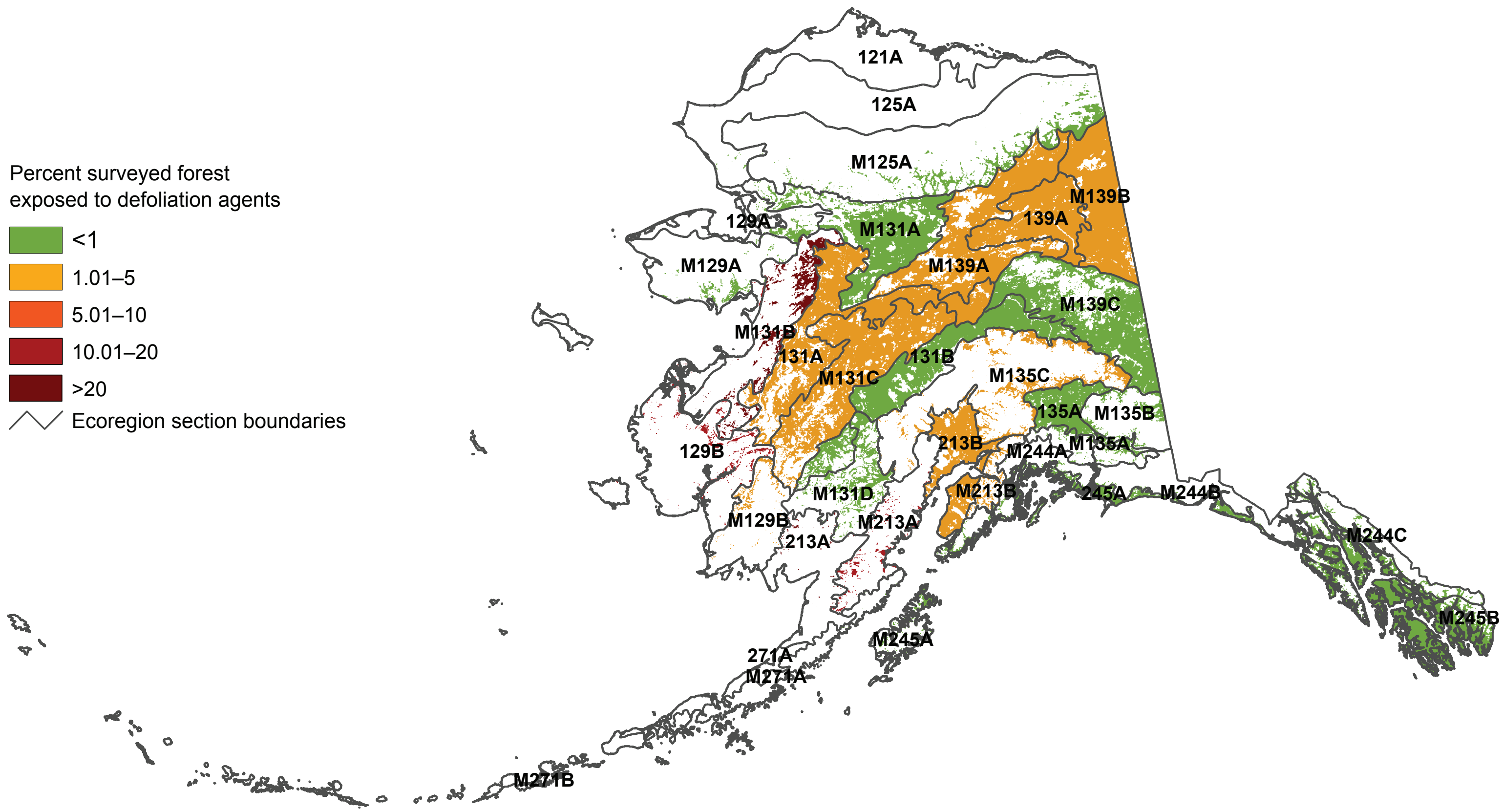

Figure 2.5—Percent of surveyed forest in Alaska ecoregion sections exposed to defoliation-causing insects and diseases in 2013. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

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