CHAPTER 2.

Large-Scale Patterns of Insect and Disease Activity in the Conterminous United States and Alaska from the National Insect and Disease Detection Survey Database, 2010

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INTRODUCTION

Analyzing patterns of forest pest infestations, diseases 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). Examining 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 pest outbreaks (Holdenrieder and others 2004). The detection of geographic clusters of disturbance is one such landscape-scale approach, which allows for the identification of areas at greatest risk of significant impact and for the selection of locations for more intensive analysis.

METHODS

Nationally compiled low-altitude aerial survey and ground survey data collected by the Forest Health Protection (FHP) Program of the Forest Service, U.S. Department of Agriculture, can be used to identify forest landscape-scale patterns associated with hot spots of forest insect and disease activity in the conterminous United States, and to summarize insect and disease activity by ecoregion section in Alaska (Potter and Koch 2012, Potter 2012, Potter 2013). Surveys covered approximately 155.6 million ha (61 percent) of the forested area in the conterminous United States in 2010, and 9.1 million ha (17.7 percent) of Alaska's forested area (fig. 2.1).

These surveys identify areas of mortality and defoliation caused by insect and pathogen activity, although some important forest insects (e.g., emerald ash borer and hemlock woolly adelgid), diseases (e.g., laurel wilt, Dutch elm disease, white pine blister rust, and thousand cankers disease), and mortality complexes (e.g., oak decline) are not easily detected or thoroughly quantified through an aerial detection survey. Such pests may attack hosts that are widely dispersed throughout diverse forests 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 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" or "aspen defoliation"). Additionally, differences in data collection, attribute recognition, and coding procedures among States and regions can complicate analysis of the data and interpretation of the results.

