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, 2009

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INTRODUCTION

Analyzing patterns of forest pest infestation, 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). 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 monitoring and 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 geographic hot spots of forest insect and disease activity in the conterminous United States, and to summarize insect and disease activity by ecoregion in Alaska (Potter and Koch 2012, Potter 2012). In 2009, FHP surveys covered approximately 156.8 million ha (61.5 percent) of the forested area in the conterminous United States, and 8.3 million ha (16.1 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 (such as emerald ash borer and hemlock woolly adelgid), 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 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 the analysis of the data and the interpretation of the results.

The 2009 mortality and defoliation polygons were used to identify the mortality and

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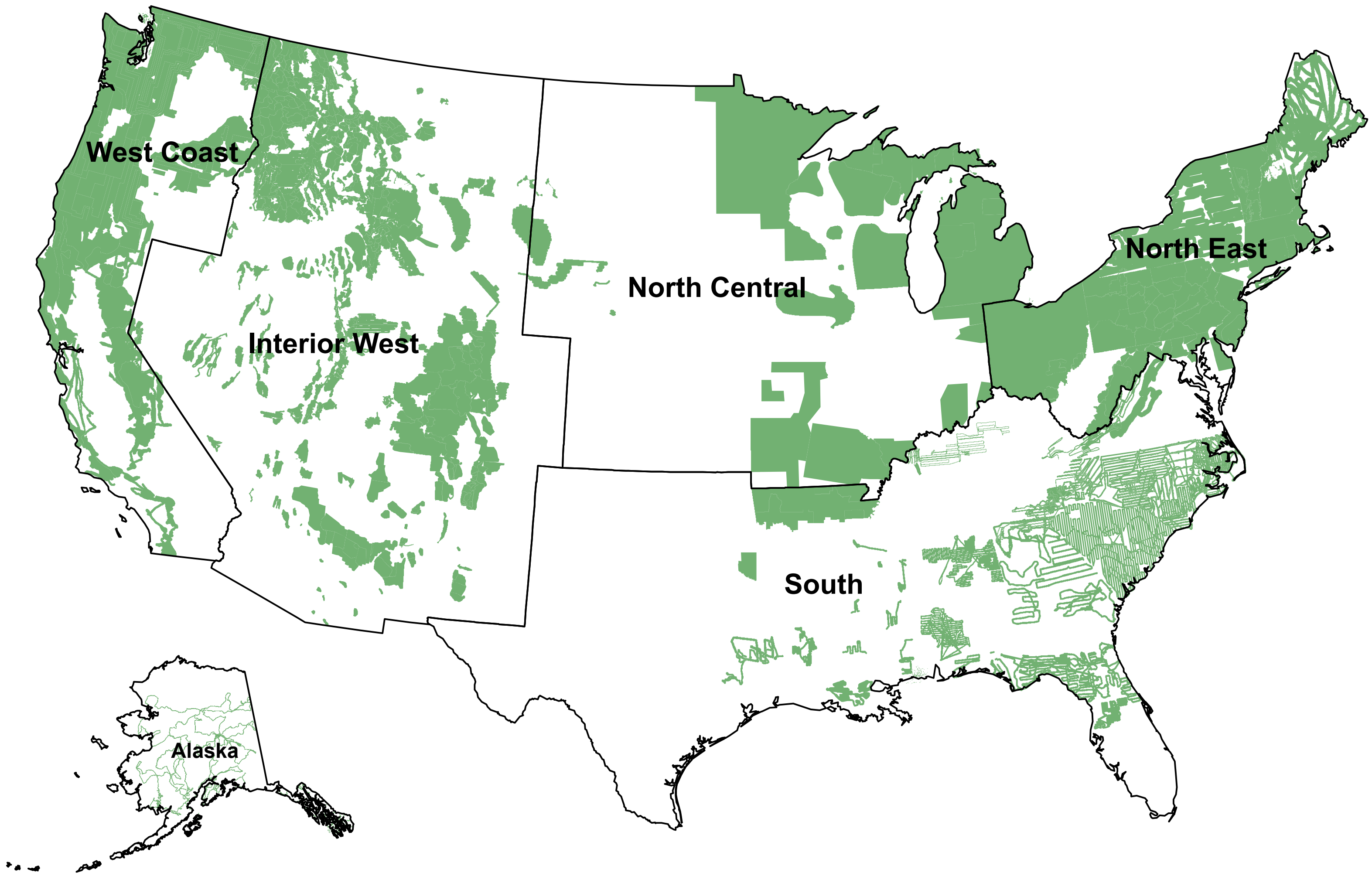