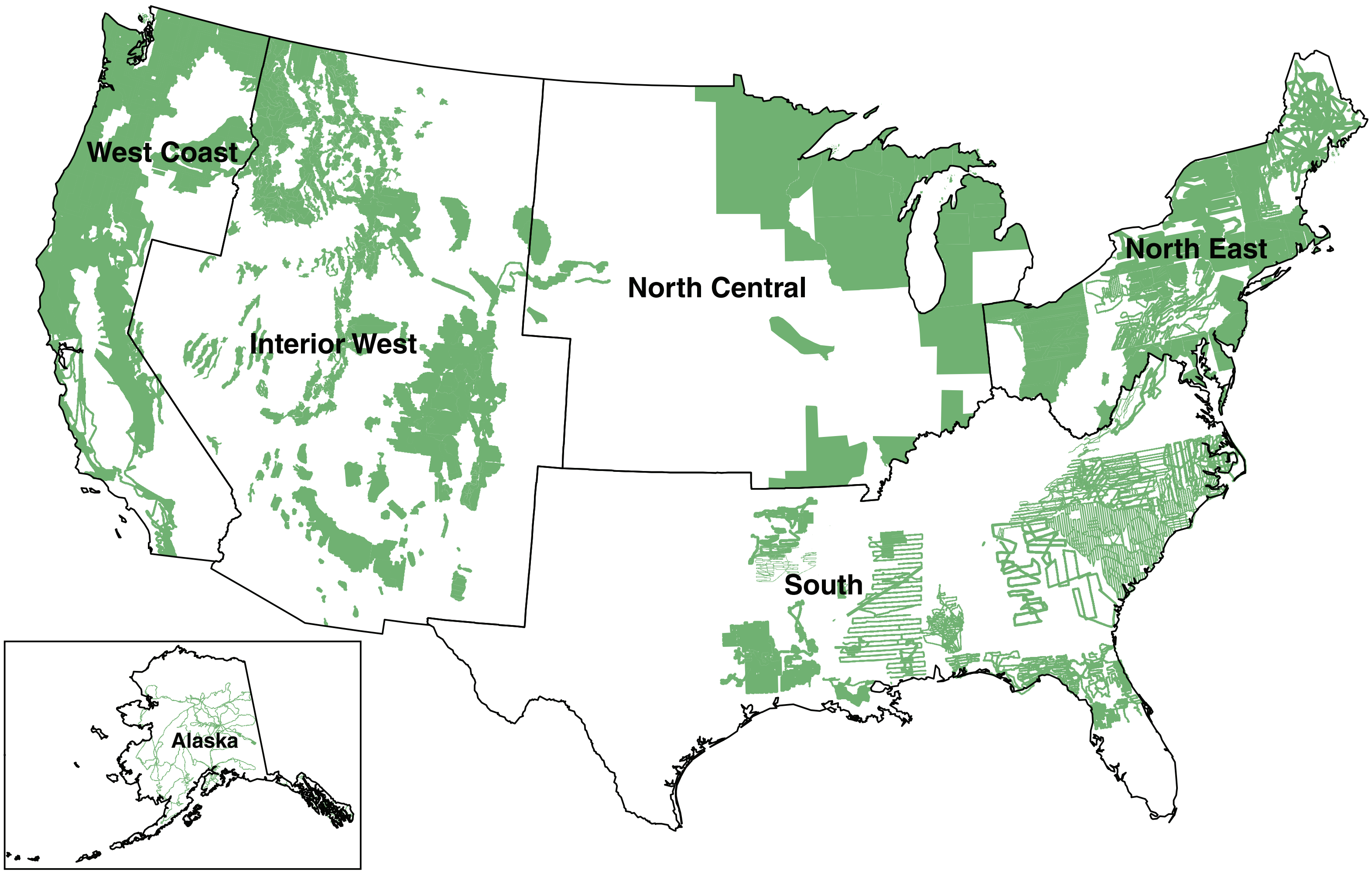

Figure 2.1—The extent of surveys for insect and disease activity conducted in the conterminous United States and Alaska in 2010. The black lines delineate Forest Health Monitoring regions. (Data source: USDA Forest Service, Forest Health Protection Program.)

The mortality and defoliation polygons were used to identify the mortality and defoliation agents and complexes in the conterminous United States found on more than 5 000 ha of forest, and to identify and list the five most widely detected defoliation and mortality agents and complexes for Alaska. As a result of the insect and disease sketchmapping process, all quantities are "footprint" areas for the agent or complex, outlining the areas 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.

A Getis-Ord hot spot analysis (Getis and Ord 1992) in ArcMap 9.2 (ESRI 2006) was employed to identify surveyed forest areas with the greatest exposure to the detected mortality-causing and defoliation-causing agents and complexes. Hexagon coordinates for North America, taken from the Environmental Monitoring and Assessment Program (White and others 1992), were intensified to develop a lattice of hexagonal cells, of approximately 2 500 km^2 extent, for the conterminous United States. This cell size allows for analysis at a medium-scale resolution of approximately the same area as a typical county. The percent of surveyed forest area in each hexagon exposed to either mortality-causing or defoliation-causing agents was then calculated by masking the surveyed area and mortality and defoliation polygons with 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 percent of forest exposed to the identified mortality or defoliation agents and complexes was calculated by dividing the 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 percent of forest exposed to mortality or defoliation agents and complexes 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 non-stationarities in a data set, such as when spatial clustering is concentrated in one subregion of the data (Anselin 1992). Non-stationarities are processes whose statistical properties vary over time or space.

The Getis-Ord G_i* statistic summed the differences between the mean values in a local sample, determined by a moving window consisting of each hexagon and its six adjacent hexagons, and the global mean of all the forested hexagonal cells in the conterminous United States. It is then standardized as a *z* score with a mean of 0 and a standard deviation of 1, with values greater than 1.96 representing significant ($p < 0.025$) local clustering of high values and values less than -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 standard deviations of the mean (Laffan 2006). In other words, a G_i* value of 1.96 indicates that the local mean of percent forest exposed to mortality-causing or defoliation-causing agents for a hexagon and its six 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 six 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, it and its six neighbors have neither consistently high nor consistently low percentages of forest exposed to mortality- or defoliation-causing agents or complexes.

The 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 2006).

The low density of data from Alaska in 2010 (fig. 2.1) precluded the use of hot spot analyses for the State. Instead, 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. For reference purposes, ecoregion sections (Cleland and others 2007) were also displayed on the geographic hot spot maps of the conterminous United States.

RESULTS AND DISCUSSION

The FHP data identified 67 different biotic mortality-causing agents and complexes on approximately 3.68 million ha of forest across the conterminous United States in 2010, an area slightly smaller than the land area of New Hampshire and Connecticut combined. Forests cover approximately 252.7 million ha of the conterminous United States (Smith and others 2009).

Mountain pine beetle (*Dendroctonus ponderosae*) was the most widespread mortality agent, detected on 2.77 million ha (table 2.1). Other mortality agents detected across very large areas, each affecting more than 100 000 ha, were fir engraver (*Scolytus ventralis*), five-needle pine decline, subalpine fir (*Abies lasiocarpa*) mortality, and spruce beetle (*Dendroctonus rufipennis*). Mortality from western bark beetles, when considered as a group (table 2.2), was detected on a total of more than 3.48 million ha in 2010, a vast majority of the total area on which mortality was recorded.