Figure 2.1—The extent of surveys for insect and disease activity conducted in the conterminous United States and Alaska in 2009. The black lines delineate Forest Health Monitoring regions. Note: Alaska is not shown to scale with map of the conterminous United States. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

defoliation agents and complexes found on more than 5000 ha in the conterminous United States in that year, and to identify and list the most widely detected defoliation and mortality agents for Alaska. All quantities are “footprint” areas for the agent or complex. 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 forest cover map (1-km^2 resolution), derived from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery by the Forest Service Remote Sensing Applications Center (USDA Forest Service 2008), was used to determine the amount and location of forest within survey defoliation and mortality polygons. A Getis-Ord hot spot analysis (Getis and Ord 1992) was then employed in ArcMap 9.2 (ESRI 2006) to identify forested areas with the greatest exposure to mortality-causing and defoliation-causing agents and complexes. The Environmental Monitoring and Assessment Program North American hexagon coordinates (White and others 1992) were intensified to develop a lattice of hexagonal cells, of approximately 2500 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 forest area in each hexagon exposed to either mortality-causing or defoliation-causing agents or complexes was then calculated by dividing the forest-masked damage area by the forest-masked surveyed area.

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 was 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 and complexes for a hexagon and its 6 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 and 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 is large enough to include several neighbors for each feature (ESRI 2006).

The low density of survey data from Alaska in 2009 (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 and complexes 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 survey data identified 62 different mortality-causing agents and complexes on approximately 4.68 million ha of forest across the conterminous United States in 2009, an area slightly larger than the land area of Maryland and Massachusetts combined. Mountain pine beetle (*Dendroctonus ponderosae*) was the most widespread mortality agent, detected on 3.47 million ha (table 2.1). Other mortality agents and complexes detected across very large areas, each affecting more than 100 000 ha, were

Table 2.1—Mortality agents and complexes affecting more than 5 000 ha in the conterminous United States in 2009

2009 mortality agents/complexes	Area
	ha
Mountain pine beetle	3 467 925
Bronze birch borer	285 539
Fir engraver	172 004
Sudden aspen decline	144 353
Subalpine fir mortality	117 793
Spruce beetle	80 064
Douglas-fir beetle	72 445
Five-needle pine decline	56 217
Gypsy moth	46 797
Bark beetles	41 909
Pinyon *Ips*	34 789
Western pine beetle	28 171
Decline (unspecified)	27 621
Beech bark disease	17 778
Forest tent caterpillar	13 928
Western balsam bark beetle	10 562
White pine blister rust	9 415
Eastern larch beetle	7 694
Balsam woolly adelgid	6 984
Pine engraver	6 714
Winter moth	6 341
Emerald ash borer	5 198
Other mortality agents	25 509
Total, all mortality agents	**4 683 511**

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.

bronze birch borer (*Agrilus anxius*), fir engraver (*Scolytus ventralis*), sudden aspen (*Populus tremuloides*) decline, and subalpine fir (*Abies lasiocarpa*) mortality.

Additionally, the survey identified 64 defoliation agents and complexes affecting approximately 3.17 million ha of forest across the conterminous United States in 2009, an area slightly smaller than the land area of New Hampshire, Delaware, and Rhode Island combined. The most widespread defoliator was western spruce budworm (*Choristoneura occidentalis*), affecting 1.81 million ha (table 2.2). Forest tent caterpillar (*Malacosoma disstria*), pinyon needle scale (*Matsucoccus acalyptus*), and gypsy moth (*Lymantria dispar*) also affected more than 100 000 ha.

The Interior West region (as defined by the Forest Health Monitoring [FHM] Program of the Forest Service) had, by far, the largest area on which mortality-causing agents and complexes were detected in 2009, approximately 3.67 million ha (table 2.3). Nearly all of the mortality was associated with mountain pine beetle. The hot spot analysis detected two major hot spots of insect and disease mortality in the region in which mountain pine beetle was by far the predominant mortality agent (fig. 2.2). A large and highly clustered hot spot was centered on the Montana ecoregion sections M332D-Belt Mountains, M332B-Northern Rockies and Bitterroot Valley, and M332E-Beaverhead Mountains. Another such hot spot was located in ecoregion section M331I-Northern Parks and Ranges of northern Colorado and

Table 2.2—Defoliation agents and complexes affecting more than 5 000 ha in the conterminous United States in 2009

2009 defoliation agents/complexes	Area
	ha
Western spruce budworm	1 812 242
Forest tent caterpillar	620 240
Pinyon needle scale	226 522
Gypsy moth	181 720
Spruce budworm	58 659
Pinyon sawfly	53 117
Unknown defoliator	52 196
Defoliators (unspecified)	23 590
Decline	19 063
Septoria leaf spot and canker	18 676
Larch casebearer	16 762
Western tent caterpillar	15 331
Aspen defoliation	8 228
Orangestriped oakworm	7 698
Larger elm leaf beetle	6 296
Jack pine budworm	5 140
Bruce spanworm	5 000
Other defoliation agents	36 146
Total, all defoliation agents	**3 165 733**

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 2.3—The top five mortality agents and complexes detected in each Forest Health Monitoring region in 2009

2009 mortality agents/complexes	Area
	ha
Interior West	
Mountain pine beetle	3 281 941
Sudden aspen decline	144 275
Subalpine fir mortality	117 840
Spruce beetle	61 351
Five-needle pine decline	57 863
Total, all mortality agents	**3 670 065**
North Central	
Bronze birch borer	285 539
Beech bark disease	11 837
Mountain pine beetle	9 115
Eastern larch beetle	7 694
Emerald ash borer	394
Total, all mortality agents	**321 939**
North East	
Gypsy moth	46 797
Forest tent caterpillar	13 901
Winter moth	6 291
Beech bark disease	5 869
Emerald ash borer	3 006
Total, all mortality agents	**82 637**

2009 biotic mortality agents/complexes	Area
	ha
South	
Hemlock woolly adelgid	862
Southern pine beetle	77
Ips	32
Black turpentine beetle	2
Laurel wilt	2
Total, all mortality agents	**955**
West Coast	
Mountain pine beetle	342 796
Fir engraver	120 367
Bark beetles	40 311
Douglas-fir beetle	39 729
Western pine beetle	21 463
Total, all mortality agents	**607 434**
Alaska	
Spruce beetle	40 718
Northern spruce engraver	14 250
Yellow-cedar decline	6 458
Eastern larch beetle	43
Total, all mortality agents	**61 471**