Table 2.1—Mortality agents and complexes affecting more than 5 000 ha in the conterminous United States in 2010

Agents/complexes causing mortality, 2010	Area
	ha
Mountain pine beetle	2 770 492.4
Fir engraver	286 653.5
Five-needle pine decline	229 561.8
Subalpine fir mortality	173 944.4
Spruce beetle	134 062.8
Western pine beetle	93 737.5
Douglas-fir beetle	70 526.8
Gypsy moth	23 163.2
Emerald ash borer	14 711.7
Balsam woolly adelgid	9 411.3
Eastern larch beetle	7 749.5
Forest tent caterpillar	6 883.8
Flathead borer	6 589.9
Jeffrey pine beetle	5 868.3
Southern pine beetle	5 778.5
White pine blister rust	5 708.9
Total, all agents	3 675 135

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 because of overlapping damage polygons.

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

Western bark beetle taxa	
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*
Northern spruce engraver beetle	*Ips perturbatus*
Roundheaded pine beetle	*Dendroctonus adjunctus*
Silver fir beetle	*Pseudohylesinus sericeus*
Spruce beetle	*Dendroctonus rufipennis*
Tip beetles	*Pityogenes* spp.
Western balsam bark beetle	*Dryocoetes confusus*
Western cedar bark beetle	*Phloeosinus punctatus*
Western pine beetle	*Dendroctonus brevicomis*
Bark beetles	Non-specific

Additionally, the survey identified 70 biotic defoliation agents and complexes affecting approximately 3.72 million ha of forest across the conterminous United States in 2010, an area slightly smaller than the land area of Maryland and Connecticut combined. The most widespread defoliators were western and eastern spruce budworms (*Choristoneura occidentalis* and *C. fumiferana*), affecting 1.08 million ha (table 2.3). Tent caterpillars (*Malacosoma* spp.), pinyon needle scale (*Matsucoccus acalyptus*), gypsy moth (*Lymantria dispar*), aspen (*Populus tremuloides*) decline, and nonspecific defoliators each affected more than 100 000 ha.

Table 2.3—Defoliation agents and complexes affecting more than 5 000 ha in the conterminous United States in 2010

Agents/complexes causing defoliation, 2010	Area
	ha
Spruce budworm (eastern and western)	1 080 861.0
Tent caterpillars	733 803.3
Pinyon needle scale	521 565.3
Gypsy moth	488 579.1
Aspen decline	152 280.4
Defoliators (non-specific)	112 485.9
Larch needle cast	47 036.0
Baldcypress leafroller	35 779.2
Winter moth	31 061.2
Needlecast	14 442.5
Linden looper	11 705.7
Pinyon sawfly	11 025.7
Aspen blotchminer	10 674.8
Pine butterfly	9 716.6
Larch casebearer	7 273.6
Douglas-fir tussock moth	6 664.0
Leaftier	6 539.7
Aspen leafminer	6 344.4
Jack pine budworm	5 468.5
Beech bark disease	5 422.5
Birch leaf fungus	5 288.2
Total, all agents	3 715 292

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 because of overlapping damage polygons.