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

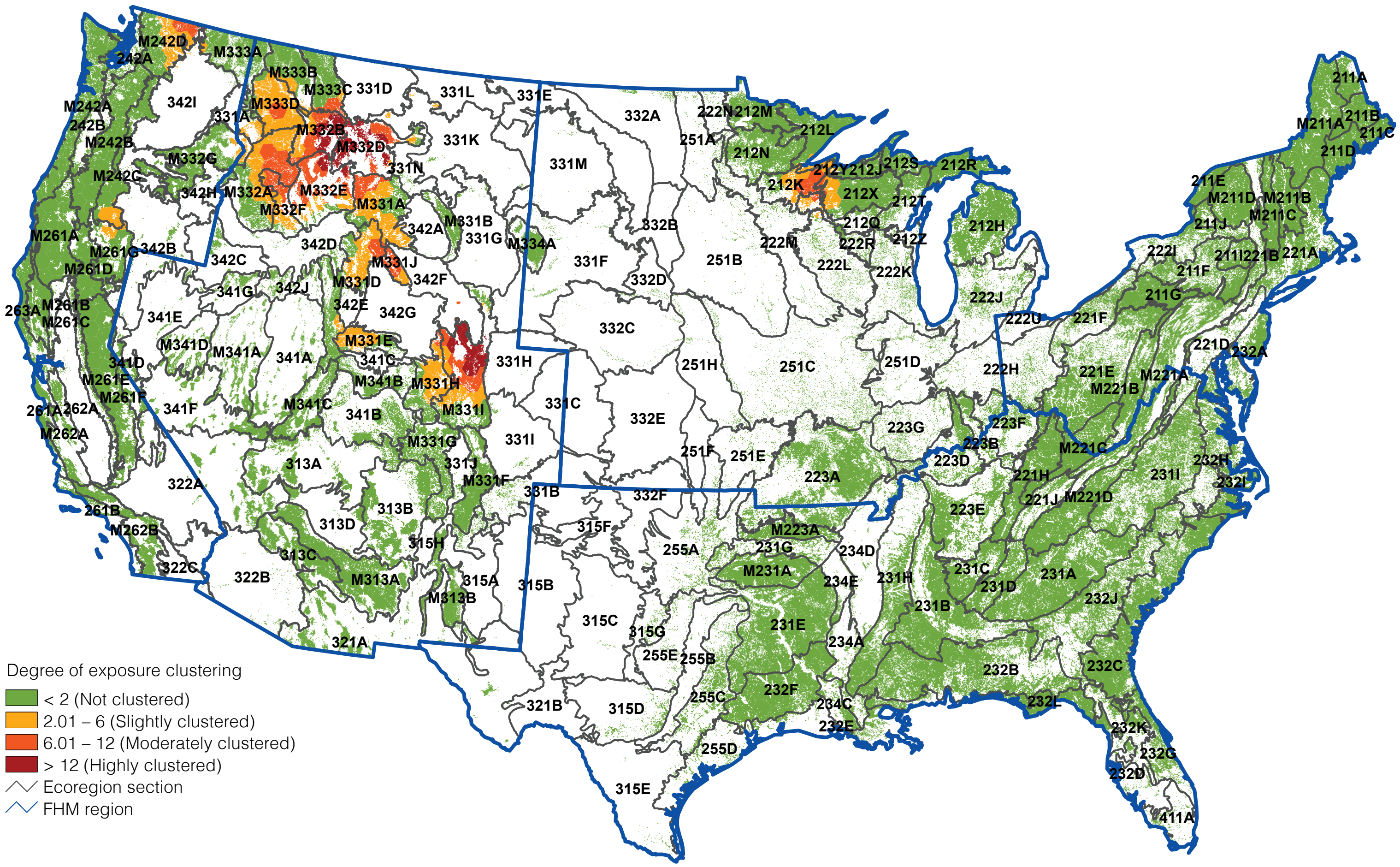

Figure 2.2—Hot spots of exposure to mortality-causing insects and diseases in 2009. Values are Getis-Ord G_i scores, with values greater than 2 representing significant clustering of high percentages of forest area exposed to mortality agents. (No areas of significant clustering of low percentages of exposure, -2, were detected.) The gray lines delineate ecoregion sections (Cleland and others 2007), and 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: U.S. Department of Agriculture Forest Service, Forest Health Protection)*

southern Wyoming. Four less concentrated hot spots of mountain pine beetle mortality were located in northern Idaho, centered in ecoregion section M333D-Bitterroot Mountains; in central Idaho, centered on ecoregion sections M332A-Idaho Batholith and M332F-Challis Volcanics; in western Wyoming, centered on ecoregion sections M331J-Wind River Mountains and M331D-Overthrust Mountains; and in northeast Utah, centered on ecoregion section M331E-Uinta Mountains.

Mountain pine beetle was also the leading cause of mortality in the West Coast region, where it was detected on approximately 343 000 ha (table 2.3). The region's two mortality hot spots were both associated with the beetle, the larger in ecoregion section M242D-Northern Cascades and the smaller in portions of ecoregion sections M242C-Eastern Cascades and M261G-Modoc Plateau (fig. 2.2). Fir engraver was another important agent of mortality in the West Coast region, affecting approximately 120 000 ha (table 2.3).

Bronze birch borer was by far the most important agent of mortality in the North Central FHM region, affecting approximately 286 000 ha (table 2.3). It was associated with the only mortality hot spot in the region, which occurred in the 212K-Western Superior Highlands, 212Q-North Central Wisconsin Highlands, and 212X-Northern Highlands (fig. 2.2).

No mortality hot spots were located in the other two FHM regions in the conterminous United States in 2009. Surveys detected forest mortality on approximately 83 000 ha in the North East region, where gypsy moth and forest tent caterpillar were the leading mortality agents (table 2.3). Surveys reported only 955 ha of mortality in the South region, where hemlock woolly adelgid (*Adelges tsugae*) was the leading mortality agent (table 2.3).

As with mortality, the Interior West FHM region encompassed the largest area on which defoliation agents and complexes were detected, at slightly more than 2 million ha (table 2.4). Western spruce budworm accounted for the largest area of detected defoliation, followed by pinyon needle scale. Several hot spots of defoliation were associated with western spruce budworm, including a major hot spot centered in ecoregion section M332D-Belt Mountains of Montana and extending into ecoregion sections M331A-Yellowstone Highlands, M332E-Beaverhead Mountains, and M332B-Northern Rockies and Bitterroot Valley (fig. 2.3). Nearby, in northern Idaho and northwestern Montana, another hot spot was located in ecoregion sections M333D-Bitterroot Mountains, M333B-Flathead Valley, and M333C-Northern Rockies. A third hot spot in central Idaho encompassed parts of ecoregion sections M332A-Idaho Batholith and M332F-Challis Volcanics. Western spruce budworm was also the causal agent relating to a hot spot of defoliation on the border between Colorado and New Mexico, in ecoregion sections M331F-Southern Parks and Rocky Mountain Range and M331G-South-Central Highlands. Finally, a defoliation hot spot in central Nevada was associated with pinyon needle scale, pinyon

Table 2.4—The top five defoliation agents and complexes detected in each Forest Health Monitoring region in 2009

2009 defoliation agents/complexes	Area
	ha
Interior West	
Western spruce budworm	1 639 697
Pinyon needle scale	226 522
Pinyon sawfly	53 117
Unknown defoliator	52 189
Decline	18 490
Total, all defoliation agents	**2 017 782**
North Central	
Forest tent caterpillar	160 661
Spruce budworm	58 527
Larch casebearer	11 221
Gypsy moth	5 238
Jack pine budworm	5 140
Total, all defoliation agents	**253 143**
North East	
Forest tent caterpillar	354 144
Gypsy moth	171 400
Defoliators (unspecified)	20 327
Septoria leaf spot and canker	18 676
Orangestriped oakworm	7 698
Total, all defoliation agents	**577 777**

2009 defoliation agents/complexes	Area
	ha
South	
Forest tent caterpillar	102 978
Gypsy moth	15 253
Larger elm leaf beetle	6 296
Baldcypress leafroller	2 223
Defoliators (unspecified)	2 128
Total, all defoliation agents	**126 004**
West Coast	
Western spruce budworm	176 149
Larch casebearer	5 532
Lodgepole needleminer	3 042
Douglas-fir tussock moth	1 746
Pine butterfly	1 561
Total, all defoliation agents	**190 690**
Alaska	
Aspen leafminer	125 696
Willow leaf blotchminer	56 515
Defoliators (unspecified)	5 973
Spear-marked black moth	5 791
Spruce bud moth	5 341
Total, all defoliation agents	**202 655**