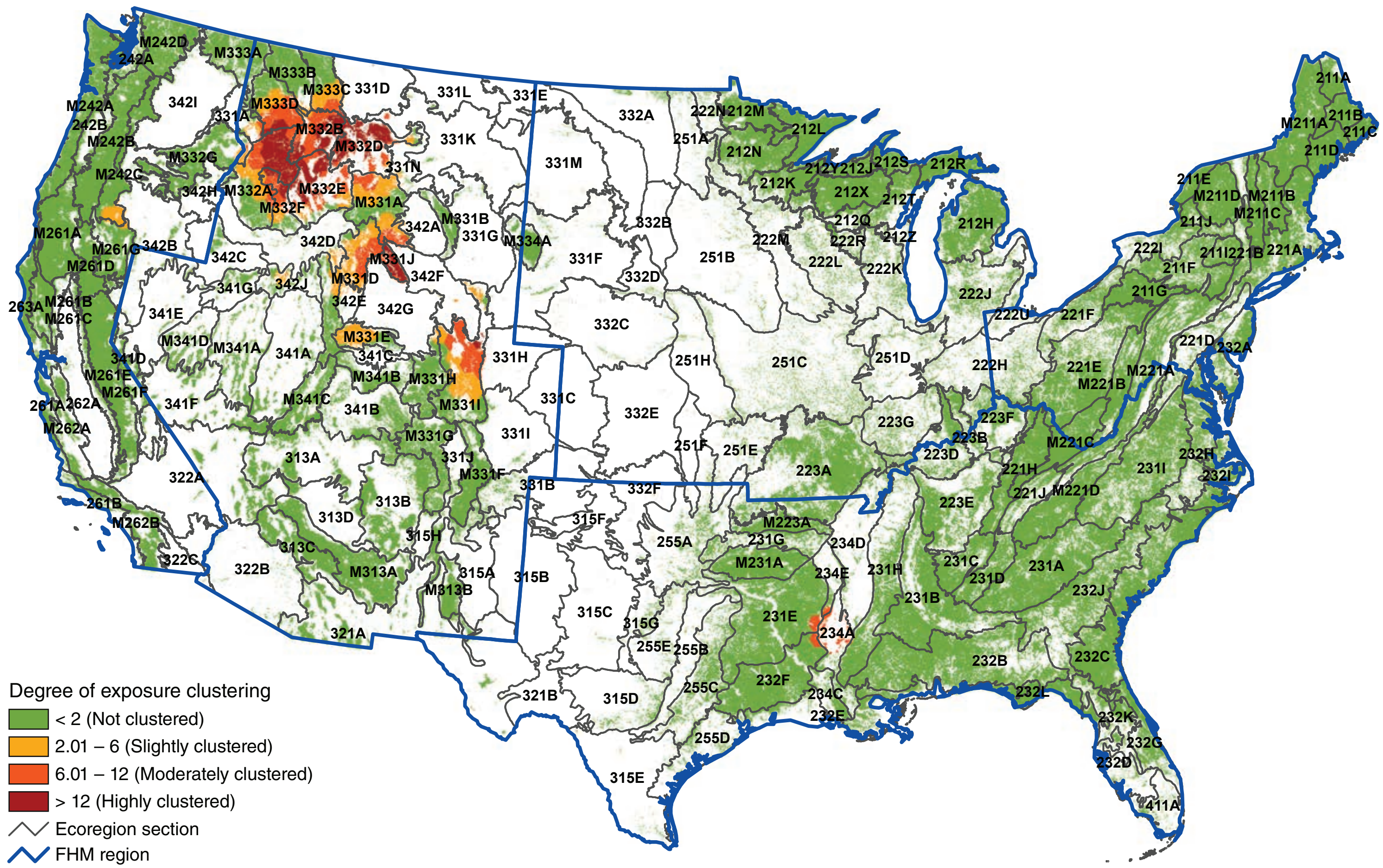

Figure 2.2—Hot spots of exposure to mortality-causing insects and diseases in 2010. Values are Getis-Ord G_i** *scores, with values greater than 2 representing significant clustering of high percentages of forest area exposed to mortality agents. (No areas of significant clustering of low percentages of exposure, -2, were detected). The gray lines delineate ecoregion sections (Cleland and others 2007); the blue lines delineate Forest Health Monitoring regions. Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: USDA Forest Service, Forest Health Protection Program.)*

The hot spot analysis detected three major hot spots of insect and disease mortality in the FHM Interior West region (fig. 2.2), the region in which mountain pine beetle was by far the predominant mortality agent. A large and highly intense hot spot occurred in Idaho and Montana, the result of extensive mountain pine beetle mortality and centered on ecoregion sections M332A-Idaho Batholith, M332B-Northern Rockies and Bitterroot Valley, M332E-Beaverhead Mountains, and M332D-Belt Mountains. A second highly intense, but smaller, hot spot was centered on ecoregion section M331J-Wind River Mountains and extending into neighboring ecoregion sections M331D-Overthrust Mountains and M331A-Yellowstone Highlands (all in Wyoming). In addition to mountain pine beetle, five-needle pine decline and subalpine fir mortality were important mortality agents in this hot spot. A third intense, but smaller, mortality hot spot was caused by mountain pine beetle, subalpine fir mortality, and spruce beetle activity in ecoregion section M331I-Northern Parks and Ranges in northern Colorado and southern Wyoming. A less intense hot spot associated with mountain pine beetle occurred in ecoregion section M331E-Uinta Mountains in northeastern Utah, while another, associated with mountain pine beetle, subalpine fir mortality, and Douglas-fir beetle, was detected in ecoregion section 342J-Eastern Basin and Range in southern Idaho and northwestern Utah.

Mountain pine beetle also was an important cause of mortality in the West Coast and North Central regions. The single, relatively low-intensity mortality hot spot in the West Coast region, in ecoregion section M242C-Eastern Cascades in south-central Oregon (fig. 2.2), was associated with mountain pine beetle and, to a lesser degree, with western pine beetle (*Dendroctonus brevicomis*).

No mortality hot spots occurred in the North Central region, where mountain pine beetle mortality occurred in the Black Hills of South Dakota, or in the North East FHM region. The South, meanwhile, contained a single hot spot, in ecoregion section 234A-Southern Mississippi Alluvial Plain in northeastern Louisiana (fig. 2.2), where an outbreak of *Ips* engraver beetles occurred. This ecoregion section is part of a large area affected by acute drought in 2010 (see chapter 4). Extensive *Ips*-caused pine mortality across much of Louisiana was largely in response to these drought conditions, with particularly large areas of damage in Franklin and Evangeline parishes (Louisiana Department of Agriculture and Forestry 2011). Due to the scattered nature of *Ips* occurrence, detection and reporting of *Ips* damage is inconsistent and incomplete; there are likely more areas of unreported damage (Louisiana Department of Agriculture and Forestry 2011).

As with mortality, the Interior West FHM region encompassed several defoliation hot spots. One intense and extensive hot spot in the region was associated with pinyon needle scale defoliation in three Nevada ecoregion sections: M341D-West Great Basin and Mountains, 341F-Southeastern Great Basin, and M341A-East Great Basin and Mountains. A second,

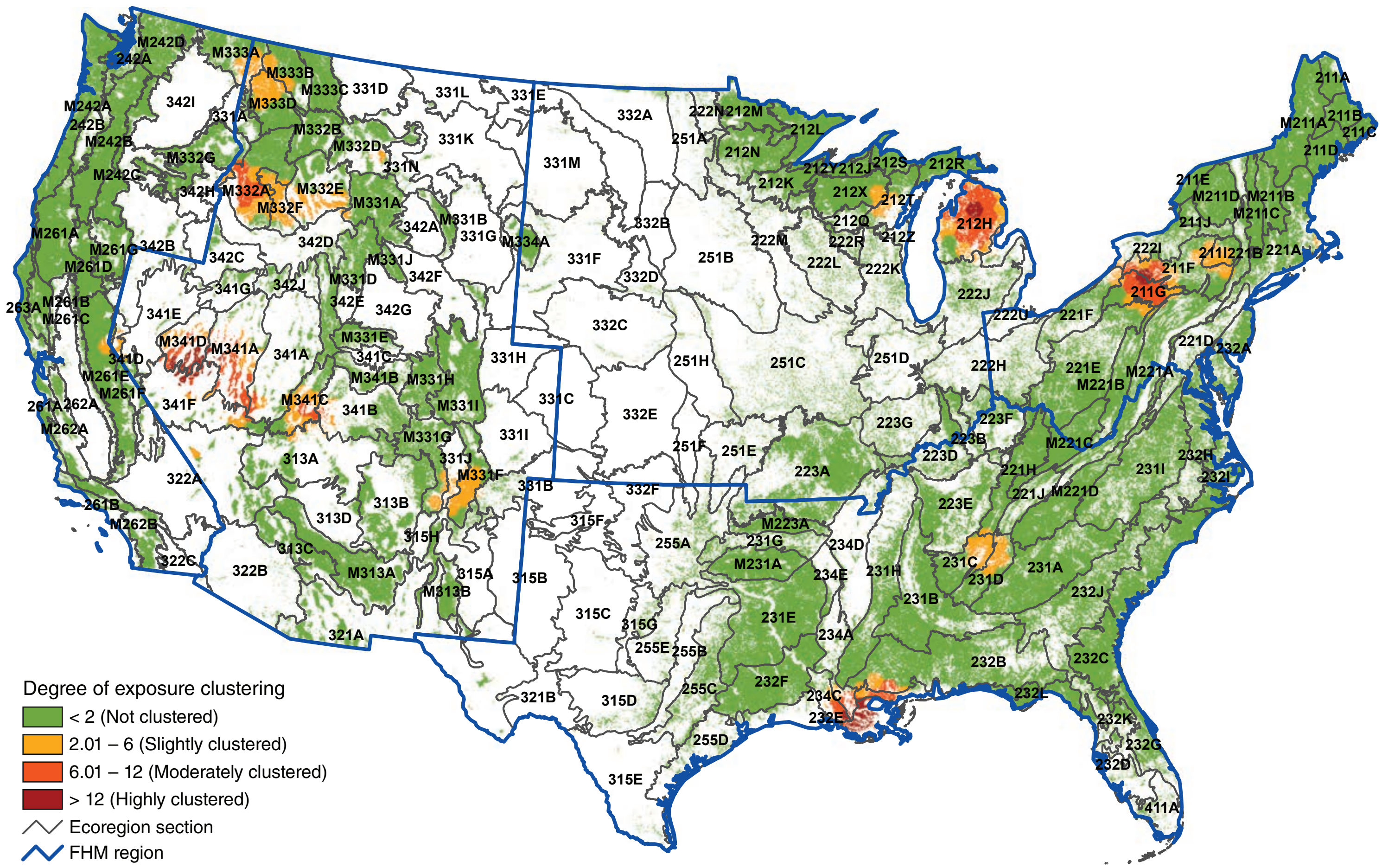

Figure 2.3—Hot spots of exposure to defoliation-causing insects and diseases in 2010. Values are Getis-Ord G_i scores, with values greater than 2 representing significant clustering of high percentages of forest area exposed to defoliation agents. (No areas of significant clustering of low percentages of exposure, -2, were detected). The gray lines delineate ecoregion sections (Cleland and others 2007); the blue lines delineate Forest Health Monitoring regions. Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: USDA Forest Service, Forest Health Protection Program.)*

less-intense hot spot was caused by pinyon needle scale, in ecoregion section 341D-Mono at the western edge of Nevada (fig. 2.3).