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

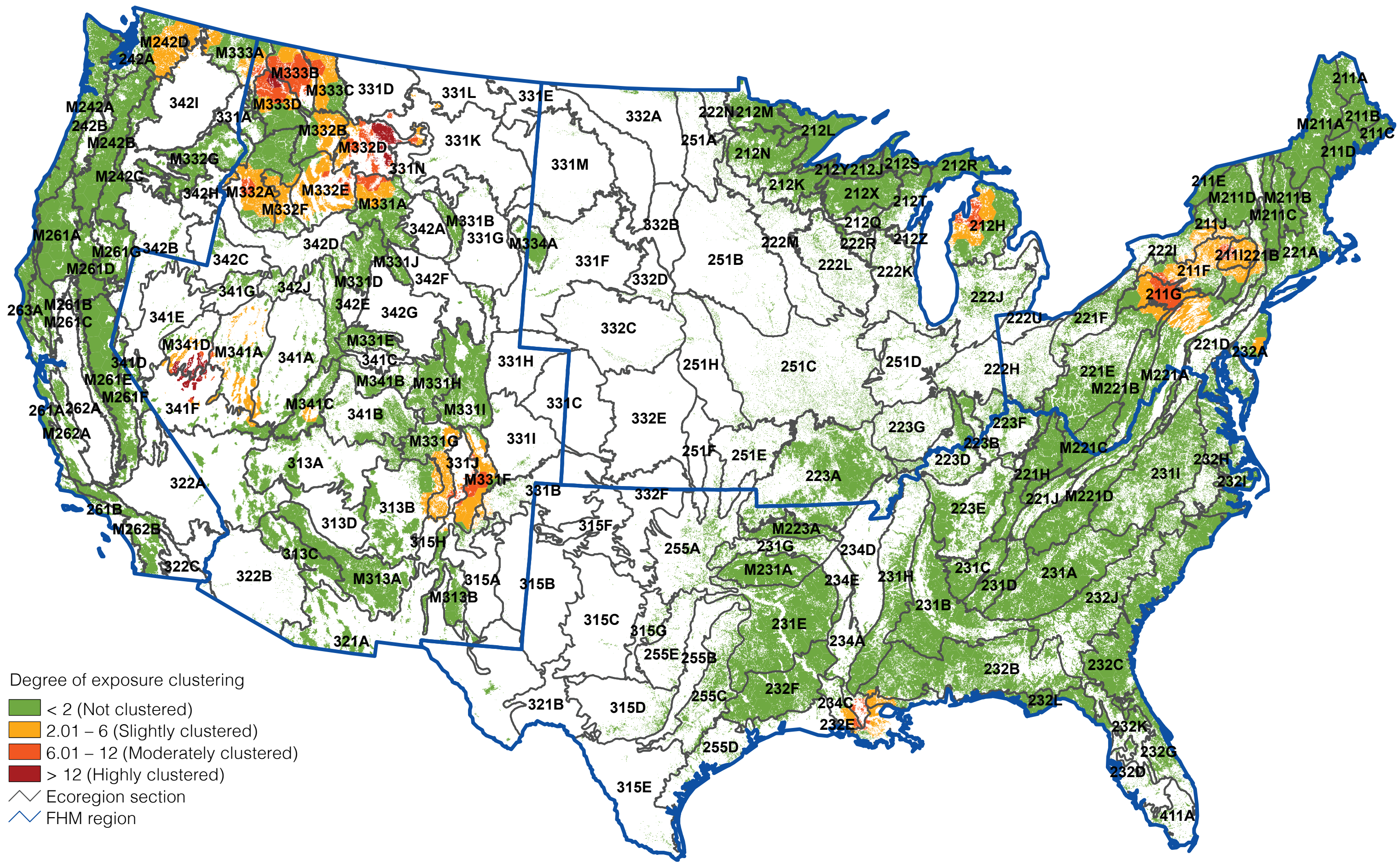

Figure 2.3—Hot spots of exposure to defoliation-causing insects and diseases in 2009. Values are Getis-Ord G_i** scores, with values greater than 2 representing significant clustering of high percentages of forest area exposed to defoliation agents. (No areas of significant clustering of low percentages of exposure, -2, were detected.) The gray lines delineate ecoregion sections (Cleland and others 2007), and 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: U.S. Department of Agriculture Forest Service, Forest Health Protection)*

sawfly, and aspen decline. This hot spot stretched across three ecoregion sections: M341D-West Great Basin and Mountains, M341A-East Great Basin and Mountains, and 341F-Southeastern Great Basin.

The western spruce budworm was also the leading cause of defoliation in the West Coast FHM region (table 2.4). This defoliation was most concentrated in a hot spot in central Washington, between ecoregion sections M242-Northern Cascades and M333A-Okanogan Highland (fig. 2.3).

Forest tent caterpillar was the leading defoliator in the three FHM regions of the Eastern United States (table 2.4), defoliating approximately 354 000 ha in the North East, approximately 161 000 ha in the North Central region, and approximately 103 000 ha in the South. At least one hot spot in each region was associated with this pest. In the North East, one hot spot was split between ecoregion sections 211F-Northern Glaciated Allegheny Plateau and 211I -Catskill Mountains in New York (fig. 2.3). A second hot spot, centered on ecoregion section 211G-Northern Unglaciated Allegheny Plateau, was caused by both forest tent caterpillar and gypsy moth. The forest tent caterpillar hot spot in the North Central region, meanwhile, was located in ecoregion section 212H-Northern Lower Peninsula of Michigan (fig. 2.3), while the hot spot in the South spanned 234C-Atchafalaya and Red River Alluvial Plains and 232E-Louisiana Coastal Prairie and Marshes ecoregion sections of southern Louisiana.

In 2009, four mortality-causing agents and complexes were reported for Alaska, affecting approximately 61 000 ha (table 2.3). Spruce beetle was the leading mortality agent, detected on about 41 000 ha, mostly in the south-central region of the State, including ecoregion sections M213A-Northern Aleutian Range and 213B-Cook Inlet Lowlands. As a result, these two ecoregions had the highest percent of exposure to mortality-causing agents and complexes in surveyed forest areas, 2.24 percent and 1.04 percent, respectively (fig. 2.4). Northern spruce engraver beetle (*Ips perturbatus*) was the second most widespread mortality agent, affecting about 14 000 ha of forest (table 2.3), mostly in the central and east-central parts of the State. Yellow-cedar (*Chamaecyparis nootkatensis*) decline was also an important mortality complex (6 458 ha) in the panhandle of the State.

Alaska forests were exposed to 12 defoliation agents and complexes recorded on approximately 202 000 ha (table 2.4). Aspen leafminer (*Phyllocnistis populiella*) had by far the largest extent, observed on approximately 126 000 ha across central Alaska. As a result of aspen leafminer, three ecoregion sections had relatively high percentages of defoliation exposure (fig. 2.5): M139C-Dawson Range, with 10.23 percent surveyed forest exposed; 139A-Yukon Flats, with 8.63 percent; and M139B-Olgivie Mountains, with 7.48 percent.