Four other defoliation hot spots in the region were associated with western spruce budworm. A moderately intense hot spot occurred in Idaho, centered on ecoregion section M332A-Idaho Batholith and extending into ecoregion sections M332F-Challis Volcanics, 342H-Blue Mountain Foothills, and M332E-Beaverhead Mountains. Another moderately intense defoliation hot spot caused by western spruce budworm was located in ecoregion section M341C-Utah High Plateau in south-central Utah. Two less intense hot spots were the result of defoliation from western spruce budworm in association with another agent: one with larch needle cast (*Meria laricis*) in ecoregion sections M333D-Bitterroot Mountains, M333B-Flathead Valley, and M333A-Okanogan Highland in northern Idaho and northwestern Montana; and one with aspen defoliation in ecoregion sections M331F-Southern Parks and Rocky Mountain Range and M331G-South Central Highlands in north-central New Mexico and south-central Colorado (fig. 2.3). There were no defoliation hot spots entirely contained within the West Coast region, where western spruce budworm was also an important defoliation agent.

The most intense defoliation hot spot on hardwoods in the North East FHM region, meanwhile, was caused by forest tent caterpillar, along with eastern tent caterpillar, in ecoregion sections 211G-Northern Unglaciated Allegheny Plateau and 211F-Northern Glaciated Allegheny Plateau in north-central Pennsylvania and southwest New York (fig. 2.3). A less intense hot spot located across ecoregion sections 211I-Catskill Mountains and 211F-Northern Glaciated Allegheny Plateau, mainly in New York, were associated with forest tent caterpillar and generic defoliators. Another low-intensity hot spot in eastern Massachusetts, and in ecoregion section 221A-Lower New England, was caused by winter moth (*Operophtera brumata*), Diplodia blight (*Sphaeropsis sapinea*) on select conifer hosts, and gypsy moth.

An intense hot spot of defoliation associated mostly with forest tent caterpillar, along with a comparatively small amount of baldcypress leafroller (*Archips goyerana*), occurred in the South FHM region, in ecoregion sections 232E-Louisiana Coastal Prairie and Marshes and 234C-Atchafalaya and Red River Alluvial Plains in southern Louisiana. The other hot spot in the region was caused by the defoliation of oaks by linden looper (*Erannis tiliaria*) in ecoregion section 231C-Southern Cumberland Plateau in northeastern Alabama (fig. 2.3).

The North Central region's single high-intensity hot spot, in ecoregion section 212H-Northern Lower Peninsula Michigan, was caused largely by gypsy moth, along with some forest tent caterpillar defoliation. Similarly, a less intense hot spot in ecoregion section 212T-Northern Green Bay Lobe in northeast Wisconsin, was associated with gypsy moth with a smaller amount of defoliation by aspen blotchminer (*Lithocolletis tremuloidiella*).

In 2010, three mortality-causing agents and complexes were reported for Alaska, affecting approximately 58 000 ha (table 2.4). Alaska contains approximately 51.3 million ha of forest (Smith and others 2009).

Spruce beetle was the most widely detected mortality agent, affecting about 32 000 ha of forest, mostly in the south-central and southeastern parts of the State. Yellow-cedar (*Chamaecyparis nootkatensis*) decline was the second most widely detected mortality agent, found on about 12 000 ha in the Alaska panhandle. Northern spruce engraver beetle (*Ips perturbatus*) was detected on about 10 000 ha of forest, mostly in the central and east-central parts of the State. The ecoregion sections with the highest percentage of surveyed forest affected by mortality agents were M213A-Northern Aleutian Range and M135A-Northern Chugach Range in southern Alaska, with 1.94 percent and 1.03 percent, respectively, and M129A-Seward Mountains in east-central Alaska, with 1.36 percent (fig. 2.4).

Alaska forests were exposed to 11 defoliation agents and complexes recorded on nearly 464 000 ha (table 2.5) in 2010. Willow leaf blotchminer (*Micrurapteryx salicifoliella*) was the most widely detected defoliator, found on approximately 228 000 ha, mostly in central and east-central Alaska. The next most important defoliator in 2010 was aspen leafminer (*Phyllocnistis populiella*), present on 184 000 ha, again mostly in the eastern and east-central parts of the State. Nonspecific defoliators were detected on nearly 28 000 ha, spruce aphid (*Elatobium abietinum*) was found on about 16 000 ha, and hemlock sawfly (*Neodiprion tsugae*) was observed on approximately 4 000 ha. Twenty percent of the forest surveyed in ecoregion section 139A-Yukon Flats was affected by defoliation agents, by far the highest level of detected defoliation activity (fig. 2.5). Ecoregion

Table 2.4—The three mortality agents and complexes detected in Alaska in 2010

Agents/complexes causing mortality, 2010	Area
	ha
Spruce beetle	31 546.3
Alaska-yellow cedar decline	12 328.4
Northern spruce engraver beetle	9 622.1
Total, all agents	58 096.7

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 because of overlapping damage polygons.

Table 2.5—The five leading defoliation agents and complexes detected in Alaska in 2010

Agents/complexes causing defoliation, 2010	Area
	ha
Willow leaf blotchminer	227 639.1
Aspen leafminer	183 539.4
Defoliators	27 649.5
Spruce aphid	16 231.8
Hemlock sawfly	3 680.5
Total, all agents	463 598.9

Note: All values are "footprint" areas for each agent or complex.

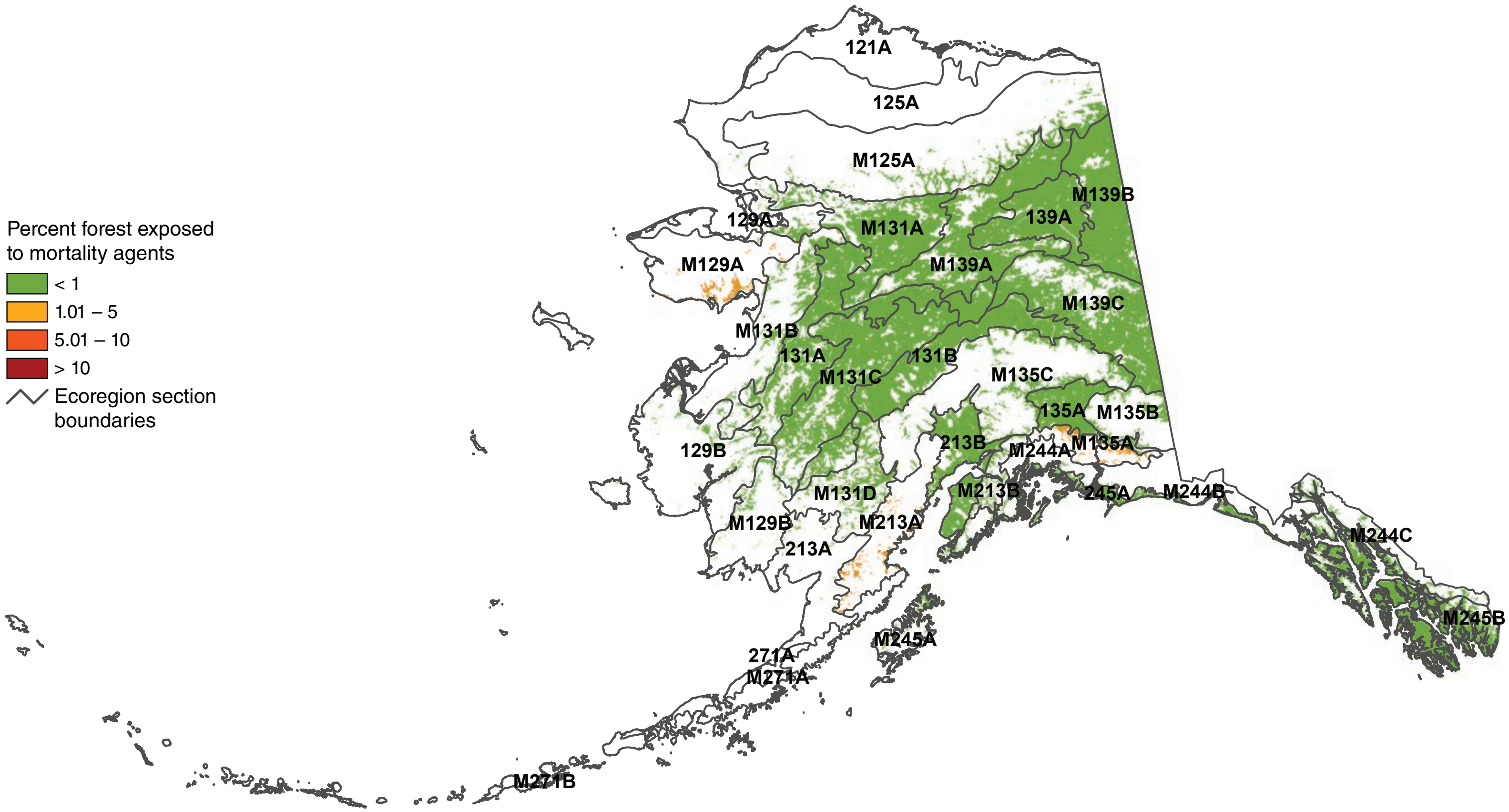

Figure 2.4—Percent of surveyed forest in Alaska ecoregion sections exposed to mortality-causing insects and diseases in 2010. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: USDA Forest Service, Forest Health Protection Program.)