A second major defoliator was willow leaf blotchminer (*Micrurapteryx salicifoliella*), which was detected on approximately 57 000 ha. Like aspen leafminer, it occurred

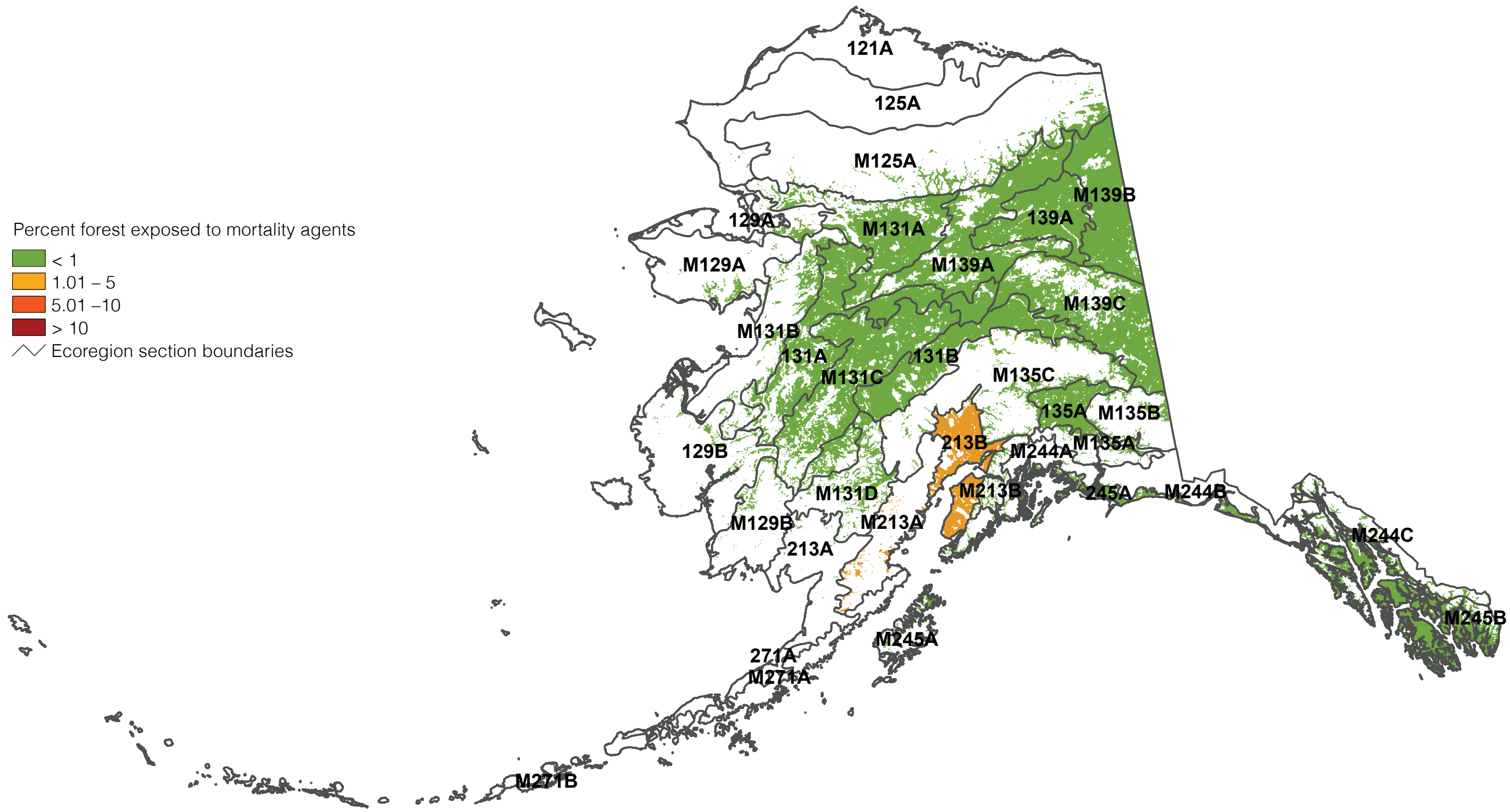

Figure 2.4—Percent of surveyed forest in Alaska ecoregion sections exposed to mortality-causing insects and diseases in 2009. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