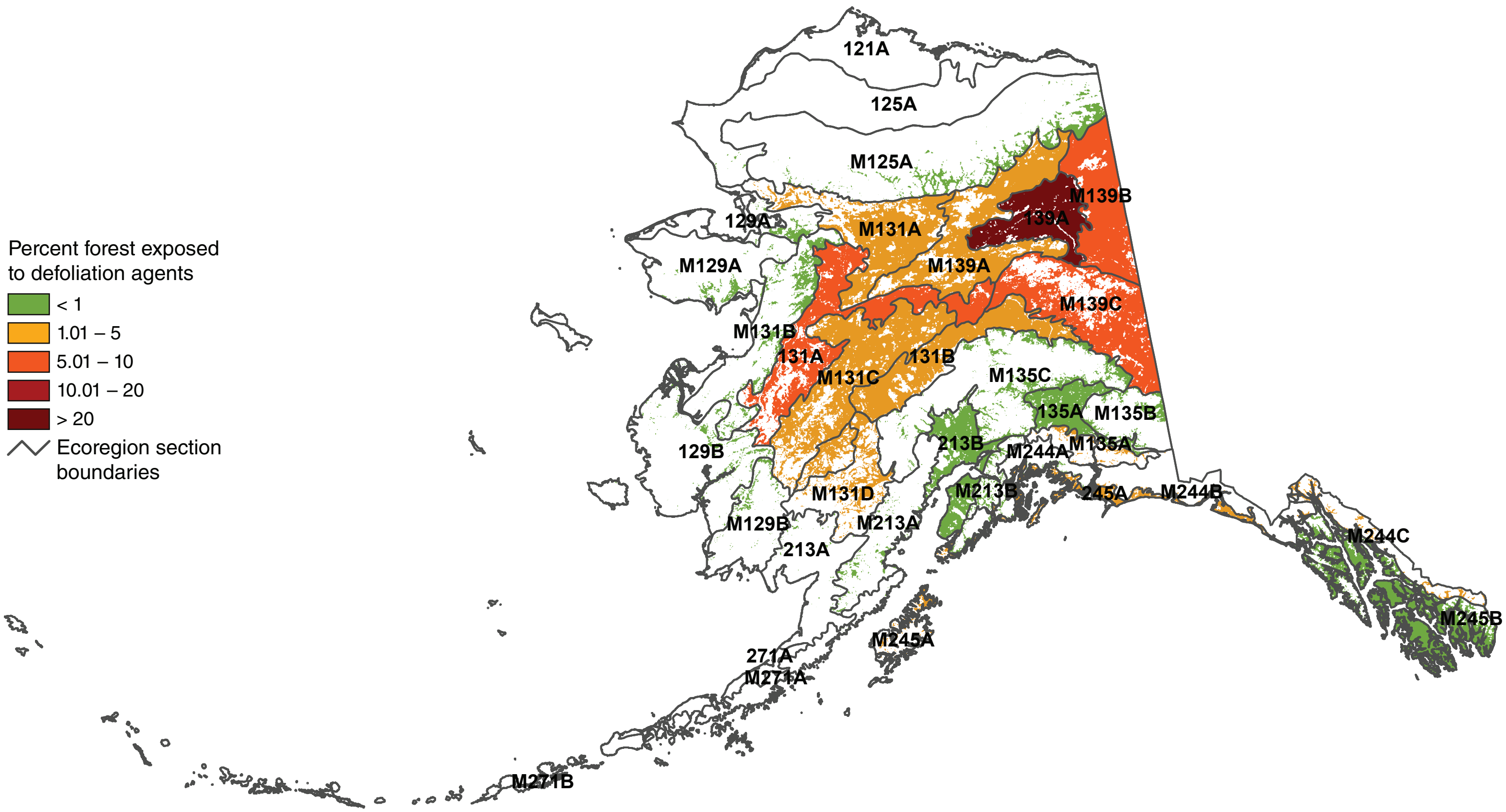

Figure 2.5—Percent of surveyed forest in Alaska ecoregion sections exposed to defoliation-causing insects and diseases in 2010. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: USDA Forest Service, Forest Health Protection Program.)

sections 131A-Yukon Bottomlands, M139B-Olgivie Mountains, and M139C-Dawson Range also had relatively high percentages of forest affected by detected defoliation activity.

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 comprise all the biotic forest health threats that should be considered when making management decisions and budget allocations. However, as these analyses demonstrate, large-scale assessments of mortality and defoliation exposure, including geographical hot spot detection analyses, offer one potentially useful approach for helping to prioritize geographic areas where the concentration of monitoring and management activities would be most effective.

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