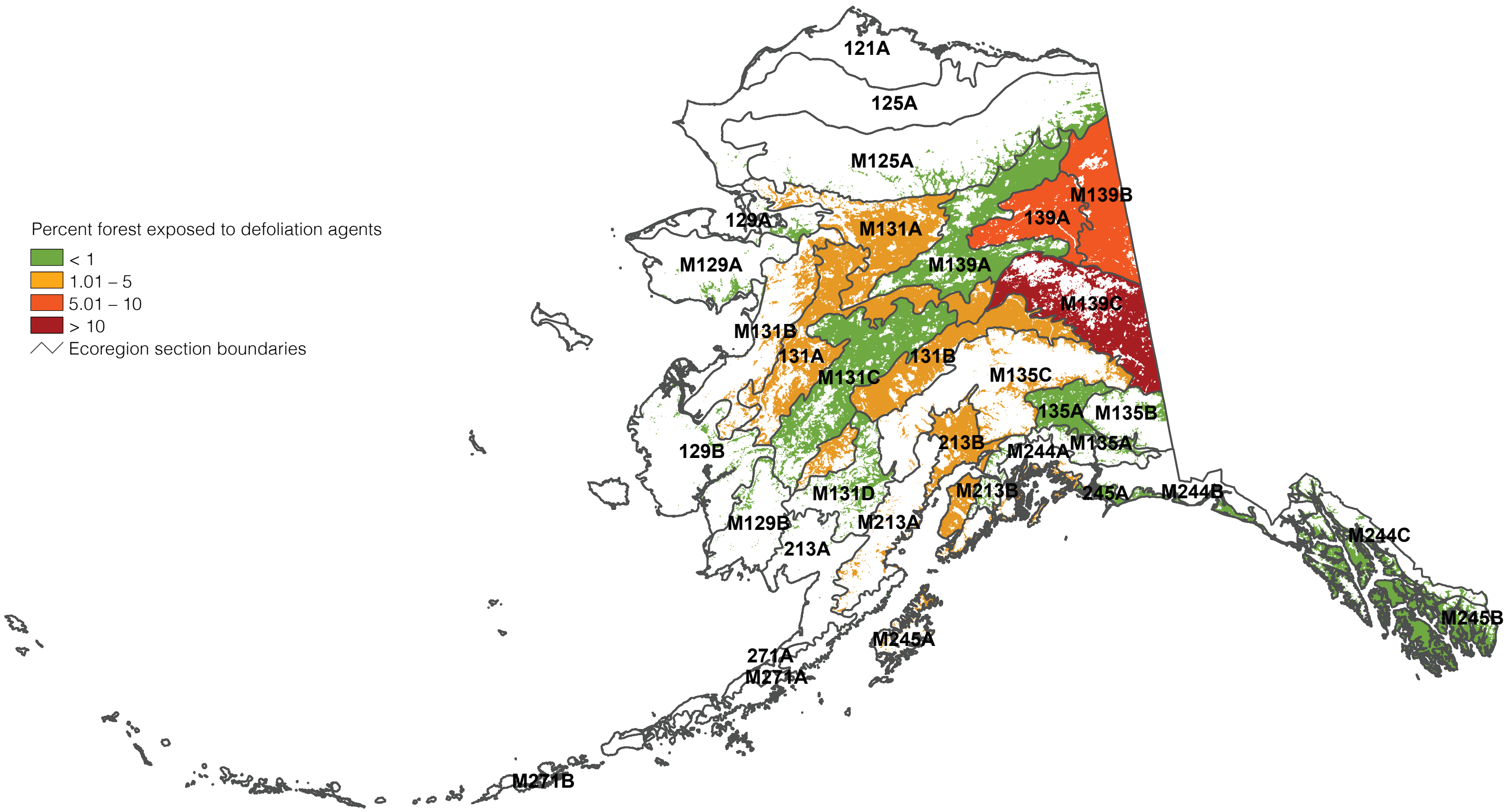

Figure 2.5—Percent of surveyed forest in Alaska ecoregion sections exposed to defoliation-causing insects and diseases in 2009. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Data source: U.S. Department of Agriculture Forest Service, Forest Health Protection)

mainly in the east-central region of the State, including ecoregion sections 139A-Yukon Flats, M139B-Olgivie Mountains, 131A-Yukon Bottomlands, M131A-Upper Kobuk-Koyukuk, and 131B-Kuskokwin Colluvial Plain. Other important defoliators in 2009 were spear-marked black moth (*Rheumaptera hastata*), spruce bud moth (*Zeiraphera canadensis*), hemlock sawfly (*Neodiprion tsugae*) (1427 ha), and northern spruce engraver (1236 ha).

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 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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